The high pressure close loop gas flow standard facility in NIM

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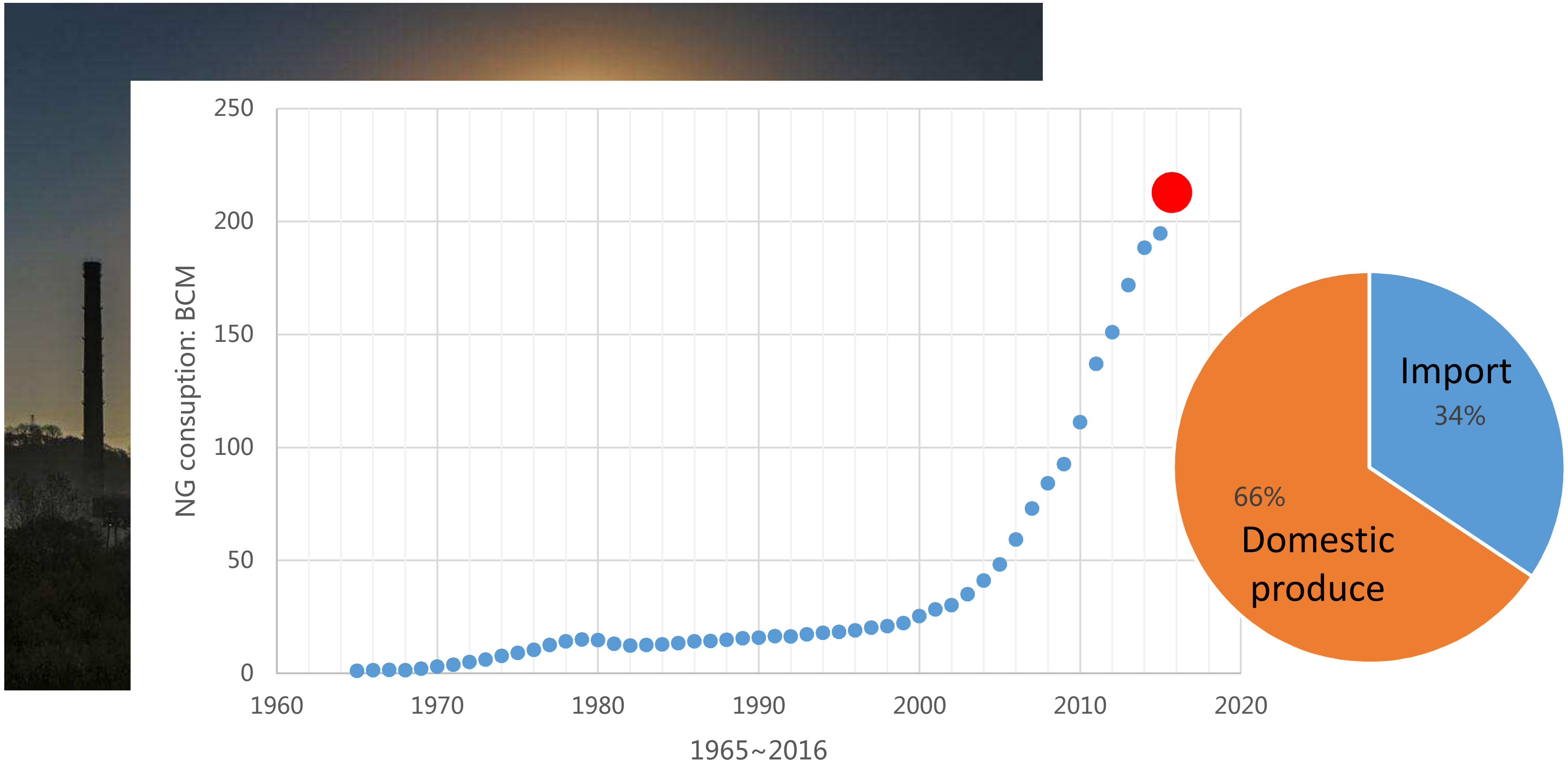
The background



The natural gas station in China

- Primary standard
- Secondary standard
- Working standard

- Secondary standard
- Working standard

Gas flow facility

pVTt facility
Nominal volume: 0.1/2 m^3
Pressure: (0.1~2.5) MPa
Temperature: (20±5) ˚C
Flowrate: (0.019~1367) kg/h
Uncertainty: 0.08% (*k*=2)

