IL NUOVO CIMENTO **44 C** (2021) 70
DOI 10.1393/ncc/i2021-21070-1

COMMUNICATIONS: SIF Congress 2020

Study of the performance of the RPC detector with new eco-friendly gas mixtures

G. PROTO

Università degli Studi di Roma Tor Vergata e INFN - Roma, Italy

received 14 January 2021

Summary. — The Resistive Plate Chambers (RPC) are very fast gaseous detectors with an excellent time resolution, mainly used as triggers in the large experiments. The present gas mixture for RPCs which work in avalanche mode, has a high Global Warming Potential, mainly due to the presence of $C_2H_2F_4$. If some additional restrictions on greenhouse gas emissions are imposed or if it becomes too expensive, it will be impossible to be used anymore. For this reason the search for a suitable alternative gas mixture is crucial. In this work, the detector performance with different alternative gas mixtures is presented.

1. – Introduction

The Resistive Plate Chambers (RPC) [1, 2] standard gas mixture, composed by $C_2H_2F_4$, i-C_4H_{10} and SF_6, has a high Global Warming Potential (GWP) of about 1465, mainly due to $C_2H_2F_4$ as the main component [3]. An alternative eco-gas mixture should be able to maintain good avalanche saturation properties and streamer-avalanche separation over a large electric field range. In principle the new generation of RPCs planned for the ATLAS Phase-II upgrade [4], due to the new layout and the development of new Front-End electronics, could work with alternative mixtures with lower GWP [5-7], based on $C_3H_2F_4$ (HFO1234ze), CO_2, $i-C_4H_{10}$ and SF_6. On the other hand, for the RPCs already installed in the experiment, an eco-gas mixture is still to be defined. With HFO-based mixtures the avalanches are wider, they carry more charge and the transition to streamers passes through multi-avalanches events with a high-charge content. A higher charge per hit generated inside the detector could worsen the rate capability and the ageing of the detector. Less HFO means less fluorine molecules in the mixture and a slower detector ageing. The goal of this work is to study the effect of the reduction of HFO fraction in eco-friendly gas mixtures candidates.

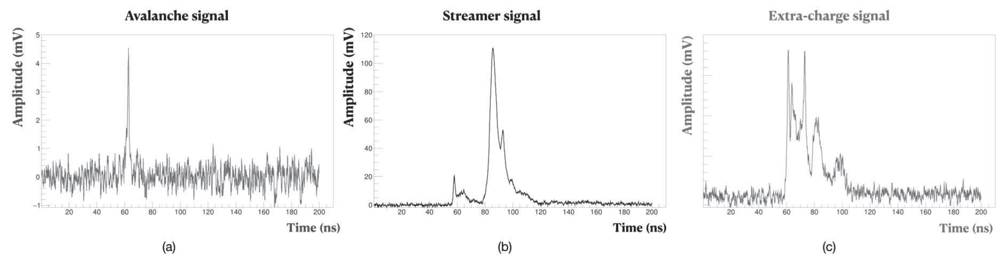

Fig. 1. – (a) Avalanche signal. (b) Streamer signal. (c) Extra-charge signal.

2. – Experimental setup and analysis parameter definition

An RPC (57×10 cm^2) with 2mm gas gap and two 1.8 mm thick electrodes has been used for this test. The prompt-induced signal is read out on both sides of a single strip line without signal amplification (oscilloscope bandwidth of 3 GHz and 10 $\frac{Gs}{s}$ sampling velocity) in a time window of 200 ns. The ionic signal is read out on a resistance of about 10 kΩ on the ground graphite electrode over a time window of 100 μs. A signal is considered efficient if it is above an amplitude threshold, defined as the 5*Root Mean Square (RMS) of the background amplitude distribution (~ 1.5 mV). The prompt and the ionic charge are measured for each acquired waveform and are defined as the integrated charge in the whole time window acquired. The charge in HFO-based mixtures takes an important contribution from multi-avalanches events, therefore a separation between those signals and streamer signals has been established. A streamer is a signal with a charge content bigger than 30 pC and a time over threshold bigger than 30 ns (fig. 1(b)). An extra-charge event, shown in fig. 1(c), has been defined as a signal with a charge content between 5 and 30 pC and a time over threshold more than 10 ns. The other signals have been considered as avalanche signals (fig. 1(a)).

