Ageing studies of Glass RPC in avalanche mode operation

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Introduction

The India-based Neutrino Observatory (**INO**) collaboration got approved to build a **50 kton** magnetized Iron Calorimeter (ICAL). Main aims of this experiment are to precisely measure the atmospheric neutrino oscillation parameters θ_{13}, θ_{23} and to determine the ordering of neutrino masses.

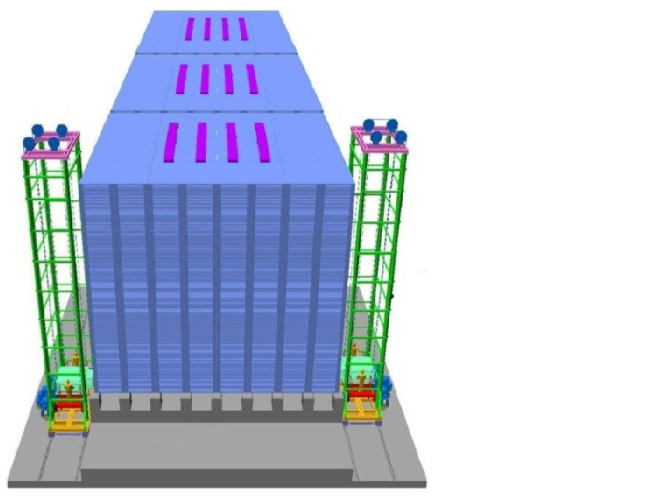

Figure 1: **The layout of three modular form of INO-ICAL detector.**

Resistive Plate Chamber (RPC)

The active elements in **ICAL** detector are glass Resistive Plate Chambers (**RPCs**), which are parallel plate gaseous detectors and that work on the ionization principle.

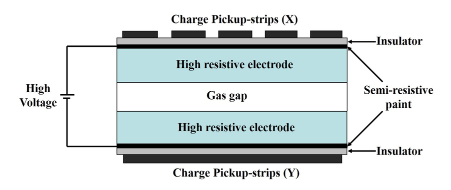

Figure 2: **Resistive Plate Chamber.**

Motivation

- The INO collaboration has chosen RPCs made up of float glass electrodes of 2 m $\times$ 2 m in area as the active detector elements and is going to deploy 28,800 of them in the ICAL detector. The RPCs will be operated in the avalanche mode with an optimized gas mixture of $HFC - R134a/iso - C_4H_{10}/SF_6 = 95/4.5/0.5$ [1]. The experiment is expected to run for more than 10 years in order to record statistically significant number of neutrino interactions for the confirmation of atmospheric neutrino oscillation. Hence, long term stability and performance of the RPCs over the duration of the experiment is of prime concern.
- About 200,000 liters of gas is going to be circulating in the RPCs during the experiment. The gas lines running into about 135km in total are going to be 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 RPCs. Considering the severe repercussions in the mammoth ICAL detector, a systematic study of this problem was undertaken.

Experimental setup

Two RPCs (*viz.*, **RPC1** and **RPC2**) of 30 cm $\times$ 30 cm in size were fabricated using 3 mm thick float glass plates that are procured from Saint-Gobain, Sriperumbudur, Tamil Nadu, India. A gas mixture of $HFC - R134a/iso - C_4H_{10}/SF_6 = 95/4.5/0.5$ was flown through the RPCs using polyurethane tubes. The block diagram of gas flow system is shown in Figure 3(a). A common telescope was set up with three plastic scintillation counters to get a 3-fold coincidence. The dimensions of the scintillation counters in length $\times$ width $\times$ thickness are 30 cm $\times$ 2 cm $\times$ 1 cm (top), 30 cm $\times$ 3 cm $\times$ 1 cm (middle), and 30 cm $\times$ 5 cm $\times$ 1 cm (bottom). The detectors were operated in avalanche mode. The water vapor was added to the RPC1 by passing the gas mixture through the water bubbler as shown in Figure 3(a). The block diagram of the stack of two RPCs and three telescope counters is shown in Figure 3(b) and the experimental setup is shown in Figure 3(c).