Sonic nozzle facility
Diameter: Dn50~Dn100
Pressure: (0.2~2.5) MPa
Temperature: (20±5) ˚C
Flowrate: (40~7200) Nm^3/h
Uncertainty: 0.15% (*k*=2)

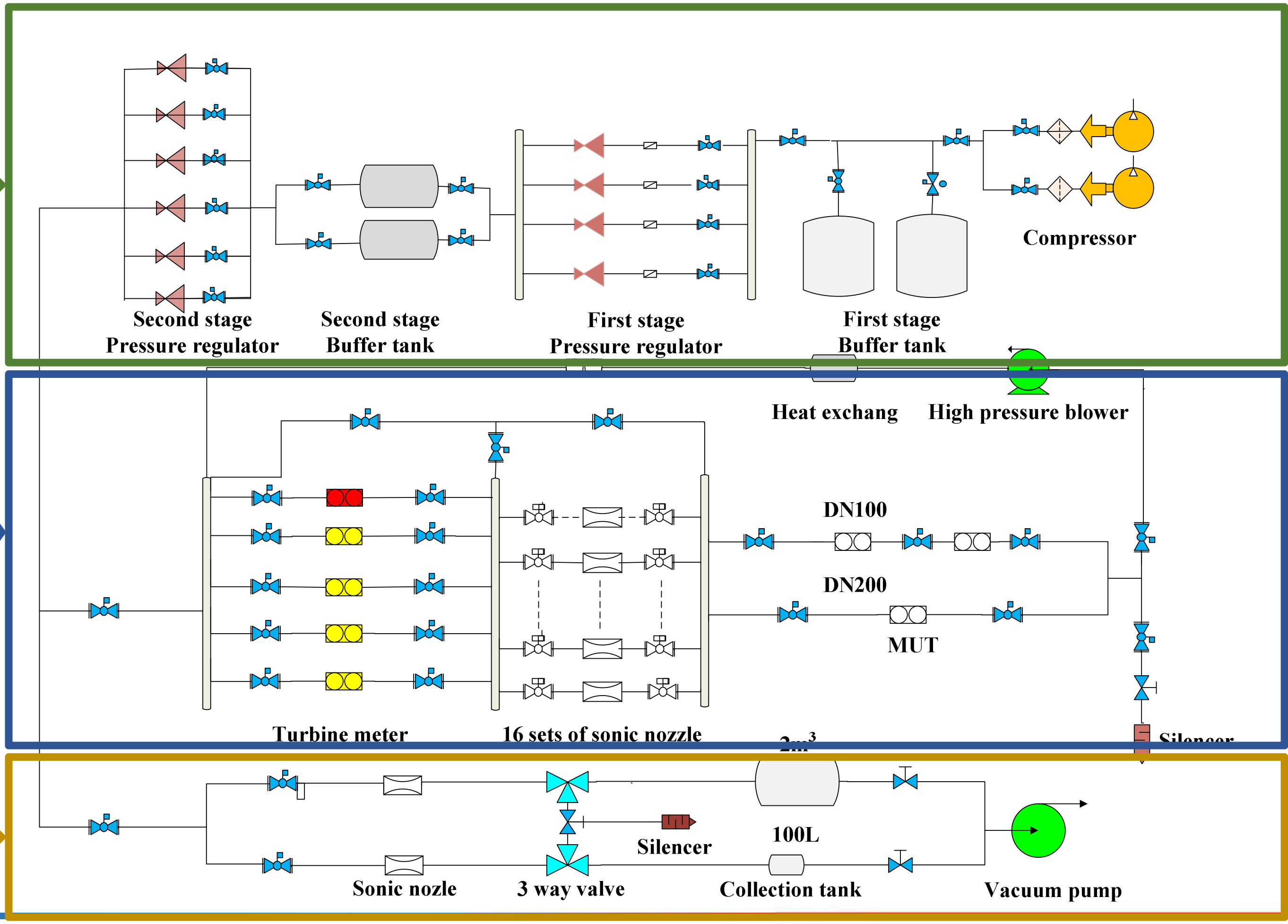
Close loop facility
Diameter: Dn50~Dn200
Pressure: (0.1~2.5) MPa
Temperature: (20±5) ˚C
Flowrate: (20~1400) m^3/h
Uncertainty: 0.20% (*k*=2)

