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Problems to note when using the nozzle to nozzle test method

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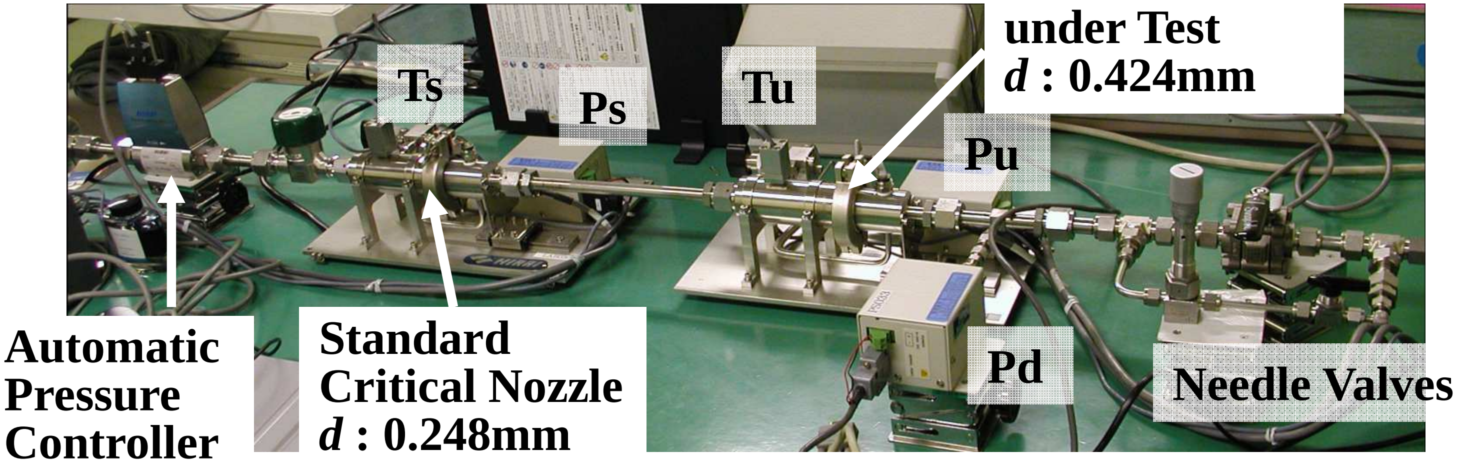
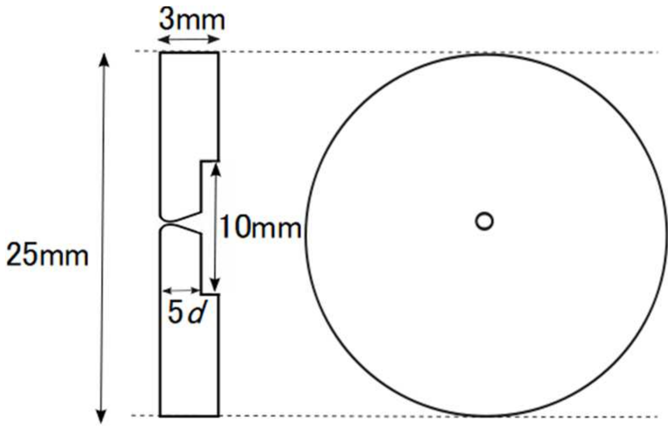
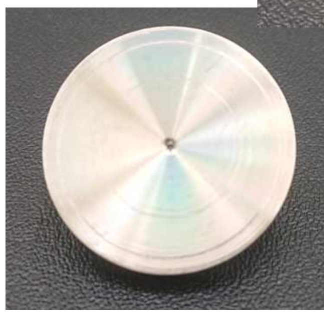
Experimental Apparatus and Dimensions of Critical Nozzles



