Performances of linseed oil-free bakelite RPC prototypes with cosmic ray muons
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Abstract
A comparative study has been performed on Resistive Plate Chambers (RPC) made of two different grades of bakelite paper laminates, produced and commercially available in India. The chambers, operated in the streamer mode using argon, tetrafluoroethane and isobutane in 34:59:7 mixing ratio, are tested for the efficiency and the stability with cosmic rays. A particular grade of bakelite (P-120, NEMA LI-1989 Grade XXX), used for high voltage insulation in humid conditions, was found to give satisfactory performance with stable efficiency of > 96% continuously for more than 130 days. A thin coating of silicone fluid on the inner surfaces of the bakelite RPC is found to be necessary for operation of the detector.

Key words: RPC; Streamer mode; Bakelite; Cosmic rays; Silicone
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1. Introduction
In the proposed India-based Neutrino Observatory (INO), the RPCs have been chosen as the prime active detector for muon detection in an Iron Calorimeter (ICAL), which will be used for studying atmospheric neutrinos. Detailed studies are being performed on glass RPCs for INO. In this article, we report a parallel effort on building and testing of the RPC modules using the bakelite obtained from the local industries in India. The aim of the study is to achieve stable performance of such a RPC detector for prolonged operation in streamer mode.

2. Construction of the RPC modules
Two 300 mm × 300 mm × 2 mm bakelite sheets are used as electrodes. The inner surfaces of the two sheets are separated by a 2 mm gap. Uniform separation of the electrodes are ensured by using five button spacers of 10 mm diameter and 2 mm thickness, and edge spacers of 300 mm × 8 mm × 2 mm dimension, both being made of polycarbonate. Two nozzles for gas inlet and outlet, also made of polycarbonate, are placed as part of the edge spacers. The edges of the modules are sealed by applying a layer of the epoxy adhesive to prevent permeation of moisture. The 2 mm thick active gas gap of the RPC modules are leak-checked using argon and helium sniffer probes.

After cleaning, a graphite coating is made on the outer surfaces of bakelite sheets to form the electrodes. A gap of 10 mm from the edges to the graphite layer is maintained to avoid external sparking. The surface resistivity varies from 500 kΩ to 2 MΩ for different electrode surfaces. The graphite coating, applied by using a spray gun, however, results in a non-uniformity (less than 20%) for a particular coated surface. Two small (20 mm × 10 mm) copper foils ∼ 20 µm thick are pasted by kapton tape on both the outer surfaces for the application of high voltage. The high voltage connectors are soldered on these copper strips. Equal high voltages with opposite polarities are applied on both surfaces.

In order to collect the accumulated induced charges, pickup strips are placed above the graphite coated surfaces. The pickup strips are made of copper (20 µm thick), pasted on one side of 10 mm thick foam. The area of each strip is 300 mm × 30 mm with a separation of 2 mm between two adjacent strips. The pick-up strips are covered with 100 µm thick kapton foils to insulate them from the graphite layers. The ground plane, made of aluminium, is pasted on the...
other side of the foam. The signals from different strips are sent through a ribbon cable, followed by RG-174/U coaxial cables using proper impedance matching.

3. Measurement of bulk resistivity of bakelite

The bakelite sheets are phenolic resin bonded paper laminates. In the present work, two types of bakelite sheets have been used to build several detector modules. They are (a) Superhylam and (b) P-120.

The P-120 grade bakelite is manufactured by Bakelite Hylam, India and the Superhylam grade is obtained from the other manufacturer Super Hylam, India. The surfaces of P-120 are matt finished whereas superhylam is glossy finished. Specifications are given in Table 1.

The bulk resistivity of the electrode plates of the RPC is an important parameter [4,5]. The high resistivity helps in controlling the time resolution, counting rate and also prevents the discharge from spreading through the whole gas [6,7,1]. We have measured the bulk resistivities of the bakelite sheets via the measurement of the leakage current. This measurement is performed at the same place and the same environment where the RPCs have been tested. The test set up is kept in an air-conditioned room. The temperature and humidity have been monitored during the experiment. The bulk resistivities of different grade materials at 4 kV are presented in Table 1. The bulk resistivity(\(\rho\)) vs. voltage(V) characteristics of different grade materials are shown in Fig. 1. It is clear from the figure that the bulk resistivity is considerably higher for the P-120 grade bakelite. Three modules are constructed with P-120 grade and these are referred to as IB1, IB2 & IB3 in the following text whereas one module is made using superhylam grade and is referred to as SH. Name, electrode materials and graphite surface resistivity of different RPCs are given in Table 2.