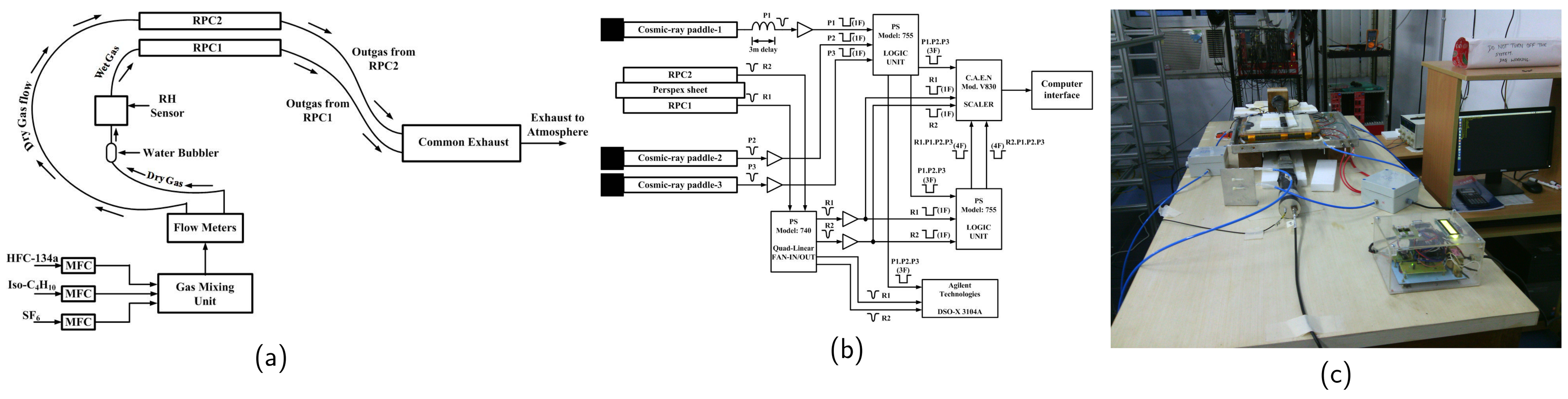

Figure 3: **(a) Block diagram of the gas flow system, (b) block diagram of the experimental setup and (c) experimental setup.**

Results

Two glass RPCs were simultaneously operated with dry gas mixture in one and gas mixture along with controlled and calibrated amount of water vapor in the other. Significant degradation was observed in the performance of RPC in which gas with water vapor was flown. The detailed results are summerized here.

Basic performance studies

The detectors were operated with 10 SCCM flow rate and the performances were as shown in the figures on the right. Both the detectors were shown >95% efficiency at the saturation level of their efficiency plateaus.

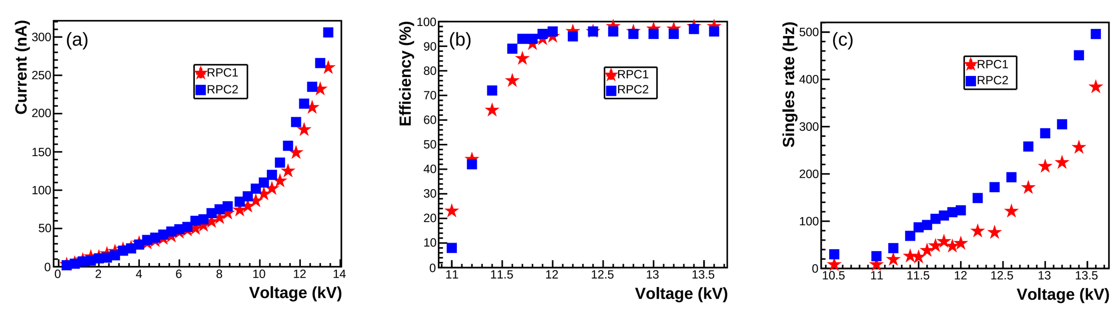

Figure 4: **(a) Voltage-current characteristics, (b) efficiency and (c) singles rate of RPC1 and RPC2 with respect to the applied voltage.**

Dry gas studies

The detectors were operated at 400 V upstream of the knee of their efficiency plateaus and the stability in their performances were monitored for about a month with dry gas flow. The results are shown in Figures 5, 6.

