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DESIGN ASPECTS OF PVTt PRIMARY STANDARD, UNCERTAINTY AND TRACEABILITY OF 50 BAR CALIBRATION AND TEST FACILITY

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ABSTRACT

Traceability of gas flow measurements are generally established by calibrating flow meters against primary standards ,based on measurements such as length, mass, and time etc. .Calibrations are accomplished by collecting a mass or volume of a flowing fluid over a period of time under steady state conditions of flow, pressure, and temperature. Traditionally, primary flow standards use either gravimetric or volumetric methods. Volume based primary standards calculate the mass of collected gas by multiplying the measured density of the gas by the volume of the collection vessel.

This paper presents the design aspects of 6.25 m^3 pressure, volume, temperature, and time (PVTt) primary flow standard meant for calibrating reference flow meters at pressures up to 50 bar and flow rates up to 1000 m^3/h. Exact volume determination of the vessel will be done using gravimetric method with gas. PVTt standard is designed to measure mass flow with an expanded uncertainty better than 0.1 %. Traceability of flow measurements in 50 bar calibration and test laboratory is explained in the paper.

Keywords: $PVTt$, Gravimetric, Critical Flow Venturi Nozzles, Uncertainty, Traceability

1. INTRODUCTION

Traceability of gas flow measurement are generally established by calibrating flow meters against primary standards ,based on measurements such as length, mass, and time etc. [1] . Calibrations are accomplished by collecting a mass or volume of a flowing fluid over a period of time under steady state conditions of flow, pressure and temperature. Direct measurement of fundamental quantities yields lowest possible uncertainty. Traditionally, primary flow standards use either gravimetric or volumetric methods. Gravimetric standards measure the mass of collected gas by directly weighing the mass of the collection vessel before and after gas accumulation. Volume, a derived quantity from the primary unit of length is conventionally accepted as a primary quantity for gas measurement. Volume based primary standards [2, 3] calculate the mass of collected gas by multiplying the measured density of the gas by the volume of the collection vessel. Volumetric primary standards include variable volume standards such as piston prover, bell prover, and constant volume standards i.e Pressure, Volume, Temperature, time (PVTt) standard.

Table 1 lists the currently available PVTt Systems at the Institute. This paper presents the design aspects of the 6.25 m^3 PVTt primary flow standard meant for calibrating master flow meters at pressures up to 51 bar (a) and flow rates up to 1000 m^3/h. It is designed to measure mass flow with an expanded uncertainty better than 0.1 % at the 95 % confidence interval. This paper also presents a detailed uncertainty analysis evaluating and explaining the various components that contribute the expanded uncertainty.

2. DESIGN METHODOLOGY OF PVTt STANDARD

It is based on the use of critical flow venturi nozzles which operate with sonic velocity at the nozzle throat and give constant mass flow over a range of nozzle downstream pressures, dependent on gas properties and nozzle geometry, combined with Pressure, Volume, Time, Temperature measurements in standard collection vessels.In $PVTt$ method, the mass of air/gas, M occupying a known volume, V of the vessel is computed using the equation of state of gas

$$M = VPM_e/(ZRT) \qquad (1)$$

Where P , Z , T are the absolute pressure, Compressibility and temperature of air/gas in the vessel and M_e is the effective molecular weight and R is the universal gas constant. Mass flow rates are determined from the difference of mass of air/gas in the vessel for two different states for a specific collection period, t. Then,

$$m = (M_2 - M_1)/t \qquad (2)$$

$$= M_e \times V/(Rt)(P_2/(Z_2T_2) - P_1/(Z_1T_1)) \qquad (3)$$

Above equation seems to be simple to work with involving only the measurement of pressure and temperatures for two states. But the uncertainty in using the above method will be approximately twice the uncertainty as algebraic subtraction is involved in the equation. Alternatively, to reduce the measurement uncertainty in the mass flow rate, the initial pressure can be made close to absolute zero i.e. $P_1 \to 0$ then the equation for mass flow rate becomes

$$m = M_eV/(Z_2Rt)P_2/T_2 \qquad (4)$$

The temperature, pressure must be the mean temperature of the air/gas in the vessel. The volume of the vessel must be large enough to allow sufficient collection time for air/gas while calibrating the nozzle at 1000 m^3/h. A volume of 6.25 m^3 will permit a minimum collection time of about 20 s. The vessel is designed for an internal pressure of 5100 kPa(a) .

