Pressures Detector Calibration and Measurement

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Abstract—This is report of my first and second projects (of 3) in NA61. I did data taking and analysis in order to do calibration of pressure detectors and verified it. I analyzed the data by ROOT software using the C ++ programming language. The first part of my project was determination of calibration factor of pressure sensors. Based on that result, I examined the relation between pressure drop, gas flow rate of in paper filter and its diameter.

Index Terms—Calibration, pressure sensor, pressure drop, flow, filter.

INTRODUCTION

In NA61 drift velocity monitors are used in the gas system to measure the drift velocity of electrons in samples of gas taken from Time Projection Chambers (TPC). The drift velocity is a crucial parameter to reconstruct 3D tracks of charged particles in TPCs. NA61 is aiming for relative precision of this parameter better than 10^{-3}. The drift velocity monitors use $^{241}\mathrm{Am}$ alpha sources. Filters are used in order to minimize possibility of Am leak to air. However, the filters create some resistance in the gas path, resulting in increase of the gas pressure in the drift velocity monitors. The increase was of order of several millibars for filters of diameter of 16 mm, which translates to several permille change in the drift velocity. This significantly decreases precision of our measurement. The idea is to use larger filters in order to reduce this effect to below 10^{-3} change. Based on Darcy's law, there is a simple proportional relationship between the instantaneous discharge (flow) rate through a porous medium, the viscosity of the fluid and the pressure drop over a given distance.[1]

$$Q = -\frac{\kappa A \Delta P}{\mu L} \qquad (1)$$

The total discharge, *Q* (units of volume per time, e.g., l/h) is equal to the product of the intrinsic permeability of the medium, κ (mm^2), the cross-sectional area to flow, *A* (units of area, e.g., mm^2), and the total pressure drop (ΔP), (mBar), all divided by the viscosity, μ (mBar·h) and the length over which the pressure drop is taking place (L). The negative sign is needed because fluid flows from high pressure to low pressure. If the change in pressure is negative, then the flow will be in the positive 'x' direction. Briefly, pressure drop is proportional to flow rate. My task was to verify experimentally this thesis, and characterize paper filters of different diameter.

I. DETERMINING CALIBRATION FACTOR OF PRESSURE SENSOR

The first part of my project was determination of calibration factor of pressure sensors, BOSCH BPM 180 digital pressure sensors. There are several sensors (named: GTPC, FTPC 2a, FTPC 2b and FTPC 1) placed in the same place to measure air pressure. Those sensors use Raspberry Pi in order to connect to computer by Ethernet. Those sensors need to be calibrated beforehand. For the calibration I used the data that have been taken earlier by the end of May 24th until June 20th. The first one I did was plotted pressure of references and several pressure sensors: against time. Figure 1 presents data collected on that period.