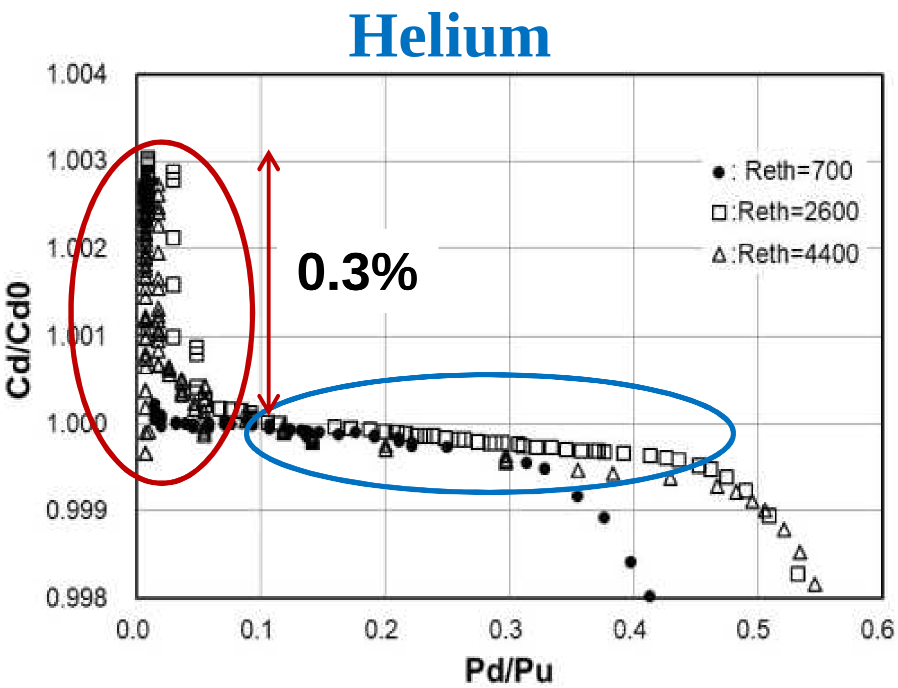
Nozzle Dimensions Shape: troidal throat Venturi nozzle	
Inlet curvature	2 *d*
Diffuser half angle	3 °
Diffuser length	3 *d*

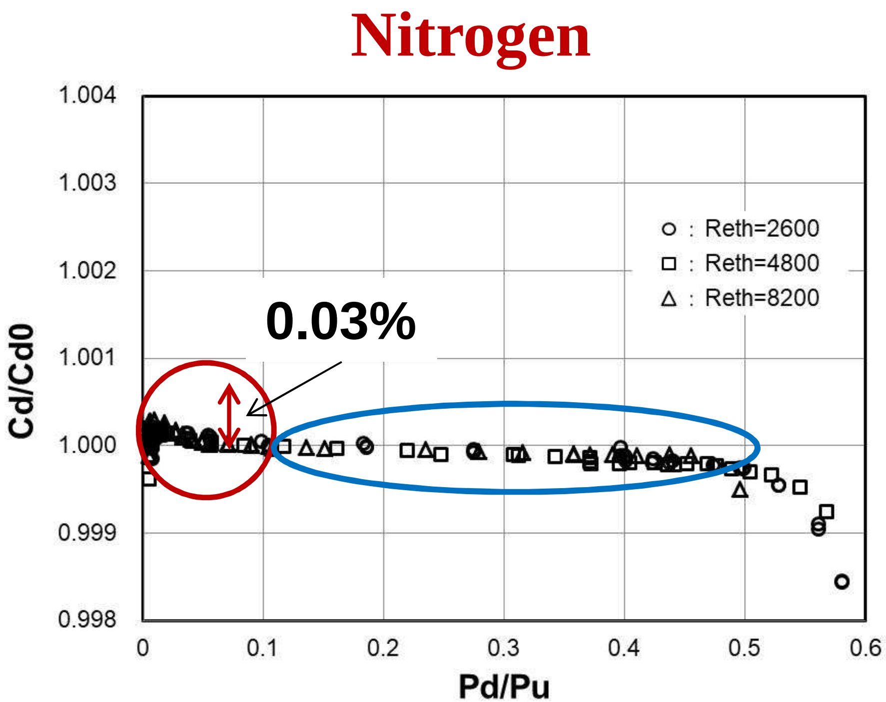




Experimental Results

Strange Behaviors of Discharge Coefficients





- **Pd/Pu<0.1: Why the peak of Cd appears?**
- **Pd/Pu>0.1: The flow is surely chocked in He?**
  If it is chocked,
  why Cd decrease larger in He ?

