RADIATION AGING STUDIES OF CO₂ HYDROCARBON MIXTURES FOR THE SLD DRIFT CHAMBER*

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Abstract

The SLD drift chamber requires a 'slow' drifting gas and low diffusion to allow wave form digitization. CO_2 provides this but requires an admixture of a quencher to provide more gain. A test chamber with an 8 sense wire cell, such as will appear in the final chamber, was exposed to an X-ray tube while containing a variety of binary admixtures of CO_2 : 8% isobutane, 8% ethane, and 2% isopropanol. It was determined that adding small fractions of water ($\leq 0.66\%$) or isopropanol (1-2%) to the CO_2 : 8% ethane, or 8% isobutane extended the useful life of the chamber so that integrated charge collections of ~1 C/cm are permissible. Results and discussions are presented.

Introduction

As part of the development of the SLD Central Drift Chamber (CDC), studies were conducted to determine the radiation hardness of various gas mixtures that might be used in the CDC. The search centers on the use of CO_2 as the main component because it has very low diffusion of the ionization electron cloud and in addition low electron drift velocity [1] (both with respect to other gases in use in other detectors). These properties allow high precision in timing the electron arrival at the sense wires using wave form digitizers or FADC's, which have limited readout speed. Beam test results have shown that a 92% CO₂ and 8% isobutane mixture allows position determination in the CDC to better than 100 μ m, which is the design requirement of the device [2].

The above mixture has, however, been shown to exhibit poor behavior [3] when subject to radiation. This phenomenon is known as aging, and results from chemical reactions of the ionized gases with the wire surface which lead to chamber degradation. As CO_2 has not been used extensively as a gas in large drift chambers, there is little data on its aging properties in the literature. Hence a detailed study is appropriate for SLD.

The study took into consideration the following criteria: the drift cell geometry and electric fields were to be as realistic as possible; the aging flux was to be uniform, irradiating feedthrough connections as well as the main wire; the flux was to be great enough to age the chamber in a time which would allow many mixtures to be studied; the detailed response of the chamber would be studied. These considerations led to the construction of a closely simulated cell in a test vessel, and the installation of an X-ray tube as the source of radiation.

Currently, seven gas mixtures have been tested. Four have --been shown to have adequate lifetime for use in the CDC. It is now planned to continue testing to optimize the gas gain and other performance characteristics of the chamber.

Experimental Set-up and Procedures

The experimental test chamber is shown in Figure 1. The chamber volume is approximately 1/2 cubic foot. Each of the

test chambers is strung with 150 micron (6 mil) gold plated aluminum wire for the field and guard wires at a tension of 400 grams. The eight sense wires are of 25 micron gold plated tungsten strung to a tension of 100 grams. The sense wires are crimped into stainless steel capillary tubes inside Celanex feedthroughs at each end of the chamber. The field and guard wires are similarly crimped in aluminum tubes. Normally, the wires are used for only one test and then the chamber is restrung.



Fig. 1. An illustration of the wire aging cell. The field and guard wires are 6 mil gold plated aluminium, and the sense wires are one mil tungsten. The cell is enclosed in an aluminum chassis with removable side plates.

A Machlett OEG-60 X-ray tube (0-30 kV, tungsten target)is used to irradiate the full 30 cm length of the wire through a 6 mil aluminium window (approximately 15 cm x 15 cm). The X-ray energy and intensity can be varied over a wide range of exposure rates, allowing wire aging tests as a function of dose.

Flow meters are used to mix the gases to be tested. Periodically, gas samples are analysed with an on-site gas chromatograph to verify proper gas mixing. The mixture can be routed by appropriate valving through a bubbler which has a temperature control to set the alcohol or water partial pressure in the mix. Oxygen content is monitored at the chamber input and output with Teledyne trace oxygen analyzer Model 310. The

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 $\rm H_2O$ level is monitored at the input. Gas temperature and pressure at the outlet are monitored by transducers. The plumbing system consists entirely of hydrogen fired copper tubing. Flow meters are placed at the inlet and outlet to monitor flow rates.