3. – Measurements strategy and experimental results

In this study the performance of the RPC with different gas mixtures are reported. The comparison between gas mixtures has been performed at the knee voltage (V_{knee}) + 200 V, where the V_{knee} is defined for convention as the voltage value at which the efficiency reaches the absolute 90%. Two series of measurements have been performed. In the first one the i-C_4H_{10}/SF_6 ratio has been kept constant, while the HFO/CO_2 fraction has been changed. In the second one the HFO/SF_6 ratio is fixed and the CO_2/ i-C_4H_{10} fraction varies.

3·1. *Performance with HFO1234ze/CO_2 variable ratio.* – In this set the i-C_4H_{10}/SF_6 concentrations are fixed at the ratio 5/1, while the HFO1234ze concentration is lowered in favour of CO_2. The mixtures studied are: HFO1234ze/CO_2 =25/69, 20/74, 15/79, 10/84 and 5/89. The results are shown in figs. 2 and 3 and are summarized in table I. The reduction of HFO produces a decrease of the operating voltage of about 500 V every 5% of HFO reduction. The absolute efficiency value is higher than 90% (increasing with the increase of HFO content) and there is no gain in terms of avalanche-streamer/extra-charge separation from 15% to 25% of HFO (fig. 2). The prompt and ionic charges do not vary when HFO concentration was increased from 15% to 25% (fig. 3).

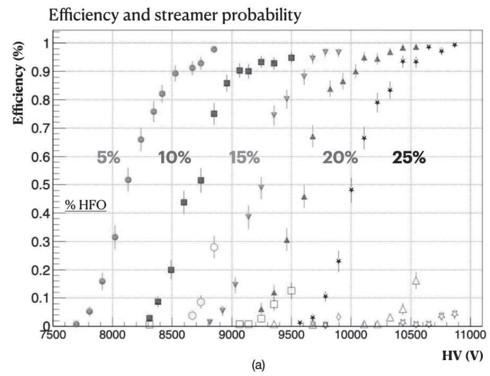

Fig. 2. – (a) Efficiency (blank markers) together with streamer probability (empty marker) as a function of the high voltage. (b) Efficiency (blank markers) and extra-charge probability (empty markers) as a function of the high voltage. The i-C_4H_{10}/SF_6 ratio is fixed at the ratio 5/1 and the HFO1234ze/CO_2 fractions under study are: 5/89 (points), 10/84 (squares), 15/79 (tip-down triangles), 20/74 (tip-up triangles), 25/69 (stars).

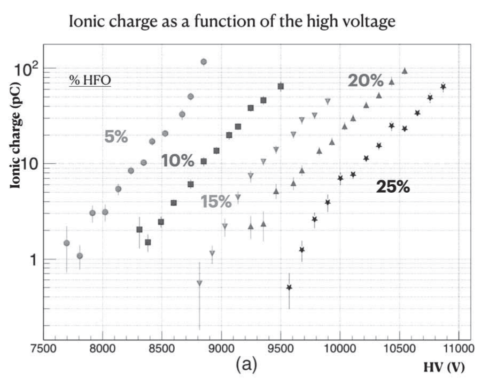

Fig. 3. – (a) Ionic charge as a function of the high voltage. (b) Prompt charge as a function of the high voltage. The i-C_4H_{10}/SF_6 ratio is fixed at 5/1 and the HFO1234ze/CO_2 fractions under study are: 5/89 (points), 10/84 (squares), 15/79 (tip-down triangles), 20/74 (tip-up triangles), 25/69 (stars).

