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Pressure Drop Versus Flow Rate Analysis of the Limited Streamer Tube Gas System of the BaBar Muon Detector Upgrade

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ABSTRACT

Pressure Drop Versus Flow Rate Analysis of the Limited Streamer Tube Gas System of the BaBar Muon Detector Upgrade. MING YI (Massachusetts Institute of Technology, Cambridge, MA, 02139) BRENDA ZARATE (Dartmouth College, Hanover, NH, 03755) CHARLES YOUNG (Stanford Linear Accelerator Center, Menlo Park, CA 94025) PETER KIM (Stanford Linear Accelerator Center, Menlo Park, CA 94025) MARK CONVERY (Stanford Linear Accelerator Center, Menlo Park, CA 94025).

It has been proposed that Limited Streamer Tubes (LST) be used in the current upgrade of the muon detector in the BaBar detector. An LST consists of a thin silver plated wire centered in a graphite-coated cell. One standard LST tube consists of eight such cells, and two or three such tubes form an LST module. Under operation, the cells are filled with a gas mixture of CO_2, argon and isobutane. During normal operation of the detector, the gas will be flushed out of the system at a constant low rate of one volume change per day. During times such as installation, however, it is often desired to flush and change the LST gas volumes very rapidly, leading to higher than normal pressure which may damage the modules. This project studied this pressure as a function of flow rate and the number of modules that are put in series in search of the maximal safe flow rate at which to flush the modules. Measurements of pressure drop versus flow rate were taken using a flow meter and a pressure transducer on configurations of one to five modules put in series. Minimal Poly-Flo tubing was used for all connections between test equipments and modules. They contributed less than 25% to all measurements. A ratio of 0.00022±0.00001 mmHg per Standard Cubic Centimeter per Minute (SCCM) per module was found, which was a slight overestimate since it included the contributions from the tubing connections. However, for

the purpose of finding a flow rate at which the modules can be safely flushed, this overestimate acts as a safety cushion. For a standard module with a volume of 16 liters and a known safe overpressure of 2 inches of water, the ratio translates into a flow rate of 17000±1000SCCM and a time requirement of 56±5 seconds to flush an entire module.

INTRODUCTION

The present Resistive Plate Chambers (RPC) in the gaps of the Instrumented Flux Return of the BaBar detector is used to detect muons and neutral hadrons. It has been proposed that the RPCs be replaced with plastic Limited Streamer Tubes (LST). The LST modules are currently in the process of being assembled and tested for quality control. Their first installation will occur in late August to September 2004, during which time the BaBar detector is accessible due to the beam line's annual downtime.

At the Stanford Linear Accelerator Center (SLAC), the detector BaBar is used to examine the decays of B and B-bar mesons. These B meson pairs are produced through electron-position annihilations at the center of mass energy of 10Gev. In the collision and decay processes, many particles are produced, including muons. Muons are leptons. They therefore possess similar properties as electrons, only 200 times heavier. Due to this property, they do not respond to electric fields as noticeably as electrons. Muons are thus able to pass through the Silicon Vertex Detector, Drift Chamber, Particle Identification Detector, and the Calorimeter to the outer part of BaBar, where the muon detector is located, while most other particles cannot [1]. After the upgrade, the LSTs will be used to detect the muons.

An LST consists of a silver plated wire 100μm in diameter centered in a cell of $15x17mm^2$ cross section. One standard LST tube consists of eight such cells, and has an outside dimension of 2cm×15cm×358cm. The cells are located on a graphite coated plastic PVC extruded structure that is open on the top. The structure is inserted into a plastic tube and sealed with end pieces for gas containment. In addition, there are gas inlets, high voltage and ground connectors, and printed circuit boards for signal reading at the two ends of the tubes [2]. Two or three such tubes are glued side by side as a module.

Under operation, the cells in the modules are filled with ionization gas. When a charged muon particle passes through an LST module, it ionizes the gas. High voltage is applied to all the wires in the LST modules, which in turn creates a strong electric field that attracts the liberated electrons from the ionized gas. Because of this strong electric field, the freed electrons gather enough energy to further ionize the gas on their way to the wires, launching an avalanche effect that creates a current in the wire as a signal to be picked up.

The outer rim of BaBar, where the muon detector is located, is divided into big blocks referred to as the sextants. Each sextant has 18 accessible layers separated by iron slabs. During installation, the LST modules will be inserted into 12 of these layers while the rest 6 layers will be filled with brass plates. Each layer will be filled up with modules lying side by side. As a muon particle travels through BaBar, it will go through many layers, producing a signal in an LST module in each layer. By connecting these signals, it is possible to trace out the trajectory of the muon particle.

The gas to be used in the LSTs is a mixture composed of 89% CO_2, 8% isobutane, and 3% argon. During normal operation of the detector, the gas will be flushed out of the system at a constant low rate of one volume change per day. During times such as installation, however, it is often desired to flush and change the LST gas volume very rapidly, leading to higher than normal pressure on the modules. This excessive pressure may damage the modules. The goal of this project is to study this pressure as a function of flow rate and also as a function of the number of modules that are put in series, so the maximal safe flow rate of the gas can be found.

