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# Effects of variation of environmental parameters on the performance of Resistive Plate Chamber detectors

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ABSTRACT

Performance of single gap Resistive Plate Chamber (RPC) detectors is investigated under variation of environmental parameters, such as temperature and relative humidity. Operational characteristics of the RPCs depend on both the environmental temperature and the relative humidity. Sensitivity to such dependence is found to be more on temperature rather than the relative humidity. Qualitative interpretation of some of the results obtained is given based on the known properties of the electrode materials and gases used in the detectors.

## 1. Introduction

Resistive Plate Chamber (RPC) detectors [1] are used in many experiments in High Energy and Astroparticle Physics, as trigger and tracking detectors or as time-of-flight (TOF) detectors because of their simple and robust structure for coverage of a large area, ease of operation, and at the same time, they can deliver good time resolution. Depending on the number of active volumes (termed as gas gaps) in a RPC detector, the two variants are the single gap RPC and the multigap RPC (termed as MRPC). The single gap RPCs are mostly used as trigger and tracking detectors for the small $p_T$ region in many High Energy Physics experiments to detect energetic ionizing particles. Long term stable operation of the RPCs and handling of high fluence rates are the major characteristics demonstrated by the RPCs, which make them preferred detectors in many such experiments.

RPCs are used in extensive air shower arrays due to their capability of large area coverage needed for tracking and imaging of sources in the intergalactic and extragalactic spaces through detection of the secondary cosmic rays. Due to low event rates in this type of experiments, long term operation under variable environmental condition is expected for these detectors. Therefore, it is important to study the influence of environmental parameters on stable operation of RPCs, and to understand the physical reasons behind it. These important research goals are pursued by several research groups [2–6,8].

RPCs are also chosen as the active detector elements in the massive iron calorimeter (ICAL) based experiment at the upcoming India-based Neutrino Observatory (INO) [10]. The experiment is aimed at resolving the mass hierarchy problem through precision measurement of the mixing parameters in the atmospheric neutrino sector. Because of the extremely low event rates expected in such experiment, long term stable and continuous operation of a large number of RPCs in a stable and controlled environment is a primary requisite for the ICAL experiment. This study is particularly important in the context of the proposed site for the INO, which is located in a fairly hot and humid environment in the southern part of India [9].

Prototype RPC detectors were fabricated in different sizes, configurations and characterized for its suitability in the Iron Calorimeter (ICAL) experiment during past few years [11–14,16]. Constructional details of the bakelite RPCs, including characterization of electrical properties of the materials in the bulk and at the electrode surfaces [12–14], characterization of surface

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roughness, its effect on the operation of bakelite RPCs, and remedial measures by inner surface coating of various types were already reported [13]. Long-term stability of operation in streamer mode was successfully demonstrated in a cosmic muon telescope test bench [12]. The same detector, operated in avalanche mode, was also exposed to the gamma irradiation facility (GIF; $^{137}$Cs source, 570 GBq) at CERN for 23 days at a stretch [15,17]. No significant degradation of performance was noticed in this study even after exposure resulting in equivalent charge accumulation of 30 C $m^{-2}$. This may be considered as equivalent to approximately 2 years of exposure to average atmospheric muon flux at the mean sea level.

Humidity and temperature dependence on the RPC performance were studied by different groups earlier [2–6,8]. Crotty et al. [2] observed temporary shift of the efficiency curve to higher bias voltage after adding 1% water vapour to the gas mixture, but the same curve shifted back to even lower bias voltage after 2–3 days of operation. Moshaii and Doroud [3] have studied the effect of water vapour on the performance of RPC in the avalanche mode of operation by Monte Carlo simulation. It was shown that the humidity in the gas has no effect on avalanche multiplication at room temperature. But at a higher temperature ($\sim 40\,^{\circ}$C), the charge content increased with the increase of humidity. In another work [4], this group has done Monte Carlo simulation to study the effect of temperature on the performance of RPC. It was observed that the charge content increased with the increase of temperature. A decrease of plate resistance with an increase in temperature was observed, which resulted in the improvement of rate capability. Long-term stability of RPC under elevated temperature and operated in streamer mode was studied by De Vincenzi [5]. It was found that there was a permanent drop in efficiency when RPC was kept at a high voltage and temperature for a long time. Ahn et al. [6] had studied the dependence of temperature and humidity on the bulk resistivity of bakelite plate under controlled environment. It was found that the bulk resistivity has a strong dependence on both the parameters. The resistivity decreased significantly as temperature and humidity were increased. Effect of temperature variation on efficiency and time resolution for streamer mode operation of RPC was explored by Abbrescia et al. [8]. The experimental results showed that the effective voltage across the gap increases with temperature and as a result, higher voltage had to be applied at a lower temperature to reach the efficiency plateau. It was also shown that the time resolution improved with increase in temperature.

