Study of the characteristics and operation of closed-loop gas recycling system (CLS) connected with RPC detectors and Characterization of the RPC connected with the CLS

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Abstract

The aim of my project is to study the characteristics and operation of the closed loop gas recycling system that monitors the gas passing through the RPC detector. Then, I have studied the leakage of gas from the system and finally tested a stable RPC with a very low leak rate. Followed by, characterization of the RPC along-with analysis of the gas-mixture inside the RPC with a Residual Gas Analyzer (RGA).

1 Introduction

The India-based Neutrino Observatory(INO)collaboration proposes to build a massive 50 kton magnetised Iron Calorimeter (ICAL)detector,to study atmospheric neutrinos and to make precise measurements of the parameters related to neutrino oscillations. The main detector element is Resistive Plate Chamber(RPC). A total of about 28800 such $2m \times 2m$ RPCs will be used. Since ICAL will be able to distinguish neutrino events from anti-neutrino events by detecting the sign of the muon produced from the neutrinos inside the detector, a high magnetic field (of magnitude 1.3 T) is applied, which is sufficient to detect the required deviations of the positively and negatively charged muons. Thus, it will be possible to study the earth matter effect and hence the neutrino mass hierarchy problem.

Cosmic Rays primarily consist of protons (90%), alpha particle (9%) and electrons (1%). The highly energetic protons interact with the atmosphere to give pions which subsequently decay by the following reactions to muons and anti-muons:

$$\pi^- \longrightarrow \mu^- + \overline{\nu}_\mu$$

$$\pi^+ \longrightarrow \mu^+ + \nu_\mu$$

Since they are comparatively more massive (about 200 times) than electrons, they are less accelerated in an electromagnetic field and hence loses less energy in the deceleration radiation. This enables muons, of a given energy, to penetrate deeper into matter than electrons. Thus, muons produced in the Cosmic rays can penetrate deep into the Earth.

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2 The ICAL Detector

The basic criteria for selecting the detector for the INO experiment are:

- A large target mass so that statistically we can get a significant number of neutrino interactions within a considerable amount of time (say 5-6 yrs) for the confirmation of atmospheric neutrino oscillation.
- Identification of the electric charge of muons to differentiate between neutrino and anti-neutrino interactions.
- Good time resolution
- technological capabilities available within the country
- compactness and ease of construction

The Iron Calorimeter (ICAL) detector, selected for the experiment satisfies all the above criteria. The ICAL is a large modular detector consisting of magnetized iron plates interleaved with layers of position sensitive detectors having a time resolution better than 2 ns. It will have a lateral size $48m \times 16m$, height of 12 m, subdivided into three modules each having a lateral size $16m \times 16m$, and will consist of a stack of 140 horizontal layers of $\sim$6 cm thick magnetised iron plates interleaved with 2.5 cm gaps to house the active detector elements [1]. The iron structure of this detector gains its stability as each layer will be resting on the layer just below it using iron spacers located every 2 m along the X-direction, thus making roads of 2 m wide in the Y-direction for insertion of RPC plates. Thus, there will be a total of 8 roads per module in a layer. The whole detector will be surrounded by an external layer of scintillation or gas proportional counters, which will act as a indicator to identify muons entering the detector from outside as well as to identify partially confined events having their vertex inside the detector.

3 Setup Of The RPC

The RPC is a special type of ionization particle detector made of high resistive plates having resistivity of the order of 2 $\times 10^{12}$ Ω-cm. Gas gap of 2mm between the two glass plates, having thickness of 3mm of each glass plate with graphite coating on their outer surfaces [2]. A constant and uniform electric field is applied between two parallel electrode plates. High resistive plate chambers help us to contain the discharge, caused by the passage of the charged particle, and preventing the discharge to spread out in the entire gas volume. The gas mixture that is flown through the gas gap have a high absorption co-efficient of ultraviolet radiation. The fig.1 shows a schematic structure of a RPC.

3.1 Working principle

The gaseous ionization detector consists of a gas gap bounded on both sides by two parallel electrodes made of commercially available float glass. The two glass plates is applied with a high voltage of $\sim$10KV. When a sufficiently energetic radiation passes through the chamber, it ionizes the gas molecules and produces a certain number of electron-ion pairs. The mean number of electron-ion pairs created is proportional to the energy deposited on the chamber. With the application of electric field, the electrons are drawn towards the anode and ions are drawn towards the cathode and gets collected. If an intense electric field is applied, further ionisations are produced by the primary electrons. The electrons produced in secondary ionisations are further accelerated to produce more ionisations and so on. This chain ionizations causes a distribution of free charge in the

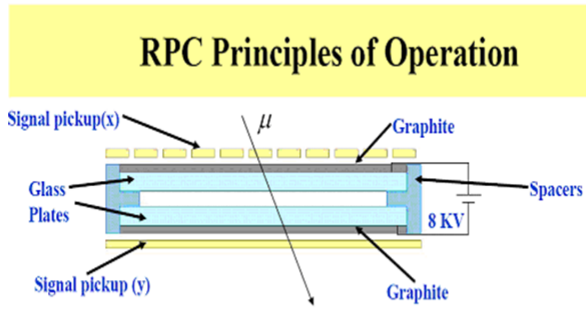


Figure 1: Schematic diagram of a RPC

gas having a characteristic shape of an avalanche. Again, recombination of electron-ion also occurs, thus liberating photons, which can also initiate secondary ionisations. When such series of several secondary avalanches are formed, a large amount of free charge is formed within the gas creating a streamer pulse. This growing number of charges propagates within the gas inducing a signal in the read-out electrodes. The gas mixture plays a vital role in determining either we are working in the Avalanche regime or Streamer regime.

3.2 Data representation

At the detector, the particle discharges as:

$$Q = Q_0 e^{-t/\tau} \text{ where } \tau = \rho\varepsilon_0\varepsilon_r$$

where ρ is the volume resistivity of the material, ε_0 is the dielectric constant and ε_r is the relative permittivity of the electrode material. The volume resistivity ρ of glass electrodes is $\sim 10^{12}$ Ω-cm, thus having a relaxation time $\tau \sim$ 1-2 ns. The ionized charges in the electrodes cause high voltage across them, thus causing the electric field in the gas gap to drop locally around the initial avalanche or discharge. As a result, the detector remains unresponsive for each avalanche for a time of the order of relaxation time, though, the rest of the detector area remains sensitive to any other avalanches. After τ time, the region gets back to its original condition gaining charge from the power supply.
As indicated in fig.1, the resistive plates are covered with graphite coating (having a surface resistivity of about 200-300 KΩ-cm. This coating helps in the distribution of high voltage over the electrode surfaces. The free charges produced in the gas induced electric pulses on the metallic (copper) strips. The readout strips of the RPC are the orthogonal pickup strips placed over the entire area of the chamber along X and Y directions on both sides of the gas gap. The width of each strip is 2.8 cm and there is a gap of 0.2 cm between each strip and the distance between two layers of RPC is 16 cm. The pulse collected from the strips, is pre-amplified and fed to the data acquisition system, which analyses, weeds out the pulses produced by disturbances (i.e. pulses created not due to ionization of gas molecules by muons) and produces a live graphical display of the cosmic ray muon track in the X and Y read-out display planes.

3.3 Operating Modes Of The RPC

The RPCs can be operated in two modes:

- **Avalanche mode:** The charged particle, being accelerated by the electric field, produces primary ions, which again produces secondary ionizations by collision with gas molecules. The electric field of this cluster of ionized particles is opposed by the external field and the multiplication process stops after sometime. This charges then drift towards the plates where from they are collected. This mode operates at a lower voltage and have a less gain. Typical pulse amplitudes is of the order of few mVs

- **Streamer mode:** Here the secondary ionization continues to occur until there is a breakdown of the gas and a continuous discharge takes place. This mode operates at a higher voltage and also results in high gain. Typical pulse amplitudes are of the order of 100-200 mV.

3.4 Choice of gas mixture

The gas mixture fixes the working mode of the RPC in 'Avalanche' or in 'Streamer' mode, which results in varying performances and characteristics. The choice of gas mixture is governed by several factors: low working voltage, high gain, good proportionality. For low voltage working condition, noble gases are usually chosen since they require very low electric field intensities for avalanche formation. The first ionization potential, the first Townsend co-efficient (i.e. the number of ionisations per unit length) and the electronegative attachment co-efficient (i.e the number of electrons captured by the gas per unit length) determine the avalanche multiplication, no of photons production, the saturated avalanche range to the streamer mode.

