Device for flow meter absolute calibration at low gas flows

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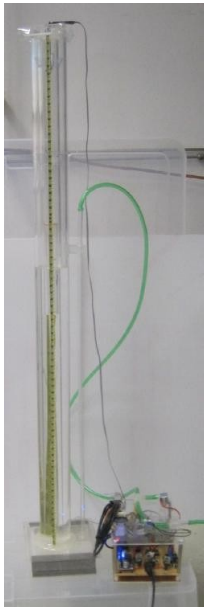
REGARD
INNOVATIVE GASEOUS DETECTORS

(Dezső Varga, Gergő Hamar,
András László et al, at Wigner RCP)



Motivation

- In lab applications, sometimes not premixes are used, but gases are mixed locally.
- In a typical gas mixture, only a fraction of quenching gas is used.
E.g. Ne(90):CO_2(10):N_2(5)
- Keeping the small proportion of additive gases stable is an issue.
(E.g. gas mixers can be used, based on thermal mass flow meters.)
- Also, quantification of the proportion of additive gases is an issue.
(Factory calibration mostly available at large flows, and limited gas types, and expensive.)
- Had negative experience with specs and reliability of factory calibrations.
(In the range of < 5 ln/h flow.)
- We needed some kind of reliable calibration mechanism.

Typical industrial solutions

- Variable Area flow meters:

  - simple solution, can be good down to ~0.5 l/h,
  - e.g. Vögtlin Q-flow 80, Q-flow 140 ; Omega FL-3207G
  - not for precision, not electronically readable, cannot be used for active control

- Thermal mass (molar) flow meters:

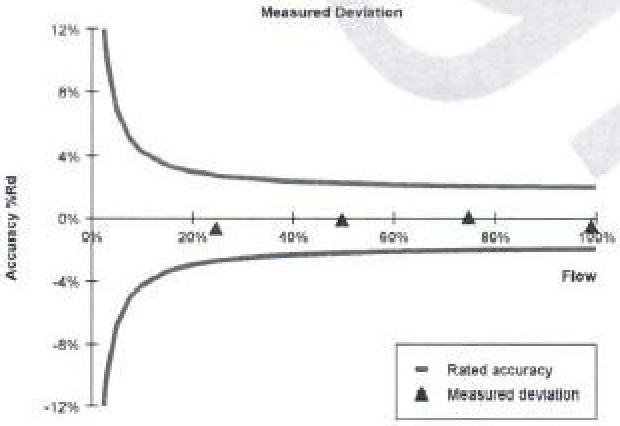
  - based on constancy of the molar specific heat of gases at constant pressure
  - electronically readable, can be used for active flow control
  - e.g. Brooks 5850TR in mixer mode ; or Bronkhorst MassView-301 / 302
  - rather expensive, ~1kEUR / channel + mixer ~5kEUR
  - not only specific heat is needed, but also device and gas dependent calib constants
  - mostly accurate for flows > 5 ln/h , calibration issues for lower flows
  - manufacturers not very helpful with sorting out calibration issues

Calibration specs not very stringent for < 5 ln/h range

Calibration results

Point	Calibrated flow AiR	Customer flow** AiR	Output signal		Measured deviation
1	0.000 mln/min	0.6660 mln/min	0.33%	0.017 V	-
2	49.76 mln/min	49.42 mln/min	24.71%	1.236 V	-0.68 % Rd
3	99.53 mln/min	99.41 mln/min	49.71%	2.485 V	-0.12 % Rd
4	149.3 mln/min	149.4 mln/min	74.69%	3.735 V	0.05 % Rd
5	199.1 mln/min	198.0 mln/min	99.02%	4.951 V	-0.53 % Rd

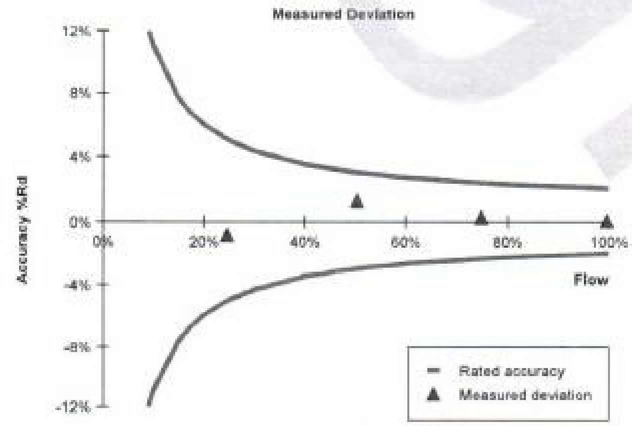
The measurement uncertainty of the calibrated AiR flow is ±0.6% Rd.