Experimental Results: Pd/Pu<0.1

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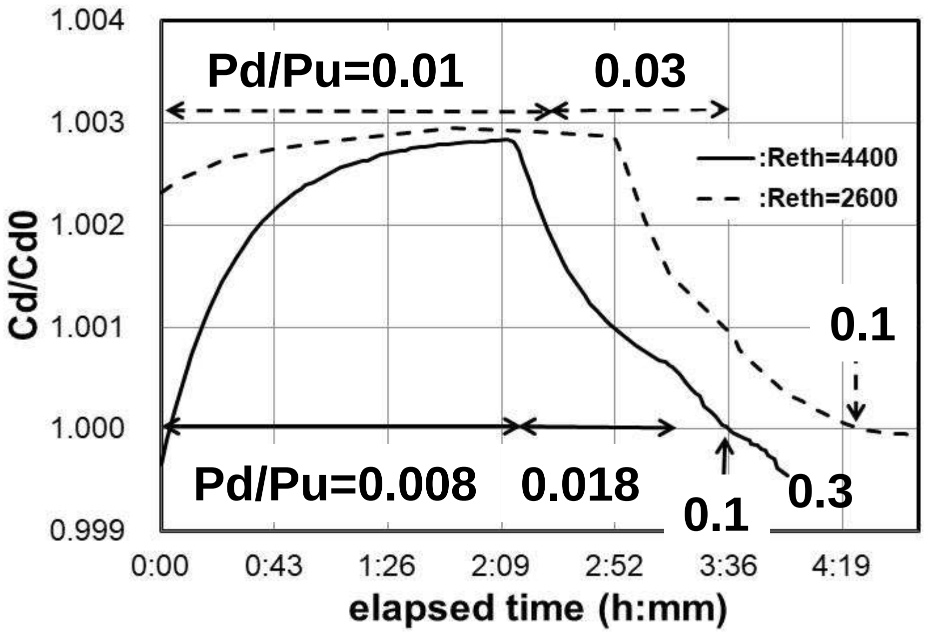
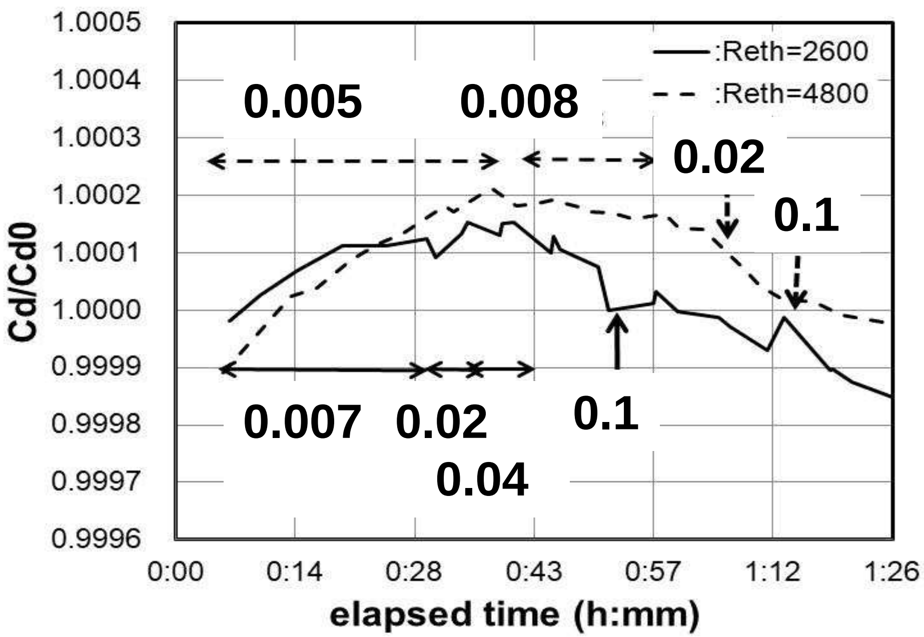
Behaviors of Discharge Coefficient with time

