Study of Mixed Gas Flow Pattern Inside RPC

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ABSTRACT
The proposed INO-ICAL detector [1] will be instrumented with 28,800 RPCs (Resistive Plate Chamber). These RPCs are of (1.8 x 1.9) m² size, consist of two glass electrodes separated by 2 mm gap and use a gas mixture of R134a (C₂H₂F₄), isobutane (iC₄H₁₀) and sulphur hexafluoride (SF₆) in the ratio of 95.3%, 4.5% and 0.2% respectively. Since the number of RPCs and the detector size is large and to improve the performance of an RPC, understanding the flow of gas mixture inside the detector is necessary. The ANSYS CFX software is used for simulation. The new design of the RPC with nozzle position at an angle of 45° is considered and then changing the position of the input and output nozzles, some studies is done. The flow of R134a and then of mixed gas simulation through an RPC is presented.

Keywords: Neutrino detectors; Particle tracking detectors (Gaseous detectors); Detector design and construction technologies and materials; Gas systems and purification.

INTRODUCTION
INO (India Based Neutrino Observatory), a large mega science project funded by Department of Science and Technology and Department of Atomic energy, Govt. of India. RPC (Resistive Plate Chamber) is one of active component for construction of 50K ton magnetised Iron Calorimeter detector (ICAL) [1]. INO ICAL will use 28800 RPC detectors of (1.8 x 1.9) m² with the gas gap of 2 mm therefore the volume of each RPC is approximately 8 liters and the total volume of gas for the final ICAL will be about 200 m³ [1].The RPCs can be operated in 2 modes namely avalanche mode and steamer mode. The gas mixture and the high voltage decide the mode of operation. For INO ICAL RPCs will be operated in the avalanche mode and therefore concentration of the mixture of gases that are being used contains R134a (95%), Isobutane (4.5%) and SF₆ (0.5%).

During the past few years, we have made significant progress in improving the flow and control of gas mixture for the Resistive Plate Chamber (RPC) performance in a closed loop system (CLS) [2]. The RPCs are continuously flushed with a gas mixture of R134a (C₂H₂F₄), i-butane (iC₄H₁₀) and sulphur hexafluoride (SF₆) in the ratio of 95.3%, 4.5% and 0.2% respectively, at a steady flow rate of about 6 Standard Cubic Centimetre per Minute (SCCM) per RPC to maintain one volume change per day in a CLS is being used.

It is known that the parameter like flow rate, variation in pressure gradient within the RPC, the external pressure, temperature, quality of the gas etc. play a vital role in the performance of the RPC. It might be possible that during the operation of the RPC, the gas may exhibit changed concentration with in the localised area within an RPC. This may affect localised or overall performance of the RPC and hence some simulation work is done.

In the study all the actual dimensions of the RPC are taken into account. All flow simulations are in 3D simulations using ANSYS CFX software. The flow of higher concentration gas among the three gasses in the RPC is considered and then the mixed gas flow is simulated. The dimensions of the nozzle and angle are considered during the simulation.

Geometry and design of RPC:
RPC is constructed by using (1.8 X 1.9) m² glass sheets (resistive plates) of 3 mm thickness. The gap of 2 mm between glass sheets is maintained by button spacers of height 2 mm and diameter 11 mm placed at distances of 200 mm both along X and Y directions and by side spacers of thickness of 2 mm, on the four edges to make glass gap. These buttons play, a crucial role in maintaining the gap throughout the area of RPC gap, so that the applied field is uniform. The elementary component of a RPC is a gap, a gas volume enclosed between two resistive plates. The glass sheets are coated with conductive paint on the outer surface. There are two gas inlets and two outlets for gas flow as shown in the Figure 1.the inlet nozzle is inclined at 45 degrees clockwise while the outlet nozzles are inclined at 45 degrees anticlockwise. To optimize the same with a RPC tray the nozzles are at 45 degrees. Current design of RPC is referred as design I in this paper.
In design I, Distance between the left edge and left nozzle in lesser, compared to the distance between the right nozzle and the right edge. Initially, during the design process of the RPC, Nozzle positions were different. The nozzles were placed in such way that the distance between the left wall and the left nozzle is equal to the distance between right nozzle and right wall and the distance between two nozzles is twice the distance between nozzle and the nearest wall. This arrangement is designated as design II in this paper. In the final ICAL it is decided to have parallel flow for 4 RPCs from a common source of gas manifold and to accommodate the high voltage cables, low voltage cables, gas tubes etc. with in a RPC tray.