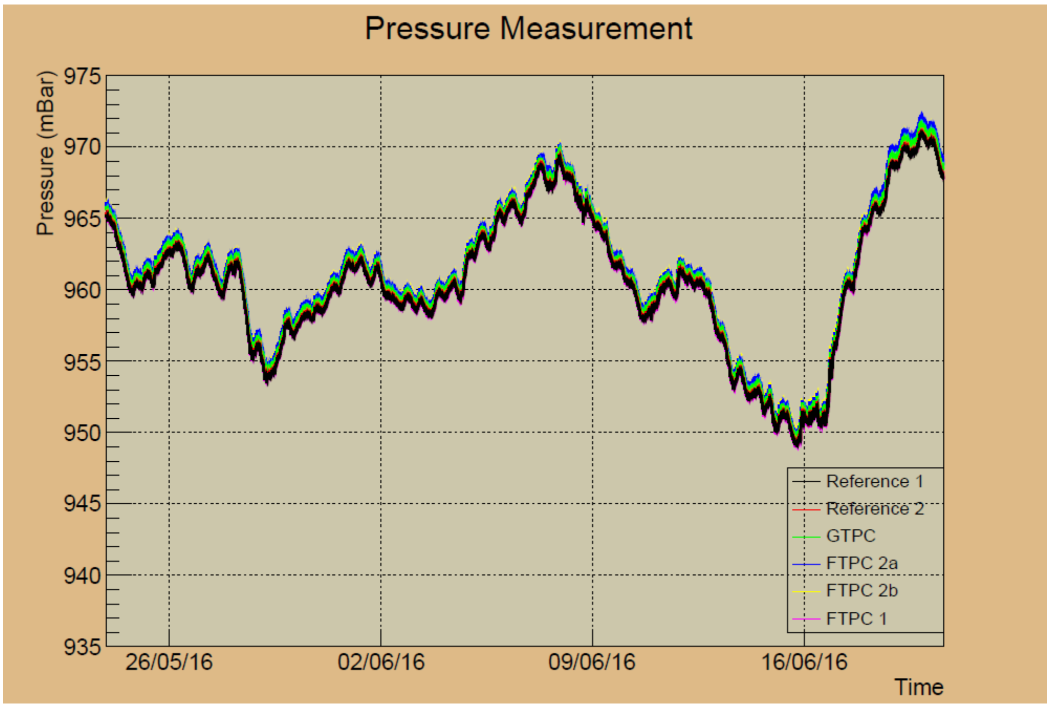


Figure 1 Pressure measurement over the time

Figure 1 shows there is an overlap between pressure of reference 1 and 2, while the others are deviated, hence calibration is necessary. Slight deviation at the end of measurement (by June 17th) happened because the temperature increase (see figure 2) due to air conditioner failure so the sensors worked on higher temperature then give excess value than references. The biggest deviation occurs in FTPC 2a, and this deviation will be propagated to the next analysis, including residual plot (figure 4) and its histogram (figure 5). I discovered this correlation shortly before finishing the project, there was no time to improve the analysis.

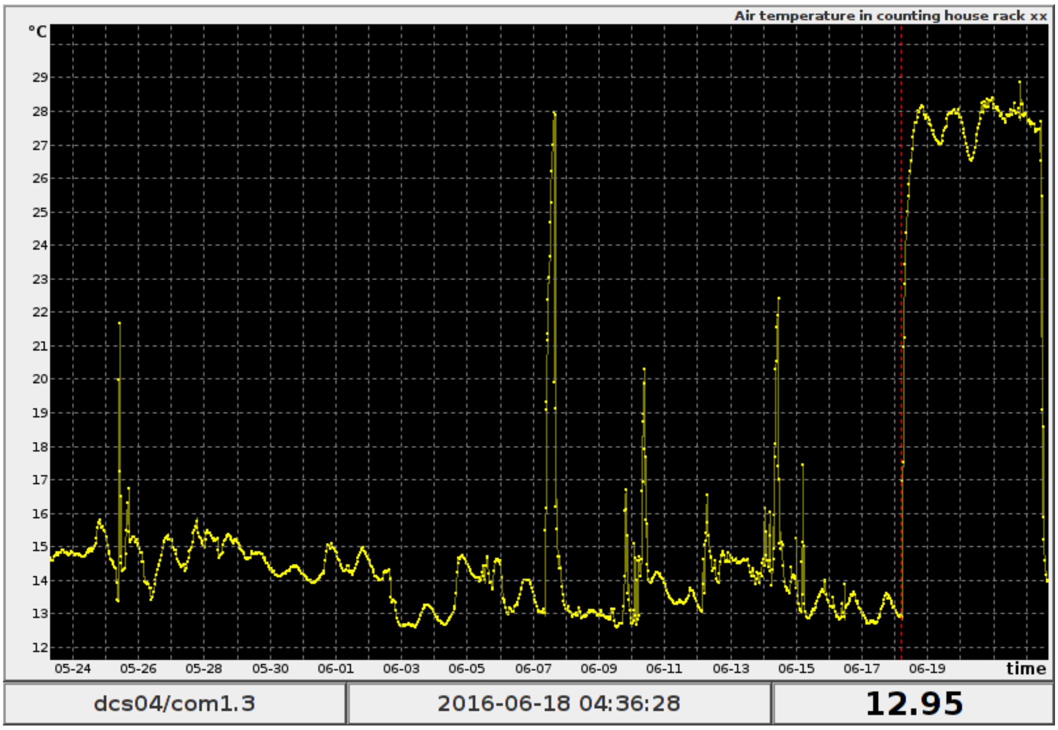
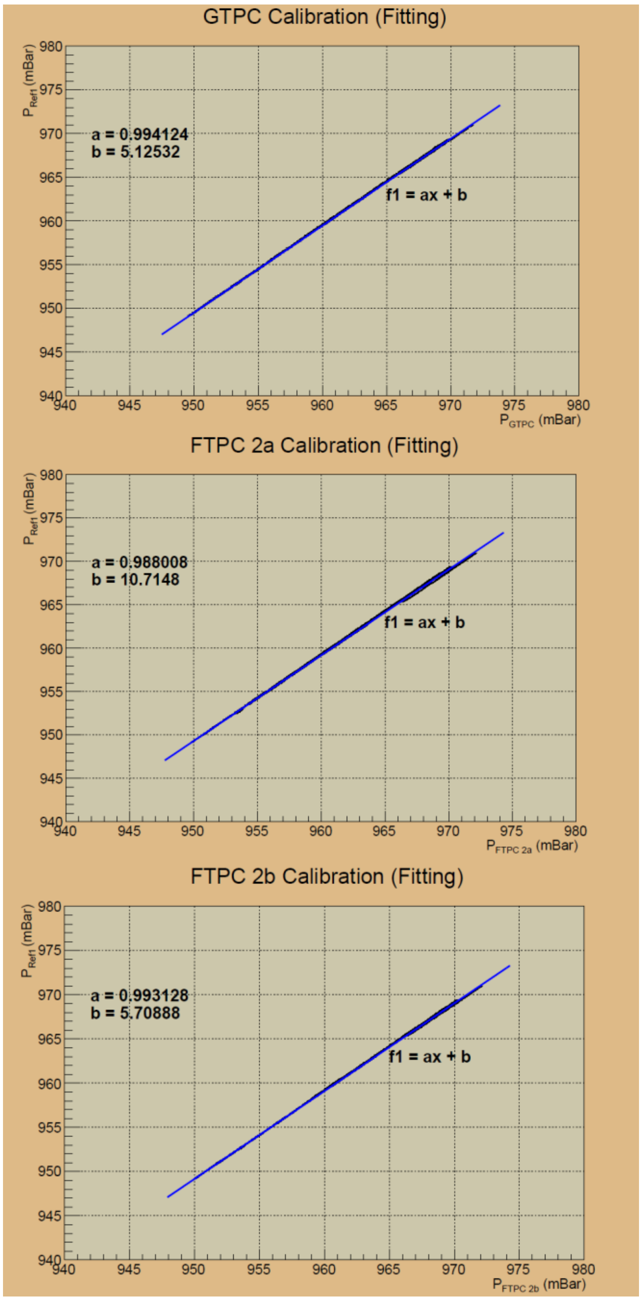