Helium



Nitrogen



When *Pd/Pu* = 0.008 at *Reth* = 4400, *Cd* reaches to the peak value over 2 hours. After changing to *Pd/Pu* = 0.018, *Cd* decreases gradually to the value at *Pd/Pu* = 0.1 . The situation of change is the same in the case of *Reth* = 2600.

***Cd* reaches to the peak value about 40 minutes. As the scale of the vertical axis is extended, *Cd* looks bumpy, but the situation of change is similar to that in He.**

Experimental Results: Pd/Pu<0.1

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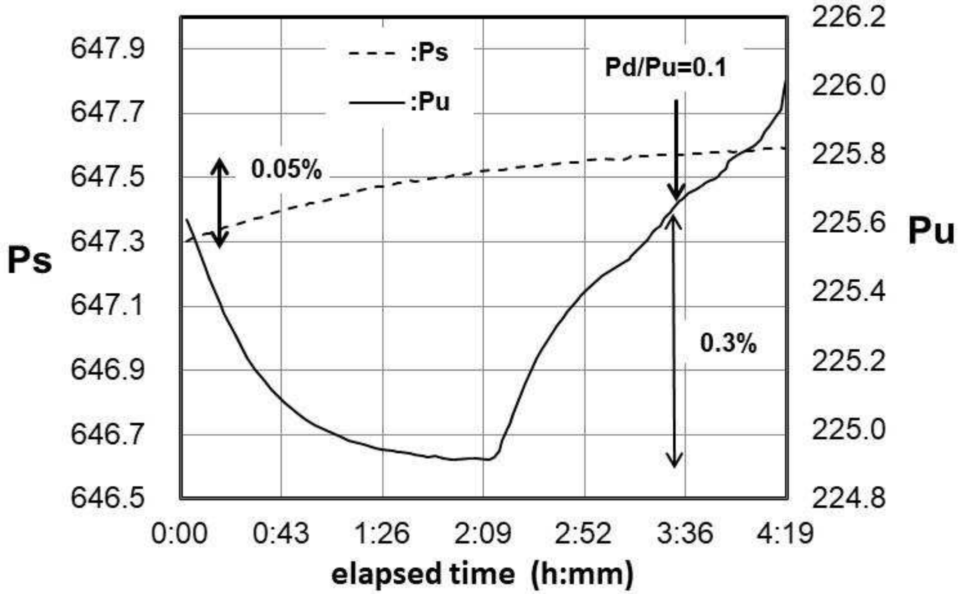
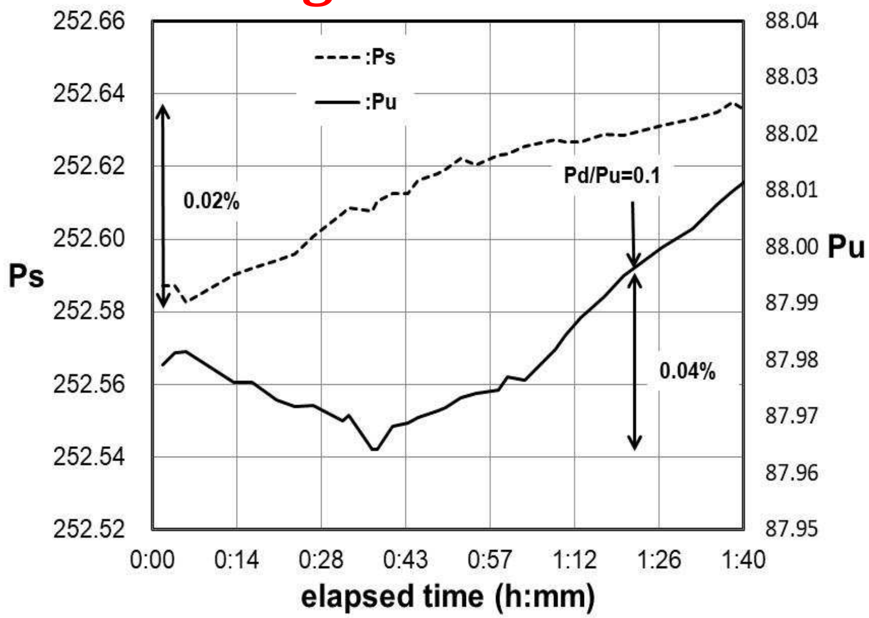
Behaviors of upstream pressures of standard critical nozzle Ps and of critical nozzle under test Pu with time