The high voltage is supplied by a Bertan 377N power supply. The currents in the sense wires are measured during the X-ray irradiation. With X-rays off, the pulse height spectrum is taken using a 55 Fe source placed next to a thin window at the top of the chamber. During the wire aging test, the accumulated charge on the wires is determined by integrating the measured current on the anode wires. A VAX 11/780 is used online to initiate and record the measured sense wire current, the voltage and current on the field and guard wires, the temperature and pressure of the chamber, and the temperature of the alcohol/water bath at any desired interval. The pulse height spectra are taken once or twice a day.

The procedure in each test was substantially the same. The X-ray tube irradiates the chamber with a continuous spectrum up to the cathode voltage. The resulting ionization of the gas produces electrons which drift to the sense wire region and are there amplified by the avalanche mechanism. A continuous sense wire current results which is monitored as described in the previous section. Currents of approximately 400-1000 nA/cm were used. Aging was continued until either the chamber response substantially changed or until sufficient charge was collected to qualify the mixture as acceptable for SLD.

-In the test cell, at the nominal settings, the field wires are at a potential of 6700 v and the guard wires are at 3400 v, which results in a drift field of ~ 1.1 kV/cm. At the sense wires the field is approximately 400 kV/cm. The surface fields on the guard wires range between 16 and 18 kV/cm, while at the field wires they vary from 10 to 48 kV/cm. The large surface fields on some of the cathode wires may be modified because

such fields could lead to chamber breakdown [4], and it has been recommended that they be kept below 20 kV/cm in Argon based gases [5]. However, it has not yet been determined if the 20 kV/cm rule applies to CO_2 -based gases, and no adverse effects are yet evident.

Experimental Results for Binary Mixtures

Table 1 summarizes the test results using the SLD-CDC aging cell. For the CO₂ isopropanol run, 300 cc/min of pure CO₂ was bubbled through the isopropanol bath at 9° C. This results in a 2% alcohol, 98% CO₂ mixture. The X-ray cathode voltage was set at 7 kV for this run, and sense wire currents were about 1 μ A, or 40 nA per cm. Voltage at the field and guard wires were nominal.

The gain decreased at a rate of 120%/C/cm for 0.1 C/cm of integrated charge. No degradation of the shape of the spectrum is observed for this mixture. However, the low gas gain eliminated this mixture from further study.

An aging run with a gas mixture of 8% isobutane 92% CO₂ was made, with operating conditions as described above. Some loss in gain (~20%/C/cm) but no deterioration of the pulse height spectrum was observed until sparking occurred after 0.035 C/cm of charge had been collected. The chamber was then opened and washed with methanol followed by a washing with distilled water. After this cleaning, the chamber was able to maintain high voltage on the wires. However, when the ⁵⁵Fe source was mounted, the chamber began drawing excessive current on the guard and sense wires. This can be interpreted as the Malter effect [6], caused by the charging up of an insulating coating on the cathode wires by positive ion bombardment. Secondary electrons can be emitted through the layer and a regenerative effect produced by their avalanches at the anode.

Gas Mixture	Total dose (C/cm)	Rel. Gain $(G_{C0_2} = 1.0)$	$\Delta G/G$, (%/C/cm)	Comments
CO ₂ :isopropanol 98:2	0.125	0.97	120	Test stopped
CO ₂ :isobutane 92:8	0.035	2.10	20	HV sparking
CO ₂ :ethane 92:8	0.005	1.8	-	Malter current
CO ₂ :ethane 92:8	0.030	1.8	150	Dark current
$CO_2/i - C_4H_{10}/C_3H_7(OH)$ 92:8+2%	0.900	1.80	5 -	Stable performance
$\frac{CO_2/i - C_4H_{10}/H_2O}{92:8+ \le 0.66\%}$	0.500	1.90	6	Stable performance
$-\frac{\text{CO}_2/\text{C}_2\text{H}_6/\text{C}_3\text{H}_7(\text{OH})}{92:8+1\%}$	0.450	1.70	8	Stable performance
CO ₂ /C ₂ H ₆ /H ₂ O 92:8+0.66%	0.700	1.75	77	Gain loss and some resolution degredation

Table 1. Wire aging results using the SLD-CDC test chamber for various gas mixtures. Adding small fractions of water or isopropanol to CO_2 : ethane, or isobutane considerably improved the chamber lifetime.