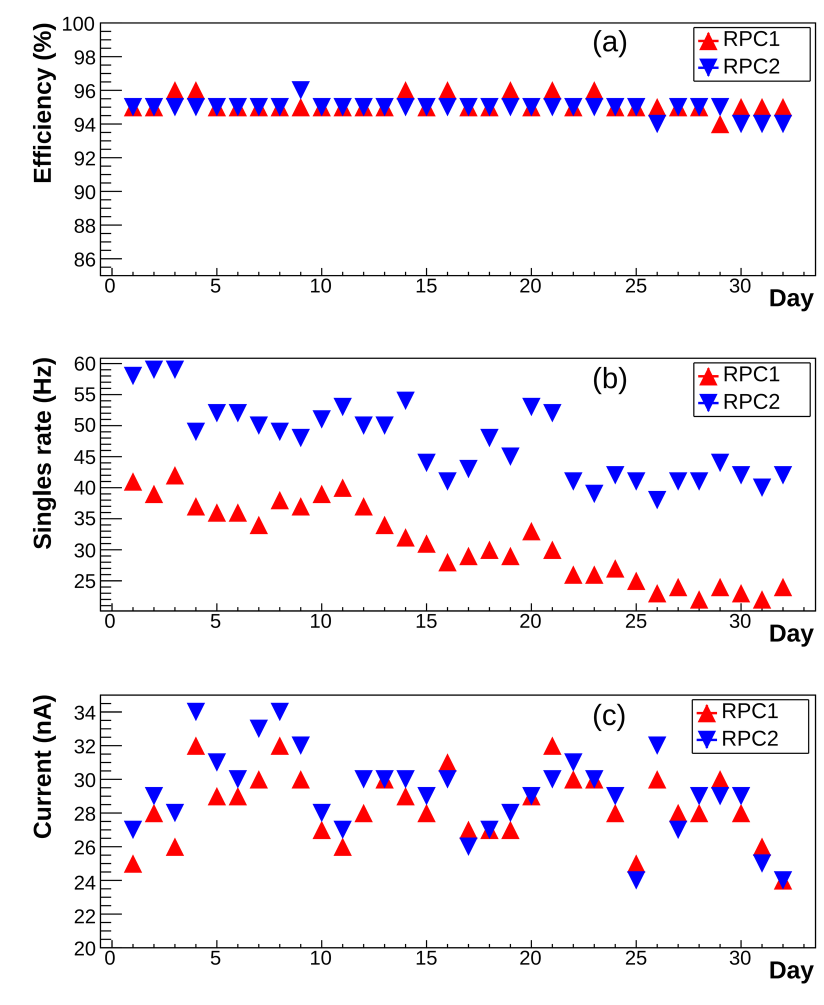

Figure 5: **Dry gas flow studies: (a) Efficiency, (b) singles rate and (c) current of RPC1 and RPC2 for 32 days.**