MATERIALS AND METHODS

To monitor and regulate the flow rate of the gas, a Matheson Tri-Gas flow meter was used. In order to obtain an accurate reading, the flow meter was required to stand in a vertical position. For the purposes of this project, the flow meter was vertically mounted onto a metal sheet, which in turn, was screwed onto a movable rack. The back of the flow meter had a gas inlet and outlet. As incoming gas went in from the inlet at the bottom of the meter, a knob could be turned to regulate the gas so that it flowed out near the top of the meter at the desired flow rate. There were two ball bearing floaters in the flow meter for reading, one steel and the other glass. As gas flowed in from the bottom, the balls were pushed up. Their positions on the marked scale in mm were read and recorded. This reading in mm was then converted to flow rate units of SCCM by reading off a calibrated conversion chart provided by the flow meter manufacturer. Because of the different densities of the two balls, they floated at different positions on the mm scale for a given flow rate, and each had an independent conversion chart that mapped to reasonably close flow rate values. Because of its lower density, the glass ball went out of range before the steel ball did. The nominal flow rate range for the glass ball was 20 ~ 830 SCCM. The nominal flow rate range for the steel ball was 60 ~ 1780 SCCM. For this project, a range from 50 SCCM to 1300 SCCM was used. For best accuracy, the average of the converted reading in SCCM of the two balls was used before the glass ball went out of range, after which, only the reading from the steel ball was recorded.

To measure pressure drop, an MKS Instrument Baratron pressure transducer was used. The transducer also had a gas inlet and outlet, and output a voltage that converted on a calibrated linear scale to units in pressure drop. The nominal conversion from voltage output to pressure provided by the manufacturer was 1VDC to 1mmHg. To check the validity of this conversion scale, a Magnehelic was added in parallel to the transducer. The Magnehelic measured the pressure difference between its gas inlet and outlet. The output was read from the position of a needle on a scale in inches of water. The output range of the Magnehelic was 0 ~ 0.25 inches of water. A series of data was taken spanning this range of both the output voltage of the pressure transducer and the Magnehelic, and the calibration curve was plotted as shown in Figure 1. The result confirmed the manufacturer's ratio of 1VDC to 1mmHg within a reasonable error of 2%.

During installation and operation of the LST modules, the gas will be mixed in an existing gas shack before the mixture is piped to IR-2, where the BaBar detector is located, and distributed to the modules [2]. For the testing purposes of this project, a gas bottle was used as the source of incoming gas flow. All connecting paths between the test equipments and the modules used Poly-Flo tubing with an inner diameter of 0.17 inch and an outer diameter of 0.25 inch. The setup for pressure drop measurement of one module, as shown in Figure 2, began with Poly-Flo tubing leading the gas from the gas bottle to the rack, where both the flow meter and the pressure transducer were located. The gas first went in the inlet of the flow meter, where its flow rate could be controlled. There was then a Poly-Flo tubing 15 feet in length bringing the gas from the outlet of the flow meter to the inlet of the module being tested. Between the end of this tubing and the inlet of the module, the inlet of the transducer was inserted through the usage of a brass T-shape gas fitting. A T-shape gas fitting is a joint with three openings. In this case, one of the openings was connected to the 15 feet tubing coming from the flow meter. Another one was connected to the inlet of the module through a 2-in. tubing. The third opening was connected to the inlet of the transducer. The outlet of the module being tested was also connected to a T-shape gas fitting through a 2-in. tubing. The second opening of the gas fitting was connected to the outlet of the pressure transducer. The third one was left open to air as gas flowed out. This way, the pressure transducer was connected in parallel to the module. The pressure drop the transducer measured in this setup reflected the pressure drop of the module being tested bypassing all tubing except the two 2-in. tubing that were unavoidable for a physical system.

When more than one module were connected in series for testing, the modules were laid in a stack. The gas tubing coming from the test equipments went into the inlet of the top module. Then Poly-Flo tubing of approximately 1 foot in length was used to connect from the outlet of one module to the inlet of the next module in the stack. The rest of the setup remained the same.

For each set of measurement, the flow rate of the gas was controlled by setting the steel ball floater of the flow meter at multiples of 5mm on the meter scale, ranging from 5mm to 105mm. Then, the position of the glass ball on the mm scale was read. A multimeter was used to read the output voltage from the transducer. After the output voltage stabilized, indicating that the gas flow in the system was stabilized, the voltage was recorded.

The main goal of this project was to measure pressure drop as a function of the flow rate as well as the number of modules connected in series. A total of five modules were used in this project since that is the maximum number of modules that will be put in series during installation. The test modules used in this project were numbered 1067, 48, 27, 1063, and 1066. Due to physical constraints of the BaBar detector, the modules to be used in the outermost accessible layer need to be shorter. The actual difference in length is 40cm, or 11.2% of a regular module. Among the five modules used in this project, one of them, module 48, had this special dimension, while the rest were standard modules.