Figure 2 Temperature increase occurred on June 17th (red line)

Then I also plot the pressure of GTPC, FTPC 2a, FTPC 2b, and FTPC 1 versus the reference pressure (figure 3). Ideally, the graphs obtained are a straight lines. I did a fitting with the approach of linear equations for each calibration plot of the pressure sensor. The slope values are symbolized by a, and the intersection with the y-axis is symbolized by b. Here the fit for all sensors is shown. Calibration results for sensors are presented in table 1. I already compensate the value of b based on previous calibration attempt (simpler calibration) by adding 1.15 mBar to readout value to each sensor.



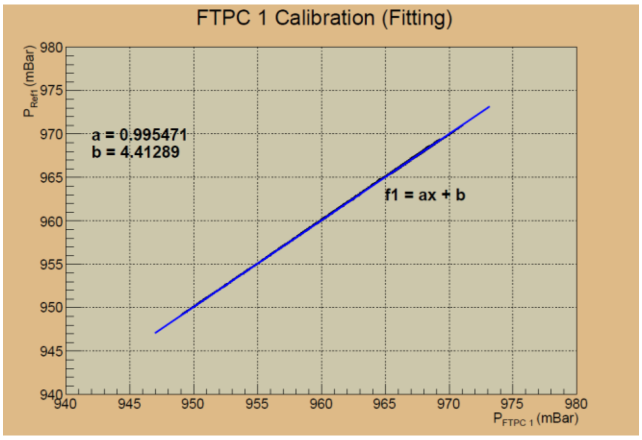
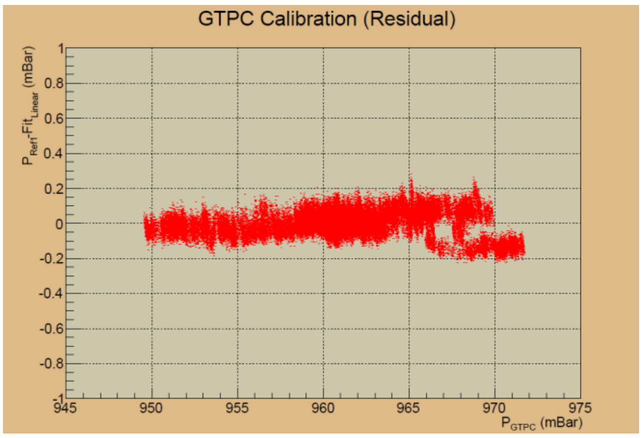


Figure 3 Fitting for pressure sensors (black points represented the data and blue line shows the fitting by linear equation)

Table 1 Calibration Value for Pressure Sensors

Sensor	a	b $(mBar)$, compensated
GTPC	0.994124±0.000038	3.98±0.04
FTPC 2a	0.988008±.0.000059	9.56±0.06
FTPC 2b	0.993128±0.000086	4.56±0.08
FTPC 1	0.995471±0.000049	3.26±0.05

From the fitting, I also plot the difference of linear equation fitting result and reference pressure. The difference is then called residuals. From the residual plot, it can be seen that the thin scatter of points close to zero is formed, it means the sensor is working properly. The residual is of order of 0.1 mBar, while measured pressure is of order of 1000 mBar, this gives 10^{-4} relative residual value.



