Effect of water vapor on the performance of glass RPCs in avalanche mode operation

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Abstract: We studied the effect of water vapor on the performance of glass Resistive Plate Chambers (RPCs) in the avalanche mode operation. Controlled amount of water vapor was added to the RPC gas mixture that has C$_2$H$_2$F$_4$ as the major component. The deterioration in the performance of RPC was observed while operating with the wet gas and recovered after switching to the standard gas.

Keywords: Large detector systems for particle and astroparticle physics; Particle tracking detectors (Gaseous detectors)

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1 Introduction

The India-based Neutrino Observatory (INO) collaboration has proposed to build a 50 kiloton magnetized Iron Calorimeter (ICAL) to precisely measure the neutrino oscillation parameters. The collaboration has chosen $2 \times 2 \text{m}^2$ size glass Resistive Plate Chambers (RPCs) as the active detector elements and is going to deploy 28,800 of them in the ICAL detector [1]. The RPCs will be operated in the avalanche mode with an optimized gas mixture of $\text{C}_2\text{H}_2\text{F}_4/\text{iso-C}_4\text{H}_{10}/\text{SF}_6 = 95.2/4.5/0.3$ [2]. The experiment is expected to run for more than 10 years in order to record statistically significant number of neutrino interactions to measure the neutrino mass hierarchy. Therefore, long-term stability and performance of the RPCs over the duration of the experiment are of prime concern.

About 200,000 liters of gas is going to be circulating in the RPCs during the experiment. The gas lines of about 135 km in total length are going to supply (receive) gas to (from) the RPC detectors. In spite of stringent QC during the RPC gas gap making or gas lines plumbing, it is impossible to prevent ambient air or water vapor entering into the gas circuit over these long periods of time. The contaminants are known cause for serious degradation in the performance or permanent damage of the RPCs [3–5].

Considering the possibility of severe repercussions in the mammoth ICAL detector, a systematic study of this problem was undertaken. Two glass RPCs of $30 \times 30 \text{cm}^2$ size were fabricated and were simultaneously operated with standard gas mixture in one and with gas mixture along with controlled amount of water vapor in the other. A common cosmic ray muon telescope was set up for studying both the RPCs. Ambient parameters such as temperature and relative humidity (RH) as well as RPCs operating and performance parameters such as currents, efficiencies, singles rates, signal charges and time resolutions for cosmic ray muon detection were systematically recorded throughout the experiment. It was observed that significant deterioration occurred in the performance of RPC in which gas with water vapor was flown.
2 Experimental setup

The RPCs of $30 \times 30 \text{cm}^2$ size were fabricated using 3 mm thick float glass plates. The outer surfaces of the glass plates were coated with specially developed conductive graphite paint for the ICAL RPCs, which facilitated applying high voltage across the electrodes [6, 7]. Readout strips of 2.8 cm width were orthogonally mounted on the external surfaces of the RPCs by keeping 0.2 cm gap between the consecutive strips. The electrode and the readout strip were separated using a layer of mylar insulator.

A telescope was set up with three plastic scintillation counters to get a 3-fold (3F) coincidence for atmospheric muons. The dimensions of scintillation counters in length $\times$ width $\times$ thickness were $30 \text{ cm} \times 2 \text{ cm} \times 1 \text{ cm}$ (top), $30 \text{ cm} \times 3 \text{ cm} \times 1 \text{ cm}$ (middle), and $30 \text{ cm} \times 5 \text{ cm} \times 1 \text{ cm}$ (bottom). The block diagram of a stack of two RPCs and three telescope counters, and the electronic circuit setup is shown in figure 1. An optimized gas mixture of C$_2$H$_2$F$_4$/ iso-C$_4$H$_{10}$/SF$_6 = 95/4.5/0.5$ was flown through the RPCs using polyurethane tubes. The block diagram of the gas flow system is shown in figure 2.

![Figure 1](image_url)

**Figure 1.** Block diagram of the experimental setup developed for the studies.

3 Measurements and observations

3.1 Standard gas studies

The RPCs were operated with the standard gas at 10 SCCM rate and their currents, efficiencies and singles rates as a function of applied voltage were measured. The measured efficiencies of RPC1 and RPC2 as a function of applied voltage are shown in figure 3. The detectors showed greater than
Figure 2. Block diagram of the gas flow system.

Figure 3. Efficiencies of RPC1 and RPC2 as a function of applied voltage.