For **Avalanche** mode, the main component should be an electronegative gas, with high enough primary ionization production but with small free path for electron capture. The high electronegative attachment coefficient limits the avalanche electrons number. These gases trap the free electrons from the gas volume before they can initiate a new avalanche. The eco-friendly *R134a* (Tetrafluoroethane, known as Freon) is used for this purpose. Another component is generally a polyatomic gas, often hydrocarbons, which have a high absorption probability for ultra violet photons, produced in electron-ion recombination. This gas is known as 'quenching gas'. This component absorbs the photons, going to higher vibrational and rotational energy levels, then dissipating this energy through dissociation or super-elastic collisions, where the kinetic energy of the two molecules in the final state is more than that in the initial state, thus avoiding photo ionization with related multiplication and limiting the lateral charge spread. Here we have used *isobutane* ($iso - C_4H_{10}$) as the 'quenching gas'. Finally we use SF_6 (Sulphur-hexafluoride) to control the excess number of electrons. The relative proportion of freon:isobutane:SF$_6$ is 95.2:4.5:0.3.

For **Streamer** mode, the main components should provide a robust first ionization signal and a large avalanche multiplication for a low electric field. One typical element can be Argon. The optimal mixture of freon:isobutane:argon for this mode is 62:8:30.

4 Gas Recycling Systems

To enhance the life and the performance of detectors, the gas content needs to be replaced at least once a day to keep harmful contaminants from accumulating. The total internal volume of the detector stack will be in the range of 200 cu.m. As direct consequence, $200m^3$ of fresh gas mixture has to be fed into the detector stack and an equal volume has to be removed and safely disposed on daily basis. This operation involves very high operating cost and also causes the concentrations of SF6 and R134a in air to exceed TLV(Threshold Limiting Value: to which a worker can safely be exposed for 12 hours a day) in the local working area. Initially, as a prototype, the open loop gas recirculation system was used, in which component gases are separated from the gas mixture coming out of the RPC, by adsorption and condensation, then purified and reused [3]. But there were some problems with this system [4]. For this reason, the closed loop gas recycling system is installed. Also, it turned out that this system also enabled us to easily check the gas-leakage from RPCs.

5 Closed Loop Gas Recycling System

The closed loop system is specifically designed for ICAL RPC detectors. The setup we are using can feed gas into 12 (2m$\times$2m) size RPC gas filled detectors. It maintains a supply pressure of 30 mm to 300 mm of Water Column (adjustable) through custom designed pressure regulator and a pneumatically operated positive displacement pump. The suction pressure in the loop is maintained between 15 to 50 mm water column for a flow rate from 10 SCCM to 100 SCCM. Some salient Features are:

- Leak of gas from the RPC can be easily monitored.
- Safety from Over-pressurization by Isolating RPCs through a pair of 3 way valves.
- Adjustable compression ratio for PD pump.
- Purification of gases by removal of water vapor (by Molecular Sieves) and Radicals(by Basic activated Alumina) .
- Continuous Moisture measurement.
- Pressure based or flow based gas mixture preparation
- Loop Flow can be varied from 10 SCCM to 1000 SCCM
- Current loop transmission (4 to 20 mA) for all pressure transmitters with sensor failure detection.
- Extraction of gas prior to regeneration by evacuation leading to 98% recovery.
- Built in air compressor for ease and safety of operation.
- 120 ltrs of gas can be stored.
- Data logging at HMI (Human-Machine Interface) level – data can be down loaded to a PC and monitored - Internet connectivity for remote operation and Diagnostics.
- Interlocks for all important functions for safe operation.
- Mass flow controllers for vent and loop flows
- Electrical safety devices are provided to avoid accidents.

A block diagram of the closed loop recycling system is given in fig. 2

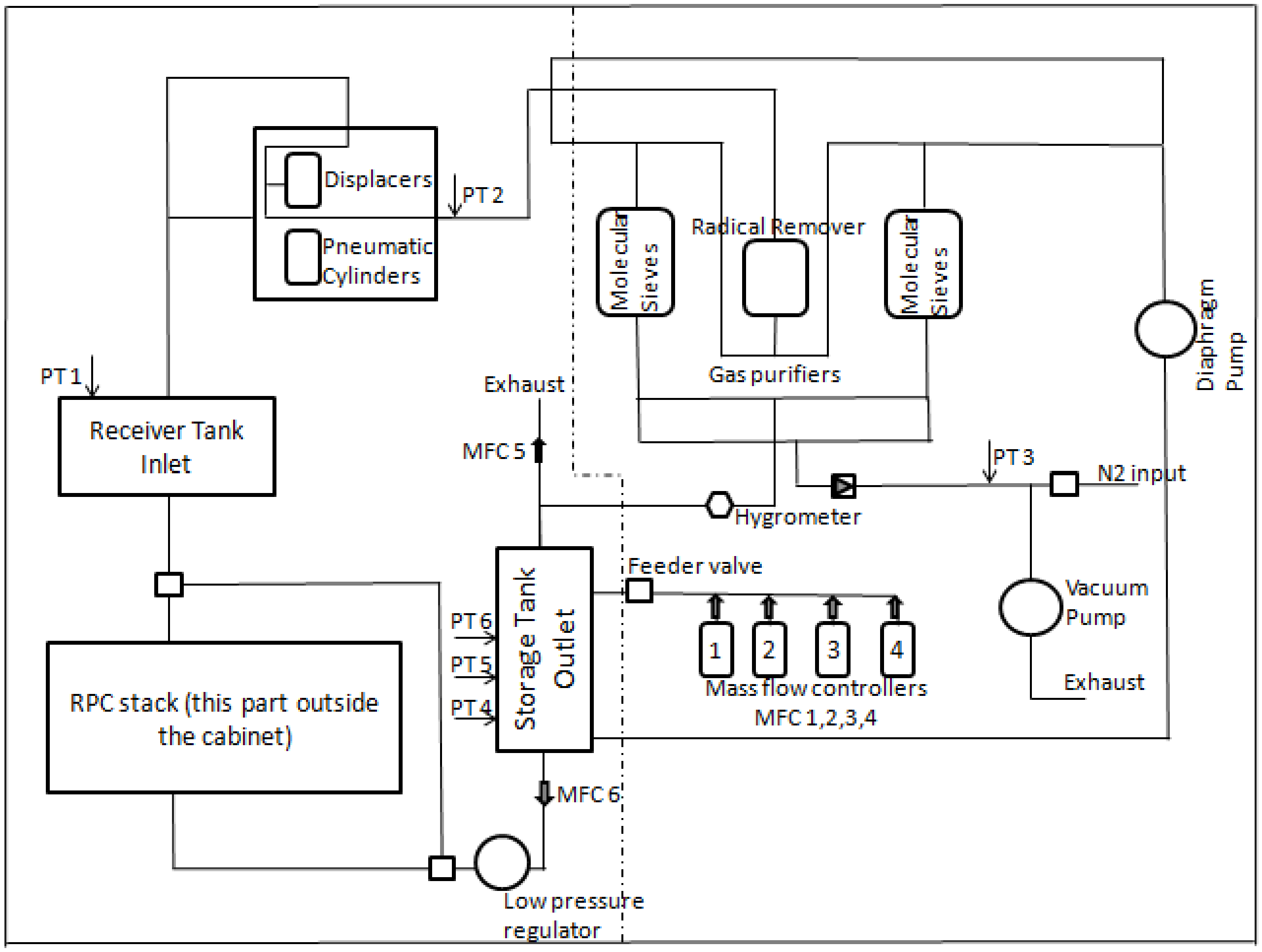


Figure 2: Schematic diagram of the closed loop system

5.1 Specifications and settings of the pumping module:

The pumping module is the most used function of the closed loop gas system. It sets up the gas flow across closed loop and through the 12 RPCs. The operating values for constants involved in pumping module are given in Table 1 :

Table 1

Sl.no	Constant	Value	Description
1	SP1	1.007 bar	Maximum value for PT1 (Receiver Pressure)
2	SP2	0.997 bar	Minimum value for PT1 (Receiver Pressure)
3	TF1	12 sec	Waiting time for delivery stroke
4	TF2	18 sec	Waiting time for suction stroke
5	FP1	Nil	Flow setting for Argon
6	FP2	14.0 sccm	Flow setting for Isobutane
7	FP3	304 sccm	Flow setting for R134a
8	FP4	1.6 sccm	Flow setting for SF_6
9	FP5	Nil	Flow setting for Exhaust Flow
10	FP6	0.700 sccm	Flow setting for Loop flow (one RPC)
11	PBS	1.150 bar	Minimum storage-tank pressure for top-up start