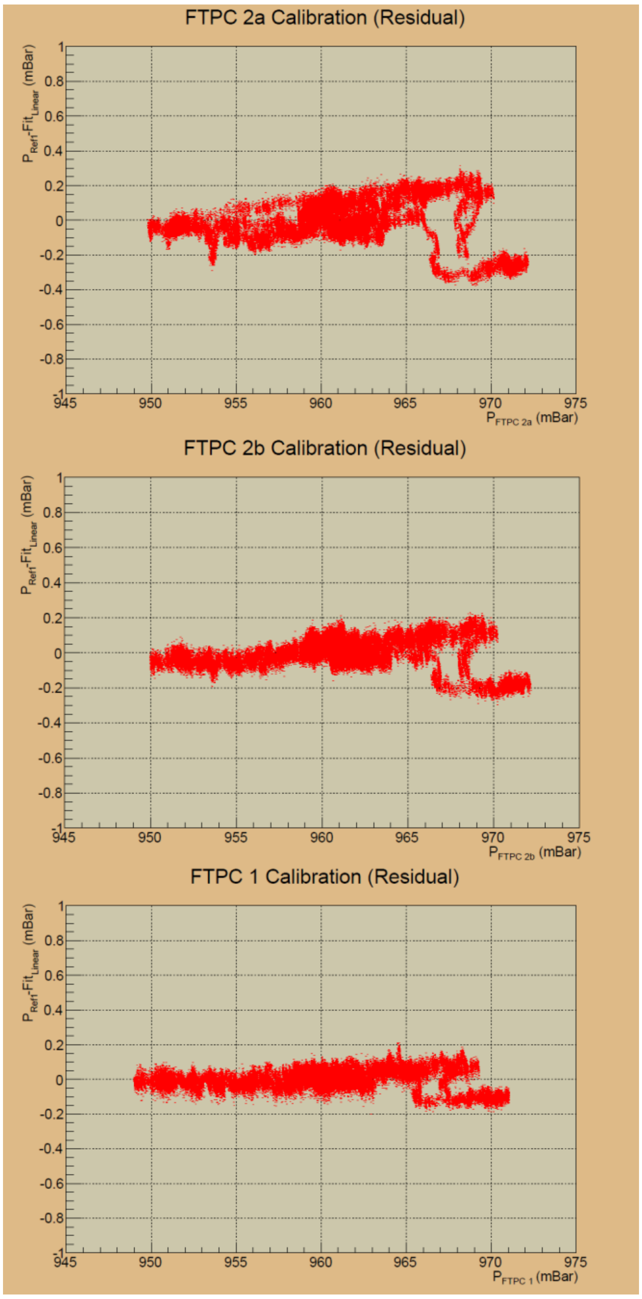
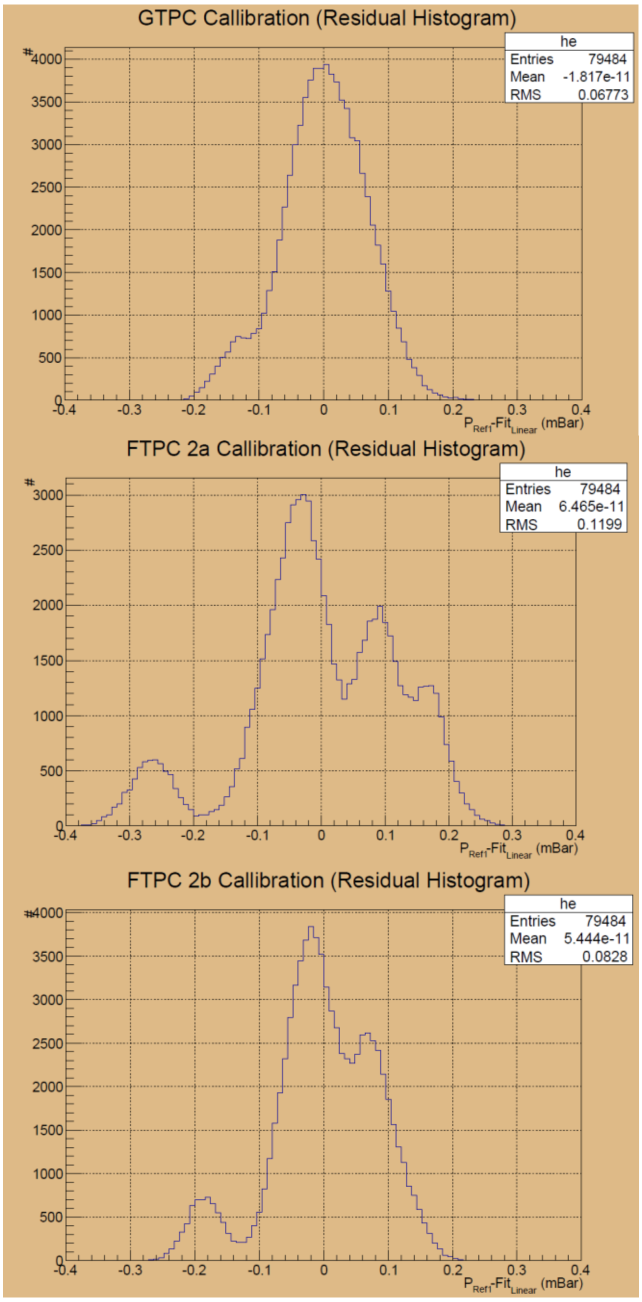


Figure 4 Fit residual plot

In figure 4, the propagating deviation due to temperature increase (from the previous analysis) can be seen clearly, especially on FTPC 2a. As it will be shown in figure 5, this effect increases the uncertainty about twice in comparison to other sensors. It happened at the end of measurement when the pressure exceeded approximately 965 mBar.