Helium *Reth* = 4400



Nitrogen *Reth* = 4800



In both gases,

***Ps* is stable during measurement, and *Pu* increase after decreasing.**

The change of *Pu* in N2 is small enough to be negligible, but

the change of *Pu* in He is about 0.3% and can not be neglected,

The change of Pu is linked to that of *Cd*.

Flow Model in Pd/Pu<0.1 (1)

why the peak of Cd appears in Pd/Pu<0.1.

(1) Under the condition of $Pd/Pu < 0.1$, a flow field outside of a critical nozzle exit is in a state of an under expanded jet.

(2) Strong expansion waves are generated at the edge of the nozzle exit.

(3) The flow along the boundary layer is strongly accelerated.

(4) The boundary layer including the throat area becomes thinner and the sonic plain area becomes larger.

(5) If the upstream condition is maintained,

The mass flow rate increases.

$$C_d \approx \frac{Q_m}{S^* P_u}$$

This is a normal situation when a critical nozzle is used.

Flow Model in Pd/Pu<0.1 (2)

why the peak of Cd appears in Pd/Pu<0.1.

In a nozzle to nozzle test method, the mass flow rate through a system is constant, which is equal to that obtained from the standard critical nozzle (the upstream side nozzle).

↓

Since the mass flow rate is constant, when the sonic plain area become larger, an upstream pressure of a critical nozzle must decrease. Otherwise, the mass flow rate will change.

↓

$$C_d \approx \frac{Q_m}{S^* P_u}$$

The discharge coefficient increases.

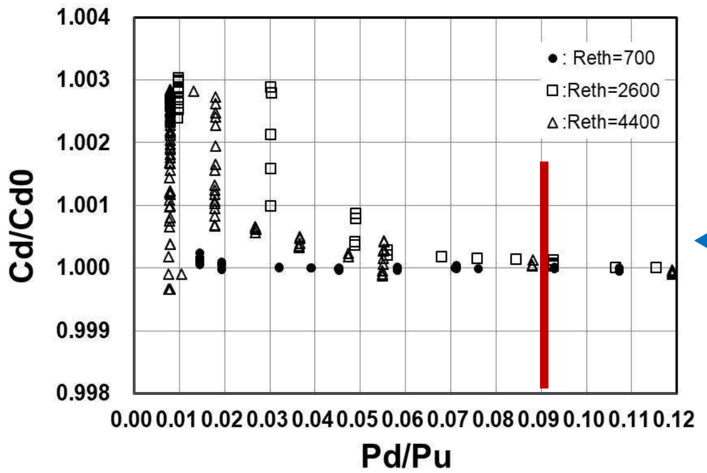
Flow Model in Pd/Pu<0.1 (3)

why the peak of Cd appears in Pd/Pu<0.1.

When a flow field outside a critical nozzle exit is an under expanded jet, the flow in the diffuser is isentropic.
A back pressure ratio at a nozzle exit, *Pe/Pu*, can be calculated from the following equations.

