

INTRODUCTION

Standard gas mixers and mass flow controllers (MFCs) used for gaseous detector setups carry a high financial cost, often exceeding €850 per unit. This project aims to make precise gas mixing far more accessible for RPC (Resistive Plate Chamber) laboratories and research institutions worldwide by providing a low-cost, modular alternative. The developed Volume-Based Gas Mixing System (VFC) utilizes stepper-motor peristaltic pumps priced at approximately €20 each. The core operating principle relies on direct volumetric displacement, where the gas flow rate ($\dot{V}_{\text{gas}}$) is directly proportional to the rotational speed (S in RPM) of the stepper motor according to $\dot{V}_{\text{gas}} \propto S$. Each motor rotation produces three volumetric increments (~ 0.139 mL/increment), establishing a conversion factor where $1 \text{ RPM} \approx 0.43 \text{ cm}^3/\text{min}$ in volume.

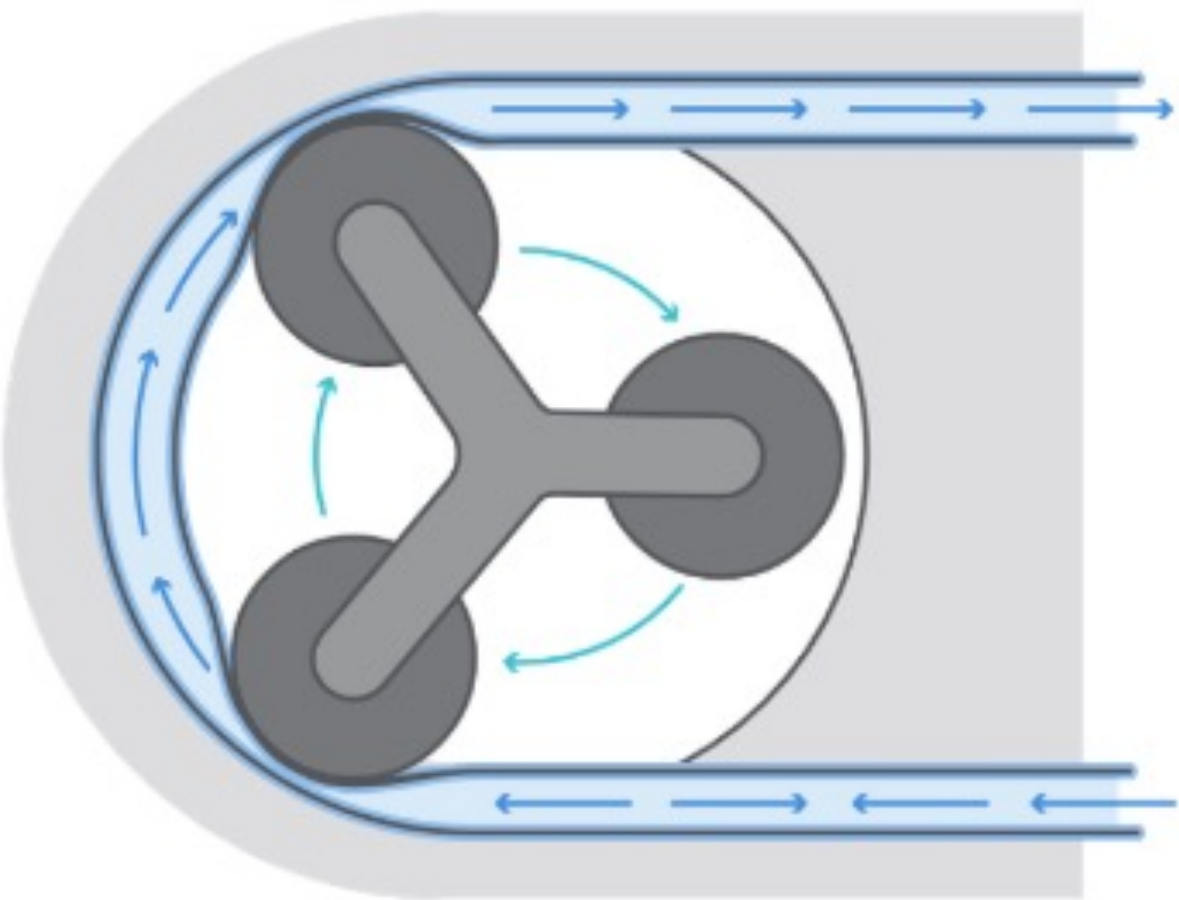


Figure 1. Peristaltic pump operating mechanics [1].

