Simulation Study of Gas Flow in a 2mm Gap RPC: Effects of Applied Pressure and Detector Dimensions

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Introduction

Gaseous detectors, particularly Resistive Plate Chambers (RPCs), have been a long-standing preference in particle physics due to their excellent performance and relatively low costs. To achieve optimal efficiency and minimize contamination, RPCs require a consistent gas flow. However, the environmental impact of gas consumption is significant for research facilities globally, alongside the expenses related to gas procurement. It is essential to maintain a gas mixture free of contaminants to prevent damage to the detector. Furthermore, the gas flow must be carefully designed to avoid regions of slower movement, which could lead to the accumulation of contaminants.

The gas system in RPCs, serving as the active detection material, directly influences the performance, efficiency, and longevity of these detectors in particle physics experiments. Optimizing the gas pressure and velocity profile within the detector is critical for ensuring gas purity and uniformity in the chamber. High purity and uniformity reduce dead zones, enhance efficiency, and ultimately lower operational costs.

Additionally, the study of gas flow is vital for efficiently flushing the detector while minimizing gas expenditure. To achieve steady and prolonged performance of RPCs, we have investigated gas flow dynamics within RPCs using the COMSOL Multiphysics simulation tool. This study aims to accomplish the following objectives:

- To analyze the velocity and pressure profiles inside the RPC and their temporal variations at different pressures.
- To evaluate the impact of RPC dimensions on gas uniformity and purity.

Simulation and Design

We employed COMSOL Multiphysics to simulate gas flow within the RPC detector, utilizing the CFD module. For initial results, we focused on a single gas (Argon) and fixed the detector's geometry at 25 cm × 25 cm. In the first part of the study, we examined the impact of pressure differences, applying values from 5 Pa to 60 Pa with inlet and outlet sizes of 2 mm, positioned at opposite corners and 1.5 cm from adjacent corners. The second part explored the dimensional effects on saturation time and uniformity by analyzing quarter, half, one-meter and tow-meter sizes at a constant pressure of 25 Pa. The flow was simulated as incompressible, with reference conditions set at 1 atm and 293.15 K.

Results and Discussion

To analyze the velocity and pressure profiles, we observed the variation in the gas velocity over time, as illustrated in Figure 1. Each row represents a different applied pressure: the first row corresponds to 5 Pa, the second to 25 Pa, and the third to 60 Pa. The first column displays the velocity profile at $t = 0$, the second column at $t = 1$ s, and the third column captures the moment of saturation.

In terms of RPC dimensions, our findings indicate that larger volumes yield a more uniform gas flow compared to smaller volumes, as shown in Figure 2. Furthermore, the simulations reveal that, at pressures up to 25 Pa,

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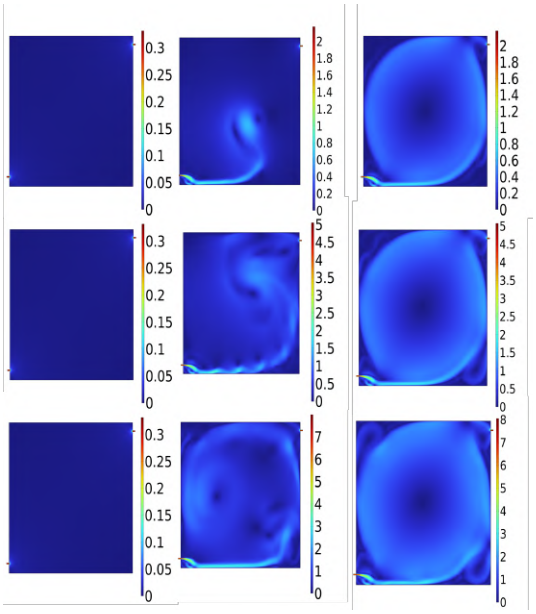

FIG. 1: Velocity profile snapshots at different pressures with time. Columns (Left to right): 0 s, 1 s and saturation time. Rows (top to bottom): 5 Pa, 25 Pa, 60Pa.

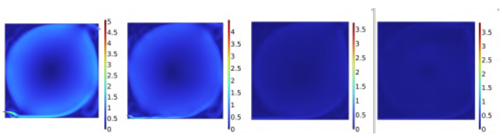

FIG. 2: The snapshots of the velocity profile of gas flow at different sizes of RPC. Left to right (25cm, 50cm, 100cm, 200cm) with saturation times at 30, 100, 120, 190 seconds respectively. Pressure is set at 25Pa for this study.

saturation time does not exhibit a linear relationship with applied pressure (see Figure 3). However, beyond 25 Pa, saturation time begins to increase but decreases for 40 Pa. Although the underlying reason for this behavior remains uncertain, it may be attributed to the onset of turbulence at higher pressures, which could contribute to this observed effect.

Conclusion and Future Work

This study examined the gas flow dynamics within Resistive Plate Chambers (RPCs),

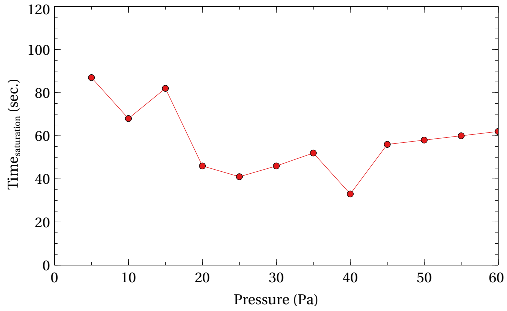

FIG. 3: A graph between saturation time of gas flow and pressure.

focusing on the velocity and pressure profiles under varying conditions. Our findings highlighted a non-linear relationship between saturation time and applied pressure, particularly noting that saturation time increases beyond 25 Pa. This behavior suggests the potential onset of turbulence at higher pressures.

Future work will aim to refine our analysis by employing finer pressure increments to achieve smoother results. Additionally, we will optimize the positioning of RPC inlet and outlet components to enhance overall efficiency, reduce dead areas, and minimize gas costs. These advancements are expected to improve the performance and sustainability of RPC systems in particle physics applications.

Acknowledgments

SM and SS acknowledge DST-New Delhi for financial support. Project. LS and VS acknowledge the DST-FIST.

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