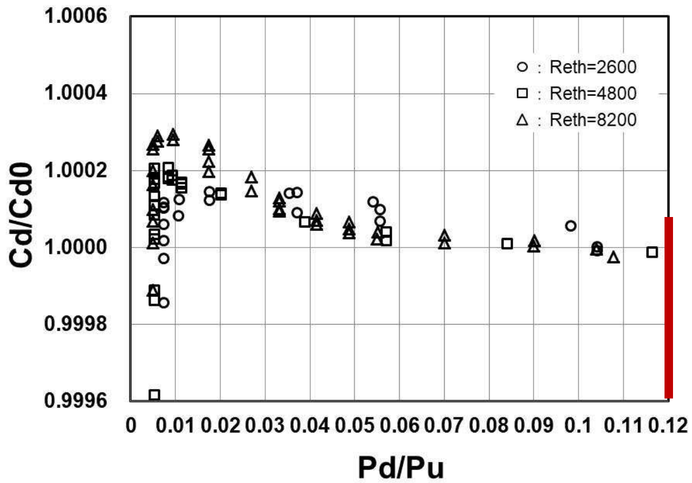
$$\left(\frac{A}{A^*}\right)^2 = \frac{1}{M^2}\left[\frac{2}{\gamma+1}\left(1+\frac{\gamma-1}{2}M^2\right)\right]^{(\gamma+1)/(\gamma-1)} \qquad \frac{P_0}{P_e} = \left(1+\frac{\gamma-1}{2}M^2\right)^{\frac{\gamma}{\gamma-1}}$$

: calculated *Pe/Pu*



Helium ←

→ **Nitrogen**



The back pressure ratio that the strange behaviors disappears is almost coincident to the back pressure ratio at the nozzle exit.

Experimental Results: Pd/Pu>0.1 (1)