For this project, a number of studies were done. Measurements were taken to study the effect of the difference in length of the modules. Measurements were also taken for 1 to 5 modules put in series. Since Poly-Flo tubing will undoubtedly play a part in the installation process and operation in the future, as it did in our project, a study was done to understand the pressure drop across the tubing as a function of length by substituting the modules in our setup with tubing of different lengths.

RESULTS

Data taken on the same modules under the same setup on different days show the day to day deviation of the measurement. Pressure drop across module 1067 as a function of gas flow rate was measured on four different days. The results are shown in Figure 3. Pressure drop across five modules in series was measured on three different days. The results are shown in Figure 4. The maximum deviations in pressure drop measurement of both sets of comparison are 0.04mmHg. Since the two sets represent the range of the measurement on modules, it is reasonable to use half of the deviation, 0.02 mmHg, as the error bar on measurements that followed.

Figure 5 shows a comparison plot of the pressure drop across the shorter module, 48, and across a normal module, 1067. The two sets of data lie within error bars of each other. It is therefore reasonable to conclude that the difference in length of the two kinds of modules is not significant enough to result in a difference in the overall pressure drop measurement. The plots of pressure drop as a function of flow rate across 1 to 5 modules with error bars are shown in Figures 6-10, respectively. All of the figures confirm a linear correlation between pressure drop and flow rate. Figure 11 is a plot of the slopes of the best fit lines of the previous five figures as a function of the number of modules put in series. It shows the relationship between pressure drop and the number of modules in series. It claims a pressure drop of 0.00022±0.00001mmHg per SCCM per module.

Measurements of pressure drop versus gas flow rate were taken across Poly-Flo tubing of different lengths. It again confirmed the fact that pressure drop was directly proportional to gas flow rate. The slopes of the linear best fits of pressure drop versus flow rate for tubing of lengths

10ft, 30ft, 40ft, 100ft, and 250ft were compiled and plotted in Figure 12. It claims a pressure drop of 7.71×10^{-5}mmHg per SCCM per foot of Poly-Flo tubing.

DISCUSSION AND CONCLUSION

Using the analysis of the pressure drop across Poly-Flo tubing, one can estimate the effect of the tubing connections used in the project. The two pieces of 2-inch tubing used contribute a total of 2.57×10^{-5}mmHg per SCCM, which is 13.0% of the measurement across a single module and 2.16% of the measurement across five modules in series. A piece of the 1-foot tubing used to connect two modules in series contributes 7.71×10^{-5}mmHg per SCCM. One such piece was used in the two-module configuration. It contributed 17.5% of the overall measurement. Four such pieces were used in the five-module configuration. They contributed 25.9% of the overall measurement. These numbers contributed to the analysis conclusion of the pressure drop of 0.00022±0.00001mmHg per SCCM per module, which means that this number is somewhat higher than the actual pressure drop per flow rate per module. Although this is the case, for the goal of finding a maximal flow rate at which the modules can be kept under a safe overpressure, this overestimate actually adds a safety cushion to the analysis.

It is known that an LST module can withstand an overpressure of 4 inches of water. It has been recommended for safety reasons that during installation, the modules be kept at 2 inches of water overpressure or under. For a pressure drop of 0.00022±0.00001mmHg per SCCM per module, 2 inches of water translates into a gas flow rate of 17000±1000SCCM. A standard LST module has a gas volume of 16 liters. For the above flow rate, the time required to flush the gas volume of a single module is 56±5 seconds. The time required to flush the gas volume of five modules in series is 4 minutes and 44±16 seconds.

There are a number of factors in the project that should be explored further for future improvements. First of all, all the plots of pressure drop versus flow rate should be strictly linear. Yet all of the plots in the study show a slight nonlinearity in the same general direction. This could very well be due to the possibility that the flow meter used was not calibrated accurately enough by the manufacturer. This would introduce a systematic error in all of the measurements taken.

Another area that would add precision to our analysis is a better understanding of the Poly-Flo tubing connections and the gas fittings used in our setup. The relative small pressure drop across the LST modules amplifies the importance of the effect of the tubing connections used. One factor worth more attention in future studies is the effect the curvature of the tubing layout has on the measured pressure drop. This information might reduce the day to day deviation of the measurement, and thus decrease the error bars on the data.

In conclusion, the flow rate of 17000SCCM is proposed to be used for flushing the LST modules during the process of installation. The various safety cushions introduced in the process of calculating this number renders a high level of confidence in this proposal for the LST installation in August and September 2004.

ACKNOWLEDGEMENTS

This research project was conducted at the Stanford Linear Accelerator Center in the summer of 2004 under the guidance of Charles Young, Peter Kim and Mark Convery. We would like to sincerely thank our mentors for their constant support, patience, enthusiasm, and encouragement, as well as their efforts at making this summer such an enriching and enjoyable research experience for us. We would also like to thank the entire LST team whose dedication made this project possible, as well as Jim McDonald for all his technical help. Many thanks also go to the U.S. Department of Energy and the Stanford Linear Accelerator Center for creating, organizing, and funding the SULI program, as well as Roberto Vega and Helen Quinn for taking the time to oversee and lead the entire program.