Calibration results

Point	Calibrated flow AiR	Customer flow** AiR	Output signal		Measured deviation
1	0.000 ln/min	0.000 ln/min	0.00%	0.000 V	-
2	0.4980 ln/min	0.4938 ln/min	24.69%	1.235 V	-0.84 % Rd
3	0.9956 ln/min	1.008 ln/min	50.41%	2.521 V	1.27 % Rd
4	1.493 ln/min	1.497 ln/min	74.86%	3.743 V	0.26 % Rd
5	1.991 ln/min	1.992 ln/min	99.61%	4.980 V	0.05 % Rd

The measurement uncertainty of the calibrated AiR flow is ±0.6% Rd.



- not only specific heat is needed, but also device and gas dependent calib constants
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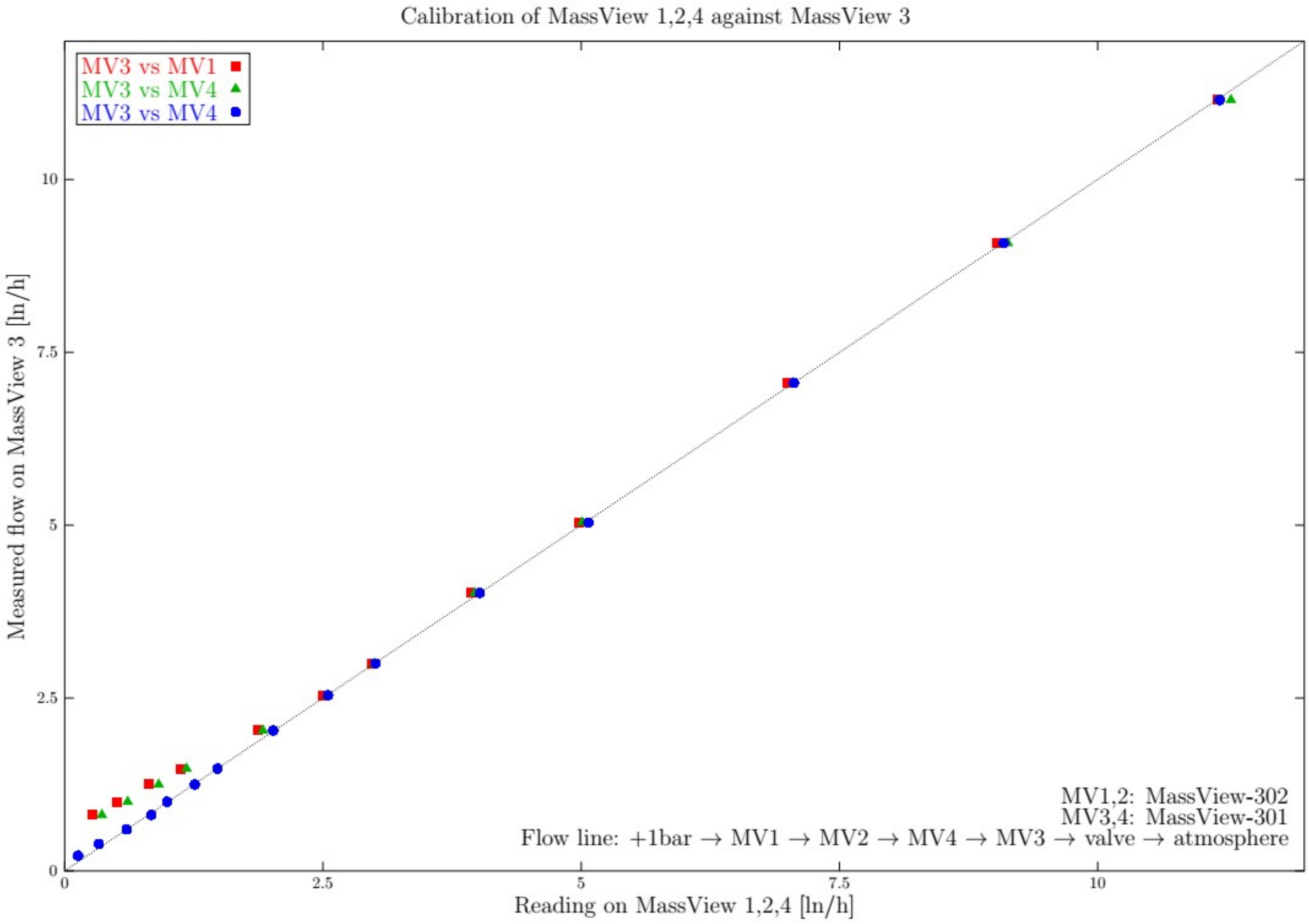
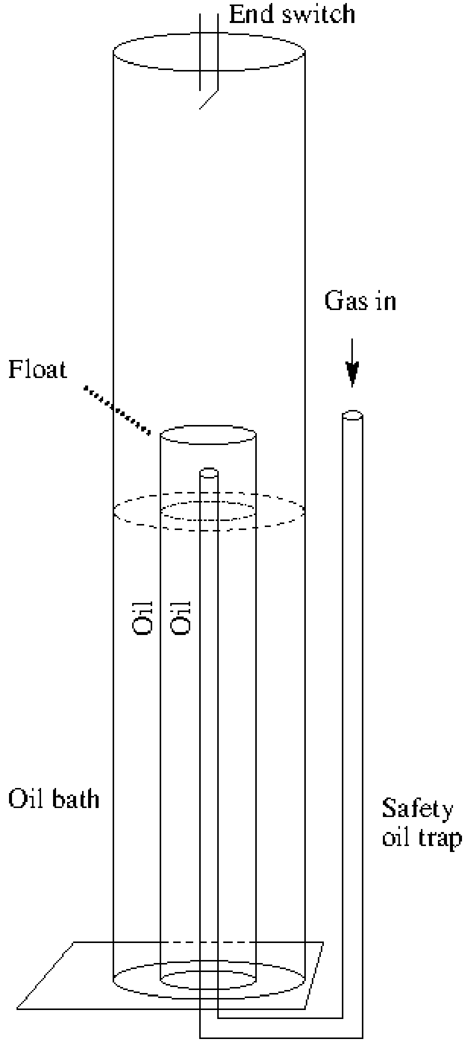
Cross-calibration issues at < 5 ln/h range