The analog input settings are given in Table 2:

Table 2

Sl.no.	Device No.	Minimum	Maximum	Description
1	PT1	0.0	2.447 bar	Receiver pressure transmitter
2	PT2	0.0	5.0 bar	Pump pressure transmitter
3	PT3	0.0	6.10 bar	Vacuum pump pressure transmitter
4	PT4	0.0	2.447 bar	Low pressure transmitter
5	PT5	0.0	6.10 bar	Medium pressure transmitter
6	PT6	0.0	6.10 bar	Comparative pressure transmitter
7	MT1	0.0	5000	Moisture transmitter
8	MFC1	0.0		Argon mass flow controller
9	MFC2	0.0	243 sccm	Isobutane mass flow controller
10	MFC3	0.0	1500 sccm	R134a mass flow controller
11	MFC4	0.0	1.6 sccm	SF_6 mass flow controller
12	MFC5	0.0	100 sccm	Vent gas mass flow controller
13	MFC6	0.0	100 sccm	Loop-flow mass flow controller
14	LP1	0.0	320	Exhaust Pressure transmitter
15	BT1	0.0	10.0	Baratron transmitter

5.2 Equipment and functional details

Flow path of the gas

In the closed-loop system the gas flows in a recycling-loop. The description, for the sake of convenience , starts from The Pump. The gas mixture is pumped by a pneumatically operated pump and raised from 1 Bar to 1.5 to 2.0 Bar pressures . The gas is moved to purifier columns . From Purifier columns the gas, under own pressure gradient flows into the storage chamber . From storage chamber the gas flows through a mass flow controller which feeds a low pressure regulator set at 25 to 50 mm water column. The gas further flows through a set of 3 way valves and into the detectors through outlet manifold for RPCs. After flowing across the RPCs the gas mixture flows into a receiving chamber . From Receiving Chamber the gas mixture is sucked by the pneumatic pump to start a new cycle.

Components of the loop

(a) **Pneumatic Pump:** This a dual Cylinder Positive Displacement(PD) Pump. It can suck and deliver gas at 0.5 Bar and 5 Bar respectively at Minimum and Maximum. The Stroke

, Compression Ratio, Stroke speed and wait time can be set and are factory adjusted. Two Check valves in the outlet keep the gas moving in and out in a positive direction.

(b) **Gas Purifier:** It has 3 cylinders of 5 ltr capacity. Inlet cylinder contains activated basic alumina (Al_2O_3 mixed with small proportion of $Al(OH)_3$). This purifier removes the unwanted radicals formed in the gaseous mixture (for e.g. SF_2, SF_4, etc.—these may cause damage to the detector by forming complex compounds with the RPC glass). The other two cylinders have Molecular Sieves (mainly made of aluminosilicate) with 4A (pore size 4Å) and 13X (pore size 10Å) type in the ratio of 90:10. The 4A adsorsbs moisture, SO_2, C_2H_4,C_2H_6,C_3H_6,ethanol but not higher hydrocarbons. Some 5A sieves (pore size 5Å),are also used for adsorbing normal(linear) hydrocarbons upto n-C_4H_{10} (not the iso-compounds). And the 13X sieves for purification of higher hydrocarbons. The purifier has set of six valves which can isolate each cylinder or put them in parallel. Heaters along with PT100 temperature transducers are attached to the cylinders for the purpose of regeneration. The gas purity is in the range of 2ppm water vapour or better.

(c) **Moisture Sensor:** The Moisture Transmitter senses the moisture content of the gas stream, in series. It produces in the form of current of 4 mA t0 20 mA proportional to the moisture content.

(d) **Storage Tank:** This is a 30 ltrs Stainless steel storage tank which can hold up to 90 ltrs of Gas mixture. This tank has four pressure transducers (BT1, PT4, PT5, PT6) which are used to fill it at different pressures. This way a volumetric ratio mixture can be prepared. The concentration of each phase can be calculated as a pressure ratio of filling pressure to full pressure. The tank is fitted with two mass flow controllers, MFC5 for allowing a small flow of gas mixture into vent and MFC6 to set up a flow rate in the loop as per number of RPCs connected.

(e) **Low Pressure Regulator:** This is a specially designed device to maintain a small positive pressure at the inlet of RPCs. No capillary impedance is required at the inlet (to drop the pressure) because we are already maintaining the pressure low. The regulator takes inlet pressure from the storage tank through MFC6 and reduces it to a adjustable range from 20 mm to 100 mm water column (2 to 10 mbar) as per setting.

(f) **Three way valves:** Pneumatically operated three way valves isolate the RPCs from the loop in case of maintenance and emergencies like pressure climb of greater than SP1 value. Both valves operate together simultaneously.

(g) **Vacuum and diaphragm Pumps:** These are used to extract gases for recovery and regeneration. Vacuum is also used to clean the system prior to filling.

(h) **Mass flow controllers(MFC):** Mass flow controllers are used to prepare a premix as well as online mix for the top up. The setting is given for top-up flow (refilling of the RPC when pressure at storage tank reaches a min. point). MFCs are connected together with isolation valves and one common feeder valves. The top-up starts when PT5 value reaches PBS value (here typically kept at 1.15 bar) and sends a gas-mixture in the (user-defined) ratio 95:4.5:0.5 of R134a, isobutane and SF_6.

(i) **Receiving chamber:** This is similar to storage chamber, difference being it works near atmospheric pressure. The pressure transmitter PT1 monitors its pressure (which is also the output pressure from RPC). It works between the max and min values set by SP1 and SP2 respectively (max being around 1.004–1.007 bar and min being around 0.997 to 1.001 bar). The pump module sucks the gas from Receiving chamber and puts it back in the loop.

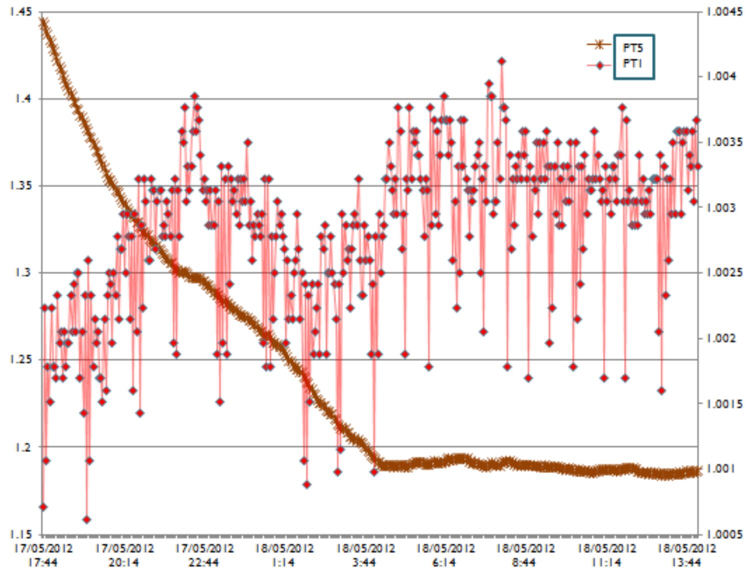


Figure 3: Variation of PT1 and PT5 value for Al04 RPC

6 Leak test of RPC in closed loop system

Since it is found that only small quantity contaminants is occasionally generated within the gas mixture, a closed loop system is built with minimum instrumentation to study the leak rate of RPC. To monitor the leakage of gas in the system , we keep track of the pressure of the gas in the receiving chamber and storage tank. The sensors PT1 and PT5 gives value of the gas-pressure within those chambers respectively. The system is adjusted in such a way that when the pressure within the tank reaches the value 1.15 bar it starts to top-up/refill and the process stops when the pressure reaches the value of 1.45 bar. The values of PT1 and PT5 vary in such a manner that when PT1 increases (within its set-points SP1 and SP2) the value of PT5 decreases and vice-versa, the reason being the suction pressure (PT1) adjusts the pressure inside the system by leaking gas more or less through the leaks depending on whether it (PT1) is increasing or decreasing.