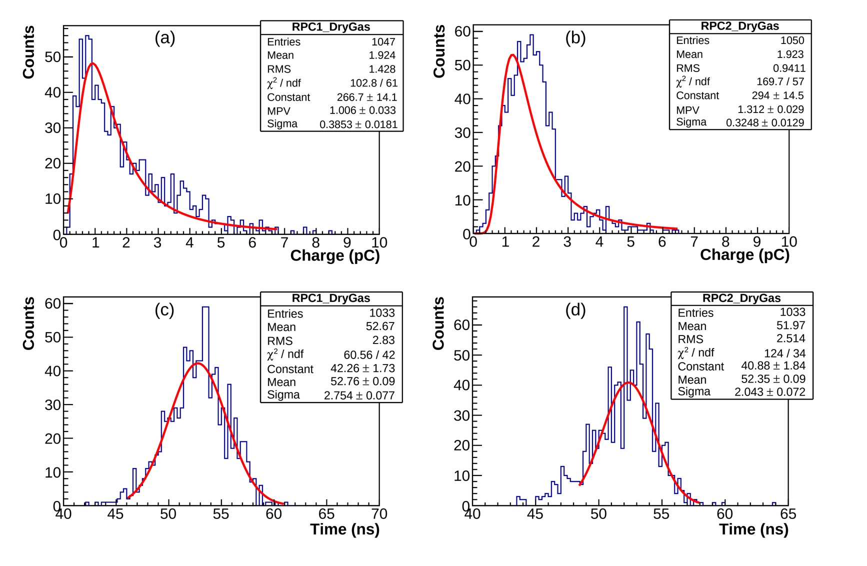

Figure 6: **Signal charge: (a) and (b); time resolution: (c) and (d) of the chambers RPC1 and RPC2, respectively, before the water vapor test.**

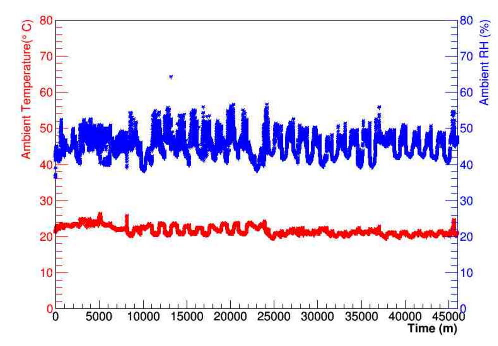

Figure 7: **Ambient RH (%) and temperaute during the dry gas studies.**

Wet gas studies

Then water vapor was added to RPC1 by passing the gas mixture via the water bubbler and the RPC2 was flown with dry gas itself. The performances of both the detectors were monitored. After few days of its operation with wet gas, the efficiency and singles rate of RPC1 dropped down to 0% and 1 Hz, respectively. The current increased gradually with time. The results are shown in Figure 8. There was a degradation observed in the signal charge and time resolution of the detector as shown in Figure 9.

