Preliminary results on optimization of gas flow rate for RPCs

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The India-based Neutrino Observatory (INO) collaboration is planning to build a 50kt magnetized iron calorimeter (ICAL) detector using glass Resistive Plate Chambers (RPCs) as active detector elements. A stack of 12 glass RPCs of 1m x 1m in area was developed to study and characterize the performance of the RPCs. In this paper, we describe the study carried out for the optimization of gas flow using this prototype stack. The gas flow was stopped up to about 3 months and RPC parameters were studied during this period. Rate of increase in the RPC's strip rate and their dark current was found to be correlated with the leak rate of its gas gap. With leak free RPCs, reducing the refreshing frequency by a factor of 30 was found possible, without compromising on the RPC performances.

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1. Introduction

The proposed INO-ICAL [1] detector will have nearly 28800 RPCs of area 2m x 2m. The RPCs gap volume (200cm x 200cm x 0.2cm) is filled with a gas mixture which is the primary signal producing medium of the detector. The gas mixture also decides the mode of operation of the detectors viz., the avalanche mode and the streamer mode. Contaminants like air, moisture, HF and CF_3 etc., in the gas mixture lead to the deterioration of the detectors lifetime and its performance [2, 3, 4]. Contaminants enter through leaks or are produced due to the ionization process in the gap.To remove the contaminants, a total volume of about 200 m^3 of gas mixture has to be replaced with a fresh gas mixture continuously. The frequency of gas refreshment/recycling plays a vital role in the reduction of cost incurred for the gas and on the environment, especially in a project that is envisaged to last for a couple of decades. Typically, the gas mixture is refreshed every 24 hours [5, 6].

In this paper we present the preliminary results of our study of the optimization of the gas refreshing rate using the prototype stack. We also show the possibility of reducing the refreshing frequency by a factor of 30 and the effect of it on the performance of the RPCs.

2. The ICAL Prototype RPC Stack

The prototype RPC stack was developed at the Tata Institute of Fundamental Research (TIFR). The detector consists of 12 layers of 1mx1m RPCs with 32 strips on either readout electrodes labeled as X and Y, with the strips in the X plane orthogonal to the strips in the Y plane. The width of the strips is 2.8 cm and the gap between adjacent strips is 0.2 cm. The layers are stacked on top of each other, separated by a distance of 16 cm which amounts to a total stack height of 1.76 m. The efficiency of the layers is about 95% at an operating voltage of 9.9 kV and the time resolution is about 1.5ns in the avalanche mode. This stack has been in continuous operation for over three years serving as a cosmic-muon telescope. An overview of the detector set-up can be found in reference [5].

2.1 Gas Distribution

The gas mixing system can supply a mixture of up to four gases namely Argon, R134a (1,1,1,2 tetrafluoro ethane), Isobutane and SF_6 (Sulphur hexafluoride). Each RPC has 4 nozzles, 2 for the gas inlet and 2 for the outlet (Fig.1). These nozzles are connected to input/output gas line by help of flexible Tygon tubing. The exhaust gas from the RPCs outlet is collected individually through output bubblers into a manifold before venting it out to the atmosphere. The RPCs are operated in the avalanche mode with gas mixture R134a (95.2%), Isobutane (4.5%) and SF_6 (0.3%).

3.Initial Study

The objective of this study was to estimate the duration for which the RPCs can be operated with optimal performance, without the refreshment of the gas mixture. For this, the tygon tubes connecting the RPC gas nozzles to the gas distribution unit were bent and pressed using surgical pinchers, first at the outlets and next at the inlets (Fig. 1). Thus the gas volume of the RPC was isolated from the gas distribution system.
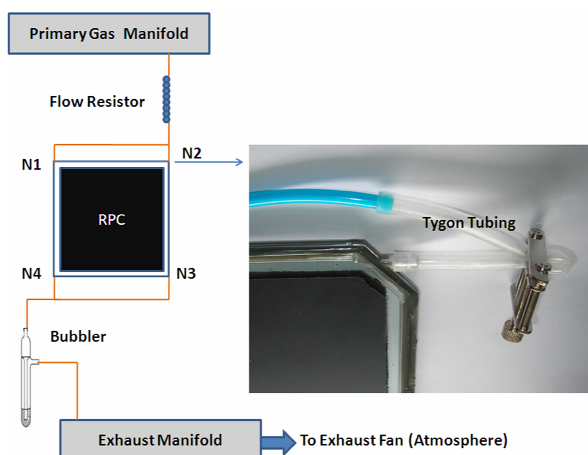