Two tests were completed using a CO_2 plus 8% ethane gas mixture (200 cc/min). In the first CO_2 -ethane test, the nominal voltages were applied to the cell, and X-ray intensity was set to produce an anode current of 1μ A/cm. After less than .005 C/cm of integrated charge on the sense wires was accumulated, a self-sustaining discharge, or dark current, continued after turning off the X-rays. Resetting the cathode voltages stopped the discharge, but it reappeared when irradiation of the chamber was restarted. The flux from the ⁵⁵Fe source (1 mC) was not sufficient to initiate the dark current.

Since the chamber might have been prematurely damaged by high fields, the second test with CO_2 :ethane::92:8 was done with a newly strung chamber, this time with lower electric fields. With all other operating conditions the same as in the first test, the voltage on the cathode wires was reduced from 6.7 to 6.5 kV for the field wires and from 3.4 to 3.2 kV for the guard wires. With these reduced cathode voltages, the dark current appeared when the chamber was exposed to the X-rays, but developed more slowly. The second test was continued until the discharge current became as large as the ionization current, at .030 C/cm integrated charge collected. For the second ethane test, a gain loss of 150%/C/cm was observed when the discharge had been quenched.

Experimental Results using Tertiary Mixtures

Other experiments [7] indicate improved chamber lifetime by adding small amounts of a third (sometimes a fourth) component to gas mixtures which previously exhibited poor or unacceptable lifetimes. The instability and poor lifetimes of the ethane and isobutane gas mixtures with CO_2 prompted tests with additions of small fractions of water or isopropanol to the above binary gases.

A gas mixture of CO₂:isobutane::92:8, was bubbled through a 9° C isopropanol bath, adding approximately 2% alcohol vapor to the mixture. A dramatic improvement in the lifetime of the chamber was observed. Figure 2 shows the gain versus integrated charge. The performance of the chamber was not measurably degraded after 0.9 C/cm of accumulated charge was collected on the anode wires. The ⁵⁵Fe pulse height spectrum remained the same throughout the run.



Fig. 2. The relative gain as a function of charge for the CO_{2-} isobutane-isopropanol run. No significant loss in gas gain was observed after more than 0.9 C/cm of accumulated charge on the anode wires.

A similar result was obtained with the CO_2 :ethane::92:8 mixture when bubbled through isopropanol, this time at a temperature of 0° C, giving a 1% admixture. After 0.45 C/cm of charge was collected, no significant aging effects were observed, and this mixture was also classified as acceptable.

The presence of alcohol in some chambers can be dangerous if epoxies and other organic materials are used in their construction. Therefore we proceeded to test the effect of water as an additive to these gases by replacing the alcohol with water in the bubbler.

With the bubbler temperature set to 1.2° C, approximately 0.66% water vapor was added to the gas. When the CO₂:ethane::92:8 mixture was used, and a guard wire potential of 3200 v applied (200 v below nominal) no aging was apparent after 0.45 C/cm of charge was collected. At this point the guard potential was increased to nominal, and the run continued. A decrease in gain was observed, corresponding to 75% loss per C/cm (see Figure 3). This would be an acceptable lifetime for the foreseen SLD conditions.



Fig. 3. The relative gas gain as a function of total charge accumulated for $CO_2/C_2H_6/C_3H_7(OH)$ and $CO_2/C_2H_6/H_2O$. When the potential on the field and guard wires was 6500 v and 3200 v respectively, no appreciable loss in gain was observed. When the potential on the field and guard wires was increased to 6700 v and 3400 v respectively, a steady decrease in gain of 77%/C/cm was observed for the $CO_2/C_2H_6/H_2O$ mixture.