The layout of facility

The compressed air supply

- The sonic nozzle facility
- The close loop facility

The pVTt facility



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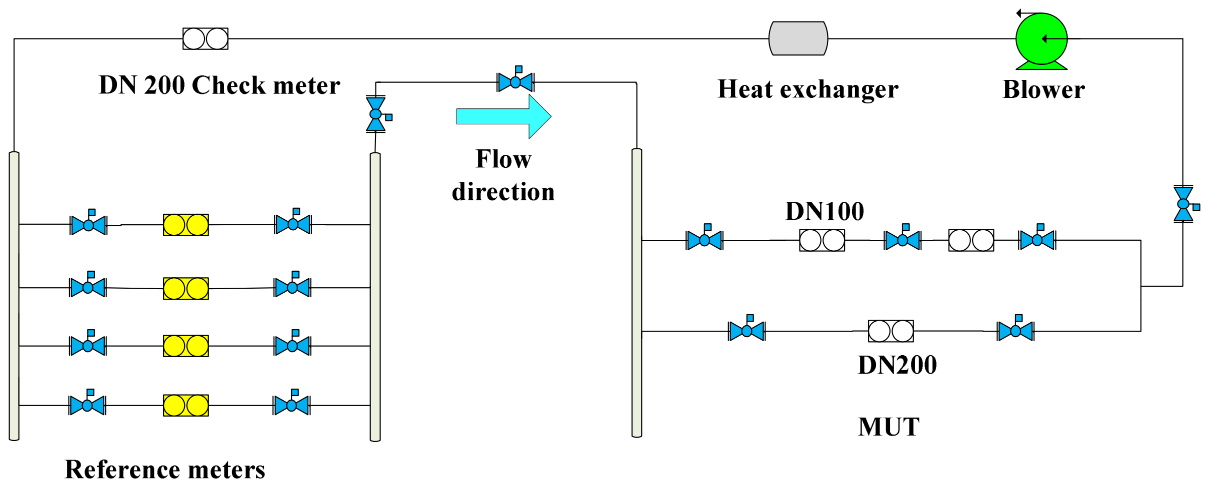
The close loop facility



$$K_{MUT,real} = \frac{N_{MUT}}{t_{MUT} q_{MUT,real}}$$

$$q_{MUT,real} = q_{ref} \cdot \frac{\rho_{ref}}{\rho_{MUT}}$$

$$= \frac{N_{ref}}{K_{ref} \cdot t_{ref}} \cdot \left(\frac{p_{ref}}{p_{MUT}} \cdot \right.$$

$$K_{MUT,real} = K_{ref} \cdot \frac{p_{MUT}}{p_{ref}} \cdot \frac{T_{ref}}{T_{MUT}} \cdot \frac{z_{ref}}{z_{MUT}} \cdot \frac{N_{MUT}}{N_{ref}} \cdot \frac{t_{ref}}{t_{MUT}}$$