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[2] M. Andreotti *et al*, “A barrel IFR instrumented with limited streamer tubes,” proposal from the BaBar collaboration to the SLAC Experimental Program Advisory Committee, May 2003.

FIGURES

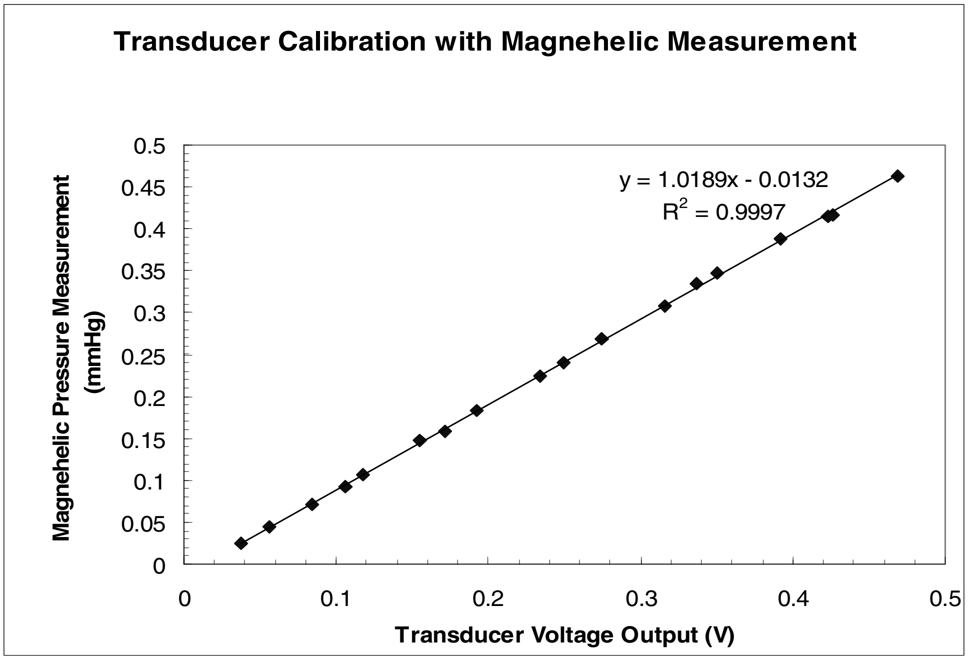

Figure 1: Calibration of pressure transducer with Magnehelic pressure measuring device.

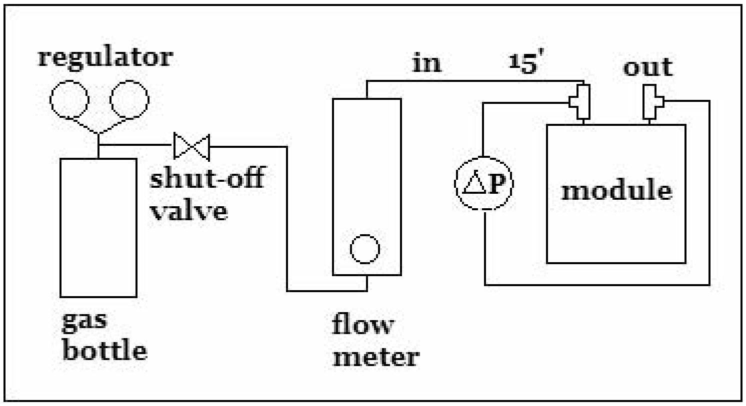

Figure 2: Test equipment setup.