The aim of this study is to establish the operating zone of the environmental parameters for safe, stable and reproducible operation of the detectors over a significantly long time span as required for the ICAL type of experiment as mentioned above. The effect of environmental temperature and humidity on the performance of bakelite RPCs, operated in different modes, is investigated in the present work. The measurable key parameters related to the intrinsic property of the detector materials, such as bulk resistance and those related to detector performance, such as efficiency, noise rate (singles counting rate) and time resolution are measured, and their inter-dependence is investigated in an attempt to understand the systematic behaviour.

## 2. Experimental details

Two bakelite RPCs of approximate size $30\,\mathrm{cm} \times 22\,\mathrm{cm}$ were operated under controlled environment in this experiment. The bakelite gas gaps were made of 2 mm thick P-120 grade bakelite plates. Constructional details, the specification of materials and initial performance studies have been reported earlier [12]. The two outer surfaces of the gas gaps were coated with dry graphite powder (99.999% purity and $-200$ mesh grain size) to form the electrically conductive layers. The surface resistivity of these conductive layers was measured and found to be fairly uniform within the range $0.8\ \mathrm{M}\Omega/\square$ – $1.3\ \mathrm{M}\Omega/\square$.

The measurements on the bakelite RPCs were done by operating them in both avalanche and streamer modes. The gas used for the streamer mode is a mixture of Argon (55%), isobutane (7.5%) and tetrafluoroethane (37.5%) and that for the avalanche mode operation was a mixture of tetrafluoroethane (95%) and isobutane (5%). The mixed gas was flown in through the inlet of RPC using a flow control valve, maintaining a pressure slightly above atmospheric pressure. The pressure variation measured at the inlet during gas flow was $\sim 2-3\%$, so that the flow can be considered as under constant pressure for all practical purpose.

The pick-up strips, used for signal read-out, were each made of 16-conductor ribbon cables of width 2 cm and thickness 0.9 mm. These were glued on a Mylar sheet of thickness 0.1 mm. Out of 16 conductors of the cable, 15 consecutive conductors were connected together to form the pick-up strip, while the remaining one was grounded. The top pick-up panel contained 10 pick-up strips and the bottom one had 14 pick-up strips. Adhesive double-sided foam tapes of 2 mm thickness were used to fix a grounded aluminium plate on top of each of the pick-up panels. The characteristic impedance of each of the strips measured by an impedance analyzer was found to be nearly uniform and of value $100 \pm 5\Omega$. The signal from the strips were taken out of the control box (to be described below) using coaxial cables.

The RPCs were placed inside a sealed weather control box made of aluminium in which, constant temperature and humidity were maintained during the measurement. The temperature inside the box can be varied and stabilized using a blower fan and a resistive heater operated under feedback control using a PID controller with a PT100 sensor. Humidity is maintained by passing moist air or dry air inside as and when needed. The temperature inside the control box was measured using another miniature PT100 sensor and the relative humidity (RH) was measured using a Honeywell HIH-4000 series humidity sensor with an accuracy of $\pm 3.5\%$. The environmental data were logged using LabVIEW$^{\mathrm{TM}}$ based data acquisition system. Electrical signals and high voltage feedthroughs, gas feed lines, blower fan module, heater enclosures and airflow ducts were sealed against permeation of moist air from outside.

A schematic diagram of the experimental setup in a cosmic muon telescope test bench and the associated electronics are shown in Fig. 1. The same test bench was used in our earlier measurements as well [12]. Two scintillators (SC I and SC II) were placed below the RPC and one (SC III) was placed above. The coincidence between SC I($93.5\,\mathrm{cm} \times 19.5\,\mathrm{cm}$), SC II($82.5\,\mathrm{cm} \times 19.5\,\mathrm{cm}$) and SC III ($17\,\mathrm{cm} \times 4\,\mathrm{cm}$) generated the 3-fold trigger as the energetic ionizing particles passed through them. This is treated as the Master Trigger. Based on a Monte Carlo simulation of the above set-up, it was found that two adjacent pick-up strips of RPC were in coincidence with the 3-scintillator muon telescope. Therefore, the signals from the two adjacent pick-up strips were OR-ed and the coincidence between this signal and the 3-fold scintillator signal were taken as the 4-fold coincidence trigger.

The measurements carried out during a period spanning over 6 months, were done at different temperatures in the range 20 °C–30 °C and RH in the range 50–70%. The results for temperatures 21 °C, 24 °C and 28 °C and RH 53%, 60% and 66% are shown here. The leakage current, noise rate, efficiency and the time resolution of RPC were measured. All the measurements, except timing data, were taken with RPC signal discrimination threshold of 10 mV. Time resolution measurements were done for two different RPC thresholds, which will be discussed later.