For simpler data presentation, I create histograms with the x-axis is the residual value, and its y-axis is the number of values of each residue value. The results of this histogram will tell whether the calibration result is good or not. From the width of the residual distributions one can read the precision of the calibrated sensors is of order of 0.5 to 1.1 mBar.



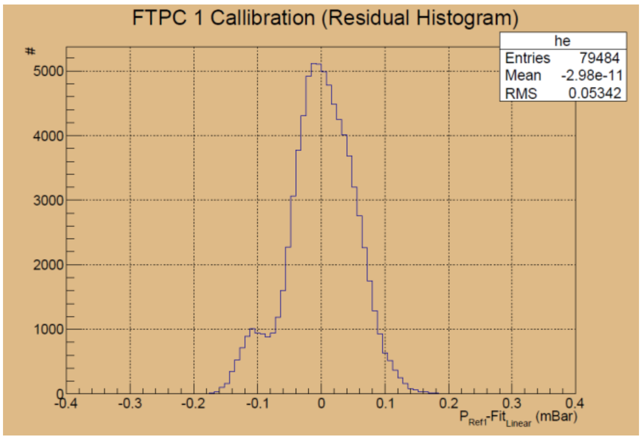


Figure 5 Residual histogram

Due to slight deviations in previous analysis, histogram certainly will not be ideal normal distribution curve. Especially on FTPC 2a which has larger deviation. There are four peaks that caused by slight deviation at high pressure at the end of measurement, the same reason as the odd result on FTPC 2a residual plot. The histograms above have a peak around zero and then tended to decrease to the side. Based on RMS values, it seems the spread of residual was relatively small.

II. CALIBRATION APPLICATION FOR MEASUREMENT

A. TESTING CONCEPT

After calibrating the sensors I investigated relation between pressure drop on a filter, its diameter and gas flow. In order to do so, an additional set of measurements needed to be done. Gas flow was measured with the flowmeter, the pressure drop was measured by using two pressure sensors, FTPC 2a and FTPC 1, where FTPC 2a will measure the pressure in the pipe before it enters the filter, and FTPC 1 will measure gas pressure after passing through the filter.

Gas flow rate can be adjusted by adjusting the valve of flowmeter. Used flowmeter range was 2 to 16 liters per hour. With the smallest scale of flowmeter is 1 liter per hour (uncertainty of the instrument is then 0.5 liter per hour).

B. TOOL SETUP

The first step of setting this experiment is to connect short pipes with different diameters, respectively 16, 25 and 40 mm. Then link the pipe to the flowmeter. Finally connect the flowmeter to the argon gas bottle with a hose. It was previously confirmed that the flowmeter and the tank is in the locked position. The tank had a pressure regulator. The photograph of the experimental setp are shown in figure 6.

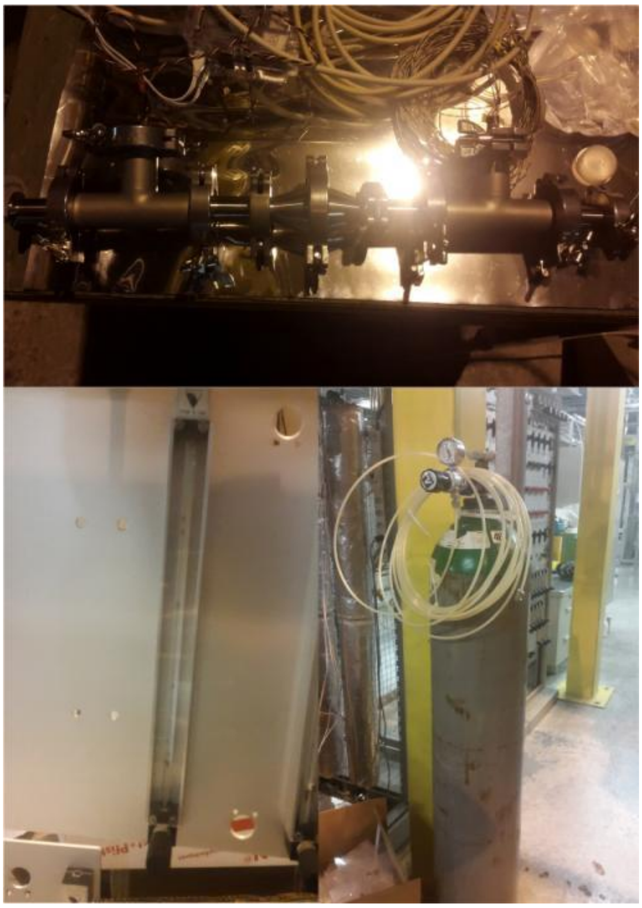


Figure 6 Tools. Pipe (top), flowmeter and gas tank (bottom)

Figure 7 shows schematic of the experiment set and placement of the filters. The next setting is the transmission of digital data collected by pressure sensors. FTPC 2a and FTPC 1 as a sensor are associated with Raspberry's Pi then connected to computer. The computer is set in advance in the terminal and ordered to perform data retrieval operation.