EXPERIMENTAL RESULTS

To validate single-pump behavior before testing multi-gas mixtures, initial baseline measurements were conducted using a single peristaltic pump. Flow rates were calibrated via a water displacement method using a measuring vessel with a volume uncertainty of ± 2.5 mL, timing the displacement for every 50 mL of gas output.

Initial testing showed a linear relationship between motor rotation frequency and volumetric flow rate across both Air and Argon. Linear regression yields essentially identical response slopes for both gases ($\alpha = 0.0251 \pm 0.0006 \text{ L/h/Hz}$ for Air vs. $0.0255 \pm 0.0006 \text{ L/h/Hz}$ for Argon).

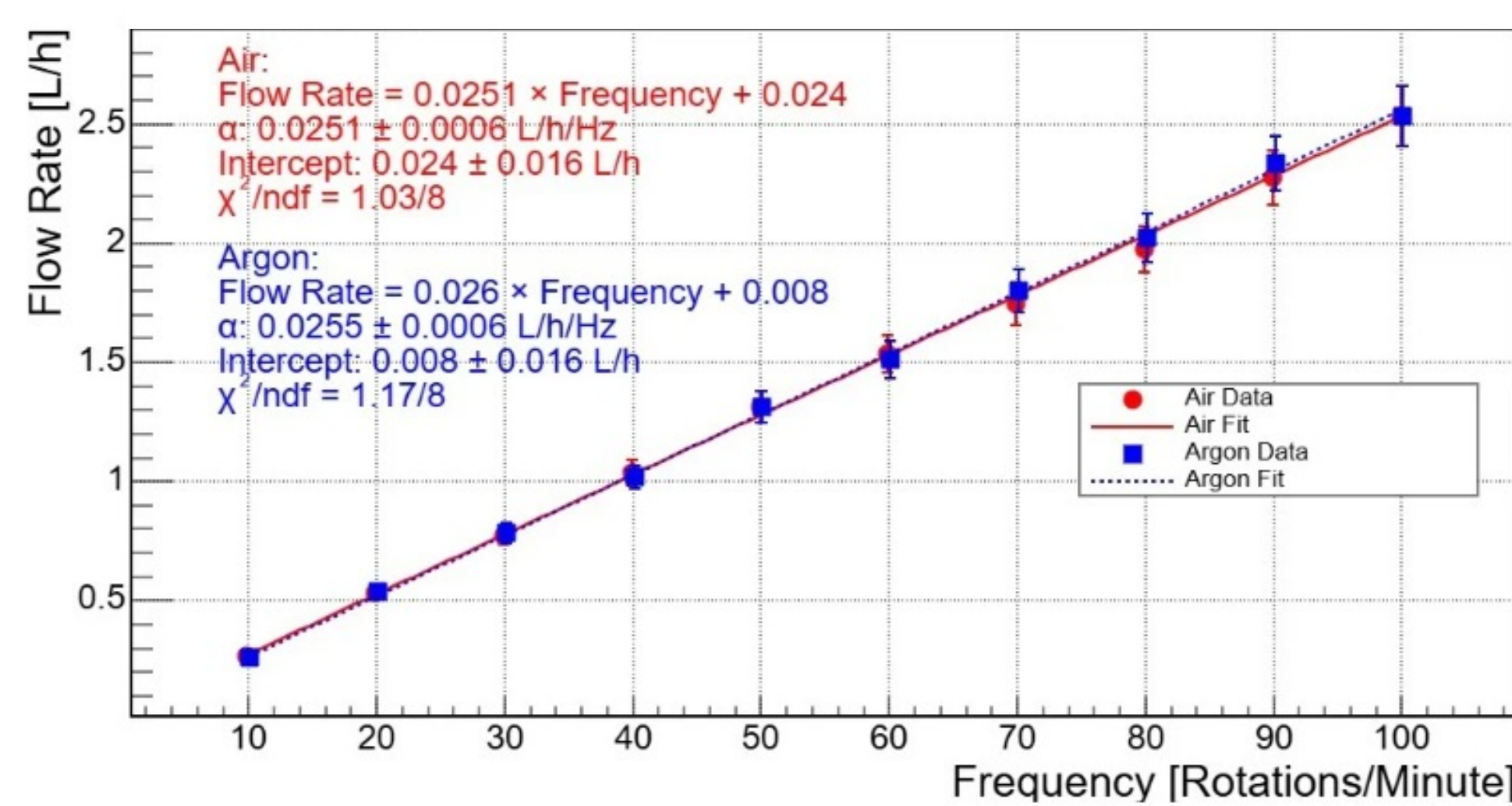


Figure 2. Flow Rate Calibration vs. Frequency of Rotation

To determine system behavior under different pressures, Argon gas was evaluated at two different upstream line pressures (100 mbar vs. 180 mbar). Increasing upstream pressure results in a systematically higher baseline flow rate across all tested frequencies (10-100 RPM). This demonstrates that line pressure changes offset baseline delivery without compromising core system linearity.