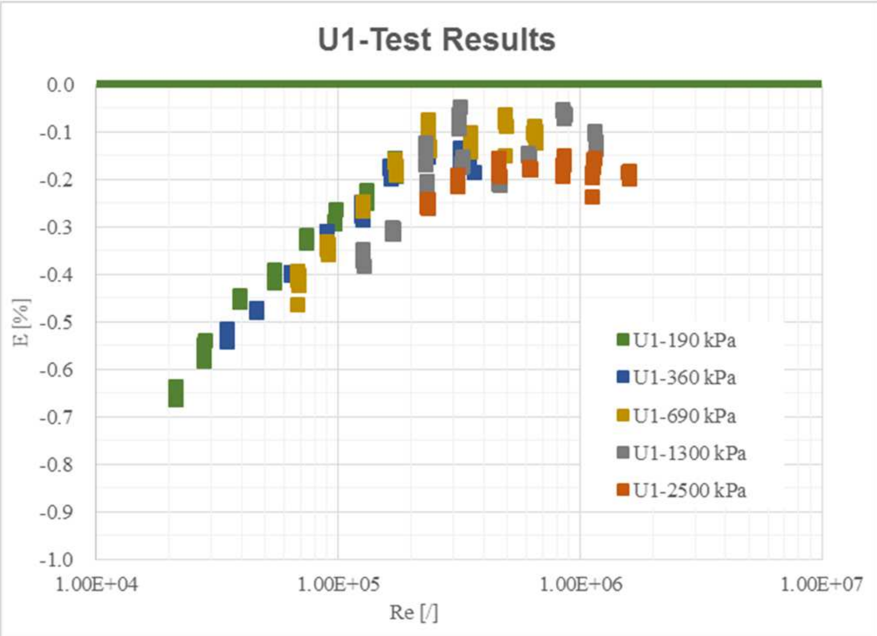
$$u(K_{MUT,real}) = \sqrt{\begin{array}{l} u(K_{ref})^2 + u(p_{ref})^2 + u(p_{MUT})^2 \\ +u(T_{ref})^2 + u(T_{MUT})^2 \\ +u(N_{ref})^2 + u(N_{MUT})^2 \\ +u(t_{ref})^2 + u(t_{MUT})^2 \\ +u_R(K_{MUT,real})^2 \end{array}}$$

The “original position” calibration

Overview of the facility

- Meter under test for sonic nozzle facility
- Master meter for close loop facility
- 16 sonic nozzles for sonic nozzle facility

The calibration procedure



- Each reference meter was calibrated at 5 pressures, ie, 190 kPa, 360 kPa, 690 kPa, 1300 kPa, and 2500 kPa.
- For each pressure, the meter was calibrated with 8 flow rate, ie, 40 m^3/h, 54 m^3/h, 76 m^3/h, 106 m^3/h, 147 m^3/h, 206 m^3/h, 288 m^3/h and 400 m^3/h.
- For each flow rate, the calibration was repeated at least 5 times.

The curve fitting

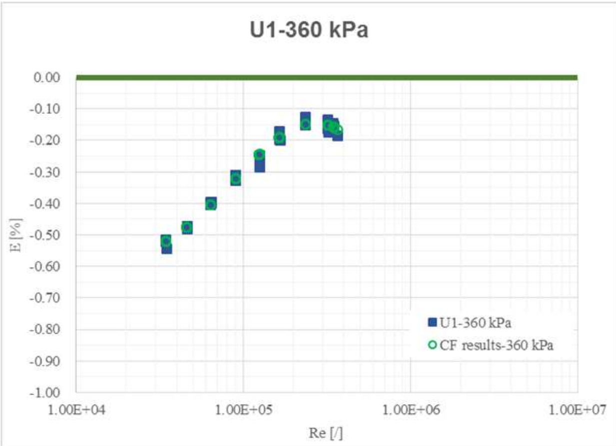
- For the pressure range within (190~400) kPa

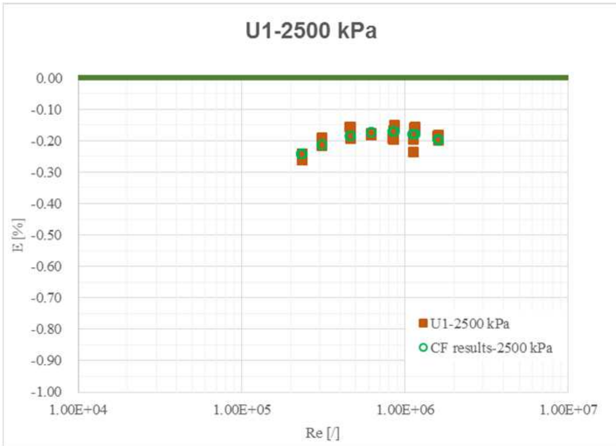
$$E_{ref,CF} = a_0 + a_1 \ln(\mathrm{Re}) + a_2 \ln(\mathrm{Re})^2 + a_3 \ln(\mathrm{Re})^3$$