4. Cosmic ray test setup

Fig. 2 shows the schematic of the setup for testing the RPC modules using cosmic rays. Three scintillators, two placed above the RPC plane and one placed below are used for obtaining the trigger from the incidence of the cosmic rays. The coincidence between scintillator I (350 mm \(\times \) 250 mm size), scintillator II (350 mm \(\times \) 250 mm size) and the finger scintillator(III) (200 mm \(\times \) 40 mm size) is taken as the Master trigger. Finally, the ORed signal obtained from two adjacent pick-up strips of the chamber is put in coincidence with the master trigger obtained above. This is referred to as the coincidence trigger of the RPC. The window of the cosmic ray telescope is of area 200 mm \(\times \) 40 mm. The width of the finger scintillator is made smaller than the total width of the two adjacent readout strips. A correction has been applied for dead zones (of area 200 mm \(\times \) 2 mm) in between two adjacent readout strips.

The high voltages to the RPC are applied at the ramping rate of 5 V/s on both the electrodes. The streamer pulses are obtained starting from the high voltage of 5 kV across the RPC. The leakage current as measured by the high voltage system is recorded for further study.

The gases used in the RPC are mixtures of Argon, Isobutane and Tetrafluoroethane (R-134a) in 34:7:59 mixing ratio. The gases are pre-mixed, stored in a stainless steel container and sent to the detector using stainless steel tubes. A typical flow rate of 0.4 ml per minute resulting in \(~ 3\) changes of gap volume per day is maintained by the gas delivery system. Variation of less than 4% is found in the mixing ratio for Argon, Isobutane and R-134a respectively in a systematic analysis by a Residual Gas Analyzer.
Table 1
Mechanical and electrical properties of different grades of bakelites.

| Trade Name | Grade | Density (g/cc) | Electrical strength (kV/mm) | Surface finish | Bulk resistivity (Ω cm) |
|------------|-------|---------------|-----------------------------|----------------|------------------------|
| Superhylam | - P2  | 1.72          | 9.5                         | Glossy         | 1.25 × 10^11           |
| P-120      | XXX   | 1.22          | 9.5                         | Matt           | 3.67 × 10^12           |

Table 2
Name and materials of different RPC.

| Detector name | Electrode material | Surface resistivity kΩ/□ |
|---------------|--------------------|--------------------------|
|               | Anode              | Cathode                  |
| SH            | Superhylam         | 500                      | 500             |
| IB1           | P-120              | 2000                     | 2000            |
| IB2           | P-120              | 1600                     | 1000            |
| IB3           | P-120              | 1300                     | 1000            |

5. Results

An important and obvious goal of any RPC detector development is to study the long term stability with high efficiency. In that spirit, the following studies are performed in the cosmic ray test bench of the RPC detectors.

The efficiency of the RPC detector, taken as the ratio between the coincidence trigger rates of the RPC and the master trigger rates of the 3-element plastic scintillator telescope as mentioned in sec. 4, is studied by varying the applied high voltage (HV) for each detector. The rates are calculated from data taken over 30 minutes duration for each HV setting. The temperature and humidity during these measurements are recorded to be about 22-25°C and 63-65% respectively. The average master trigger rate is ≃ 0.005 Hz/cm^2. The variation of efficiency with applied HV is shown in the Fig. 3(a) and that of the counting rates with the HV is shown in the Fig. 3(b). It is seen that for both the bakelite grades, the efficiency has increased from 20% to 75% as HV is ramped up from 6.5 kV to 6.8 kV. The efficiency for the SH RPC gradually increases and reaches the plateau at ~ 96% from 7.5 kV, while that of the IB1 RPC reaches a maximum of ~ 79% at 7.2 kV and then decreases steadily up to ~ 35% as the HV is increased to 9 kV. The counting rates in both the cases, however, have increased more or less exponentially with sudden jumps around 6.5-7.0 kV (see Fig. 3(b)), i.e. near the points where the efficiency becomes uniform (in case of SH) or starts to decrease (in case of IB1). This possibly indicates the onset of a breakdown regime that recovers in a reasonable time for the SH but works the other way for the IB1. Similar behavior is observed also for IB2 and IB3. IB2 and IB3 are made to study the consistency of the results. It should, however, be noted that the counting rate and the leakage current of the SH are both larger than those of the IB1, IB2 & IB3, which are expected on the basis of smaller bulk resistivity of the superhylam grade bakelite [8].