6.1 Studying leak of RPC Al04

We put the RPC Al04 in the Closed loop system (CLS) for 20 hrs and monitored the PT5 value. The variation of PT1 and PT5 is found as in fig. 3

So we found that there is a considerable leakage of gas, with a reduction of pressure of 0.258 bar in 20 hrs. Hence there is a loss of 7.74 ltrs of gas in 20 hrs i.e. 0.39 ltrs/hr. The reason for the near constant value after about 10 hrs of run is that since we kept the system working at a low pressure with a flow rate (low FP6 value), there is not enough gas-pressure in the RPC to further leak gas through the leakage joints (the pressure in the system being nearly equal to the atmospheric pressure). Thus, we infer that this RPC have a high leak rate, much higher than the allowable leak rate.

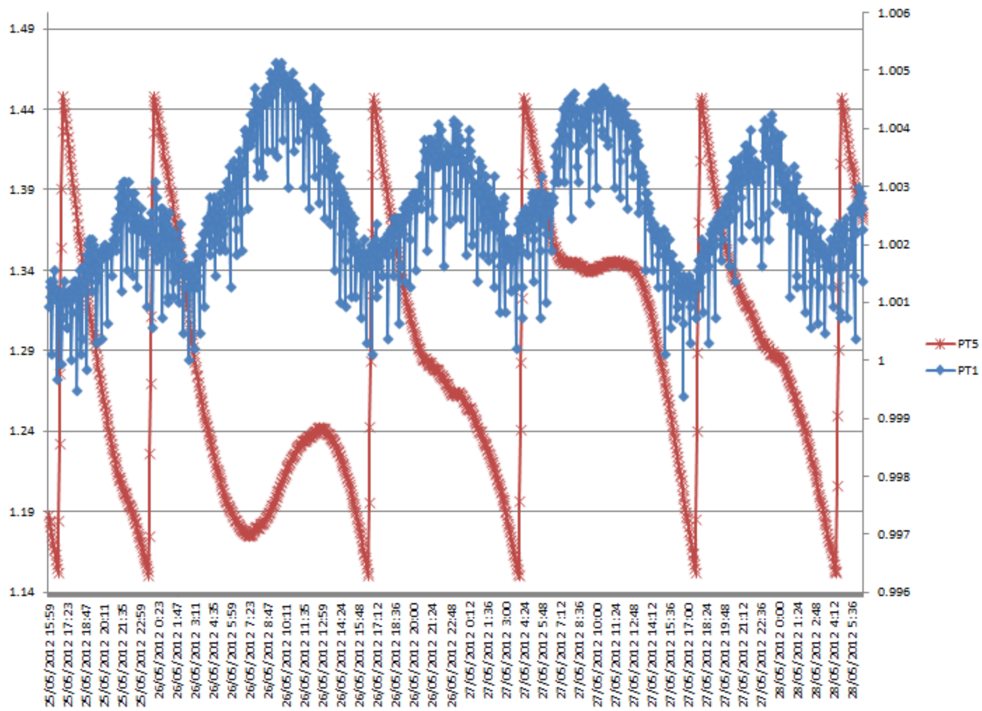


Figure 4: Variation of PT1 and PT5 value for Al10 RPC

6.2 Studying leak of RPC Al10

Then, we connected only the RPC Al10 in CLS for 37.5 hrs. The FP6 (flow set point for gas-loop flow) is increased to 2.5 ltrs/hr. The variation of pressure value at PT5, alongwith PT1, is found out to be as in fig. 4

Thus, this RPC refills, on the average after every 10.5 hrs, rising from PT5 value of 1.15 bar to 1.45 bar i.e. the leak rate is 9 ltrs in every 10.5 hrs, so an avg of 0.86 ltrs/hr. That's a huge amount of leak in comparison to the allowable rate. Also, the rise in PT5 value from ∼1.17 bar to ∼1.25 bar between time 7:23 (26/05/12) to 12:59 (26/05/12) alongwith the MFC2, MFC3, MFC4 indicating value 0 (or negligible) indicates that there is a leakage in path due to which air is entering into the system. The leak is latter found with the help of a 'leak sniffer' at the corner of the RPC, which is then taken care of.

6.3 Studying leak bypassing the RPC

We wanted to know if the leak is itself in the flow path itself or the RPC. So, we by-passed the RPC, keeping only the CLS alongwith the tubes in the loop. Then, we monitored the PT5 value and the variation is found as in fig. 5.

We kept the system running for 27 hrs. We started the system from a lower pressure and watched for 2.5 hrs that when the system is at lower pressure, the leak rate is much less (0.00065 bar in 2.5 hrs i.e. 0.006 ltrs/hr). When started from a higher pressure, the reduction in pressure is 0.024 bar in 24 hrs, so 0.022 ltrs/hr. Since, this leakage rate is much less than the leak with the RPCs, we infer that the gas seepage is occurring mainly due to either the connections with the RPC or from the RPC itself. But, still to make the system leak-free, we also did another test of isolating

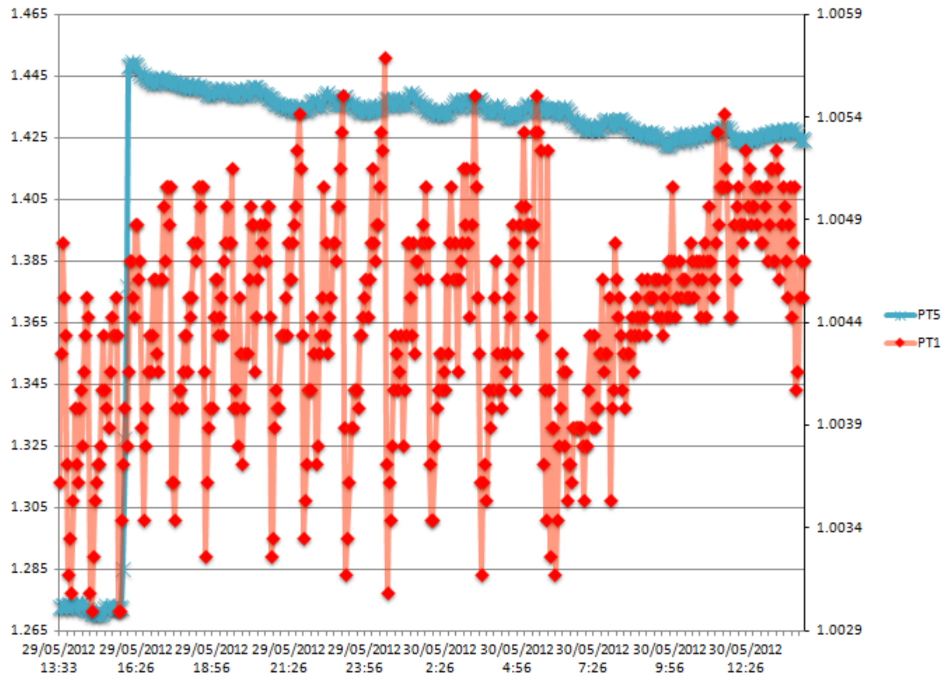


Figure 5: Variation of PT1 and PT5 value for bypassed RPC

the CLS from any of the external connections (no RPC, no external tubes) and kept circulating the gas only within the CLS (for 3 hrs). The leak rate is found to be negligible. Moreover, the leak in the previous case (with the tubes, no RPC) can be further reduced by changing pipes with Stainless Steel (SS) tubes and proper joints, and also using TYGON tubes, rather than PVC pipes, along-with tightening the junctions and connections.

6.4 Studying leak of Al10 with SS tubes and TYGON pipes

We replaced the PVC pipes with Stainless Steel(SS) tubes and connections with TYGON pipes and again put the Al10 in CLS with a higher flow-rate set-point (5.0 ltrs/hr) and observed for 24 hrs (fig. 6)

The leak rate increased to 1.34 ltrs/hr. The continuous gradual decrease of PT5 at the extreme right of the graph is caused due to power-cut. Also, if we give a small tap(push) somewhere near the center of the RPC, we found that there is a bulge and some gas was coming out, thus inferring that the spacers couldn't hold the two glass plates. This might have been caused due to the higher flow-rate that we have set, due to which gas couldn't get out from the RPC through the very fine outlets, thus accumulating inside and creating enough pressure to cause the problem. Also, we checked with a leak sniffer at different joints of the RPC and we found that it is leaking gas through one of the openings where it is connected to the CLS input. Thus, this RPC is replaced from the stack.