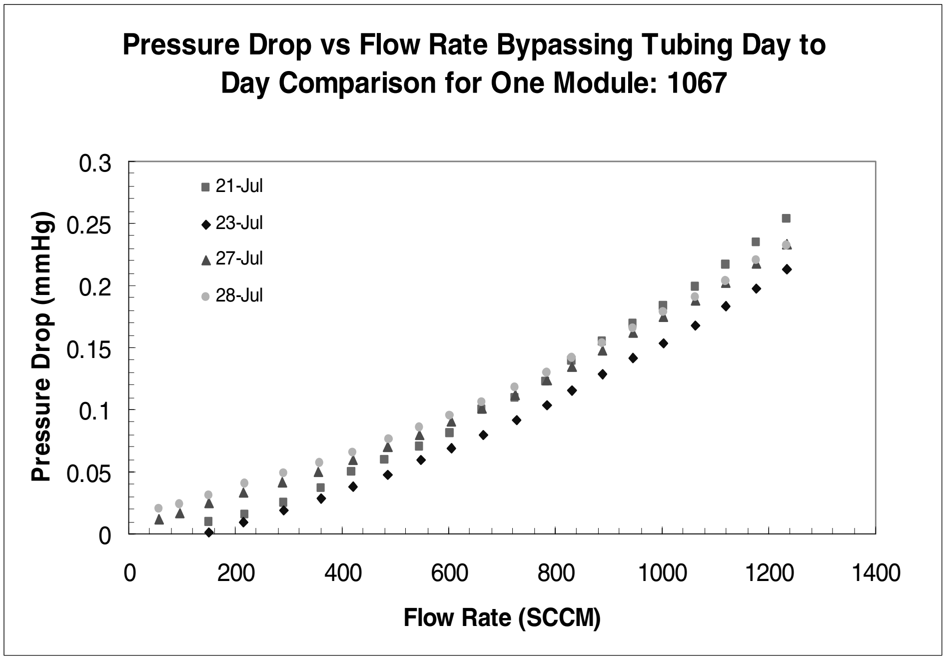

Figure 3: Day to day measurement deviation for single module.

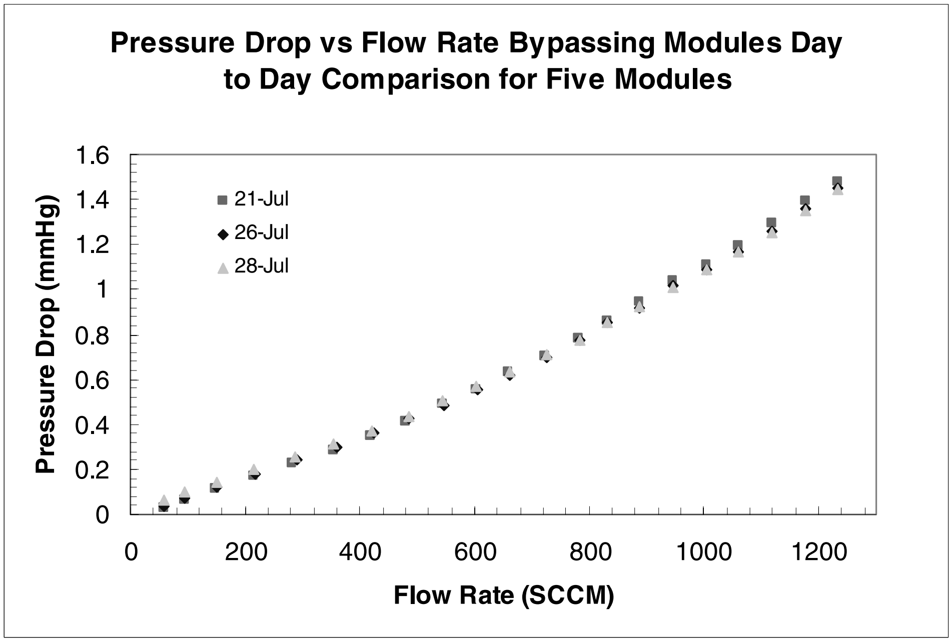

Figure 4: Day to day measurement deviation for five modules in series.

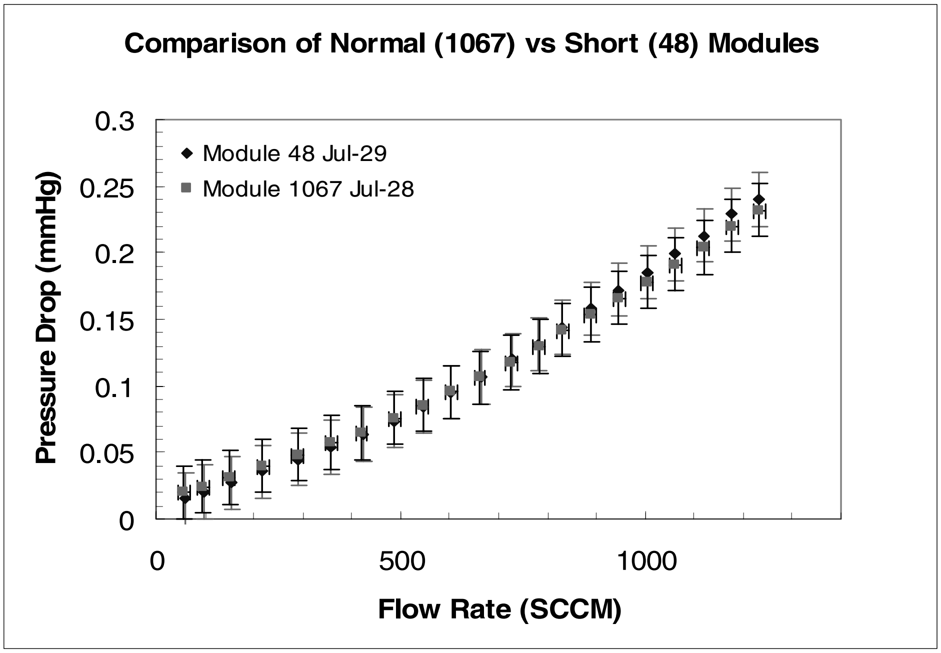

Figure 5: Comparison of normal and short modules.