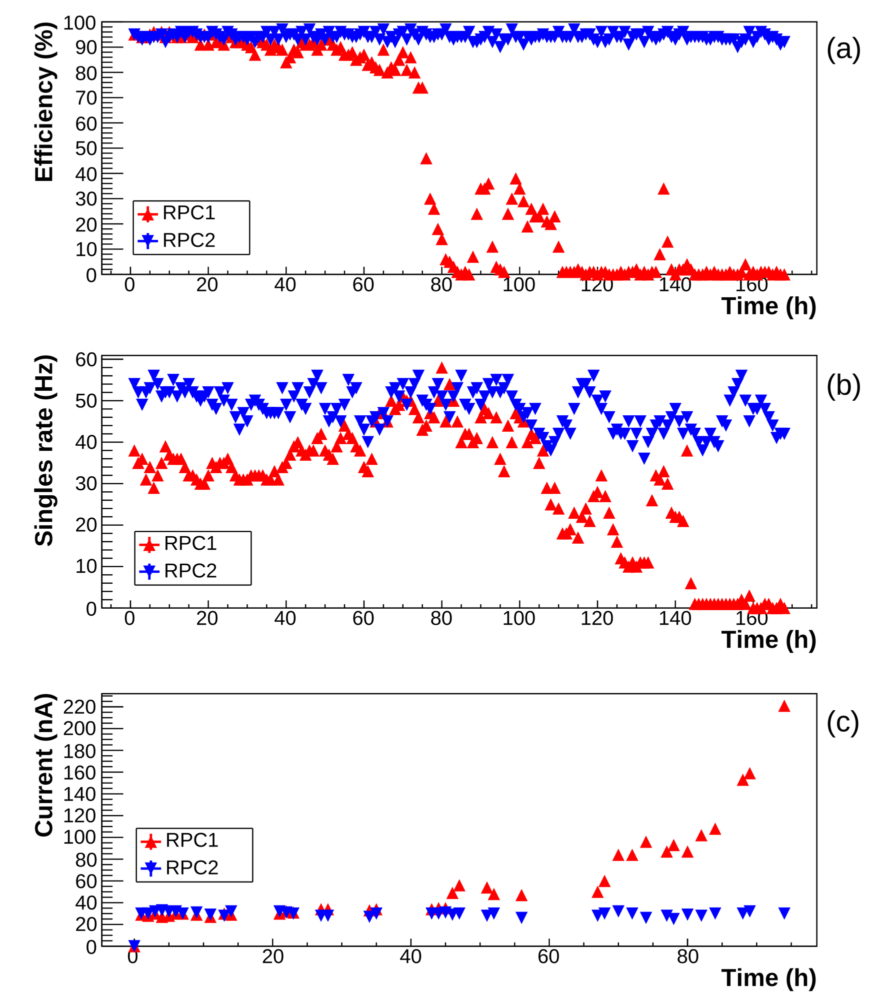

Figure 8: **(a) Efficiency, (b) singles rate and (c) current of RPC1, which was flown with wet gas, and RPC2, which was flown with dry gas.**

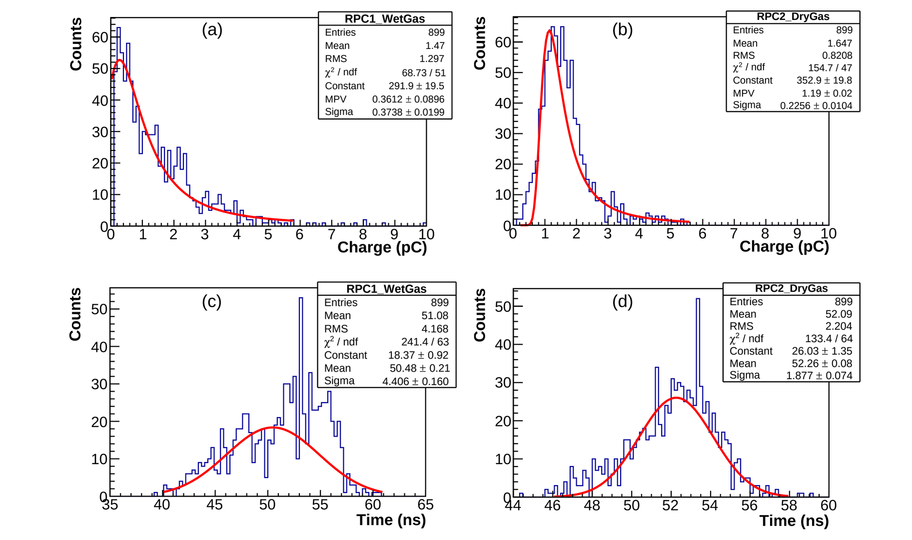

Figure 9: **(a) Signal charge and (c) time resolutions of RPC1, which was flown with wet gas; and (b) signal charge and (d) time resolutions of RPC2, which was flown with dry gas.**

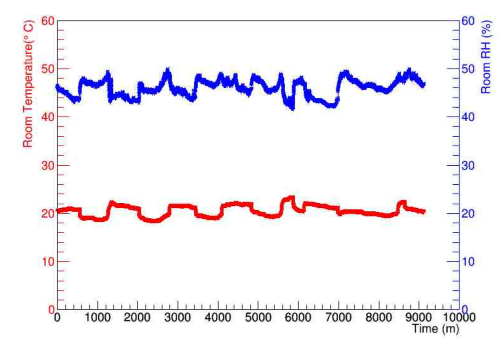

Figure 10: **Ambient RH (%) and temperatue during the wet gas studies.**

Flow rate and recovery studies

The water vapor was flown into RPC1 with different flow rates and its efficiency was monitored with respect to time. The degradation in efficiency was faster with the increase in gas flow rate. The detector was operated with 0% efficiency for a day and then swiched to dry gas flow. With the dry gas flow, the efficiency of detector was recovered to >95% within an hour. The results are shown in Figure 11. The wet gas RH (%) for different gas flow rates is shown in Figure 12. Then the detector was opened and the electrodes inner surfaces were scanned under "BRUKER ContourGT Optical Microscope". There was no serious damage observed on the electrode surfaces as shown in Figure 13.