In order to investigate the reason for the phenomena of
To judge the improvement in the overall performance of the RPC detector, we have measured the leakage current through the RPC detector with and without silicone coating and the plot of these as a function of applied HV is shown in the Fig. 5. Both the plots show a common feature that the current-voltage curves have two distinctly different slopes as it has been shown earlier [11]. While the gas gap behaves as an insulator in the lower range of applied voltage and hence the slope over this span scales as the conductance of the polycarbonate spacers, at higher range of voltage, the gas behaves as a conducting medium due to the formation of the streamers. Therefore, the slope over this range scales as the conductance of the gas gap. It is seen that the slope in the higher range of voltage is much steeper for the RPC without silicone coating and hence it points to the fact that some sort of uncontrolled streamers are being formed in the gas gap causing a degradation of the efficiency [12]. This possibly does not happen in the RPC detectors with silicone coating.

The long term stability of the bakelite RPCs has been studied using the same cosmic ray test set-up. The coincidence trigger counts of the RPCs and the master trigger counts, accumulated over every 2 hours, have been recorded continuously for more than 4 months at a HV of 8 kV. The average room temperature and the relative humidity have been recorded to be 22-25°C and 63-65%, respectively. The count rates of the RPCs have also been recorded simultaneously. Figs. 6(a) and 6(b) depict the variation of efficiency and count rates over the above mentioned period for both the grades of RPCs. The SH RPC had worked with an efficiency of >95% which remained steady for 25 days, but beyond that, it deteriorated gradually to ~86% efficiency within next 13 days. The count rate, however, had increased from 1 Hz/cm² to 10 Hz/cm² within 10 days, and then it increased slowly over the next 28 days. After that period,
the count rate shot up to > 30 Hz/cm². The leakage current gradually increased from 3-4 µA to > 10 µA within that period. The test on this RPC was discontinued after 38 days and the silicone coated IB1 RPC was mounted. The efficiency measured was ∼96% and above and has remained steady for more than 130 days. The count rate also has remained steady around 0.1 Hz/cm². The leakage current was found to be marginally dependent on temperature and humidity, though it has remained steady at ∼400 nA during the operation.

The SH RPC has also been tested again after a gap of a few months. It has shown the same higher leakage current (> 10 µA) and lower efficiency (∼86%) indicating that some intrinsic breakdown of the bulk material may have taken place.

6. Conclusions and outlook

In conclusion, a comparative study of bakelite RPCs made from two different grades of bakelites commercially available in India is performed. The RPC, made of superhy-lam grade bakelite with glossy finished surface is found to have a shorter life. On the other hand, the RPCs made from P-120 grade bakelite with matt finished surfaces, which are coated with a thin layer of viscous silicone fluid, are found to work steadily for more than 130 days showing a constant efficiency of > 96% without any degradation. The detector is found to be less immune to variation in humidity which makes it a viable alternative to semiconductive glass based RPC for use in the ICAL detector of the INO.

Application of silicone fluid on the surface shows improved performance, suggesting the making of a smoother surface. As a future plan, we will perform in detail the study of the properties of the surfaces after silicone coating. A detailed analysis will be performed on the exhaust gas to understand the effect of silicone, if any. Further studies include performance of RPCs at higher rate and of larger size.

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References
[1] R. Santonico, R. Cardarelli, Nucl. Inst. and Meth. 187, (1981) 377.
[2] INO Project Report, INO/2006/01, June 2006, ⟨http://www.imsc.res.in/~ino/⟩.
[3] N.K. Mondal, Nucl. Inst. and Meth. A, (2008) these Proceedings.
[4] G. Aielli et al., Nucl. Inst. and Meth. A 533, (2004) 86.
[5] G. Bencivenni et al., Nucl. Inst. and Meth. A 332, (1993) 368.
[6] R. Cardarelli, A. Di Ciaccio and R. Santonico, Nucl. Inst. and Meth. A 333, (1993) 399.
[7] H. Czyrkowski et al., Nucl. Inst. and Meth. A 419, (1998) 490.
[8] Gy. L. Bencze et al., Nucl. Inst. and Meth. A 340, (1994) 466.
[9] F. Anulli et al., Nucl. Inst. and Meth. A 508, (2003) 128.
[10] F. Anulli et al., Nucl. Inst. and Meth. A 539, (2005) 155.
[11] J. Zhang et al., Nucl. Inst. and Meth. A 540, (2005) 102.
[12] I. Crotty et al., Nucl. Inst. and Meth. A 337, (1994) 370.