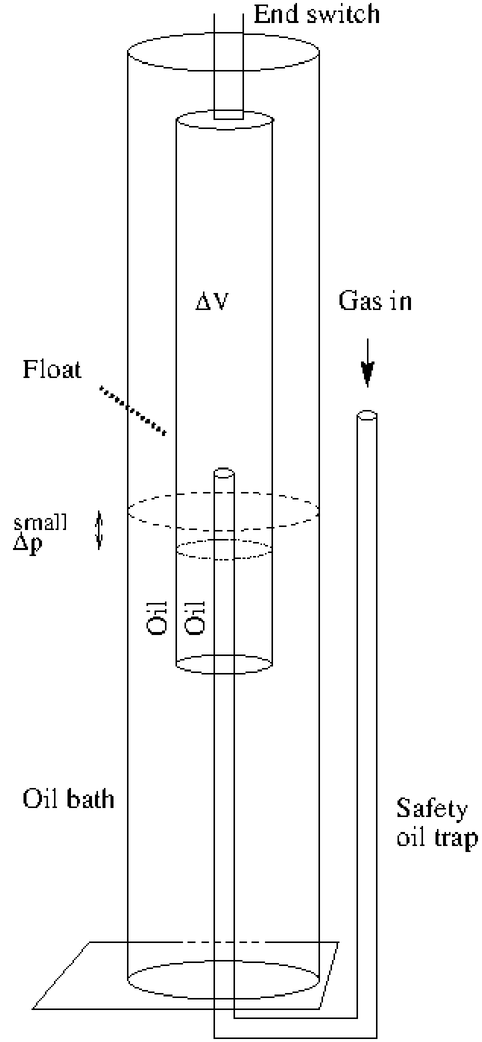


Solution: build a calibration device

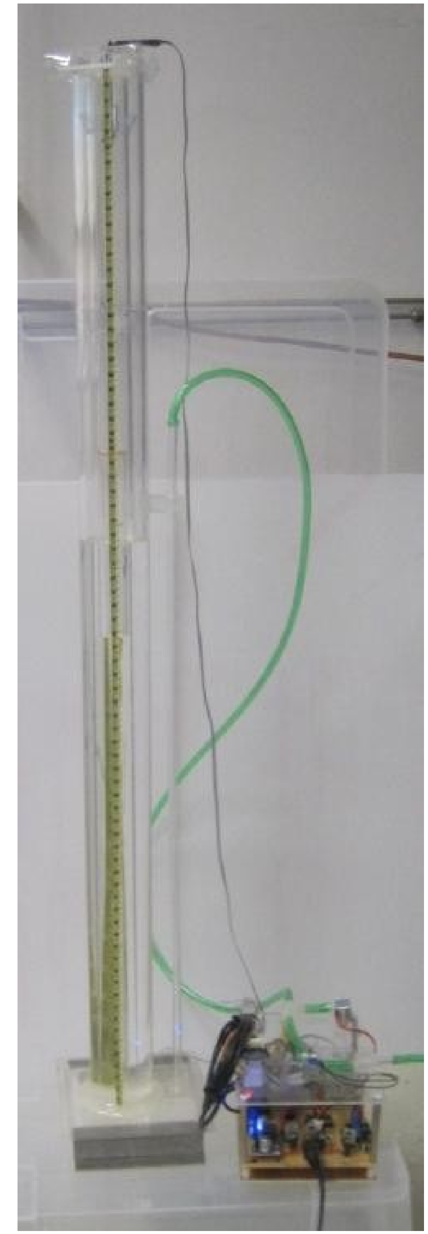
- A volumeter, with an end switch
- Input valves controlled by a Raspberry Pi



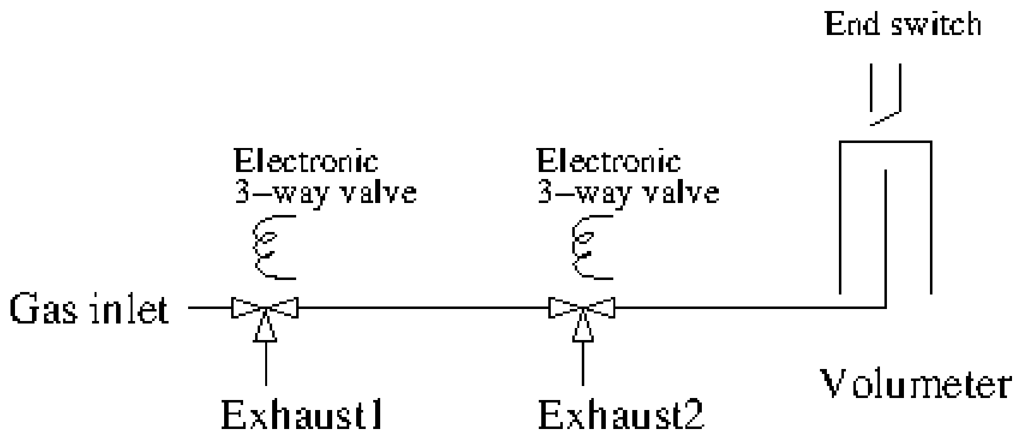
Volumeter in reset state



Volumeter in action



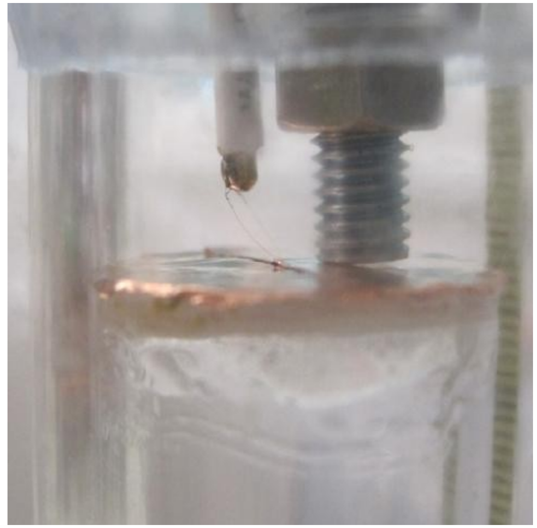
Working principle:



- Standby:
  - „Gas inlet" connected to „Exhaust1"
  - „Volumeter" connected to „Exhaust2"
- Measurement:
  - „Exhaust2" closed
  - „Exhaust1" closed
- Measurement stopped when end switch activated:
  - „Exhaust1" opened
  - Elapsed time measured => volumetric flow obtained
  - Volumetric flow converted to mass (molar) flow using ambient temperature and pressure