In the case of the CO₂:isobutane::92:8 mixture with 0.66% water vapor, the chamber performance was not significantly altered after 0.3 C/cm of charge was collected. At the 0.3 C/cm point, the water content was reduced by 50% (0.33, 0.16%, etc.) at 0.1 C/cm intervals until 0.5 C/cm of total charge was accumulated on the anode wires. The chamber performance was not degraded with water levels above 0.16%, see Figure 4.

With the water vapor level below 0.16%, a dark current appeared on the anode wires after very brief irradiation, (i.e., 10^{-4} C/cm). The chamber was revived by increasing the water vapor in the gas mixture. As the water level increased, the dark current effect decreased and completely disappeared when the water vapor level reached 0.66%. At no time did the pulse height distribution show any significant signs of degradation. A similar behavior for propane with 0.2% water vapor has been observed [8] by the Argus experiment.

Pulse Height Spectra and Gain

The pulse height distributions observed in CO_2 dominant gas mixtures does not show the simple behavior found in Argonhydrocarbon mixtures. Rather than the singly peaked spectrum of the latter, the former shows a clear double-peaked structure. Figure 5 shows three examples using the same voltage conditions in the chamber in each case: (a) pure CO_2 ; (b) CO_2 :ethane::92:8;



Fig. 4. The relative gas gain as a function of total charge accumulated for $CO_2/i - C_4H_{10}$ adding various amounts of water vapor. The chamber performance was stable until the water vapor level was reduced to 0.1%. At that level a self-sustaining discharge (dark current) was observed. The chamber was revived by increasing the water level.



Fig. 5. The pulse height spectra for a) pure CO_2 b) CO_2/C_2H_6 (92:8) and c) CO_2/C_2H_6 (86:14) show the double-peak structure.

and (c) CO_2 :ethane::86:14. In case (a) the two peaks are almost merged, while in (b) and (c) they are well separated. If higher fields are applied, the higher peak becomes more populated.

The double peak structure was investigated by inserting a small, well collimated and movable ⁵⁵Fe source in the chamber next to the cell, see Figure 6. This source provided a beam of ionizing radiation with width of about $\sigma = 0.9$ mm in the drift direction within one sense wire's sensitive volume. The gas fill was CO₂-isobutane-water.

When the source was irradiating the sense wire plane, the pulse height distribution showed a single peak (see Figure 7a) corresponding to the higher gain value found in the previous case (Figure 5b). When irradiating the drift region, it produced a single peak which corresponded in gain to the lower gain peak in Figure 5b, as is illustrated in Figure 7b. It is clear that the



Fig. 6. Illustration of the setup to study the double peak structure. A collimated ⁵⁵Fe source was mounted at the end of a movable shaft so that different regions of the cell could be irradiated.

higher drift fields near the sense wires are responsible, and from the ratio of integrated counts in the peaks, we can deduce that the higher gain region extends to about 1 cm from the sense wires.



Fig. 7. The ⁵⁵Fe pulse height spectrum found when the collimated source was irradiating a) the sense wire region and b) the drift field region.

It has been suggested [9] that the different behavior is caused by recombination of the primary ionization [10], which occurs when the drift field is not strong enough to separate the initial electron and positive ion clouds, and thus allows recombination to occur. This hypothesis explains most of the observed behavior of the peaks.

Conclusions

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The use of CO₂, mixed with 8% isobutane or ethane, as a drift chamber gas for the SLD-CDC has been shown to be inadvisable, even though excellent position resolution can be obtained, because the mixture is unstable to radiation damage. The addition of isopropanol or water can extend the useful life of these mixtures so that integrated charge collections of order 1 C/cm are permissible. Although the isopropanol admixture may be marginally preferable as far a lifetime is concerned, water would be excellent for chambers with alcohol soluble components.

The pulse height spectrum seen with low hydrocarbon admixtures shows two peaks in the SLD-CDC geometry. This behavior is expected not to compromise operation, even for dE/dxmeasurements, because the pulse height can be correlated with position in the sensitive region of the cell.

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