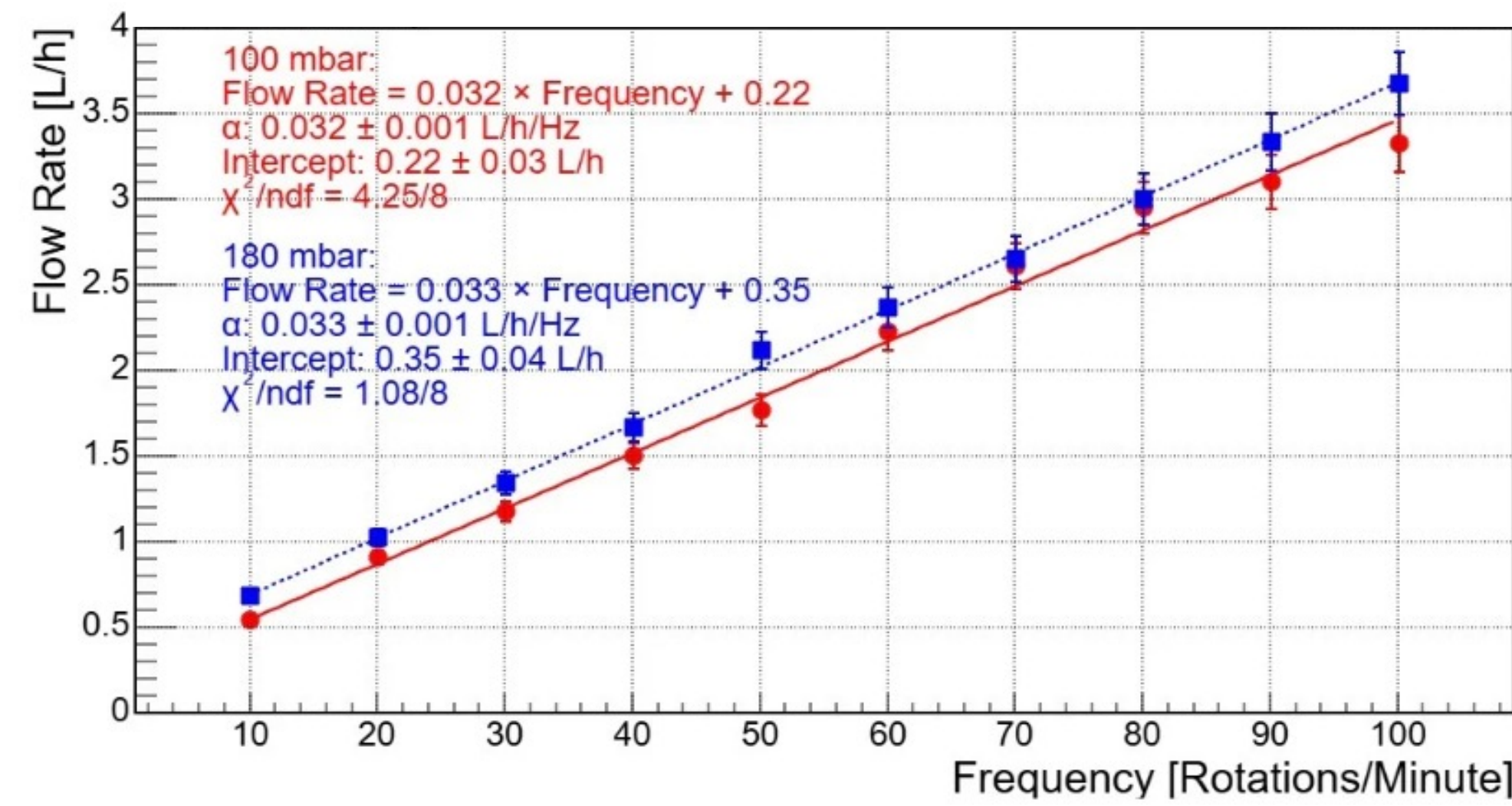


Figure 3. Flow Rate Dependence on Inlet Pressure

The next set of experimental tests were carried to validate binary gas mixing performance using Argon (Ar) and Carbon Dioxide (CO_2). Upstream supply lines for both gas species pass through independent pressure regulators and inline pressure sensors to monitor inlet feed stability before entering the Volumetric Flow Control (VFC) setup. Within the VFC, two peristaltic pumps driven by motor controllers and powered by 20V power supplies meter each gas component independently. The metered streams