6.5 Studying of a new RPC Al11

We connected a new RPC Al11 without putting in the stack and connecting with PVC pipes. Also, we connected a safety bubbler and a manometer in the input alongwith an isolation bubbler and a

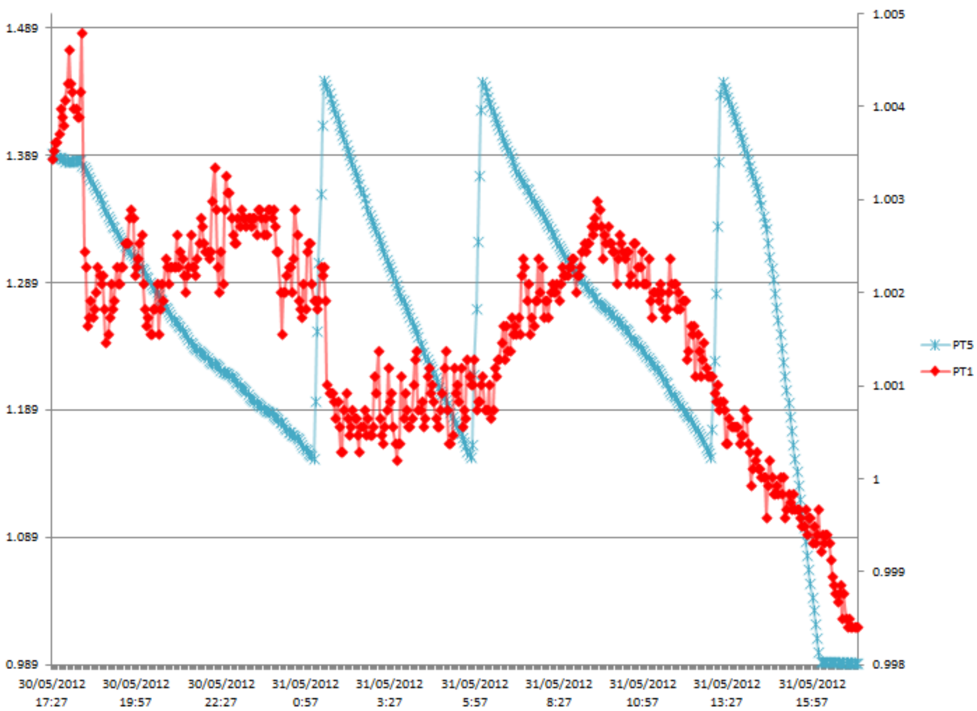


Figure 6: Variation of PT1 and PT5 value for Al10 RPC with SS tubes and TYGON pipes

manometer in the output in the manner as shown in fig.7, and monitor the pressure at the input P_i and pressure at the output P_o.

The values of input manometer and output manometer are found as given in Table 3

Table 3: Variation of input and output pressure

Date-time	input manometer(mm water column)	output manometer(mm water column)
7/6/12 @16:00	25	22
7/6/12 @17:30	32	30
7/6/12 @20:00	30	30
8/6/12 @15:05	12	10
8/6/12 @22;30	5^a	5^a
9/6/12 @10:30	12^a	10^a
10/6/12 @10:30	12^a	10^a
11/6/12 @11:10	35^b	35^b

Note:
^{a} in these cases, the P_i and P_o are less than atmospheric pressure
^{b} the system is restarted here

The variation of PT5 and PT1 is as given in fig 8

The PT5 value decrease by 0.034 bar in 42 hrs i.e. the leak rate is 0.024 ltrs/hr. Thus, this RPC is found to leaking very less and ready for putting in the stack.