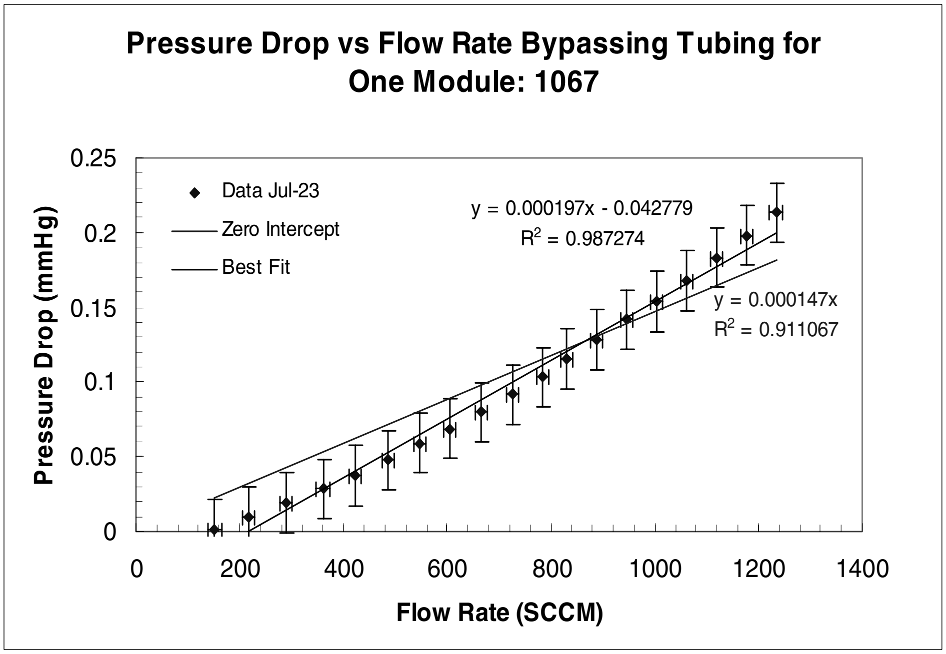

Figure 6: Pressure drop versus flow rate for one module.

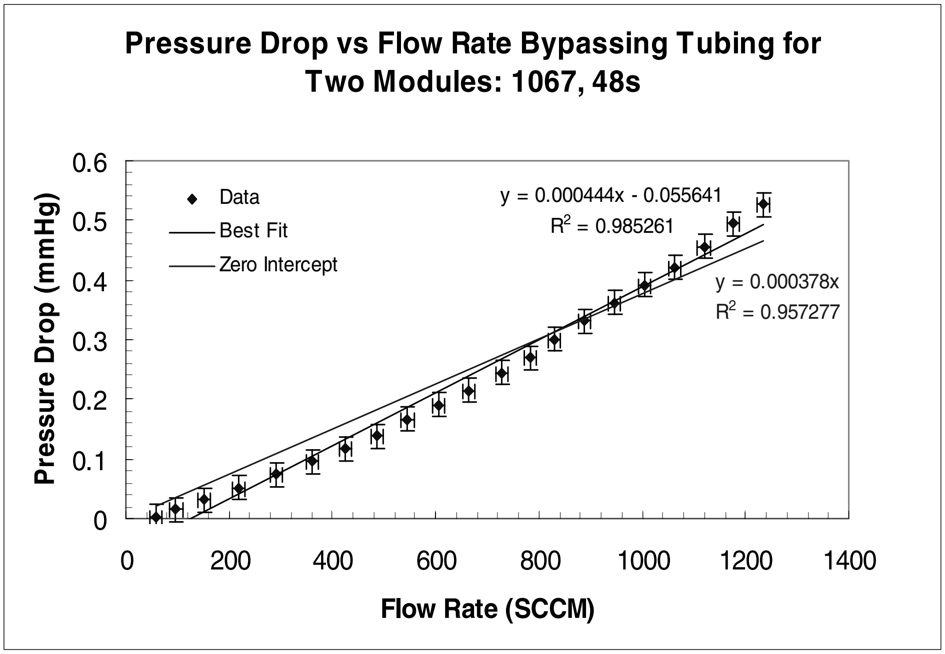

Figure 7: Pressure drop versus flow rate for two modules.