join downstream into a diffusion volume to ensure thorough gas phase mixing prior to analytical verification. The blended output is routed directly into a Binary Gas Analyzer (BGA). The BGA continuously monitors real-time gas concentration ratios and composition stability before venting to atmosphere.

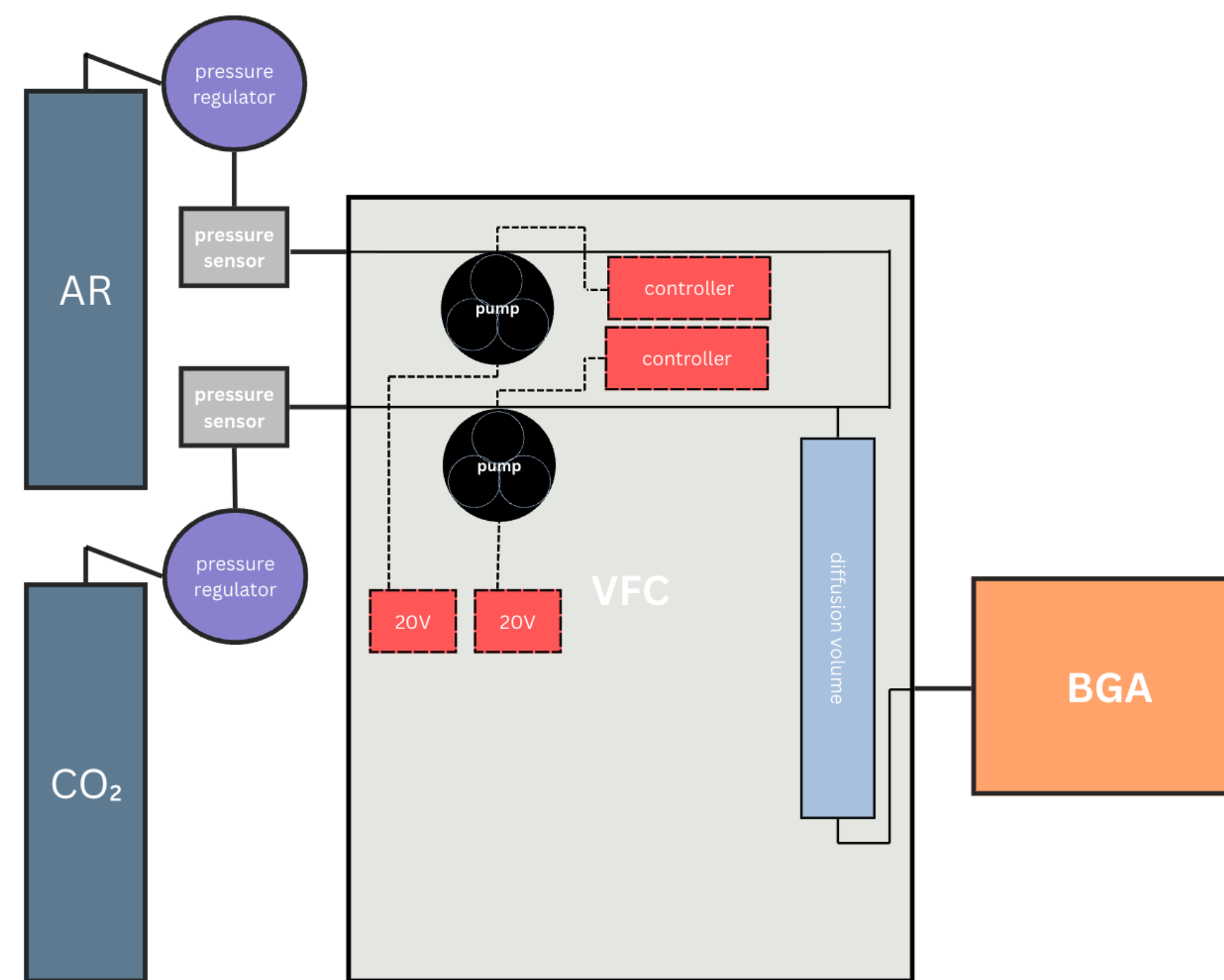


Figure 4. VFC Testing Setup Using the Binary Gas Analyzer

Individual pump motor frequencies (in RPM) were adjusted to deliver target volumetric concentration ratios across runs 1-5 (50%, 40%, 30%, 10, and 5% of CO_2 , and the rest Argon).