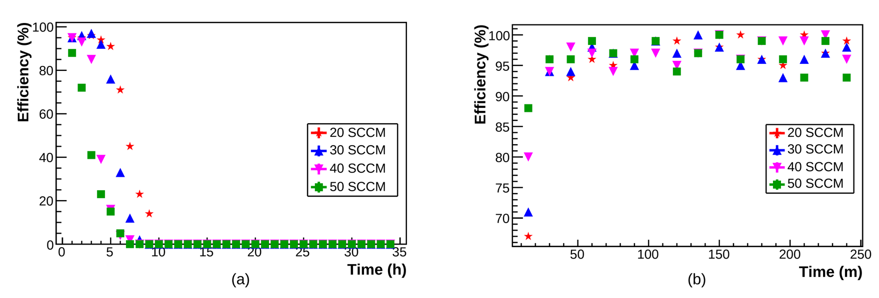

Figure 11: **Gas flow rate studies**

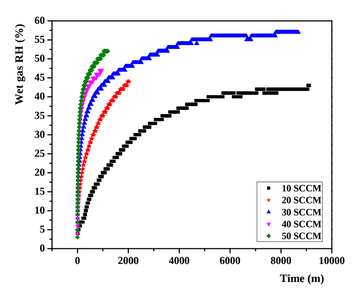

Figure 12: **Wet gas RH (%) for different gas flow rates.**

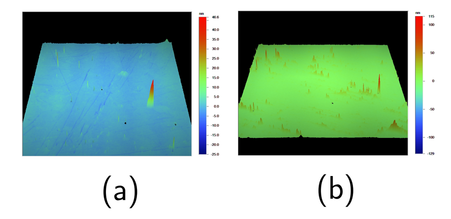

Figure 13: **Optical microscope images of (a) anode: Rq = 1.29 nm and (b) cathode: Rq = 2.68 nm. Here Rq is RMS roughness. The size of each scan is 50 μm x 50 μm.**

Long term studies

The long term studies were undertaken by flowing the water vapor into RPC2 with 30 SCCM gas flow rate. The detector was operated for 47 days with wet gas. Throughout the period, except few hours on the first day, the detector was operated at 0% efficiency and ~1 Hz singles rate. The current was gradually increased and got saturated at ~800 nA from day 6 onwards. The results are shown in Figure 14.

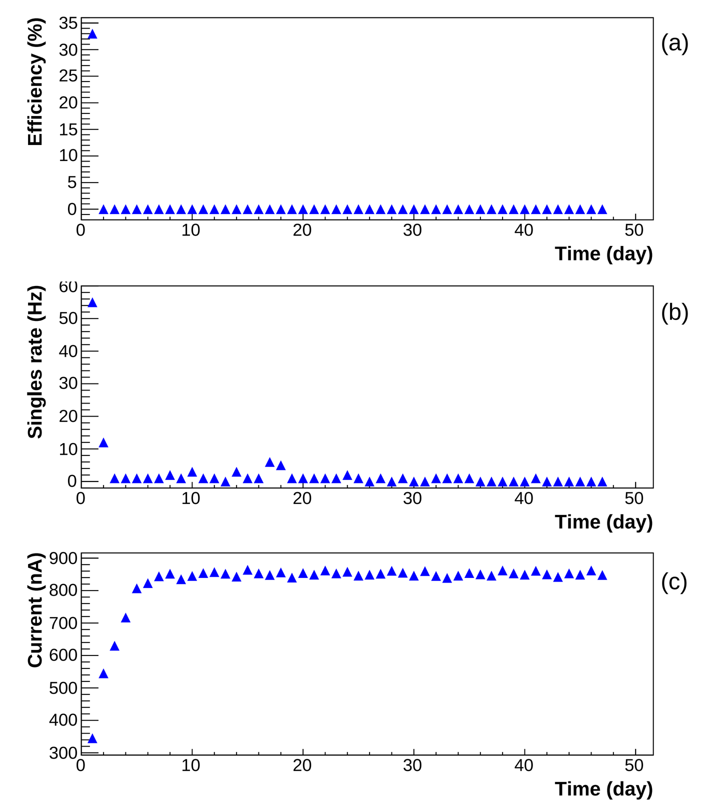

Figure 14: **(a) Efficiency, (b) singles rate and (c) current of the detector while operating it with wet gas for 47 days.**