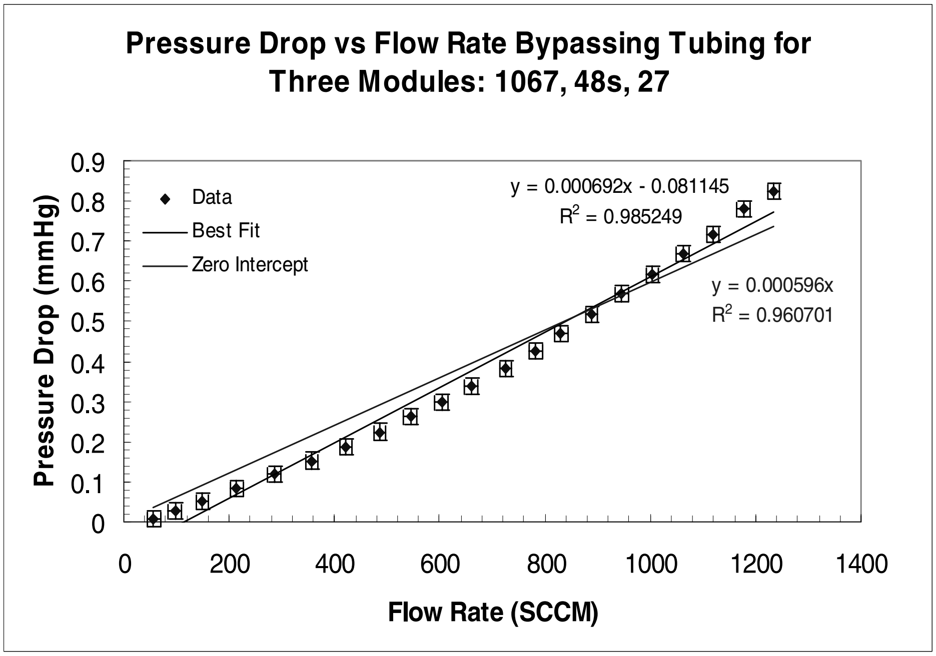

Figure 8: Pressure drop versus flow rate for three modules.

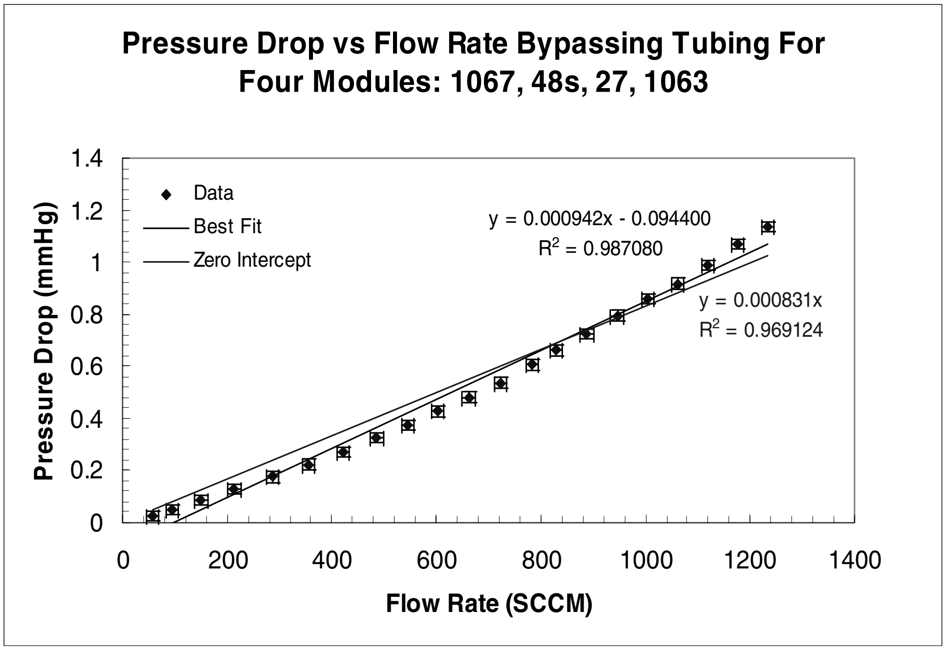

Figure 9: Pressure drop versus flow rate for four modules.

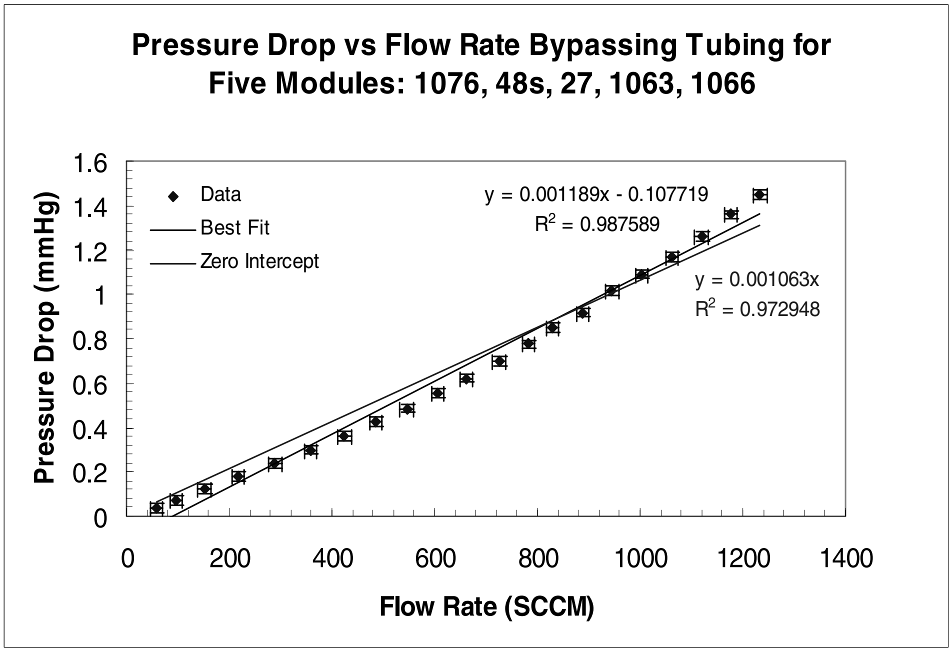

Figure 10: Pressure drop versus flow rate for five modules.