3. TECHNICAL FEATURES OF PVTt STANDARD

This unique primary calibration facility is established to achieve the following prime objectives:

i) Primary calibration of reference Ultrasonic/Turbine meters having nominal flow capacities in the range 25 - 1000 m^3/h with uncertainties better than ±0.1% using high pressure air/gas .

ii) Primary calibration of critical flow venturi nozzles having nominal flow capacities 25 - 800 m^3/h with uncertainties better than ±0.1% using ambient air/gas.

The following are the salient features of the facility. Table 2 list the design parameters

Method	: $PVTt$ method
Medium	: Compressed Air/gas.
Temperature	:Ambient (uncontrolled)
Pressure of air/gas	: Lowest (Initial)

: 0.9 x upstream
:45 bar (Max)
Volume of vessel : 6.25 m^3
Collection time : 20 s (minimum)
Valve opening / closing time : 100 ms
Flow rate : 25 – 1000 m^3/h
Uncertainty (Target) : Better than ± 0.1%

4. DESCRIPTION OF PVTt STANDARD

The main components of the *PVTt* calibration system include a source of steady flow, a set of appropriately sized Critical flow Venturi Nozzles to cover the flow range, the collection/bye pass vessel, a timing mechanism, a data acquisition system/SCADA/PLC, pressure and temperature instrumentation. The schematic of the *PVTt* system is depicted in Fig. 1.

Pressure Vessels

The 'heart' of the standard is the horizontal volume vessel with two hemi spherical dishends System comprises three types of Vessels i.e the storage, bypass and PVTt Vessels. The vessels have approximate volumes of 35.4, 5.11 and 6.25 m^3. They are designed according to ASME, Sec VIII, Div 2, Boiler and Pressure Vessel code [4]. The design temperature for the vessel is 45 °C. The working fluid is filtered, dry air/gas supplied by a compressor in series with a heatless desiccant drier. The compressor delivers air flow at line pressures up to 7000 kPa at nominal room temperature conditions.

Pressure Control

The gas to the system is supplied via a power dome pressure reducing valve from two numbers of inter connected storage pressure vessels of the system.

Pressure control system comprises of two flanged (as per ANSI B 16.5 Class 600 RF) power dome pressure-reducing valves mounted at the upstream of the system. The valve uses a dome charged with gas at an operating pressure reference. The dome is charged via an internal passageway from the inlet pressure line to the valve. The gas charge in the dome acting upon the diaphragm holds the valve open until the pressure in the outlet line, sensed onto the underside of the diaphragm balances the gas charge above the diaphragm causing the valve to close. The valve assembly has a rubber seat sealing. Inlet pressure for the dome valve is 75 bar maximum and outlet pressure is 6-51 bar. A scheme is illustrated in Fig.2

Critical Flow Venturi Nozzle

Critical Flow Venturi Nozzles are pseudo primary flow measuring devices that operate at the maximum possible flowrate for the existing upstream conditions. The air/gas flow accelerates to the critical velocity at the throat, which is equivalent to the local sound velocity. The geometry of toroidal throat Critical Flow Venturi Nozzles [5] used to validate the facility is shown in Fig.3.

Six numbers of critical flow venturi nozzles cover a range of flow rates from 25 m^3/h to 1000 m^3/h and are installed at upstream of the PVTt system. The nozzle housings have 4,6 and 8" NB Schedule 40 seamless pipes with ANSI B16.5, 300 Class flanges. Each nozzle assembly is provided with perforated plate flow conditioner at upstream. For nozzle, to ensure critical flow, a maximum back pressure ratio of about 0.9 must be maintained across the nozzle. Installation requirements for the nozzle are also indicated in Fig 4. The Nozzle plays following roles.

i. They isolate the steady upstream

flow at upstream of flow meters and Nozzle from downstream pressure fluctuations that occur during actuation of the bypass and vessel inlet valves.

ii. the nozzle throat , in conjunction with the bypass and vessel inlet valves, provides a definite boundary for the inventory volume.

iii. They serve as a check standard to help ensure that the *PVTt* system performs consistently over time.