Fig. 1 The Schematic diagram of gas flow for RPC. In four corners at N1, N2, N3 and N4, nozzles are connected via Tygon tubing.
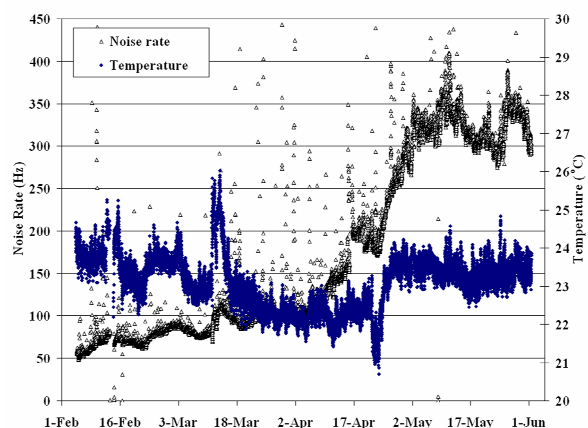

Fig. 2 The variation of the noise rate and the lab temperature during the period of sealing.

The first study was done by isolating a 1m x 1m RPC for a period 130 days after filling it with a fresh gas mixture. The operating parameters such as noise rate and current were monitored during this period along with laboratory temperature and relative humidity. The time-line plot of the strip noise rate and lab temperature is shown in Fig. 2. The strip noise rate plot shows two distinct regions. In the first 70 days the noise rate increases steadily and then shoots up almost by a factor of 6. The small fluctuations have a correlation with the temperature.
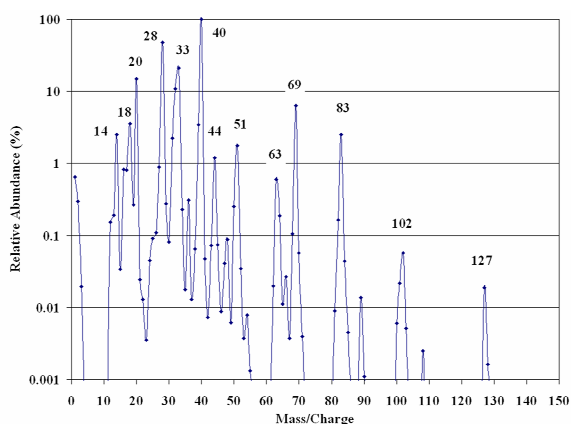

Fig. 3 RGA Spectra of sealed gas.

After 130 days of uninterrupted operation, the gas inside RPC was analyzed using a Residual Gas Analyzer (RGA). The relative abundance of fragments in the gas mixture from the RGA is shown in Fig. 3. Major fragments of R134a are in mass number (m/e) $33(CH_2F^+)$, $69(CF_3^+)$, $83(CH_2F_3^+)$, $51(CHF_2^+)$, $32(CHF^+)$ and $102(CH_2F_4^+)$.

Similarly for Isobutane the mass number are $43(C_3H_7^+)$, $41(C_3H_5^+)$, $42(C_3H_6^+)$ and $27(C_2H_3^+)$ and for SF_6 are $127(SF_5^+)$, $89(SF_3^+)$ and $108(SF_4^+)$. The results from the RGA showed the presence of a considerable proportion of contaminants like air and moisture. The amount of air is found to be more than 50% of gas inside RPC. Removing air and moisture component, major fragments are of R134a. The amount of Isobutane seems to have decreased from 4.5% to 0.2% probably due to leaking away over a period of time because of their smaller molecular size.

4. Study with prototype stack

Simultaneously, it was decided to extend the study to the prototype stack to verify the consistency of the results by isolating 9 layers out of the 12 layers in the stack. The remaining 3 layers (Layer 0,4 and 11) were used as a reference. In this study the ambient parameters as well as RPC parameters like the noise rate, dark current and tracking efficiency etc., were monitored. It was observed that the noise rates as well as the dark current of the isolated RPCs increased gradually. However the rate of increase seemed to vary among the RPCs. The rate of increase was high for layers 3, 6, 7, 9 and 10 and therefore their isolation was removed and fresh gas flow started after 32 days. The noise rate and the dark current returned to the normal values after about 24 hours. The other layers 1, 2, 5 and 8 were retained in an isolated condition for 83 days. For these layers, the noise rate increased by a factor of 2 in a month and by a factor of 6 towards the end of the isolation period. Fig.4 shows the time series plot of strip noise rate for 3 RPCs.
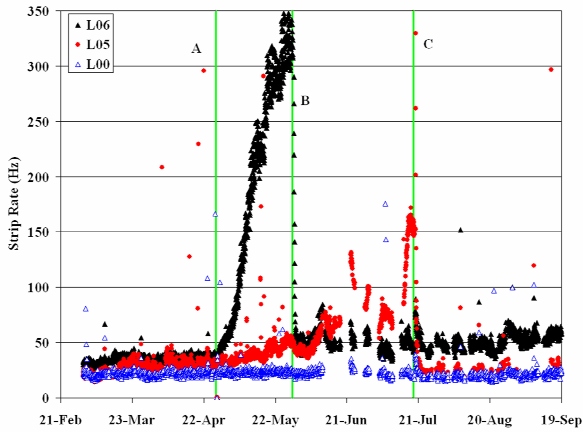