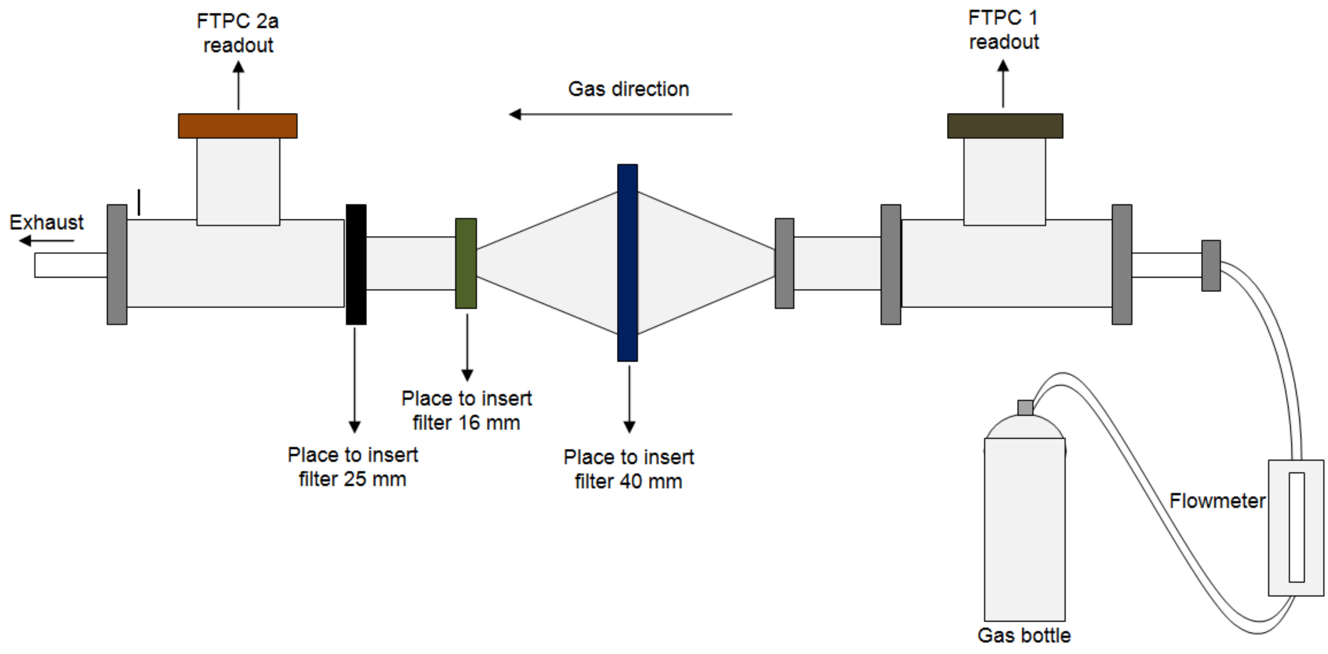


Figure 7 Experiment setup

C. Data Collection

After all settings experiment setup was finished, the measurement begins, argon gas tank slowly opened to 800 mBar. Data output is the average of the 20 measurements taken in a few seconds. It represented temperature and pressure, but just pressure was used. Data collection is done by changing flow from 2 to 16 liters per hour with a step of 1 liter per hour. As I changed the flow rate, need to wait about 1 minute until the next two measurements were taken, so that the flow rate was approximately constant. After increasing flow rate to 16 liters per hour, I repeat the flow rate scan back from 16 to 2 liters per hour.

Table 2 Measurement result

Q (l/h)	No Filter		NW16		NW25		NW40	
	Pref1 (mBar)	Pref2a (mBar)	Pref1 (mBar)	Pref2a (mBar)	Pref1 (mBar)	Pref2a (mBar)	Pref1 (mBar)	Pref2a (mBar)
2	962.375	961.327	960.881	960.151	961.021	960.171	962.116	961.129
3	962.285	961.267	960.921	960.299	961.031	960.210	962.146	961.208
4	962.285	961.248	960.891	960.349	961.021	960.240	962.136	961.178
5	962.235	961.238	960.881	960.477	961.041	960.289	962.136	961.198
6	962.205	961.208	960.881	960.665	961.011	960.358	962.106	961.228
7	962.195	961.178	960.851	960.793	961.041	960.447	962.076	961.208
8	962.205	961.208	960.861	960.961	961.001	960.546	962.056	961.228
9	962.205	961.149	960.842	961.080	961.021	960.596	962.076	961.258
10	962.205	961.178	960.851	961.248	961.041	960.684	962.056	961.218
11	962.205	961.149	960.851	961.406	961.031	960.724	962.066	961.287
12	962.205	961.149	960.832	961.593	961.021	960.783	962.026	961.297
13	962.185	961.169	960.832	961.682	961.001	960.852	961.986	961.307
14	962.225	961.208	960.792	961.811	960.991	960.902	961.996	961.287
15	962.215	961.159	960.812	961.989	961.001	961.001	961.986	961.327
16	962.215	961.178	960.822	962.127	960.991	961.060	961.946	961.287
15	962.185	961.198	960.802	962.058	960.981	961.011	961.966	961.287
14	962.185	961.178	960.802	961.850	960.971	960.941	961.946	961.238