Fig.5 presents the nozzles capacities

Diverter mechanism

The flow can be switched from the bypass Vessel to the PVTt vessel by actuating two 200 mm butterfly valves (flanged as per ANSI B 16.5 Class 300) simultaneously so that as one opens the other closes. The operation of the PVTt valve also provides signal to start and stop the electronic timer which measures the diversion period. At high flow rates, the diversion time can be quite short and that is important that the diverter mechanism operates as quickly as possible. Fast operation with valve changeover less than 100 ms is to be accomplished by using a rack and pinion drive to the valve shafts which is powered by a double acting pneumatic cylinder with Air/Gas/Nitrogen

Data Acquisition System /SCADA/PLC

Flow measurements using *PVTt* flow standard are semi-automated using SCADA /PLC/ LabVIEW software. This software controls each facet of the calibration process including setting the nominal flow, actuating the valves, filling and evacuating the collection vessel, taking the appropriate pressure and temperature data, measuring the collection time interval, and reducing the data. The post-processed calibration data can be verified by recalculating the data on a spreadsheet. The *PVTt* system is equipped with various safety features that prevent over pressurizing the collection vessel during a calibration.

5. PVTt MASS FLOW RATE EQUATIONS

PVTt systems measure the mass flow using timed-collection techniques based on the principle of conservation of mass i.e the rate of mass accumulation in the control volume equals the net influx of mass through its boundaries. In Fig. 6 we take the control volume to include both the collection vessel and the inventory volume so that the statement of mass conservation is

$$m_a = \frac{dM}{t} = \frac{\Delta M}{t} \tag{5}$$

Total mass comprises the mass in collection vessel and the Inventory

$$M = M_V + M_I \tag{6}$$

Average mass flow rate is given by

$$m_a = (M_2 - M_1)/t \tag{7}$$

$$M_1 = M_{V1} + M_{I1} \tag{8}$$

$$M_2 = M_{V2} + M_{I2} \tag{9}$$

Mass is the product of volume and density and is

$$m_a = (\frac{M_e V_V}{Rt})[\frac{P_{V2}}{Z_{V2}T_{V2}} - \frac{P_{V1}}{Z_{V1}T_{V1}}] + (\frac{M_e V_I}{Rt})[\frac{P_{I2}}{Z_{I2}T_{I2}} - \frac{P_{I1}}{Z_{I1}T_{I1}}]$$

(10)

V : Vessel, I : Inventory.1:Initial,2: Final

6. PVTt OPERATING PROCEDURES

The typical process for measuring mass flow with the PVTt standard entails the following procedure:

i. Close pneumatically operated Butterfly Valves ,POBFVO1 and POBFVO2 of PVTt and By Pass Vessels
ii. Open selected critical flow venturi nozzles using the manual Butterfly Valves
iii. Adjust proportional regulator, and apply required pressure to the Dome loaded regulator
iv. Open the pneumatic positioner controlled ball valve of storage vessels.
v. Evacuate the PVTt Vessel
vi. Open the POBFVO2 of Bypass Vessel as required
vii. Observe the Test meter pressure for steadiness.
viii. Acquire the following initial data at a specified interval.
    i. Pressure of PVTt Vessel
    ii. Temperatures of PVTt Vessel
    iii. Pressure of Ultrasonic meter
    iv. Temperature of ultrasonic meter
    v. Pressure of Nozzle (Upstream)
    vi. Temperature of Nozzle (Upstream)
    vii. Pressure of Nozzle (Downstream)
    viii. Temperature of Nozzle (Downstream)
ix. Divert the gas flow into PVTt Vessel . Open POBFVO1 and close POBFV02 simultaneously and initiate Meter pulse counter, timer simultaneously, Valve opening time and acquisition.
x. If the ratio of nozzle downstream to upstream pressure reaches 0.9, stop acquisition, stop the pulse counter, and acquire the data.
xi. Stop acquisition of process data, close the POBFV01 and acquire valve opening time.
xii. Allow stabilization of the PVTt Vessel.
xiii. On stabilization acquire the following data
    i. Pressure of PVTt Vessel
    ii. Temperature of PVTt Vessel.
xiv. Perform the following calculations:-
    i. Calculate the mean and standard deviation
xv. Repeat the above steps five times at each flow rate.
xvi. Repeat the above steps for different flow rates in the range
xvii. Adjust the proportional regulator to various outlet pressures in the range
xviii. Repeat the above calibrations at each Pressure