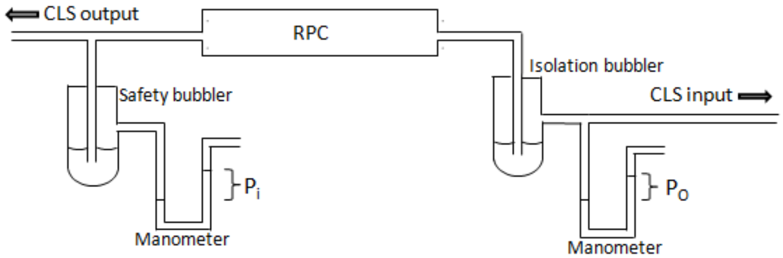


Figure 7: Connecting Al11 with CLS, bubblers and manometer

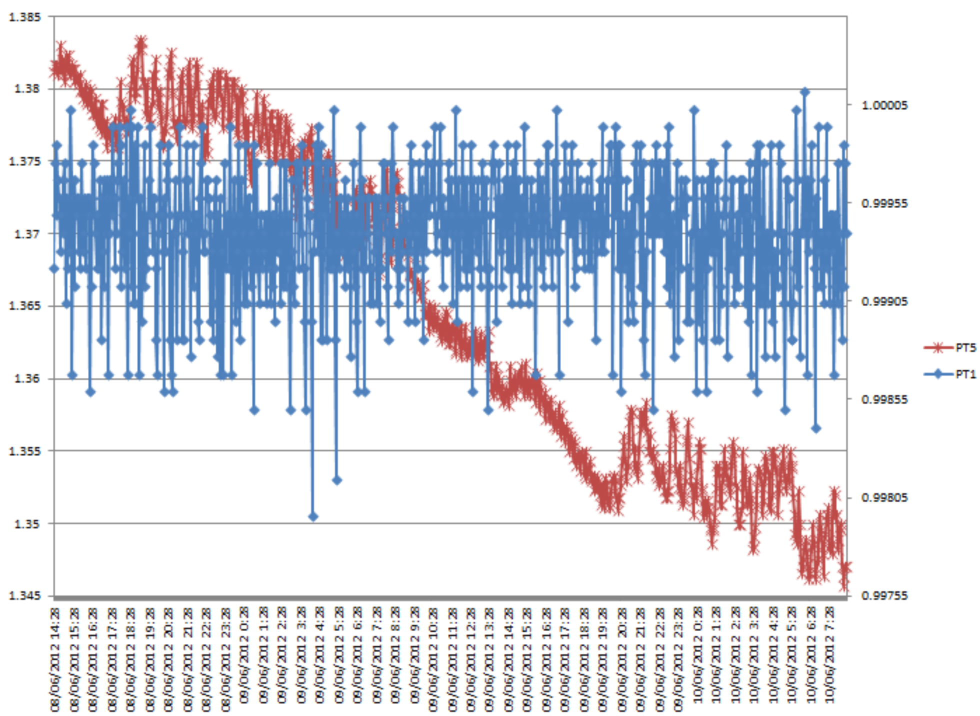


Figure 8: Variation of PT1 and PT5 value for RPC Al11 outside the RPC stack

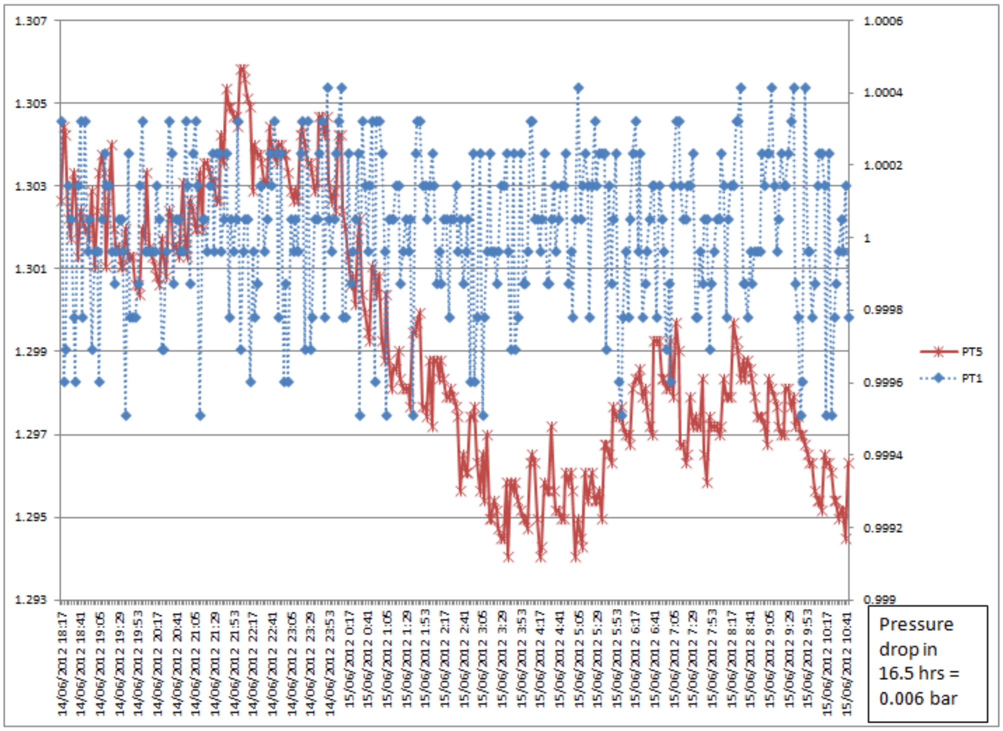


Figure 9: Variation of PT1 and PT5 value for RPC Al11 in the RPC stack

6.6 Studying leak of Al11 putting in stack

The Al11 RPC is put on the stack and the electrical connections are made. The flow rate is reduced by changing the MFC6, thus decreasing the flow rate to full-scale set-point of 216 sccm. It is connected with SS tubes and TYGON pipes with the CLS and the pressure variation monitored as found as in fig. 9 The reduction in pressure is found to be 0.006 bar in 16.5 hrs i.e. 0.011 ltrs/hr. The reduction is leak rate is caused due to lowering of the flow-rate by changing the MFC6. Since, this leak-rate is within the allowable leak-rate, the RPC is ready for further characterization. Also, the rise in PT5 at $\sim$1.294 bar to $\sim$1.3 bar is due to leak in tube connection, which was later found to be at the input nozzle to the RPC from the CLS which is later replaced.

6.7 Reason for the local variation of the PT1 and PT5 value

The loop flow of gas is schematically shown as fig. 10. The PT1 operates between two extreme points – SP1 (maximum value) and SP2 (minimum value). The algorithm of the CLS Auto Pumping Module is as follows: When the PT1 value reaches SP1, it goes to the mode "PD pump suction on, MFC6 flow off". During this period, gas flows from the receiving chamber to the storage tank; thus PT5 value increases . But, as gas goes out from receiving chamber, PT1 value decreases. When it reaches SP2 value, it goes to the mode "PD pump suction off, MFC6 flow on". Thus, during this time, gas flows from the storage tank through the RPCs to the receiving chamber. The gas-pressure inside the tank decreases, thus reducing PT5 value. This process carries on all the time thus causing the local variation of the PT5 value as well as the PT1 value.

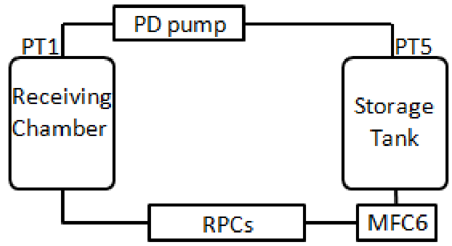
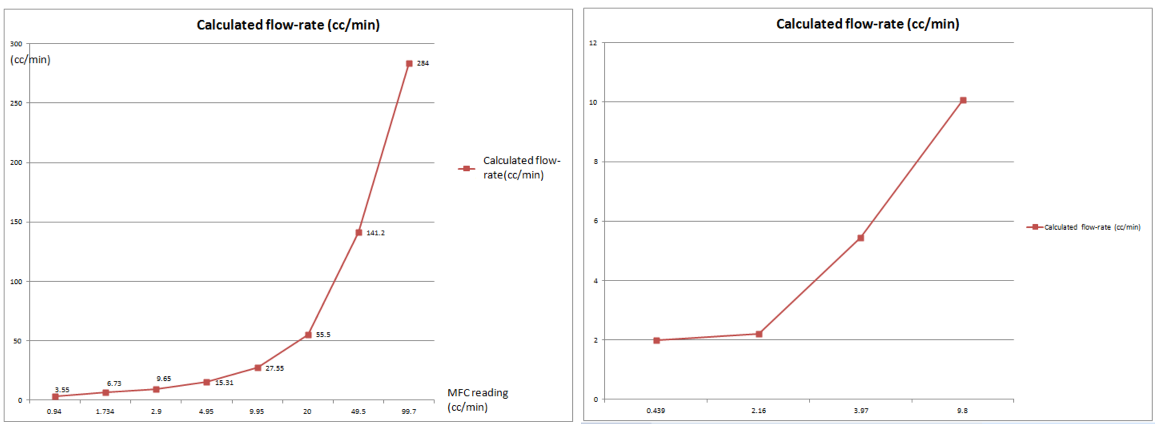


Figure 10: Schematic diag. of gas-flow in closed-loop (clockwise)



(a) Before calibration

(b) After calibration

Figure 11: Calibration Curves

7 Calibrating the MFC6 (flow-rate in the closed-loop)

It is found that the value of MFC6 flow-rate displayed (in the HMI) and the one observed by calculating the number of bubbles of the liquid evolving in the isolation bubbler are different. This signifies we need to calibrate the MFC6 flow-rate. So, the CLS is disconnected from the loop and the gas-output of the CLS is inserted into a long graduated measuring tube – inverted and dipped in a bucket of water. The gas is fluxed into the tube and then water is allowed to flow through the tube. The gas apply the pressure on the water and water bubble flows through the tube and we can determine the rate of flow by measuring the change in volume in some fixed time with the help of stop watch and by means of the formula:

$$Flux = (Change\ in\ volume)/\Delta t$$

Then we calculated the flow-rate observed for each flow-set-point of MFC6. The relation between the MFC6 reading and observed flow-rate before and after calibration is as shown in fig. 11.

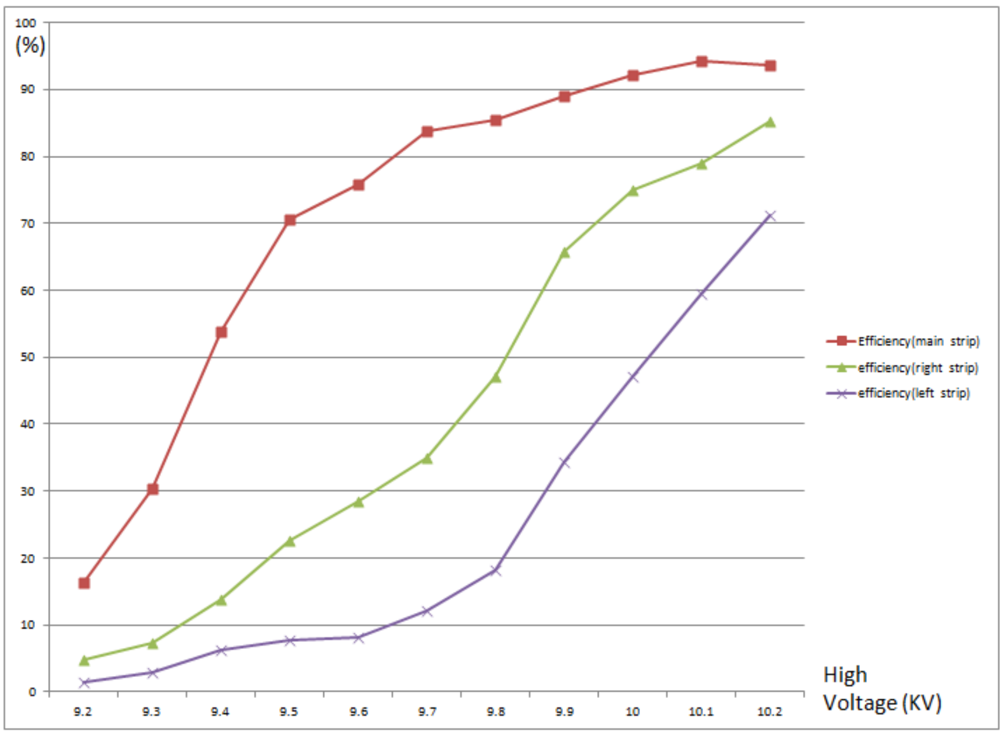


Figure 12: Variation of efficiency of the RPC with High Voltage

8 Characterization of the RPC AL11

8.1 Determining the efficiency of the RPC

The efficiency of the RPC signifies its ability to respond to external radiation by producing distinct, fast and well-distinguished signal. The higher the efficiency of the RPC, the more accurate it will be in tracking a particle passing through the detector. To measure the efficiency, we used Cosmic ray muons (minimum ionizing particles) alongwith a Scintillator paddle-based telescope. The efficiency of the RPC is equal to the ratio of the number of cosmic ray muon triggers detected in a strip of the RPC to the actual number of the muon triggers signals generated by the telescope over a period of time. We varied the High Voltage across the RPC from 9.2 KV to 10.2 KV and calculated the efficiency at each voltage. The variation of efficiency with voltage is as given in fig. 12.