PHYSICAL PERSPECTIVE AND PERFORMANCE PARAMETER

In the final ICAL the number of RPCs is huge and a Closed Loop System is mandatory. The RPCs performance depends on the quality of gas, the flow rate, applied high voltage, temperature, pressure, humidity etc. Unlike the Bakelite RPCs at CMS and ATLAS use flow of few litres per hour, the INO glass RPCs a flow rate of 6 SCCM which approximately corresponds to one volume change per day is being used. The function of the three gases are, R134a is the main ionisation gas, isobutene for secondary UV photon absorber and SF6 to control the gain and hence reduce the pulse height and noise of the output pulse of an RPC.

METHODOLOGY FOR SIMULATIONS

The 3D CAD Models are designed in the SOLIDWORKS platform. The fluid volume was constructed by referring to the actual dimensions of the RPC. A fine mesh of 1334760 unstructured elements is created in ANSYS Meshing. The area of the inlet gas nozzle is 4.15475 mm². The study of the flow pattern through the RPC is done for the volumetric flow of 6 SCCM, which corresponds to the inlet velocity of 0.012034 m/s as flow of 3 SCCM will be the flow per nozzle.

The major component of the mixed gas is R134a and hence is considered for the initial simulations. Further the mixed gas simulations are carried out.

For the mixed simulation, at the inlet, the gas mixture consists of R134a (95%), Isobutane (4.5%) and SF6 (0.5%). The outlet of the nozzle is kept as atmospheric opening and the volume fraction of the gas components at the outlet are assumed to be same as inlet.

The simulation was also done by assuming the gas mixture flowing through the RPC as fixed component mixture. Transient simulation for the time of 60 sec has been performed. Flow was assumed to be in the laminar region during the simulation because of very low velocity of gases, all the surfaces like polycarbonate buttons, glass sheets assumed to be smooth. The force exerted by the gas on the glass is not considerably great and the gas leakage from the RPC is assumed to be zero.

The simulations are also performed for design II by keeping the mesh settings same. The fluid simulations are done by using ANSYS CFX solver.
(II) SIMULATION RESULTS FOR FLOW OF R134a GAS THROUGH RPC

(ii.i) velocity contour for design I  
(ii.ii) velocity contour for design II

(III) SIMULATION RESULTS FOR DESIGN I (CURRENT CONFIGRATION OF RPC)

(iii.i) R134a gas contour  
(iii.iv) R134a volume fraction contour

(iii.ii) Iso butane gas contour  
(iii.v) Iso butane volume fraction contour
(iv.iii) SF$_6$ gas contour (iv.vi) SF$_6$ volume fraction contour

(IV) SIMULATION RESULTS FOR DESIGN II

(iv.i) R134a velocity contour (iv.iv) R134a volume fraction contour

(iv.ii) Iso butane velocity contour (iv.v) Iso butane volume fraction contour
RESULTS AND INTERPRETATION

In the Design I, the distance between the left wall and the left inlet is less compared to the distance between the right nozzle and right wall. The direction of the velocity vector of the gas at the inlet is 45 degrees in the direction of the left wall. Due to this particular configuration, gas entering the setup from the left nozzle has little space to flow compared to the gas entering from the right nozzle. As a result, a velocity of the gas in the left side of the RPC is greater than the velocity of the gas from the right nozzle. The volume rate remains constant throughout the RPC hence the velocity of the gas decreases after entering the RPC, reaches a minimum and then increases as the gas approaches the outlet.

The velocity contour and streamlines are almost symmetric in all simulations for the design II. But in this case flow rate in the right outlet nozzle is more to that of the left outlet nozzle. The results for both the cases are compared in Table 1.

The volume fraction of all 3 gases is hardly changing for both configurations.
In the figures (iii.vi) and (iv.vi) we can see that in the green area the volume fraction of the SF6 is varying from the values 4.998e-003 to 5.012e-003. This is ±2.4 % change with respect to the assumed value. Similar results have been observed for the R134a and Isobutane figure (III) and (IV).

For the given set of boundary condition Flow pattern in the RPC design is almost same for the R134a gas, mixed gas and fixed composition mixture.

CONCLUSION

For the flow of 6 SCCM, for both designs, the volume concentration of the gases is not changing significantly. The main concern during the study is the change in the concentration in the SF6. As discussed earlier, for the flow of 6 SCCM the change in the volume concentration is very small for the sulphur hexafluoride for both designs. So the overall performance of the RPC will not be affected.

Some dead places for the gas flows are also observed in both designs. In the design I, at the right side of the RPC the velocity of the gases is very low. As a result in the practical arrangement, gas may stagnate. Consequently, the formation of radicals at these spots will affect the performance the RPC.

In the second design, such dead zones are not observed. The previous design of the RPC seems to be a better design both as flow lines are spread out and pressure drop across it compared to the design I is less. As previously mentioned due to some physical constraints nozzle positions are changed. So to improve the flow of gases, more optimisation needs to be done.

REFERENCES

