

The bilateral comparison between NIM and PTB for small gas flow

Chunhui Li¹, Bodo Mickan², Shan Gao³

¹NIM, No.18 Beisanhuan Donglu, Beijing, China

²PTB, Braunschweig, Germany

³Hebei University, Baoding, China

E-mail: lich@nim.ac.cn

Abstract

With the development in the field of biomedicine, environmental monitoring, and so on, the requirement on the accuracy of small gas flow measurement is dramatically increased, which results in the increasing requirement on the accuracy of small gas flow facility. In NIM, the 100L pVTt facility was developed for small gas flow rate, which was built in 2010. But, the leakage and the big mass change in the inventory volume showed significant impact on the accuracy of the facility, especially for small gas flow rate, which was solved at the end of 2017. The uncertainty of the discharge coefficient for the sonic nozzle could be 0.15% ($k=2$) when the flow rate is larger than 0.1 m³/h, while it could be 0.25% ($k=2$) for smaller flow rate. The bilateral comparison between NIM and PTB for small gas flow rate was carried out with 4 sonic nozzles with flow rate 0.02 m³/h, 0.04 m³/h, 0.13 m³/h, 0.50 m³/h, and pressure range (85~1000) kPa. On the base of the good consistency of the comparison results, the uncertainty and the measurement capability of the 100 L pVTt facility were verified.

1. Introduction

With the development of biology medicine and environment monitoring, the accuracy requirement was significantly increased for small gas flow. For example, the uncertainty should be smaller than 0.65% ($k=2$) for the gas sampler in the environment monitoring. In general, the small gas meter is traceable small gas flow facility. So, the accuracy of the small gas flow facility is the key parameter to guarantee the accuracy of the gas flow meter.

The piston prover [1~3] was widely used in many NIMs as the primary standard, especially for small rate. The double piston prover was used to achieve the smallest flowrate (0.005-5) L/h with the uncertainty of 0.05% ($k=2$) in PTB [2], which can be used to calibrate sonic nozzle, laminar flowmeter, mass flowmeter and so on. The piston was driven by step motor for the double piston prover, which was typically called passive type piston prover. The piston prover was utilized in KRISS [3] for the smallest flowrate (0.002-20) L/min with the uncertainty of 0.11% ($k=2$). The piston was driven by the working medium, which was typically called active type piston prover.

In 2005, Nakao et al [4] built the small pVTt facility in NMIJ. The minimum flowrate could be 0.01 mg/min with the uncertainty of 0.21% ($k=2$). Berg et

al [5] presented the similar pVTt facility. The flow range could be (0.1 mL/min ~ 1 L/min) with uncertainty of 0.05% ($k=2$).

Since 1986, the pVTt facility with collection tank of 2 m³ and 20 m³ in NIM had been as the national primary standard in China. The working medium is the humid air with the atmospheric pressure. At the end of 2014, the new pVTt facility with collection tank of 100 L and 2 m³ was built in NIM. The working medium is the dry air with the pressure range of (0.1~2.5) MPa. The capability of the new pVTt facility with collection tank 2 m³ was verified with the comparison among PTB, LNE, NIST and NIM [6].

The technical improvement for the new pVTt facility with the collection tank of 100 L was made, especially for the leakage control and evaluation, the mass cancellation in the inventory volume. From 2017 to 2018, the comparison between PTB and NIM was conducted to verify the capability of the facility.

2. The technical improvement for 100 L pVTt facility in NIM

2.1 The structure of pVTt facility

There are two compressors with dryer and filter to produce the high pressure dry air. The dry air from the compressors is saved in the buffer tank. There

are two stages of buffer tank. The first stage buffer tank is consisted with 2 tanks with the volume of 10 m³ individually, and the second stage buffer tank is consisted with 2 tanks with the volume of 7.5 m³

individually. The maximum pressure in the first stage buffer tank is 10 MPa, while it is 5 MPa in the second stage.