13	962.175	961.139	960.792	961.682	960.981	960.833	961.927	961.159
12	962.185	961.169	960.792	961.554	960.961	960.783	961.877	961.169
11	962.185	961.178	960.802	961.366	960.981	960.724	961.857	961.119
10	962.185	961.159	960.802	961.188	960.971	960.625	961.797	961.030
9	962.195	961.169	960.782	961.080	960.971	960.566	961.827	961.050
8	962.195	961.169	960.762	960.941	960.971	960.536	961.827	961.040
7	962.205	961.169	960.762	960.813	960.961	960.477	961.797	961.001
6	962.205	961.129	960.782	960.675	960.981	960.398	961.797	960.971
5	962.165	961.119	960.772	960.457	960.971	960.319	961.827	960.981
4	962.195	961.129	960.742	960.299	960.991	960.220	961.867	960.941
3	962.175	961.109	960.752	960.171	960.991	960.210	961.867	960.912
2	962.165	961.099	960.732	960.052	960.981	960.121	961.827	960.882

Later experiments continued by inserting a filters of different diameter, 40, 25 and 16 mm. Measurements were made by the same method. Table 2 shows the measurement result for each filter. Pressure drop calculated by subtracting Pref2a from Pref1.

D. Results and Analysis

During the analysis, first of all I apply a calibration factor for each data from FTPC 2a and 1 from the table 1, and add 1.15 mBar (this compensate of previous calibration attempt that used simpler calibration). Then based on the calibration results, I subtract FTPC 2a pressure values from FTPC 1 to get the pressure drop on a filter. Hence, the plotting of pressure drop over the flow is done, shown by figure 8. Linear dependence shows that pressure drop directly proportional to the flow rate. Blue and red points represented data of increasing and decreasing flow rate measurement respectively. The difference between values obtained when increasing and decreasing flow rate are small.

Then I conducted fits (with the approach of linear equations) to find the slope of the graph. The slope and intersection graph on the y axis is symbolized respectively by c and d. Fitting is done for the condition without filters, as well as for each filter size 16, 25 and 40 mm. For comparison, each of these graphs is made in one figure to see the effect qualitatively.

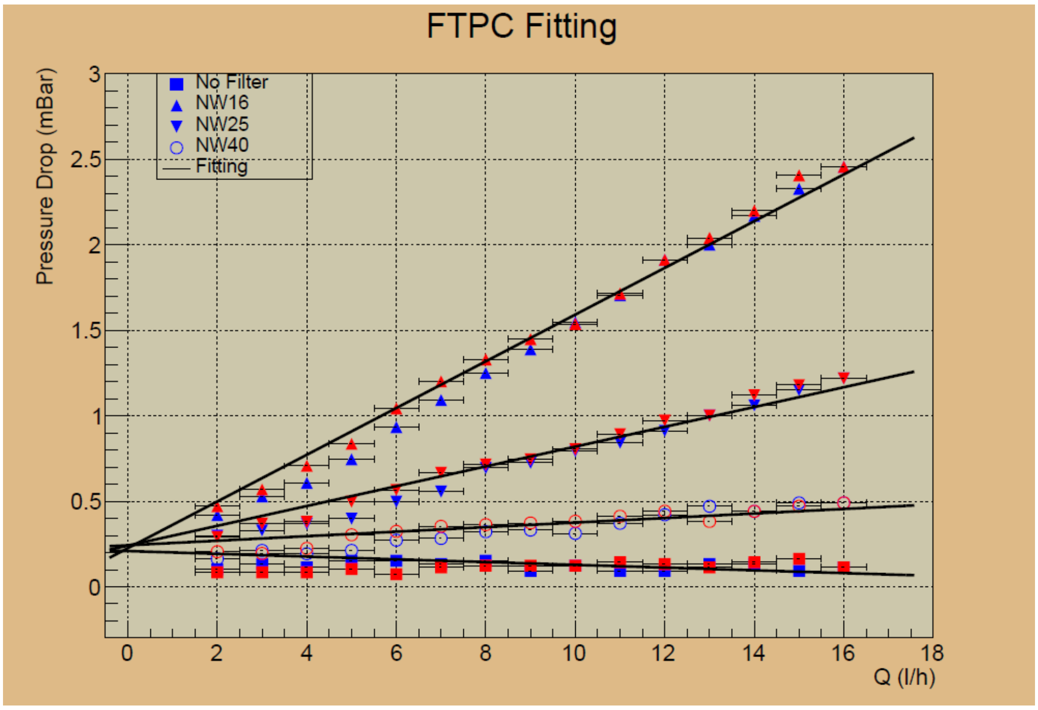


Figure 8 Pressure drop over the flow rate. Pressure drop defined by P_{ref1}-P_{ref2a}