Fig. 4 Time series plot of strip rate for (a) reference RPC (L00), (b) RPC sealed for 31 days (L06) and (c) RPC sealed for 83 days (L05). At A, layers 5 and 6 were isolated. At B and C, the gas flow was restarted for layer 5 and layer 6 respectively.
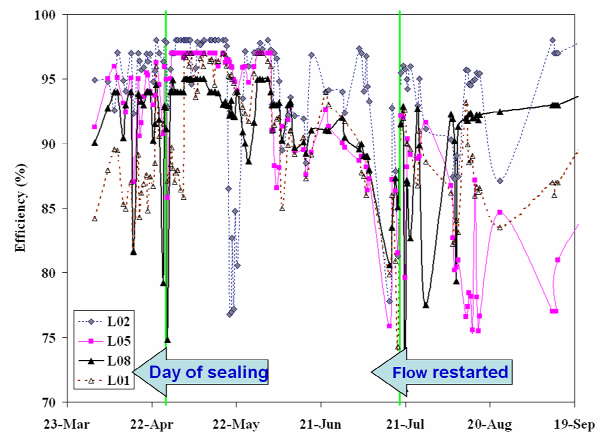
Fig. 5 Tracking efficiencies of RPCs isolated for 83 days. The region between the two green vertical lines is the duration of isolation.

The tracking efficiencies (using cosmic muons) of layers 1, 2, 5 and 8, were stable up to 15-20 days and started decreasing thereafter as shown in Fig.5.

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The isolation also affected the dark current as shown by their increase with time. Fig. 6 shows time series plot of dark current for two RPCs (layer 0=AB06 and layer 9=AB04). The region between the two green vertical lines (at A and B) is the duration of isolation. The dark current increased by a factor of three in 20 days and exponentially thereafter. Again, the values returned to normal after a fresh flow of gas. Fig.7 shows a summary of the variation of the dark current in all the RPCs a) before isolation, b) during the isolation period and c) after the start of fresh gas flow. It is to be noted that all the operating parameters of the RPCs have come back to their normal values after refreshing them with fresh gas.
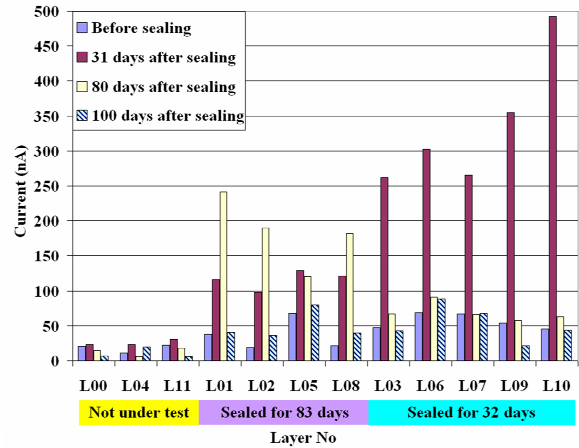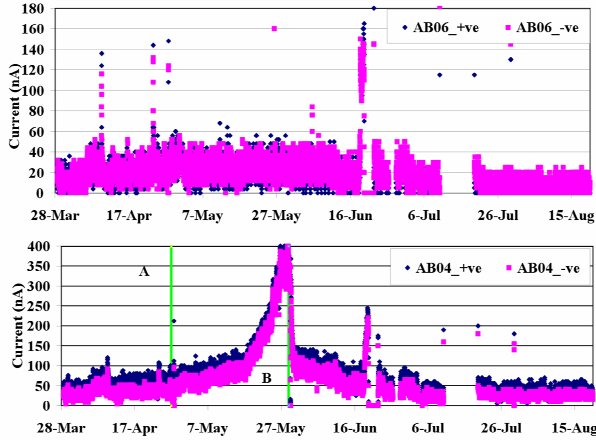

Fig. 6 Time series plot of dark current of reference RPC(top) and RPC sealed for 32 days(bottom).

Fig. 7 Summary of dark current of all the RPCs.