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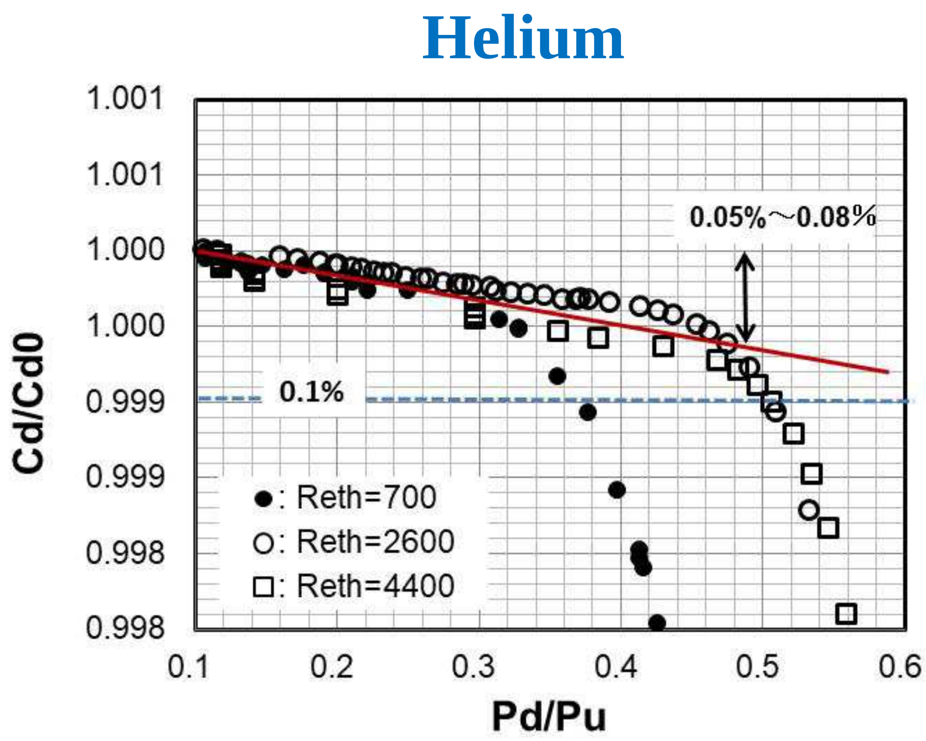
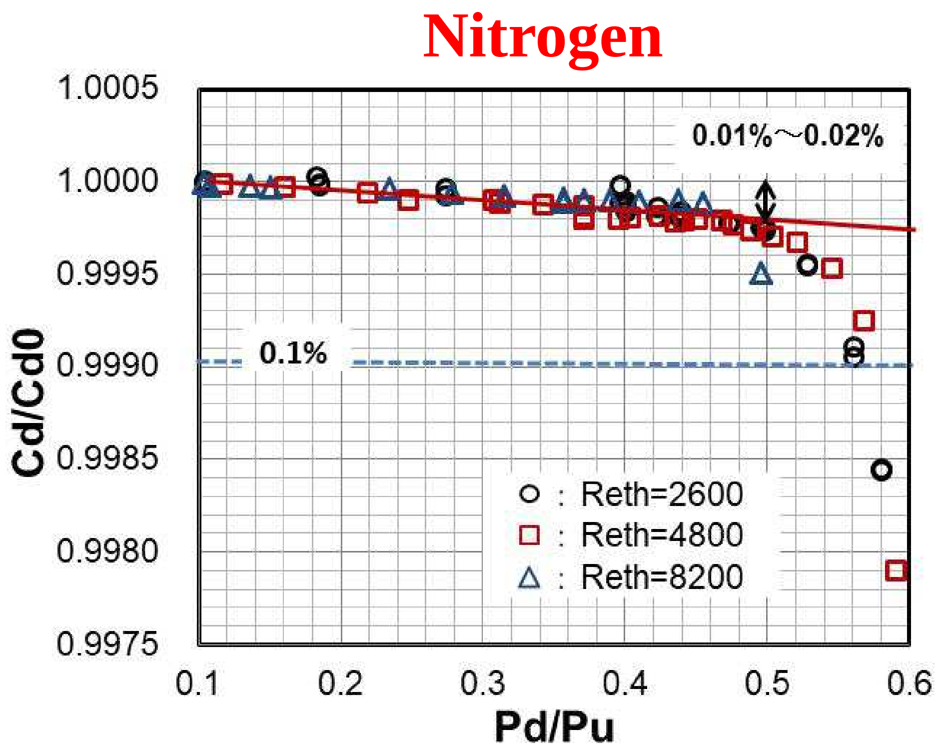
Behaviors of Discharge Coefficient





In both gases, Cd decreases gradually, but certainly.
This decrease of Cd always happens?
The decreasing rate in N2 is acceptable, but in He, is undesirable for flow measurements.
Why the decreasing rate in He is larger?

Experimental Results: Pd/Pu>0.1(2)

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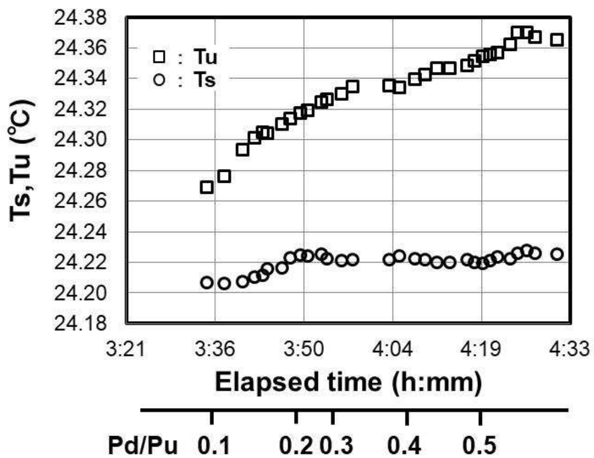
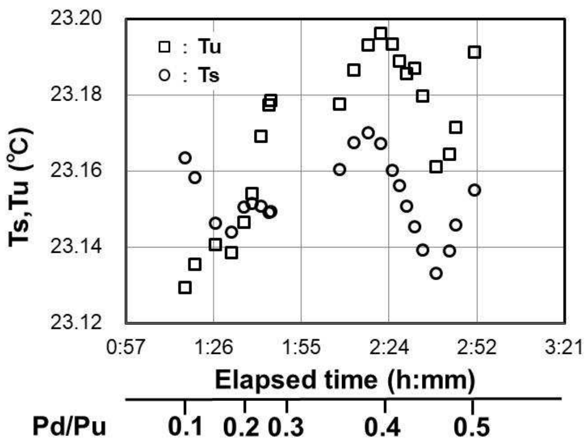
Behaviors of Pressure and Temperature with time