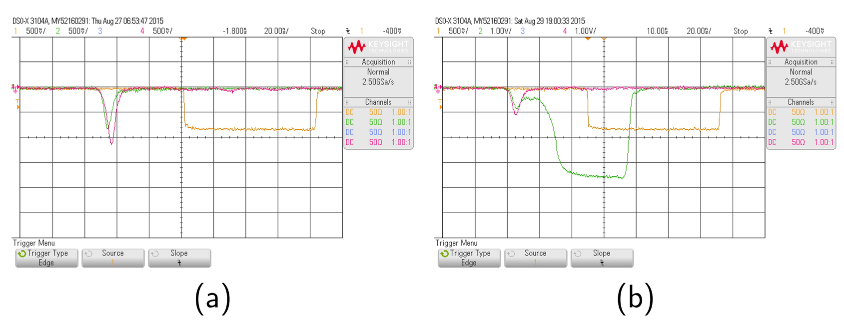

Figure 15: **Muon pulses from (a) RPC1 and RPC2 with dry gas flow; (b) RPC1 with wet gas flow and RPC2 with dry gas flow. In the figure, green pulse: from RPC1, magenta pulse: from RPC2 and yellow pulse: coincidence pulse from the telescope.**

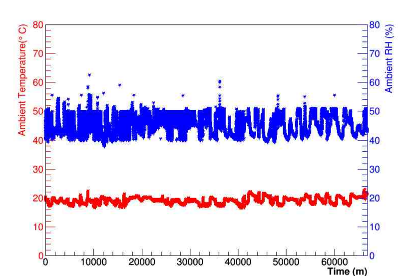

Figure 16: **Ambient RH (%) and temperature during the long term studies.**

Electrode analysis

To study, if any permanent damage to the inner surface of electrodes has occurred, as reported in [2, 3, 4], the RPC2 was opened after 47 days of operation with wet gas, and the surfaces were scanned under "BRUKER ContourGT Optical Microscope". On the anode comparatively thinner and more uniformly distributed spikes were observed, where as on the cathode larger diameter spikes were observed as shown in Figure 17.

