IL NUOVO CIMENTO **45 C** (2022) 128
DOI 10.1393/ncc/i2022-22128-2

Communications: SIF Congress 2021

Study of the performance of the Resistive Plate Chambers with ecological gas mixtures

G. Proto[1][2]

[1] *INFN, Sezione di Roma Tor Vergata - Roma, Italy*
[2] *Dipartimento di Fisica, Università degli Studi di Roma Tor Vergata - Roma, Italy*

received 30 January 2022

Summary. — The Resistive Plate Chambers (RPC) are very fast gaseous detectors with an excellent time resolution, mainly used with the function of triggering on muons at particle physics experiments. The present gas mixture for RPCs which work in avalanche mode has a high Global Warming Potential, mainly due to the presence of $C_2H_2F_4$. In order to work with an eco-friendly gas and to face the problem of availability of this component in the near future, the search for a suitable alternative gas mixture is crucial. In this work we present the results on the detector performance working with an eco-gas mixture.

1. – Introduction

The Resistive Plate Chambers (RPC) [1] standard mixture, composed by $C_2H_2F_4$, i-C_4H_{10} and SF_6, allows the operation of the RPCs in "saturated avalanche" mode over a large electric field range before streamers occur and with a modest charge content, granting high rate capability and the reduction of the detector ageing. This mixture has a high Global Warming Potential (GWP) of about 1450, which is the index which quantifies the greenhouse impact of a gas taken the CO_2 as a reference (GWP = 1). This is mainly due to its main component, the $C_2H_2F_4$. The additional restrictions on the greenhouse gas emissions [2] and, consequently, the difficulty in finding this gas due to a reduction in the industrial demand, makes it problematic to use it in the next future. An alternative gas should maintain the excellent performance obtained with the standard one.

In this work, the $C_2H_2F_4$ is replaced with a mixture of $CO_2/C_3H_2F_4$ (HFO1233ze) which has a GWP of few units. The i-C_4H_{10} and SF_6 are the other components of the gas. This mixture has a GWP $\sim$ 200. On the other hand, the gas density is lower if compared with the standard gas and this could affect the efficiency for thinner detectors. The intrinsic efficiency depends on the gas mixture density and on the gas gap width. The thicker the gap and the higher the density, the higher the efficiency, since both define the detector effective active area. In table I the efficiency value for different gas gaps width operating with the standard gas are shown [3].

Table I. – *Intrinsic detection efficiency with the standard gas mixture for different gas gap width.*

Gas gap width	HV (V)	Efficiency
2 mm	10290	99%
1 mm	6560	98.5%
0.5 mm	3900	85%

In this work, the detection efficiency, the streamer probability and the charge delivered inside the gas is studied on a RPC with a gas gap of 1 mm.

2. – Experimental setup and analysis parameter definition

An RPC ($57 \times 10\,\text{cm}^2$) with 1 mm gas gap and two 0.8 mm thick electrodes have been used for this test. The prompt induced signal is read out on both sides of a single strip line without signal amplification. One of the two signals is acquired with the maximum oscilloscope sensibility to optimize the efficiency measurement, while the other is acquired with a variable scale to study the streamers. The oscilloscope has a bandwidth of 3 GHz and a sampling velocity of 10 Gs/s and the time window acquired is 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. The trigger consists of three 2 mm gas gap RPCs. 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 which is equal to 0.8 mV. The prompt and ionic charge are measured for each acquired waveform and are defined as the integrated charge in the whole time window acquired.

3. – Measurements strategy and experimental results

In this study, the performance of the RPC with a gas mixture composed of $CO_2/C_3H_2F_4$/i-C_4H_{10}/SF_6 is reported. The mixture is mainly composed of HFO ($\sim$90/95%) in order to test the active target available and make the comparison with the $C_2H_2F_4$. The detection efficiency as a function of the high voltage is shown in fig. 1(a).

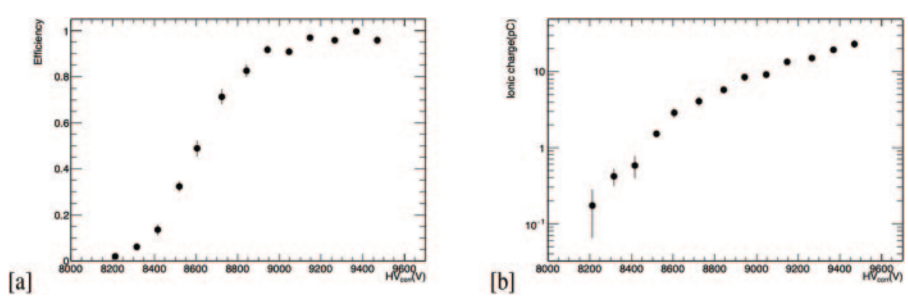

Fig. 1. – Efficiency (a) and ionic charge (b) as a function of the high voltage. The errors on the efficiency are calculated with the binomial formula.