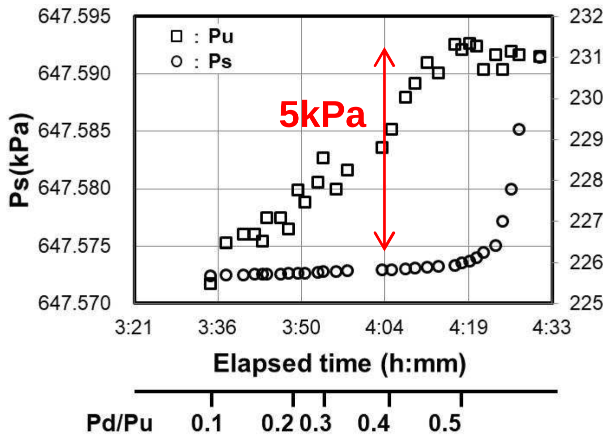
Helium : *Reth*=4400

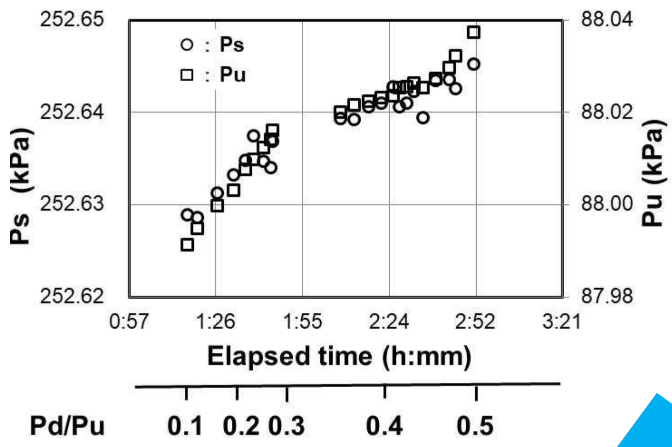


Nitrogen : *Reth*=4800



In both gases,
the changes of *Ts* and *Tu*
are stable within 0.1deg.C.





In N2,
the changes of *Pu* and
Ps are about 15 Pa.
In He,
Pu change is about
5kPa.
This is the cause of large change of *Cd* in He.

Why the large change of Pu is caused in He?

Experimental Results: Pd/Pu>0.1(3)

In Helium,
why Pu increases and Cd decreases larger ?

In an actual flow filed, the upstream side and the downstream side of a critical nozzle is not completely separated by a sonic plain.
The pressure wave travels through the boundary layer from the upstream side to the downstream side or vice versa.
Therefore,

An upstream pressure of a critical nozzle always changes when the back pressure changes.

Normally,

The change of the upstream pressure appears as the change of the mass flow rate.

However,

the mass flow rate is constant,

The upstream pressure change comes out as Cd change.

Conclusion

(1)The strange and interesting behaviors of the discharge coefficient was reported, which is appeared when the critical nozzle is operated under the condition that the mass flow rate is constant.

(2)These behaviors of the discharge coefficient may appear under the limited conditions, a kind of gases like He, H2, moderate Reynolds number.

(3)The situation of the boundary layer around the throat area is affecting, for example , its thickness being thicker, easy to change by change of outside flow conditions , et al.

When a critical nozzle is used, there are two type upstream conditions;

the mass flow rate is constant

or

the upstream pressure is constant.

Their results are not always the same.