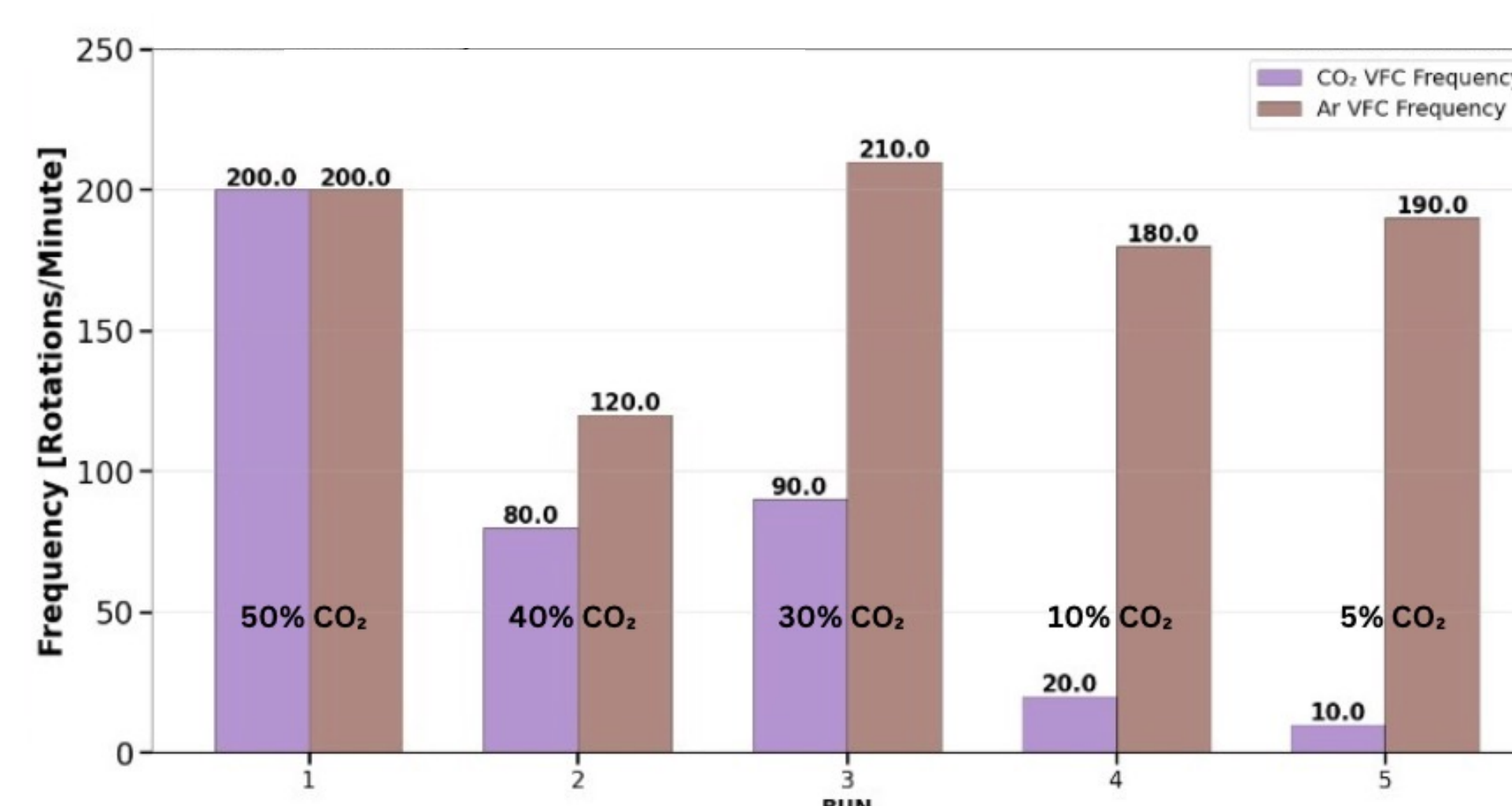


Figure 5. Frequency (RPM) Settings Across Experimental Runs

The inlet pressure ratios across the CO_2 and Argon delivery lines were calibrated to maintain stable volumetric mixing across five target concentrations. With the Argon line held at a constant working point of 80 mbar, adjusting the relative CO_2 inlet pressure optimizes flow conditions for each corresponding motor frequency pair, confirming that pneumatic balancing yields reliable mixture stability.