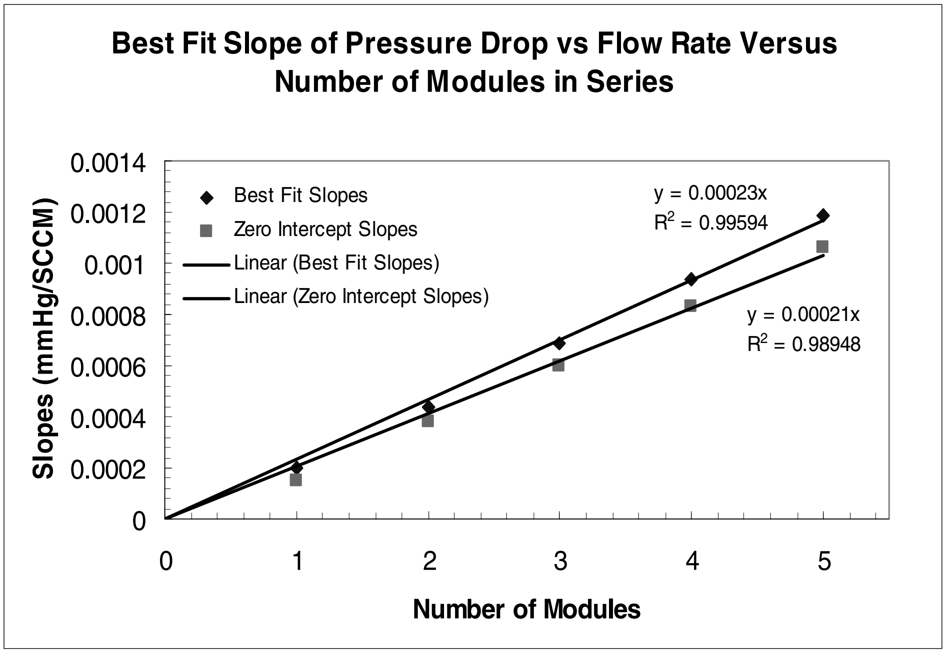

Figure 11: Correlation between pressure drop-flow rate ratio and the number of modules put in series.

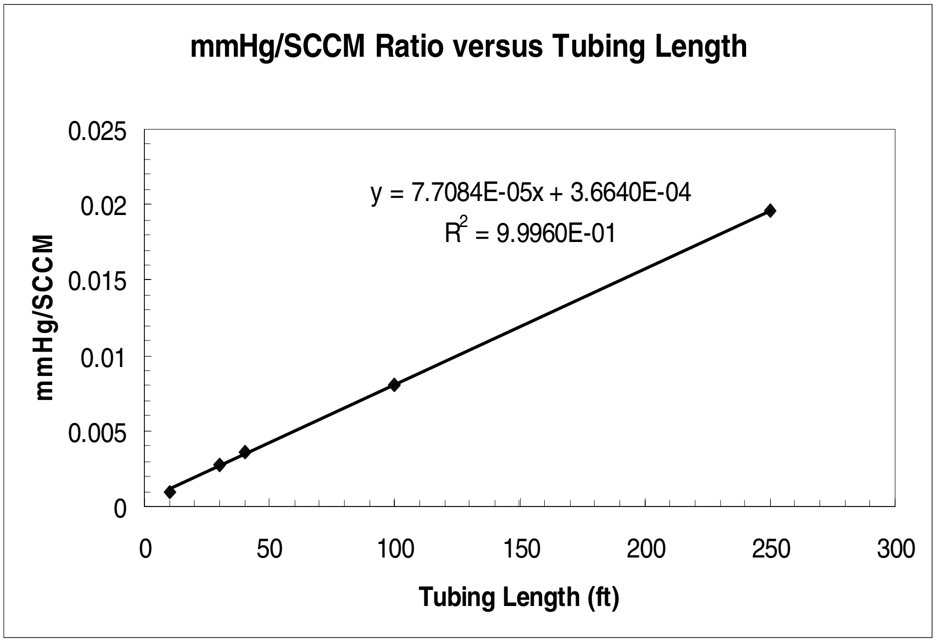

Figure 12: Plot of the slopes of the linear best fits of the measurement of pressure drop across Poly-Flo tubing as a function of flow rate for tubing of different lengths.