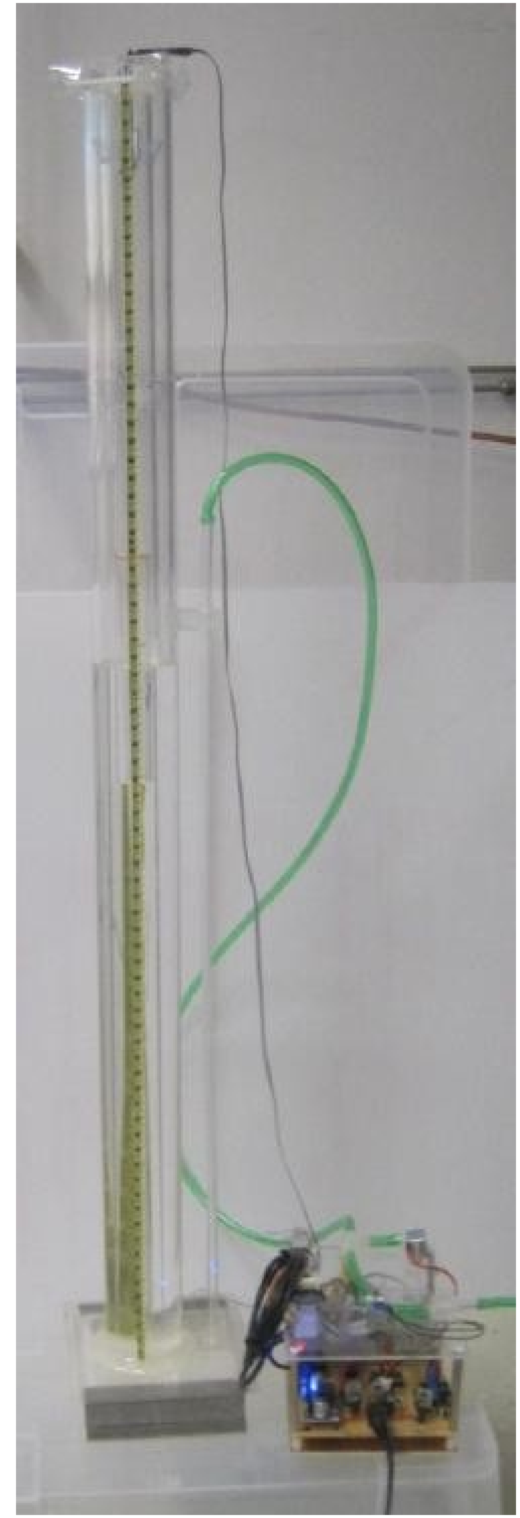
Main components:

- Volumeter with a very light weight floating cylinder
- Custom made end switch



- 2 piece of 3-way solenoid valve

- Air temperature sensor (DS18B20)
- Air pressure sensor (Bosch BME280)
- Raspberry Pi Model 4



Pressure buildup correction

- Generally:

$$p\,V = n\,R\,T$$

- At reset state:

$$p_{atm}\,V_0 = n_0\,R\,T_{atm}$$

- At end state:

$$(p_{atm} + \Delta p)(V_0 + \Delta V) = (n_0 + \Delta n)\,R\,T_{atm}$$

- Therefore, molar increase of gas amount (measured in normalized volume):

$$\Delta V_N := \Delta n\,R\,T_N / p_N = T_N / T_{atm}\,(\,p_{atm} / p_N\,\Delta V + \Delta p / p_N\,\Delta V + \Delta p / p_N\,V_0\,)$$