From the plot, we can see that the plateau region of operation of the RPC is beyond 10 KV with an efficiency 94.18%. But this RPC being new and high voltage applied across it for the first time, we didn't go beyond 10.2 KV for efficiency calculation on account of precautionary measure. The main strip shows the maximum efficiency as the paddle was along the main strip. The plot also shows that cross-talks are larger in number at higher voltage.

8.2 V-I characteristics of the RPC

The electrical equivalent circuit of the RPC is represented by taking the RPC gas-gap as a parallel combination of spacers (Ohmic) resistance and gas ionisation volume of the gap (represented by a Zener diode)as shown in fig. 13.

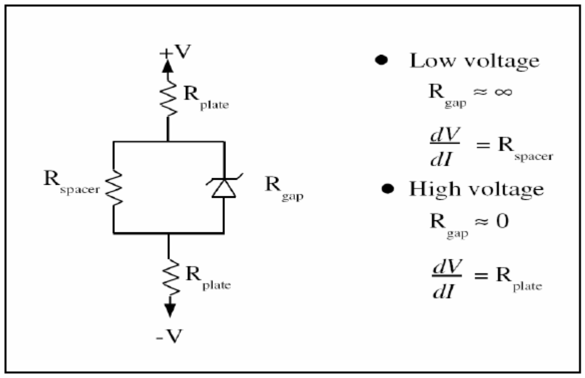


Figure 13: The electrical equivalent circuit of the RPC

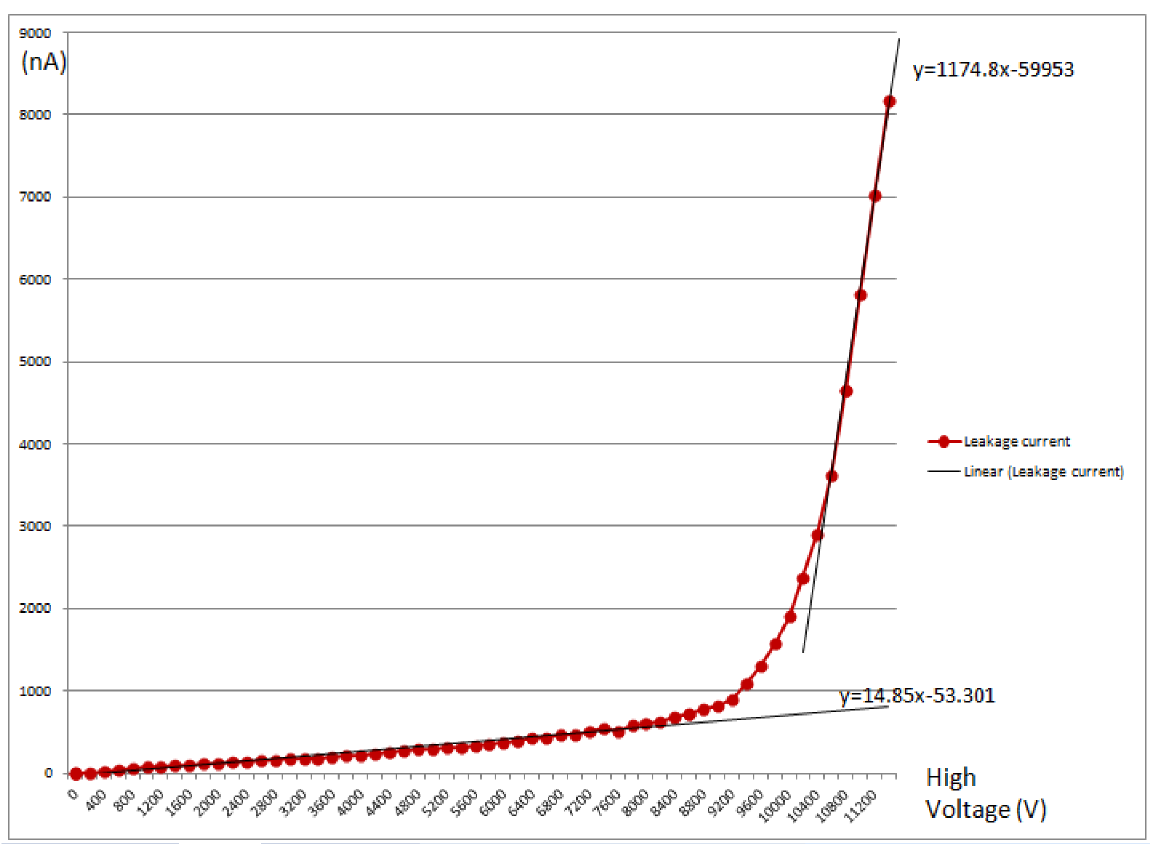


Figure 14: I-V characteristics of the RPC

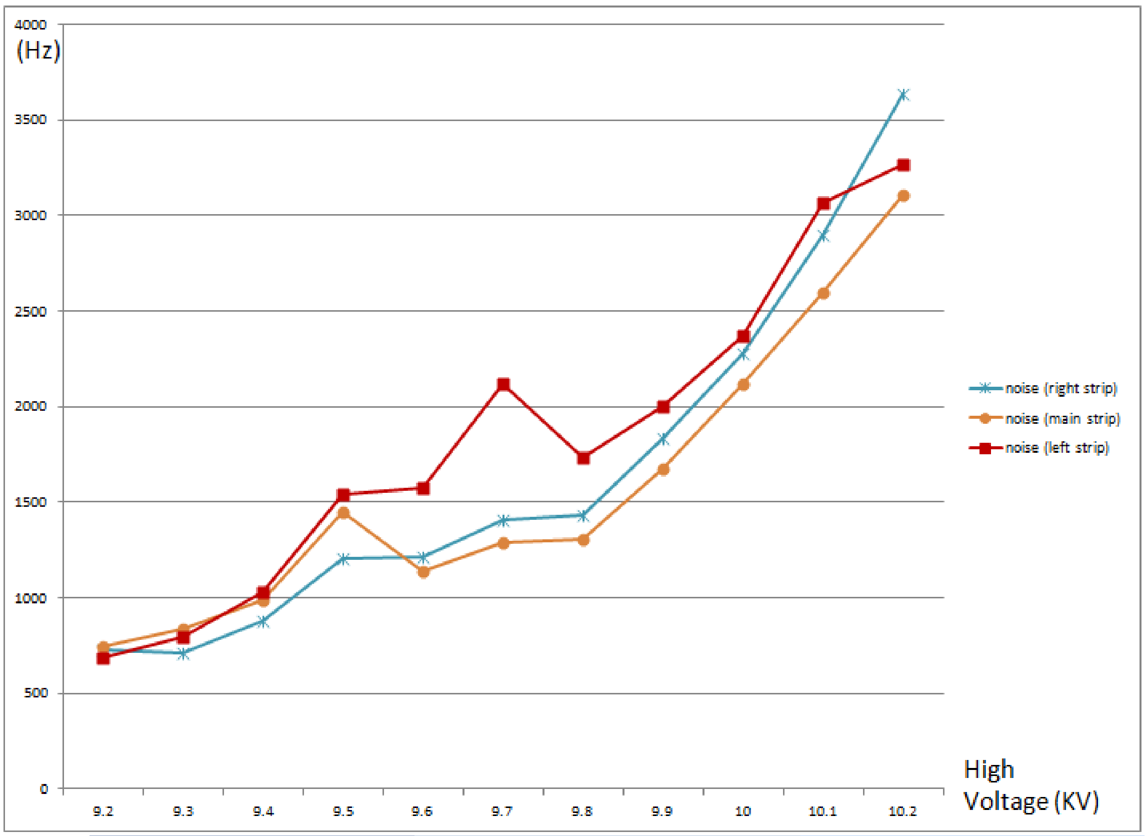


Figure 15: Noise rate vs. high voltage across the RPC

At lower applied voltages, the primary ionizations in the gas-gap do not cause development of avalanches. Therefore, the gas gap offers infinite resistance and hence, the current flowing through the RPC then is entirely determined by the spacer resistance. But as avalanches grow up in the gas volume, the gas gap starts offering negligible resistance. During this condition, when currently entirely passes through the gas gap, the magnitute of the current depends on the glass-plate resistance. The Current-Voltage variation of the RPC is shown in fig. 14.