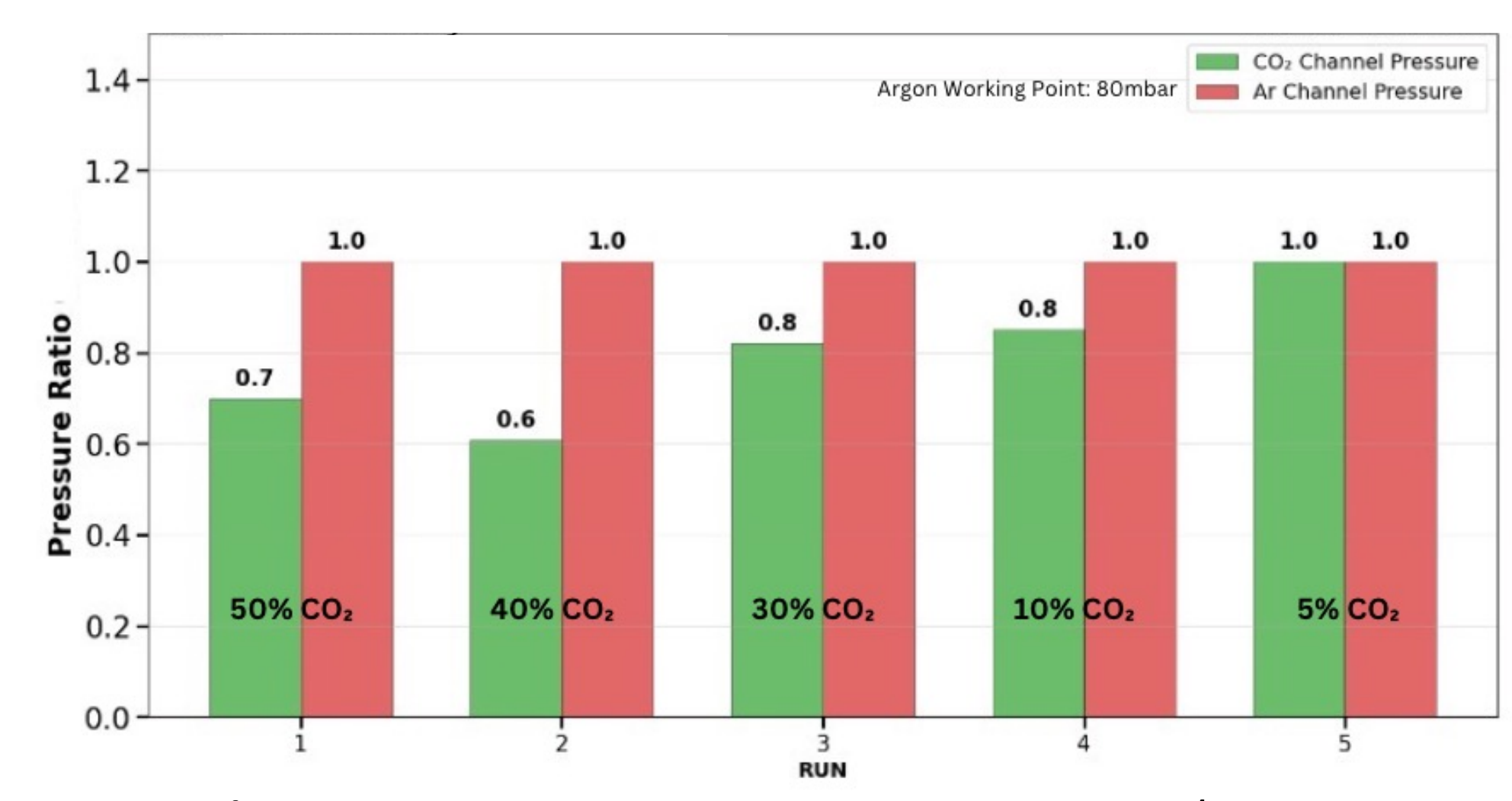


Figure 6. Gas Line Pressures Across Experimental Runs

To validate the mixing accuracy of the VFC system, output gas compositions were verified using a Binary Gas Analyzer (BGA). The measured CO_2 molar concentrations show agreement with nominal set points across all runs (e.g., $49.88\% \pm 0.19\%$ measured vs. 50.00% target as shown in figure 7). Minor discrepancies remain well within the instrument's systematic error bounds.