- For the pressure range within (400~2500) kPa

$$E_{ref,CF} = a_0 + a_1 \ln(\mathrm{Re}) + a_2 \ln(\mathrm{Re})^2$$

The uncertainty





$$u(E_{ref,CF}) = \sqrt{\frac{(E_{ref,CF} - E_{ref})^2}{N - m}} = u(K_{ref,CF})$$

$$u(K_{ref}) = \sqrt{u(K_{ref,SN})^2 + u(K_{ref,CF})^2}$$
$$= \sqrt{0.075^2 + 0.05^2}\,\% = 0.0885\%$$

The "absolute + differential"

$$\frac{p_{MUT}}{p_{ref}} = \frac{p_{abs} + \Delta p_{MUT}}{p_{abs} + \Delta p_{ref}} = 1 + \frac{\Delta p_{MUT}}{p_{abs}} - \frac{\Delta p_{ref}}{p_{abs}}$$

$$u(p_{ref}) = \frac{\Delta p_{ref}}{p_{abs}} \sqrt{u(\Delta p_{ref})^2 + u(p_{abs})^2}$$

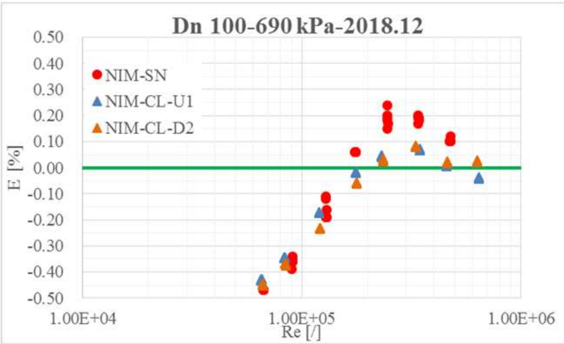
$$u(p_{MUT}) = \frac{\Delta p_{MUT}}{p_{abs}} \sqrt{u(\Delta p_{MUT})^2 + u(p_{abs})^2}$$

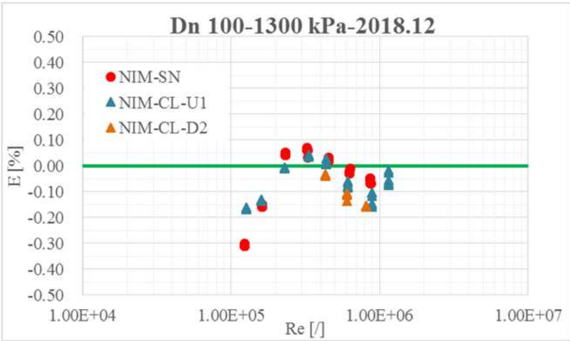
The uncertainty of CL facility

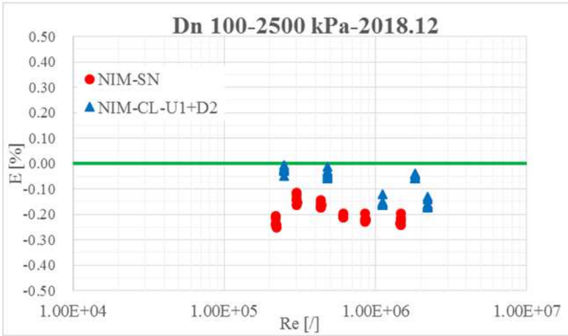
SN	Symbols	Meaning	u [%]	c [/]	$u \cdot c$ [%]
1	$u(K_{ref})$	The meter factor of reference meter	0.0899	1	0.0899
2	$u(p_{abs})$	The absolute pressure	0.0058	0.028	0.0002
3	$u(\Delta p_{ref})$	The differential pressure of reference meter	0.0289	0.02	0.0006
4	$u(\Delta p_{MUT})$	The differential pressure of MUT	0.0289	0.02	0.0006
5	$u(T_{ref})$	The temperature of reference meter	0.0085	1	0.0085
6	$u(T_{MUT})$	The temperature of MUT	0.0085	1	0.0085
7	$u(N_{ref})$	The pulse number of reference meter	0.0029	1	0.0029
8	$u(N_{MUT})$	The pulse number of MUT	0.0029	1	0.0029
9	$u(t_{ref})$	The time of the reference meter	0.0002	1	0.0002
10	$u(t_{MUT})$	The time of MUT	0.0002	1	0.0002
12	$u_R(K_{MUT,real})$	The repeatability	0.040	1	0.040
$u(K_{MUT,real})$ =0.098%, $U(K_{MUT,real})$ =0.20% (k=2)					

The verification

- Dn 100 turbine meter was used as the transfer meter to make the comparison between the sonic nozzle facility and the close loop facility.
- The comparison results were shown with different pressures, 690 kPa, 1300 kPa and 2500 kPa.