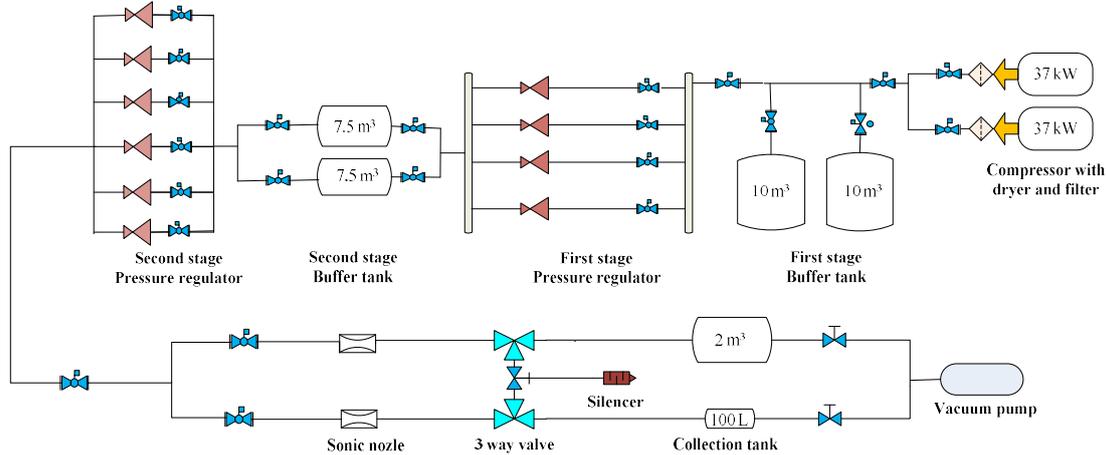


Figure 1 the systematic diagram of pVTt facility

In general, the flowrate measured by the pVTt facility could be expressed [7],

$$q_m = \frac{\Delta m}{t} \quad (1)$$

where q_m is the flowrate measured by the pVTt facility; Δm is the mass change measured by the density change in the collection tank; t is the test time.

In reality, the leak and the mass change in the inventory volume directly influence the flowrate, furthermore, Equ.(1) could be expressed as,

$$q_m = \frac{\Delta m + m_{leak} + \Delta m_{inv}}{t} = \frac{\Delta m}{t} \left(1 + \frac{m_{leak}}{\Delta m} + \frac{\Delta m_{inv}}{\Delta m} \right) \quad (2)$$

where Δm_{leak} is the total leak during the measurement process; Δm_{inv} is the mass change in the inventory volume during the measurement process.

So, the uncertainty of the pVTt facility can be expressed as

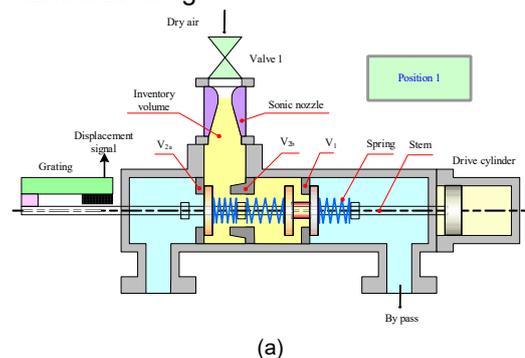
$$u_r(q_m) = \left\{ \begin{aligned} & \left[\frac{1}{1 + \frac{m_{leak}}{\Delta m} + \frac{\Delta m_{inv}}{\Delta m}} u_r(\Delta m) \right]^2 \\ & + \left[\frac{\frac{m_{leak}}{\Delta m}}{1 + \frac{m_{leak}}{\Delta m} + \frac{\Delta m_{inv}}{\Delta m}} u_r(m_{leak}) \right]^2 \\ & + \left[\frac{\frac{\Delta m_{inv}}{\Delta m}}{1 + \frac{m_{leak}}{\Delta m} + \frac{\Delta m_{inv}}{\Delta m}} u_r(\Delta m_{inv}) \right]^2 + u_r(t)^2 \end{aligned} \right\}^{0.5} \quad (3)$$

To improve the uncertainty of the pVTt facility, it is required to minimize the effect of leak and mass change inventory volume.