Table 3 Fitting Result

Filter	$c\ (mBar\ h/l)$	$d\ (mBar)$
No Filter	-0.008±0.031	0.209±0.003
NW16	0.137±0.021	0.226±0.002
NW25	0.058±0.018	0.241±0.002
NW40	0.013±0.016	0.243±0.002

When there is no filter, the pressure drop must be zero (a straight line with zero slope), but from the fitting it has negative slope. The value is consistent with zero within the fit uncertainty. Based on the result of table 3, I did plotting of the value of the slope c over the filter diameter. Expected results will be inversely quadratic, in accordance with the decrease in the following equation:

$$\Delta P = \frac{4\mu LQ}{k\pi d_f^2} \quad (2)$$

For the fitting I use the equation:

$$c = \frac{e}{(d-f)^2} \quad (3)$$

Where c is slope from the recent fitting ($\Delta P/Q$), e is constant, based on equation (2) it have to be $4\mu L/\pi$. f appears because of filter diameter (d) is not the same as the inner pipe diameter.

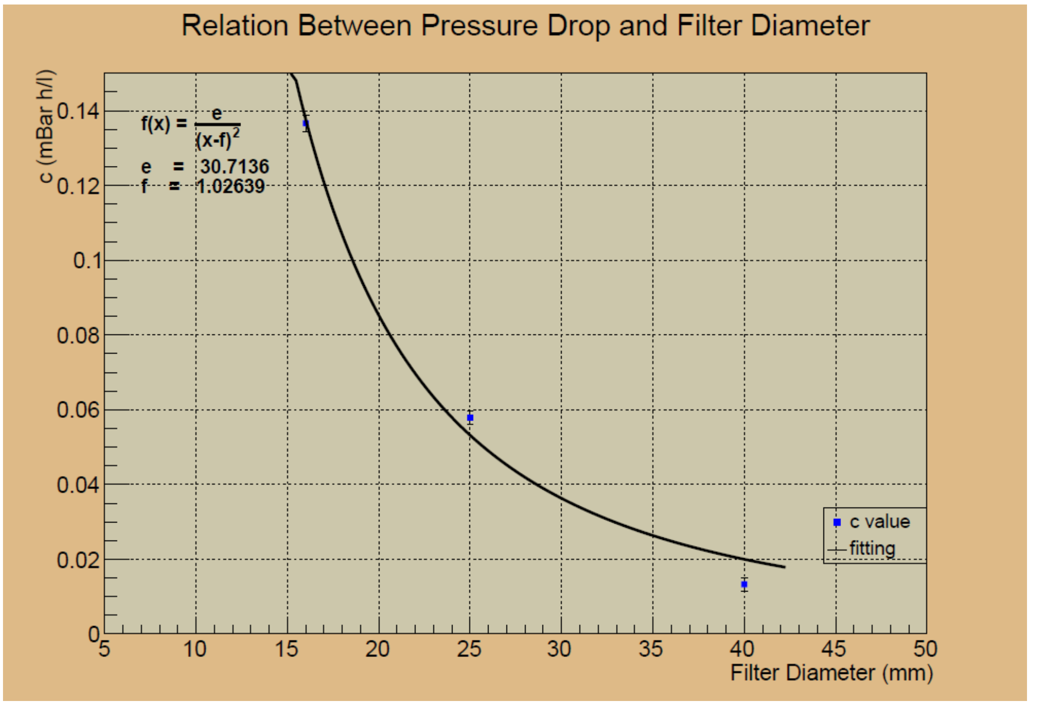


Figure 9 Pressure drop over the flow rate

From the fitting, it found:

$$e = (30 \pm 20)\ mBar\ \frac{h}{l}\ mm^2$$

$$f = (1 \pm 5)\ mm$$

The value of f seems good, because in real observation, the difference between filter diameter and inner pipe diameter is around 1 to 2 mm. But there is a big uncertainty (about 500%) caused by the small number of points, given that only three filter diameter variations that can be done.

III. CONCLUSION

I successfully performed calibration of the pressure sensors, calibration factor for all pressure sensors have been obtained.

The application of pressure calibration has also been successfully applied to the verification of the relationship of pressure drop, gas flow and filter diameter. Pressure drop decreases significantly with the increase of filter diameter, which follows Darcy's Law. These results demonstrate that we can increase the precision of drift velocity by increasing the filter diameter.

Data analysis has been successfully performed by using ROOT software. Including make some graph fittings and histograms.

Better quality of calibration is generated. Previous calibration uses simple calibration method that only added calibration factor of 1.15 mBar, but now the calibration with linear function fit obtained by thorough data analysis.

REFERENCE

[1] L.P. Dake, Fundamentals of Reservoir Engineering, 1st ed. Amsterdam: Elsevier, 1978, pp. 103-130.