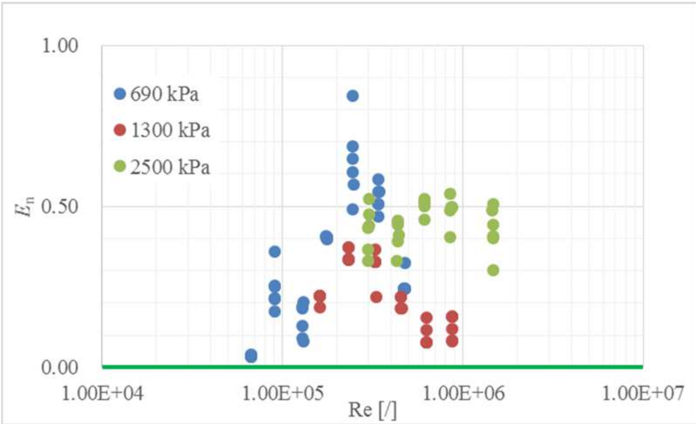




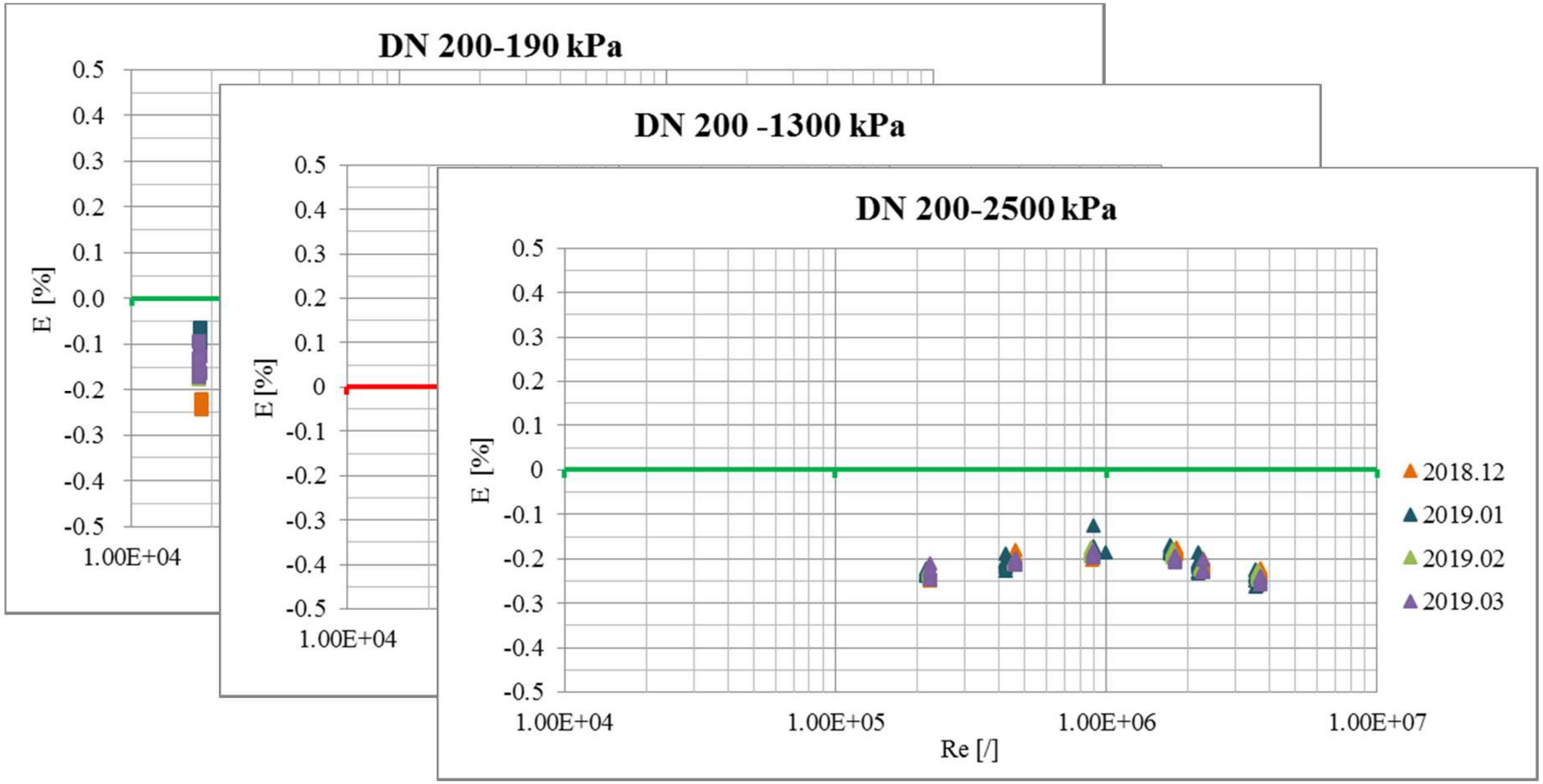
The consistence

$$E_n = \frac{\left| E_{MUT,CL,CF} - E_{MUT,SN} \right|}{\sqrt{U^2_{MUT,CL} + U^2_{MUT,SN} + U^2_{CF}}} \quad E_{MUT,CF} = a_0 + a_1 \ln(\mathrm{Re}) + a_2 \ln(\mathrm{Re})^2$$

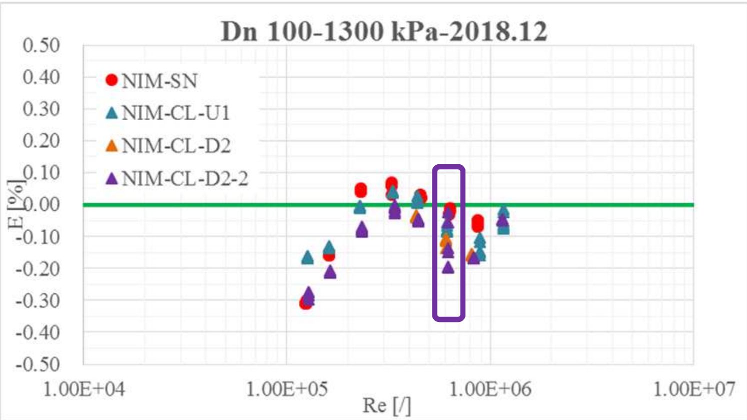
Pressure [kPa]	Re range for CF	$U_{MUT,SN}$ [%]	$U_{MUT,CL}$ [%]	U_{CF} [%]	E_n
690	$6.5\mathrm{X}10^4$~$6.4\mathrm{X}10^5$	0.15	0.20	0.06	0.03~0.84
1300	$1.3\mathrm{X}10^5$~$1.2\mathrm{X}10^6$	0.15	0.20	0.11	0.08~0.37
2500	$2.5\mathrm{X}10^5$~$2.2\mathrm{X}10^6$	0.15	0.20	0.09	0.30~0.54