95% efficiency on the plateau. The measured signal charges and time resolutions of the detectors are shown in figure 4. At the operating voltage of 12.2 kV, the signal charges of RPC1 and RPC2 are found to be 0.99 pC and 1.24 pC, and the time resolutions are 2.8 ns and 2.3 ns, respectively.

Then, the RPCs were operated at 12.2 kV and their performances monitored for 32 days. The RPCs efficiencies, singles rates and operating currents in this time period are shown in figure 5. Their performances were stable throughout the period.

3.2 Wet gas studies

The water vapor was added to RPC1 gas mixture using a water bubbler, as shown in figure 2. The amount of water vapor in the gas mixture was measured in a controlled way using a RH sensor and it is shown in figure 6. Throughout these studies, RPC2 was continued with the standard gas flow itself and was a reference detector. Then, the performances of both the detectors were monitored continuously.
Figure 4. Signal charges: (a) and (b), and time resolutions: (c) and (d) of RPC1 and RPC2, respectively, with the standard gas operation at 12.2 kV.

Figure 5. (a) Efficiencies, (b) singles rates and (c) currents of both the RPCs with the standard gas operation for 32 days.

Figure 6. The quantity of water vapor addition to the RPC1 for 10 SCCM and 30 SCCM gas flow rates.
With the wet gas operation for a few days, the efficiency and singles rate of RPC1 degraded to 0% and 1 Hz, respectively. The currents drawn by the detector increased gradually with time. The efficiency, singles rate and current drawn by RPC1 during the wet gas operation in comparison to RPC2 operated with the standard gas is shown in figure 7.

Figure 7. The (a) efficiencies, (b) singles rates and (c) currents of RPC1 with the wet gas operation, and those of RPC2 with the standard gas operation.

The signal charge of RPC1 became smaller (0.36 pC) with the wet gas operation, whereas that of RPC2 with standard gas operation (1.19 pC) remained similar to its measured value shown in figure 4b (1.24 pC). The signal charge distributions of RPC1 with wet gas and RPC2 with standard gas operations are shown in figures 8a and 8b, respectively.

The timing distribution of RPC1 with the wet gas operation deteriorated as shown in figure 8c. Whereas, that of RPC2 with the standard gas operation (1.19 pC) remained similar to its measured value shown in figure 4d (2.3 ns).

Figure 8. Signal charge of: (a) RPC1 with the wet gas operation and (b) RPC2 with the standard gas operation, and time resolution of: (c) RPC1 with the wet gas operation and (d) RPC2 with the standard gas operation.
3.3 Recovery studies

RPC1 was operated with the wet gas at various flow rates and the deterioration in the detector’s efficiency was observed as a function of time. It was observed that higher the flow rate, faster the deterioration as shown in figure 9a. The detector was operated with the wet gas at 0% efficiency for a day and then switched to the standard gas. Then, the efficiency of detector recovered to greater than 95% in less than an hour as shown in figure 9b.

![Figure 9](image-url) (a) The deterioration in efficiency of RPC1 with the wet gas operation at various flow rates and (b) its recovery with the standard gas operation.

4 Discussion and summary

The effect of water vapor on the performance of glass RPC in the avalanche mode operation was studied. We used the gas mixture $C_2H_2F_4/iso-C_4H_{10}/SF_6 = 95/4.5/0.5$ throughout the studies. The detector showed greater than 95% efficiency with the standard gas operation, its signal charge and time resolution were 0.99 pC and 2.8 ns, respectively. The detector’s efficiency decreased to 0% after a few days of operation using a gas mixture with a water vapor contamination larger than 1000 ppm (1110 ppm is equal to 7.25% of RH). Its signal charge became 0.36 pC and timing distribution deteriorated. The RPC was operated at 0% efficiency with the wet gas for a day and then switched to standard gas, recovering an efficiency greater than 95%. Therefore, it indicates that no damages occurred to the inner surfaces of the RPC electrodes.

These results are similar to the performance of type III chambers discussed in [3]. In the studies, the RPCs were operated in the streamer mode. If the RPCs were operated with higher level of water contamination (> 1000 ppm), they stopped generating the signals after a short period of time and recovered fully after returning to dry gas. In the present studies, we could reproduce the similar performance of the RPCs in the avalanche mode operation.

In the case of type I chambers in [3], the RPCs were operated with about 1000 ppm of water vapor contamination. After a month time of operation, the performance of RPCs deteriorated and permanent damages to the electrodes were observed. For the avalanche mode operation, the signal discharges in RPC are smaller compared to the streamer mode operation. Therefore, similar permanent damages to the electrodes can be expected to occur after operating the RPCs for several months in the avalanche mode with lower level of water vapor contamination.
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