2.2 The leakage control and evaluation

In the pVTt facility, the special designed 3 way valve was developed. The basic structure of the 3 way valve was show in Figure.1. There are three independent sealing positions.

- **Position 1:** the sealing is in the position V_{2a} , and the dry air flow through by pass. This position is the original condition for pVTt facility.
- **Position 2:** the sealing is in the position V_{2a} and the positon V_1 , and the dry air flow in the inventory volume. This position is the condition, where the timer was switched on and off.
- **Position 3:** the sealing is in the position V_1 , and the dry air flow through the collection tank. This position is the condition, where the collection tank was filling.



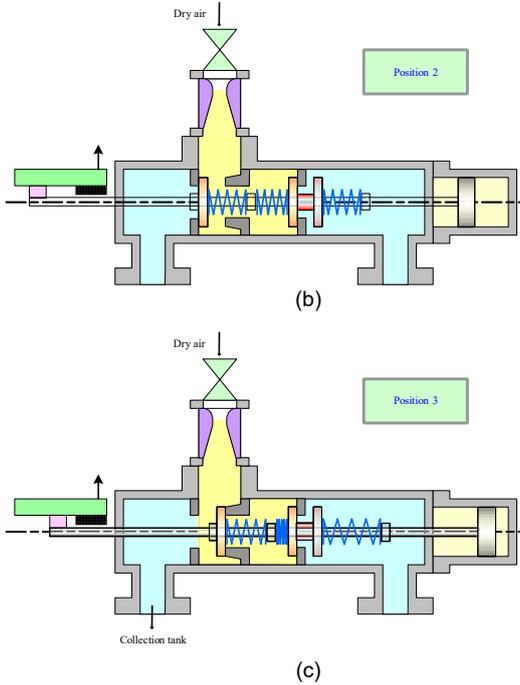


Figure 2 the systemic diagram of 3 way valve

During the test process, the leak could happen in Position 1 and Position 2, so, the total leak can be consisted of two parts

$$m_{leak} = m_{leak,1} + m_{leak,2} \quad (4)$$

Where, $m_{leak,1}$ is the leak coming from the filling process; $m_{leak,2}$ is the leak coming from the waiting process after filling process.

When the temperature is assumed stable, Equ. (4) can be simplified as,

$$m_{leak} = V(\Delta p_{leak,1} + \Delta p_{leak,2}) \frac{M}{R_u T Z} \quad (5)$$

Where, V is the volume of the collection tank; $\Delta p_{leak,1}$ is the pressure change during the filling process due to leak; $\Delta p_{leak,2}$ is the pressure change during the waiting process after the filling process due to leak;

Furthermore, $\Delta p_{leak,1}$ could be expressed as,

$$\Delta p_{leak,1} = \frac{t_{filling}}{p_f - p_i} \int_{p_i}^{p_f} \Delta p_{leak}(p) dp \quad (6)$$

$\Delta p_{leak,2}$ could be expressed as,

$$\Delta p_{leak,2} = \Delta p_{leak,p_f} t_{wait} \quad (7)$$

The pressure change at different pressure in the collection tank was measured, on the base of which the curve fitting was made to compensate the leak effect for 100 L pVTt facility. The test result for the leak during the filling was shown in Figure 3.

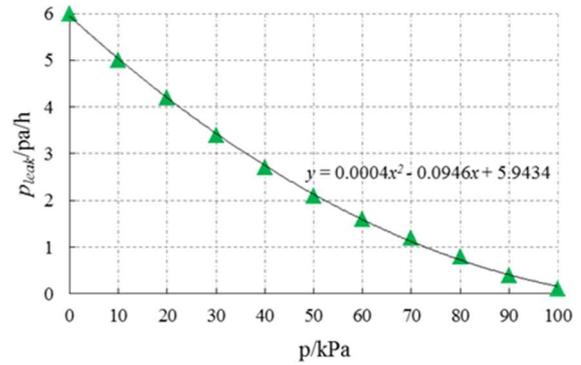


Figure 3 the leak measure during the filling

2.3 The mass cancellation in the inventory volume

During the opening and closing of the 3 way valve, the position of the stem was measured by the displacement signal from the grating with the resolution of 20 μ m. At the same time, the pressure with high speed in the inventory volume was measured and recorded with frequency above 5000 Hz.