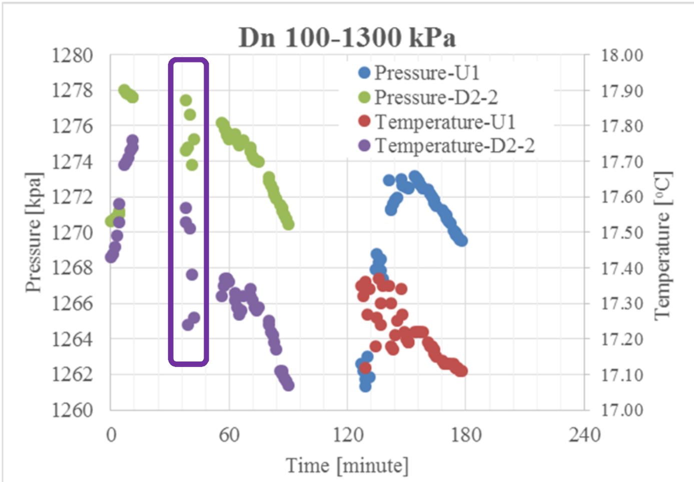


The stability of the facility



The temperature effect



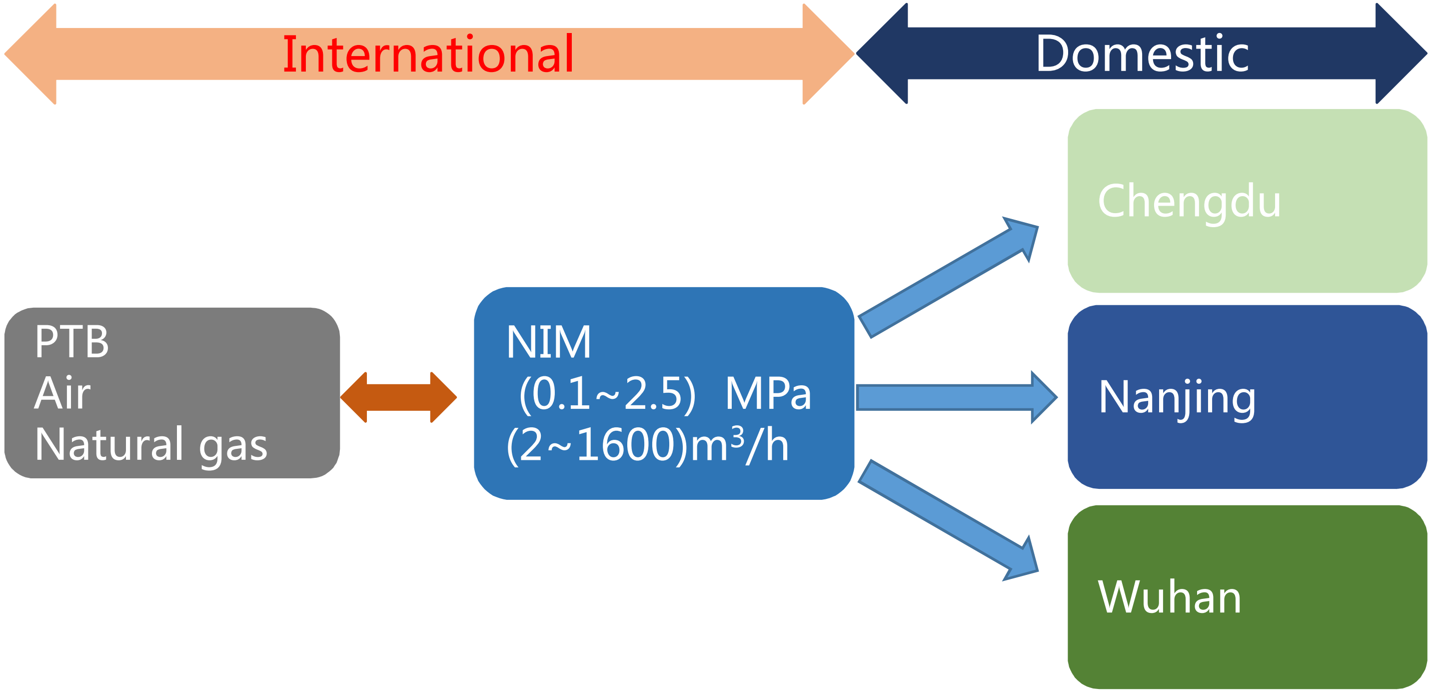


- The temperature change was kept within 0.3 °C in one hour for the close loop facility

Conclusions

- The close loop facility with 4 sets of Dn 100 turbine meters as the reference meters was built in NIM. The flow range is within (40~1300) m^3/h, while the pressure range is within the (190~2500) kPa.
  - The reference meters were designed directly in "original position" traceable to the sonic nozzle facility (SN).
  - To decrease the pressure measurement uncertainty, there is an absolute pressure instrument in the manifold in the upstream of the reference meters, the differential pressure transducers were used for the reference meter and MUT.
- The expanded uncertainty of meter factor for meter under test (MUT) was 0.20% (k=2), which was verified with the comparison between sonic nozzle facility and close loop facility.

Outlook



- 2016~2018, sonic nozzle;
- 2018.06, DN 100 flow meter;
- 2018.12, DN 200 flow meter

- 2018, sonic nozzle
- 2019.6, DN 100 meter
- 2019.12, DN 200 meter

Thanks!

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