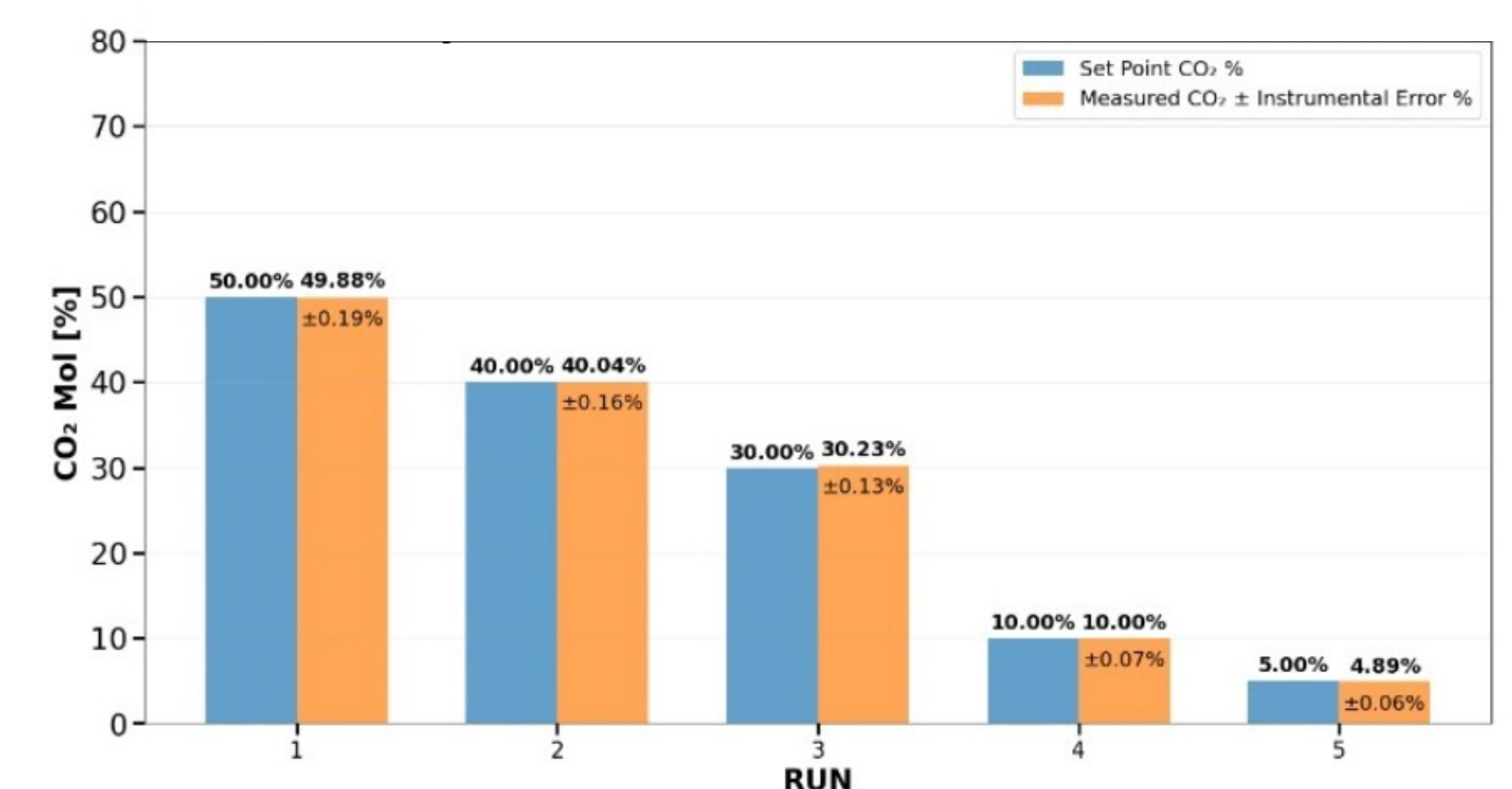


Figure 7. Expected vs. Measured CO_2 Concentration

System performance was evaluated by calculating the VFC relative percentage error, defined as:

$$\text{Error} = \frac{|\text{Measured Value} - \text{Set Point}|}{\text{Set Point}} \times 100\%$$

The relative error remains below 1.0% across higher CO_2 fractions (10%--50%), peaking at $\sim 2.2\%$ at the lowest concentration (5% CO_2).