TABLE II. – *Operating voltage, plateau efficiency, ionic and electronic charge at the 90% efficiency for the standard and ecogas mixtures.*

Gas mixture	Operating voltage (OP)	Efficiency @OP	Ionic charge @$\epsilon = 90\%$	Electronic charge @$\epsilon = 90\%$
Standard gas	6560	98.5%	8.5	0.51
Eco gas	9100	97.5%	8	0.8

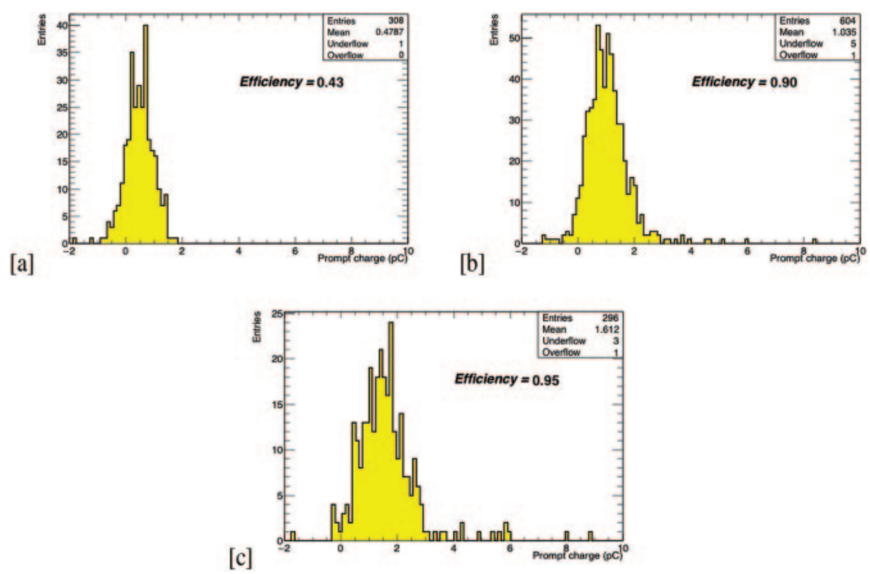

Fig. 2. – Total prompt charge distribution at $\epsilon = 43\%$ (a), 90% (b), 95% (c).

The efficiency plateau value at the operating voltage (9.1 kV) is about 97.5%, which is one percent less than that obtained with the mixture mainly composed of $C_2H_2F_4$. Streamers have not been observed.

The ionic charge as a function of the high voltage is shown in fig. 1(b). The ionic charge value at the operating voltage gives a good estimation of the total charge delivered inside the gas gap.

In the mixture mainly composed of HFO, the ionic charge at 9.1 kV is around 9 pC and the corresponding electronic charge is around 1 pC. If we compare these results with those obtained with the standard gas we obtain that the charges are comparable at the same efficiency value (90% taken as reference). The results are summarized in table II.

In fig. 2 the total electronic charge distributions obtained with the ecological mixture for different efficiency values (ϵ = 43%, 90% and 95%) are shown. These distributions show that the charge saturation effect, typical of the standard gas, can be reached also with a mixture mainly based on HFO.

4. – Conclusions

In this work, the performance of the Resistive Plate Chamber detector with 1 mm gas gap operating with an ecological gas mixture mainly based on HFO1234ze is shown. One of the issues moving from the standard gas to an eco-gas when the gas gap is in the millimeter range size is the reduction of the effective active target.

The results obtained on the efficiency, streamer probability and ionic/electronic charges measurements are:

- The efficiency plateau value is 97.5% with the ecogas, one percent less with respect to the standard gas
- The ionic and prompt charges at $\epsilon = 90\%$ in the two gas mixtures are comparable and equal respectively to 8 pC and 0.8 pC
- The total prompt charge in the eco-gas mixture shows the charge saturation also at high efficiency

These results will be taken as a reference for the further study that will be performed by increasing the CO_2 percentage inside the gas mixture. In this way, it will be possible to observe which is the minimum amount of HFO needed in this gas mixture in order to maintain good detector performance.

REFERENCES

[1] Santonico R. and Cardarelli R., *Nucl. Instrum. Methods*, **187** (1981) 377.
[2] `https://ec.europa.eu/clima/policies/`.
[3] Aielli G. *et al.*, *JINST*, **11** (2016) P07014.