Surface roughness studies

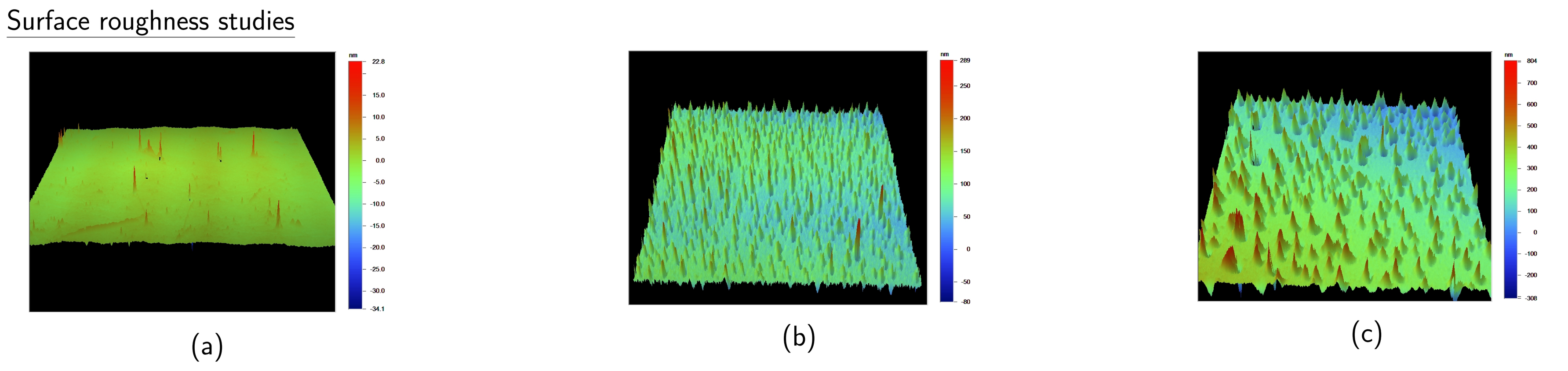

Figure 17: **Optical microscope images of (a) brand new glass: Rq = 0.97 nm, (b) anode: Rq = 21.61 nm and (c) cathode: Rq= 106.01 nm. Here Rq is RMS roughness. The size of each scan is 50 μm x 50 μm.**

Elemental composition

The elemental composition measurements of the electrode surfaces were obtained from the Energy-dispersive X-ray spectroscopy (EDS) technique. The composition of both the electrodes was identical to that of the brand new glass. The results in fractional atomic percent are summarized in Table 1.

(a)

Element	Area-1 (%)	Area-2 (%)
Silicon (Si)	17.24	17.69
Oxygen (O)	71.03	70.65
Sodium (Na)	8.70	8.21
Magnesium (Mg)	1.64	2.19
Calcium (Ca)	1.39	1.26

(b)

Element	Area-1 (%)	Area-2 (%)
Silicon (Si)	18.33	18.23
Oxygen (O)	70.14	70.26
Sodium (Na)	8.29	7.64
Magnesium (Mg)	1.87	2.28
Calcium (Ca)	1.36	1.59
Fluorine (F)	0	0

(c)

Element	Area-1 (%)	Area-2 (%)
Silicon (Si)	20.22	19.26
Oxygen (O)	69.6	69.41
Sodium (Na)	7.21	8.11
Magnesium (Mg)	1.53	1.78
Calcium (Ca)	1.45	1.44
Fluorine (F)	0	0

Table 1: **Elemental composition of (a) brand new glass, (b) anode and (c) cathode.**

References

[1] M. Salim et al., Experimental and numerical studies on the effect of SF_6 in a glass RPC, JINST 7 (2012) P11019.

[2] H. Sakai et al., Study of the effect of water vapor on a resistive plate chamber with glass electrodes, Nucl. Instr. and Meth. A 484 (2002) 153-161.

[3] T. Kubo et al., Study of the effect of water vapor on a glass RPC with and without freon, Nucl. Instr. and Meth. A 508 (2003) 50-55.

[4] S. S. Bhinde et al., On aging problem of glass Resistive Plate Chambers, Nucl. Phys. B (Proc. Suppl.) 158 (2006) 195-198.

Conclusions

Studies have been performed on the effect of water vapor on a glass RPC performance in avalanche mode operation. Two 30 cm $\times$ 30 cm size glass RPCs were operated with dry gas mixture in one and gas mixture along with controlled and calibrated amount of water vapor in the other. Significant degradation in the performance of RPC was observed in which gas with water vapor was flown. The degradation in RPC performance with different wet gas flow rates was studied. The efficiency of the detector went down to 0% in several hours of operation with wet gas. The detector was operated with wet gas flow at 0% efficiency for a day and then switched to dry gas flow and its efficiency got recovered to >95% within an hour. The detector was opened and scanned under optical microscope. There was no serious damage observed on the electrode surfaces. Then the second RPC was operated with wet gas for 47 days with 30 SCCM flow rate and monitored its performance. Its efficiency was 0% throughout the period, except few hours in the first day, and count rate was ~1 Hz. The current was increased gradually and got saturated at ~800 nA from day 6 onwards. The detector was opened and the inner surface electrode analysis was performed. Comparatively larger diameter spikes were observed on the surfaces of the cathode, where as on the anode thinner and uniformly distributed spikes were observed. The elemental composition of both the electrodes was identical to the brand new glass composition. Further investigations are going on to understand the causes of degradation.