For different flowrate, the typical pressure change in the inventory volume was shown in Figure 4.

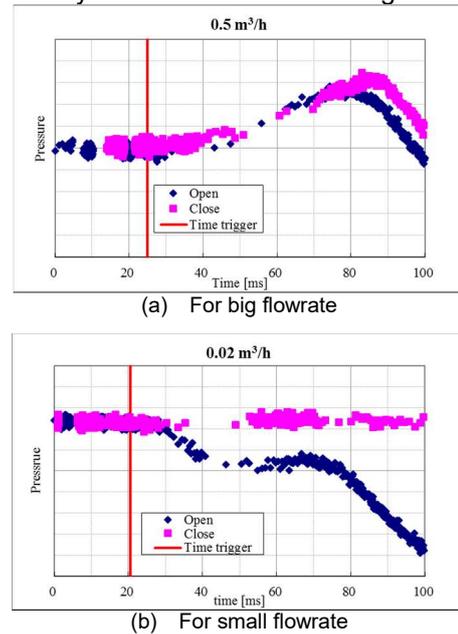


Figure 4 the pressure change in the inventory volume during filling process

It was clear that

- For large flowrate, the pressure overlap occurred, so the time correction almost could be neglected, and the mass cancellation could be achieved [8].
- For small flowrate, there was no obviously pressure overlap, the time correction was determined by the geometrical parameter of

the valve, which was consistent with the number of the signal.

3. Comparison results and analyses

With the technical improvement of the 100 L pVTt facility, the uncertainty of the discharge coefficient for the sonic nozzle was 0.15% ($k=2$) when the flow rate was larger than 0.1 m³/h, while it was 0.25% ($k=2$) for smaller flow rate.

To verify the capability of the 100 L pVTt facility, the bilateral comparison was conducted between NIM and PTB from 2017 to 2018.

According to the flowrate, the small sonic nozzle facility and two other gas facilities were used in PTB. The uncertainty of the discharge coefficient was 0.10% ($k=2$) when the flowrate is bigger than 0.1 m³/h, which was 0.15% ($k=2$) for smaller flowrate.

Due the high accuracy and long term stability, the critical flow Venturi nozzle (CFVN) was chosen as the transfer meter in this comparison [9]. The information on the CFVNs was shown in Table 1.

Table 1 the information on the comparison

SN	Nominal flowrate [m ³ /h]	NIM [kPa]	PTB [kPa]
625	0.5	200~1000	85~230
623	0.13		
03574_320	0.04	85~230	
03575_250	0.02		

- The SN.625 and SN.623 were the transfer standards in NIM, which were calibrated in NIM in July, 2018. Then, they were calibrated in PTB in August, 2018.
- The SN.03574_320 and SN.03575_250 were the transfer meters in PTB, which were calibrated in PTB twice in March, 2017. Then, they were calibrated in NIM in November, 2018.

All the comparison data were shown in Figure 5.