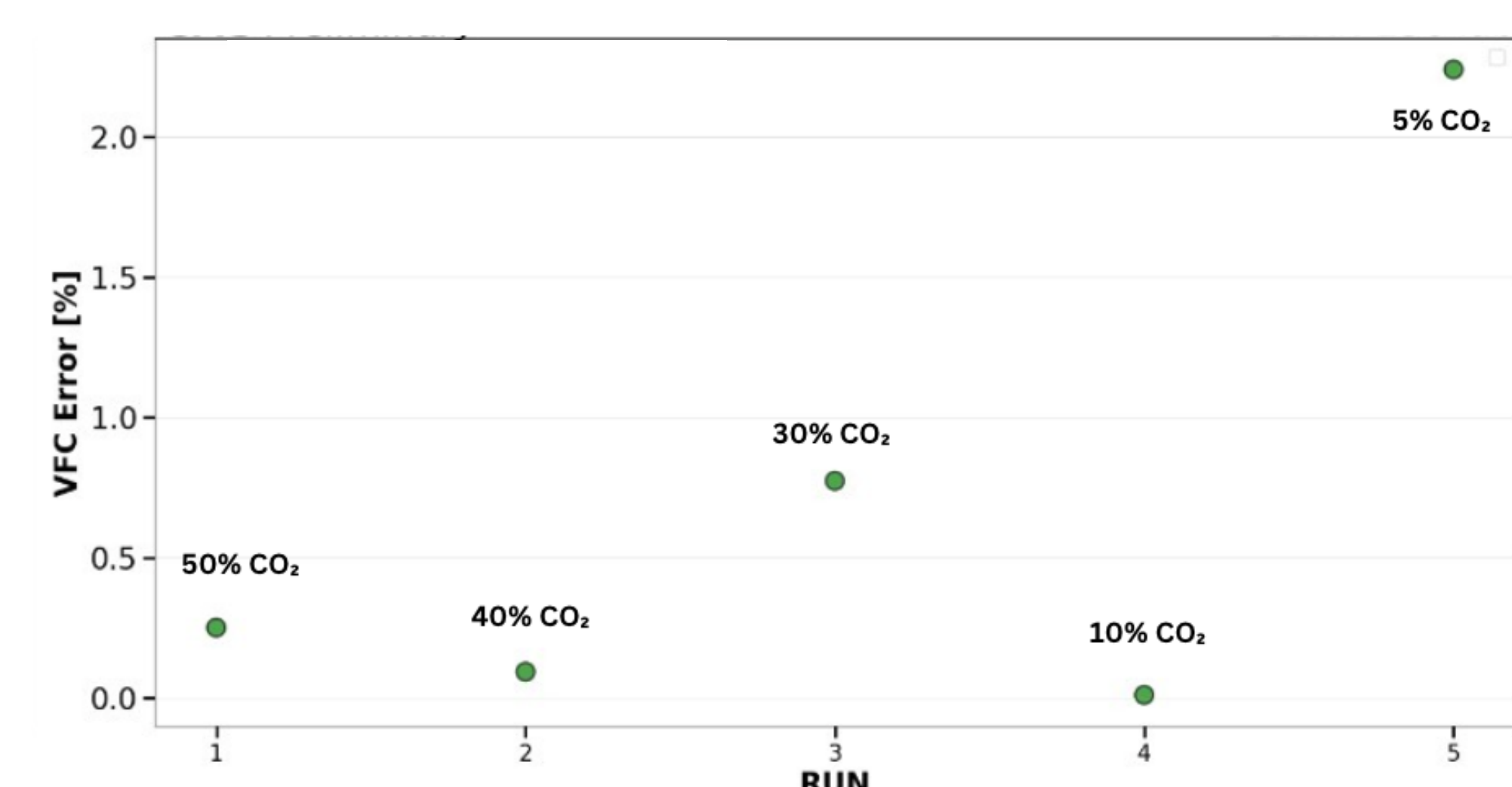


Figure 8. VFC Results

CONCLUSION

This trend is primarily driven by stepper-motor step resolution constraints at low rotational frequencies. Considering the hardware cost (€20 per pump unit), maintaining sub-2.5% relative deviation demonstrates feasibility for general detector R&D and preliminary testing setups. Future iterations incorporating micro-stepping drivers or higher-resolution encoders offer a clear path to further improve precision at lower flow rates.

REFERENCES

- [1] Ossila Ltd., "Peristaltic Pumps: Working Principles and Guide," Ossila Technical Guides. [Online]. Available: <https://www.ossila.com/pages/peristaltic-pumps-working-principles>.