4.1 Pressurised Leak Test

From the results of the study, it seems that the variations in the parameters during the isolation period are different in each of the RPCs under test. This could be attributed to the variations in the corresponding leak rates. Therefore, a pressurized leak test was carried out for all the RPCs. RPC was placed on a horizontal table with foam sheets on either side. Sufficient weights were placed over the entire area of the RPC. Two diagonally opposite nozzles were sealed and one of the nozzle was connected to a water column manometer. The gas gap was pressurized to 30 mm of water with respect to atmosphere using R134a gas via the remaining nozzle. The gas inlet was then isolated. The height of the water column was noted periodically and the presence of leaks, which showed an occasional variation with time, (and the variations in them) in different RPCs was thus established. Fig. 8 shows the normalized leak rate of all RPCs found from pressurized leak test. To locate the leaks, Freon was flown continuously through the gas gap with the output connected to the bubbler to ensure the flow of gas. A Freon detector (Riken Keiki Fine Instrument Co. Ltd) was used to detect the leak locations. These locations and its adjoining places were then sealed by reapplying the glue. After the glue dried up, the Freon detection test was repeated to ensure that no leaks existed. After this procedure the pressurised

leak test was repeated. Fig. 9 shows the normalized pressure variation inside layer 03 with time, before and after reapplication of the glue. The other chambers also follow similar pattern. Fig. 10 shows the rate of increase in current and noise rate with leak rate for 5 RPCs. It can be seen that they are correlated.
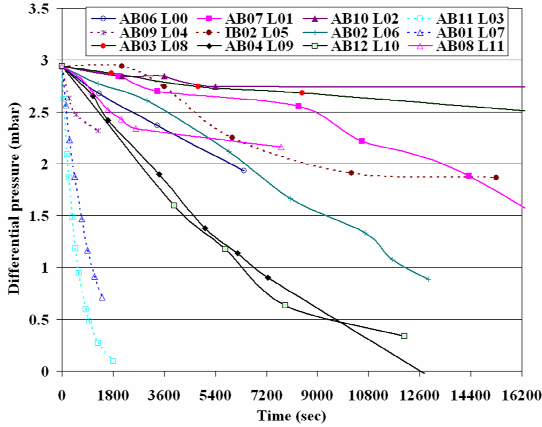

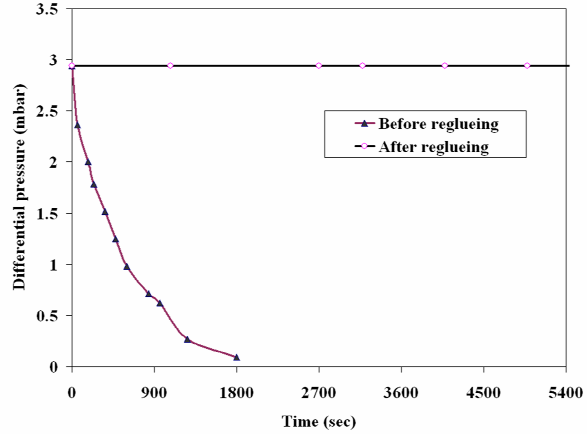Fig. 8 Leak rates of all the RPCs. Legends show RPC name with layer number.

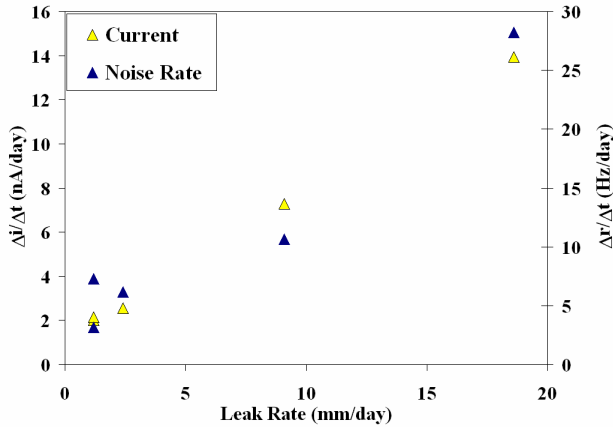Fig. 9 Pressure variation inside layer 03 with time, before and after sealing the leak location.

Fig. 10 Plot of rate of increase in current and noise rate with leak rate for RPCs: i = current; r = noise rate.

5.Conclusions

From the study presented here it is seen that the variation in noise rates and dark current in the RPCs may be attributed to their different leak rates. If the sealing of the RPCs with glue is done properly and the leak rates included as an important parameter in the quality control and assessments, these detectors can be operated satisfactorily for more than a month, with a single gas fill. The cost of replenishing gas could thus be reduced considerably, by up to a factor of 30.

The gas purification and recirculation system needed might be simpler and more efficient than one where 1-2 gas volumes are changed per day.

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