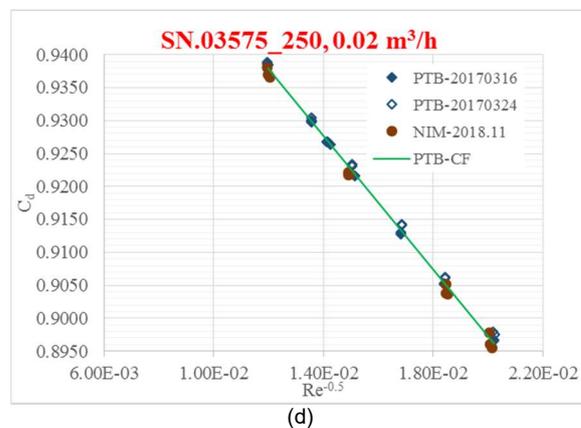
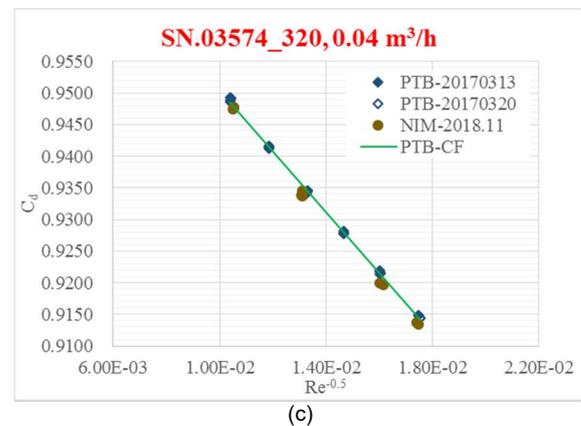
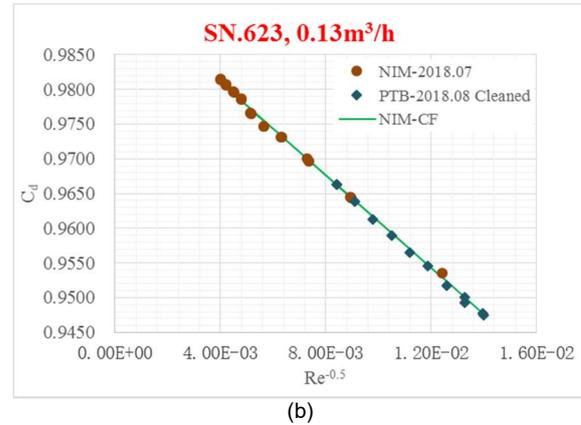
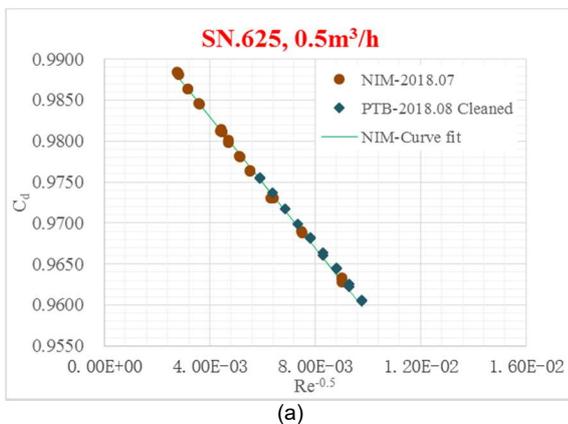


Figure 5 the comparison results

The curve fitting was made to analyse the consistent of the result. For this comparison, the flow was within laminar region, the curve fitting was expressed as,

$$C_{d,CF} = a - \frac{b}{\sqrt{Re}} \quad (8)$$

- For the results of the SN.625 and SN.623, the curve fitting was based on the result of NIM.
- For the results of the SN.03574_320 and SN.03575_250, the curve fitting was based on the result of PTB.

The E_n value [10~11] was used to evaluate the result,

$$E_n = \frac{|C_{d,CF} - C_{d,NMI}|}{\sqrt{U_{NIM}^2 + U_{PTB}^2 + U_{CF}^2}} \quad (10)$$

where $C_{d,CF}$ is the discharge coefficient was calculated according to the curve fitting, at the same Reynolds number, $C_{d,NMI}$. Due to the curve fitting, the additional curve fitting uncertainty, U_{CF} , which was evaluated by the residual between the test data and the curve fitting results.

$$U_{CF} = 2\sqrt{\frac{(C_{d,CF} - C_d)^2}{N - 2}} \quad (11)$$

The comparison results analyses were shown in Table 2.