From fig. 14, we get,
$R_{spacer} = 1/14.85$ GΩ $= 67.3$ MΩ, at low voltages
$R_{plate} = 1/1174.8$ GΩ $= 0.85$ MΩ, at high voltage (beyond 10.2 KV).

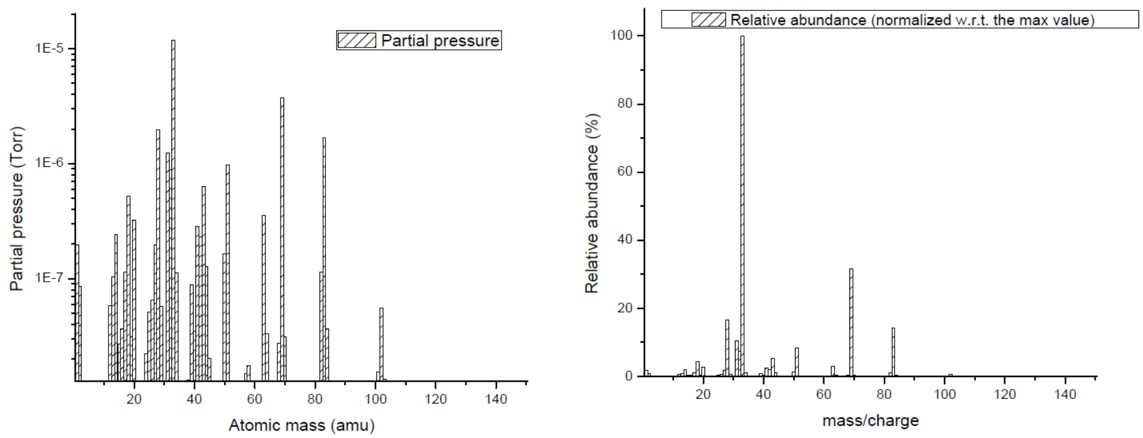
8.3 Noise rate of the RPC

Noise rate of a RPC is the total number of signals detected along a strip of the RPC above a certain discriminator threshold per unit time. These signals are produced by the cosmic ray charged particles of varying energies, due to the leakage current of the chamber as well as due to the surrounding stray radioactivity. The noise rate is a good indicator of the the long-term stability of the chamber as well as its leakage (dark) current. This rate per unit cross-sectional area of a particular RPC should be consistent when averaged over a reasonable period of time. For instance, if the leakage current of a RPC increases drastically, there will be a sharp increase in the noise rate. This will lead to reduction of the actual voltage applied across the electrodes and hence the RPCâĂŹs gain as well as its efficiency decreases. The fig. 15 shows the variation of noise-rate with high voltage. As we increase the voltage, even ionization created by lower energy particles are also amplified enough to be detected which results in increased noise rate.

9 Analyzing the gas-mixture in RPC connected with the CLS with a RGA

A residual gas analyzer (RGA)is a miniature-sized mass spectrometer that is connected to a vacuum system and whose function is to analyze the gas-mixture inside the vacuum chamber. A small fraction of gas molecules are injected into the chamber which are ionized (positive ions), and the resulting ions are separated, detected and measured according to their molecular masses. In the present case the composition of the gas-mixture inside the RPC is measured by RGA, manufactured by Standford Research Systems(SRS) model RGA 300 probe [5]. The probe is interfaced with the chamber and turbo vacuum pump. This analyzer has a capacity to detect and measure upto mass number 300. Operating pressure for measurement is fixed at around 3.0×10^{-5} mbar whereas background vacuum is at 1×10^{-7} mbar. Reference scans for each pure constituent gas is generated by sampling the gas directly from their cylinders separately. As the library does not contain reference for the R134a gas and Isobutane gas, scan for these gases were acquired and used as reference.

First, analyze the gas-mixture for the discrete atomic mass range 1 amu to 150 amu with the RGA taking a large no. of scans (in this case about 40 to 50). Now, from the scanned ASCII data, neglect any negetive values (because they do not correspond to physical values)calculate the standard deviation (SD) of the partial pressures for each atomic mass for all the scans. If the SD/(mean of the partial pressures for that atomic mass) is greater than some threshold value (say 0.1), then look into the scan data for that atomic mass and find the scan(s) that caused the high value of the SD. When we detect that scan no(s), we remove all the data corresponding to that scan(s). Then repeat the above process again, find the mean partial pressures for each atomic mass and normalize them with respect to the maximum partial pressure among the constituents. Then plot this normalized partial pressures against the atomic mass no. The figs.16(a) and 16(b) shows the analysis of the gas-mixture inside the RPC connected with the RPC.



(a) RGA spectra of the gas-mixture

(b) Relative abundance of different gases w.r.t the major component

Figure 16: RGA mass spectra of the gas-mixture in the RPC connected to the CLS

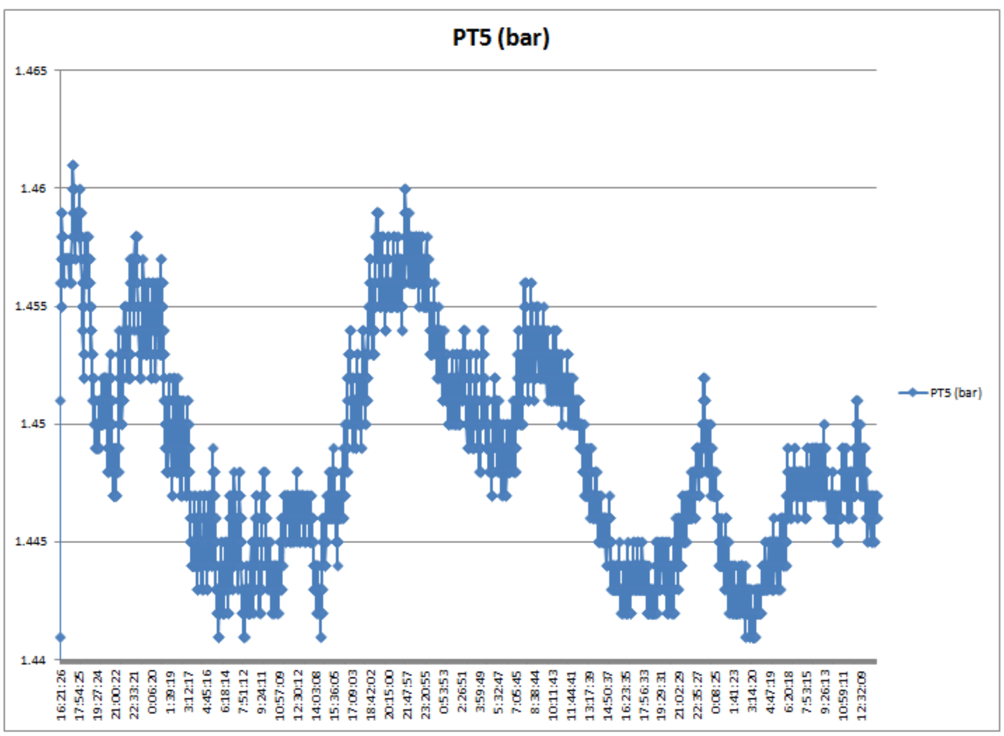


Figure 17: Variation in PT5 value for monitored over 72 hrs

Now, from the data we got from the RGA spectra and combining the results with the pure spectra of each component gases gives that the gas-mixture inside the RPC have – r134a: 82.4%, Iso-butane: 5.1%, Air: 9.8%, Water: 2.5% and SF_6: 0.2%.

10 Conclusion

In the conclusion, I would like to state an issue that is observed. When the RPC AL11 is kept under constant pressure monitoring for about 72 hrs, the variation of PT5 is as shown in fig. 17.

The reason for the local variation of PT5 value is as explained before. But, the reason for increase in PT5 value (by about 5 mbar to 10 mbar) after certain large intervals (of ∼7–10 hrs) is not addressed. During those periods, the MFC 2,3 and 4 values remained 0 sccm, so this increase in pressure is not caused by the top-up of gas-mixture from the CLS. I monitored the Temperature, Pressure and Humidity variation inside the lab throughout that period to see if the pressure variation shown by the PT5 is due to the sensitivity of the Pressure Transmitter sensor, but I found that there is no correlation between the variation of the above mentioned parameters with the PT5 value. Further analysis of the RPC and the CLS is required to understand this behaviour.

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[5] www.thinksrs.com/products/RGA.htm