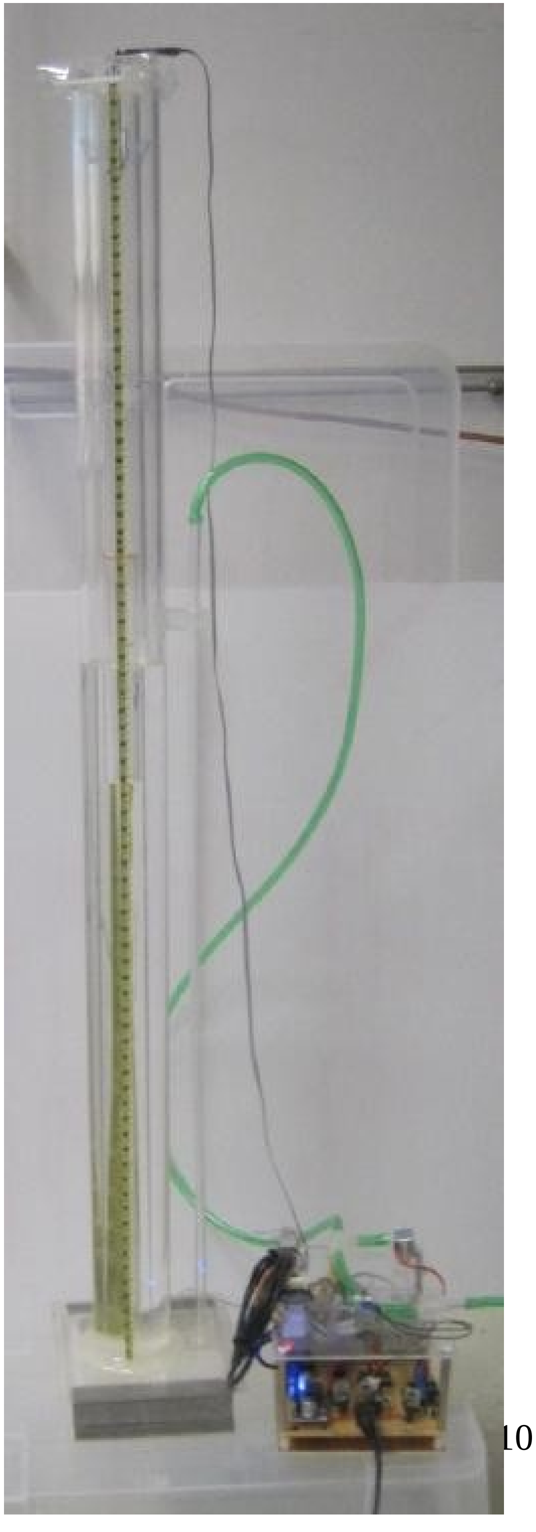
($p_N := 101325$ Pa , $T_N := 20\,^{o}C$)

Characteristics:

- Repeatability error for 0.3-5.0 ln/h range : ~ 0.5% (upper bound)

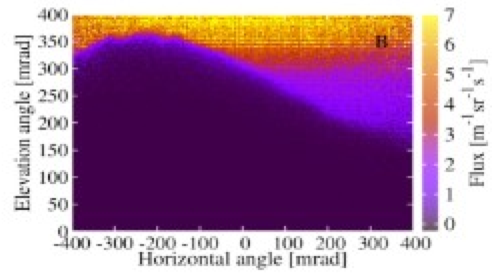
- Systematic corrections taken into account:
  - buildup of oil pressure: ~ 1% correction
  - compression of gas in buffer volume: ~ 0.5% correction

- Final systematic uncertainties (global):
  - from uncertainty of oil pressure buildup: ~0.05%
  - from compression of gas in buffer volume: ~0.05%
  - volumeter dimensions uncertainty: ~1%
  - timing uncertainty: max ~0.1% due to sampling



Spinoff: gas supply for extreme low consumption systems

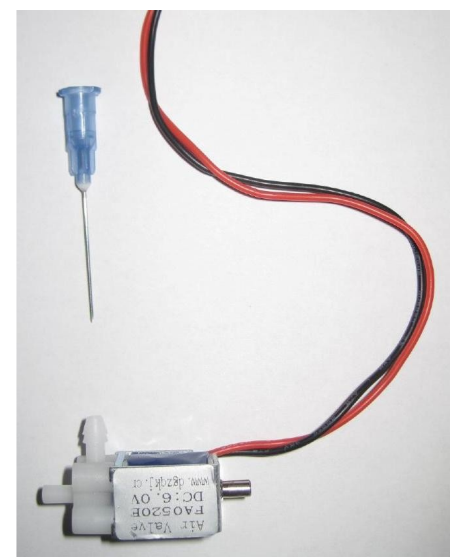
- Sometimes gaseous detectors are used in field applications.



(E.g. Sakurajima Muography Observatory, Sci.Rept.8(2018)3207. Or in caves etc.)

- Only tracking and multiple scattering => no perfect gas needed => can work at low flows
- It is <u>very</u> advantageous if gas bottle exchange is only 1-2 x per year.

- Gas dosaging using solenoid valve:



Concluding remarks

- Encountered calibration issues with industrial mass flow meters at < 5 ln/h range.
- Decided to build a calibration device.
- Based on: volumeter with an end switch + solenoid valves, Rpi controller.
- Repeatability error: ~0.5%
- Systematic uncertainty (global normalization, correlated): ~1%
- Strength: very high relative accuracy at low (< 1 ln/h) flows.

- A small spinoff application: gas dosaging systems with solenoid valves, for extremely low consumption systems (field applications).

Backup