Table 2 the comparison results analyses

SN	U_{NIM} , %	U_{PTB} , %	U_{CF} , %	E_n
625	0.15	0.10	0.06	0.07~0.47
623	0.15	0.10	0.09	0.02~0.34
03574_320	0.25	0.15	0.07	0.01~0.18
03575_250	0.25	0.15	0.13	0.02~0.38

The detailed value for each CFVN was shown in Figure 6.

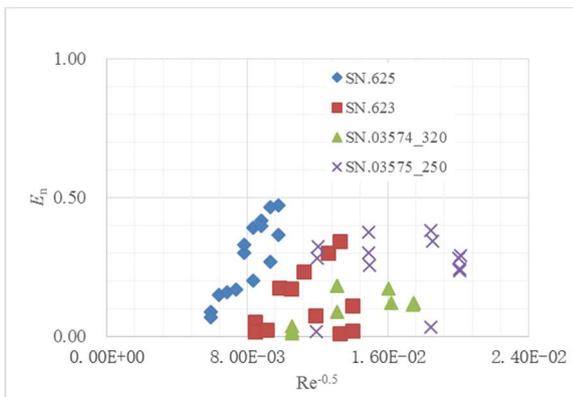


Figure 6 the E_n value for this comparison

With the combination of Table 2 and Figure 5, all the E_n value was smaller than 1, which meant the uncertainty of the 100 L pVTt facility was verified.

4. Conclusion and discussion

For the 100 L pVTt facility, the leak evaluation and mass evaluation in the inventory volume were analyzed and qualified in this paper. The uncertainty of the discharge coefficient for the sonic nozzle was 0.15% ($k=2$) when the flow rate was larger than 0.1 m³/h, while it was 0.25% ($k=2$) for smaller flow rate. With 4 CFVNs as the transfer meter, the bilateral comparison were conducted to verify the uncertainty of 100 L pVTt facility. On the base of the good consistency of the comparison results, the

uncertainty and the measurement capability of the 100 L pVTt facility were verified.

During this comparison, the maximum diameter was about 1 mm. The surface quality took significant effect on the test result.

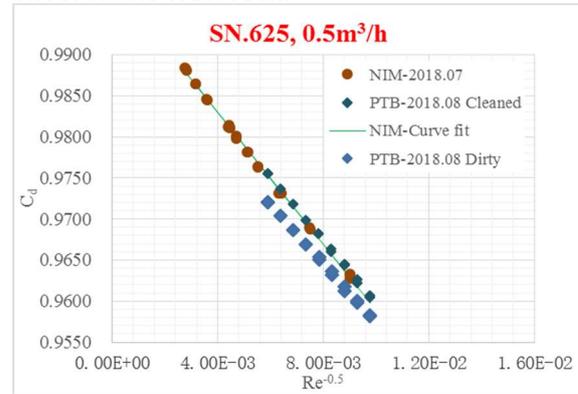


Figure 7 the surface quality effect

As shown in Figure 7, the change of the discharge coefficient could be larger than 0.3% for the same sonic nozzle with different surface quality, which was larger than the uncertainty of the test results.

The surface quality could be qualified with microscope as shown in Figure 8.

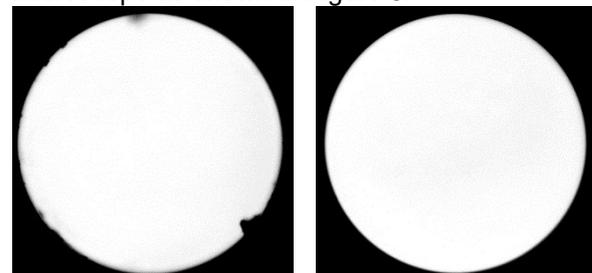


Figure 8 the surface quality

It was clear that there was dust near to the throat, which affected the results very much. So, the clean of CFVN was necessary, especially for small size. In this comparison, the CFVNs were clean with ultrasonic bath before the test.

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