3˙2. *Performance with the CO_2/i-C_4H_{10} variable ratio.* – In this set of measurements the HFO/SF_6 ratio is fixed at the ratio 5/1 and the CO_2/i-C_4H_{10} fraction varies. The mixtures studied are: CO_2/i-C_4H_{10}= 89/5, 84/10, 79/15. The results are summarized in Table II. The increase of i-C_4H_{10} does not change the operating voltage, but it decreases significantly the streamers and extra-charge fractions. In addition, the separation between avalanche and streamer/extra charge appearance is improved and the prompt and ionic charge are reduced. A percentage of i-C_4H_{10} more than 7% make the mixture flammable.

Table I. – *Variables under study at the high voltage reference value which is equal to* V_{knee}+ *200 V. The i-*C_4H_{10}/SF_6 *ratio is fixed at the ratio 5/1 and the HFO1234ze/*CO_2 *fractions under study are: 5/89, 10/84, 15/79, 20/74, 25/69.*

HFO %	V_{knee} (kV)	Efficiency @plateau	Streamer (%)	Extra charge (%)	Prompt charge (pC)	Ionic charge (pC)
5	8.5	93%	8.5	46	11.5	50
10	9	93.5%	3	41	7	38
15	9.5	96.5%	0.6	31	4.3	32
20	9.9	98%	0.8	30	4	31
25	10.4	98%	0.7	37	5	34
STD MIX	10.3	98%	0	0	3	25

Table II. – *Variables under study at the high voltage reference value which is equal to* V_{knee}+ *200 V. The HFO1234ze/*SF_6 *ratio is fixed at 5/1. The i-*C_4H_{10}/CO_2 *fractions under study are: 5/89, 10/84, 15/79.*

i-C_4H_{10} %	V_{knee} (kV)	Streamer (%)	Extra charge (%)	Prompt charge (pC)	Ionic charge (pC)
5	8.5	8.5	46	11.5	50
10	8.45	3.5	46	7.3	37
15	8.4	1	35	5.3	30

4. – Conclusions

In this work a systematic performance study of a small size RPC operated with four-components gas mixtures $C_3H_2F_4/CO_2$/i-C_4H_{10}/SF_6 with an HFO content lower than 25% has been performed. The mixtures under study have a Global Warming Potential of about 225 (due to the presence of SF_6). The decrease of HFO in the HFO/CO_2 ratio produces a reduction of the operating voltage and there is not a great gain in terms of avalanche-streamer/extra-charge separation and charge delivered inside the detector when the HFO fraction is increased from 15% to 25%. The smaller amount of fluorine molecules inside the gas mixture could reduce the ageing effects and a higher CO_2 content increase the i-C_4H_{10} flammable limit. The increase of i-C_4H_{10} gives a lot of benefits in terms of avalanche-streamer/extra charge separation and in terms of charge content. The mixture with an HFO fraction equal to 15% gives the most promising improvement also in terms of intrinsic efficiency, which is greater than 96%.

REFERENCES

[1] Santonico R. and Cardarelli R., *Nucl. Instrum. Methods*, **187** (1981) 377.
[2] Camarri P. *et al.*, *Nucl. Instrum. Methods*, **414** (1998) 317.
[3] https://ec.europa.eu/clima/policies/.
[4] The ATLAS Collaboration, *Technical Design Report for the Phase-II Upgrade of the ATLAS Muon Spectrometer*, CERN-LHCC-2017-017 (ATLAS-TDR-026 17-28, 101-155) 2016.
[5] Liberti B. *et al.*, *J. Instrum.*, **11** (2017) C09012.
[6] Guida R., Capéans-Garrido M. and Mandelli B., *J. Instrum.*, **11** (2016) C07016; Abbrescia M. *et al.*, *J. Instrum.*, **11** (2016) C09018.
[7] Cardarelli R. *et al.*, *J. Instrum.*, **9** (2014) C11003.