Table 3 lists the instrumentation to make the pressure, temperature and time measurements as well as their normal range of values during a calibration.

8 PROPOSED CALIBRATIONS

Vessel Volume and Inventory Volume

Volumes V_V and V_I constitute the base volume. Measurement of pressure and temperature within this volume are used to calculate density. The product of density and volume gives mass. The change in mass with time gives mass flow rate. Volumes V_I in Fig.6 is called a "trapped volume". Mass in trapped volume must be accounted appropriately in the calculations of the actual mass flow rates.The volume V_V and V_I are determined using a gravimetric weighing procedure whereby a measured mass of gas is transferred into unknown volumes. The volume is determined by dividing the mass of gas transferred into by the change in gas density attributed to filling. The source of gas for the volume determination is an array of high pressure gas cylinders. The mass of gas displaced into the collection vessel is determined by subtracting the initial cylinder mass (before filling the vessel) with the mass after the filling process.

Critical Flow Venturi Nozzle

With the vessel valve in closed condition, lowest possible initial pressure is created using a vacuum pump. Subsequently the pump is isolated and pressure inside the vessel is monitored to detect leakage if any and measured after temperature and pressure stabilization inside the vessel. By opening the quick acting butterfly valve, the compressed air/gas is drawn into the vessel through the nozzle and flow meters and simultaneously triggering a timer. When the pressure of air/gas in vessel reaches about 0.9 time upstream pressure, the valve is closed stopping the timer at the same time. Thus the timer measures the duration of valve opening or time of collection of air/gas in the vessel. Sufficient time is allowed for stabilization of vessel conditions. The final pressure and temperature of air/gas in the vessel are recorded after stabilization. The actual mass of air/gas is calculated from the final density of air/gas in the vessel and volume. The entire calibration is repeated a number of times to assess random uncertainty associated with calibration. Actual mass flowrate is given by

$$m_a = (\frac{M_e V_V}{Rt})[\frac{P_{V2}}{Z_{V2}T_{V2}} - \frac{P_{V1}}{Z_{V1}T_{V1}}] + (\frac{M_e V_I}{Rt})[\frac{P_{I2}}{Z_{I2}T_{I2}} - \frac{P_{I1}}{Z_{I1}T_{I1}}] \qquad (11)$$

The theoretical flow rate, m_t assuming the coefficient of discharge, C_d = 1 is calculated from the expression:

$$m_t = \pi \times d^2 / 4 \times C^* \times P_o \times \sqrt{M_e / (R \times T_o)} \qquad (12)$$

where P_0 and T_0 are the pressure and temperature measured at the upstream of the nozzle, d is the throat diameter and C^* is critical flow factor. The coefficient of discharge of the nozzle defined as the ratio of actual mass flow rate to theoretical flow rate is calculated as:

$$C_d = m_a / m_t \qquad (13)$$

and the corresponding Reynolds number based on throat diameter is:

$$\mathrm{Re}_d = 4 \times m_a / (\pi \times d \times \pi) \qquad (14)$$

where μ is the dynamic viscosity of air/gas at calibration temperature. This process is repeated for various inlet pressures.

Calibration of Reference Flow Meters

This facility offers calibrations of gas flow meters in order to provide traceability to flow meter manufacturers, secondary flow calibration laboratories, and flow meter users. Flow meters of sizes upto 150 mm (6") can be calibrated and include ultrasonic and turbine meters.

150 mm Ultrasonic flow meters will be proved in the PVTt system at inlet pressures 6-51 bar (a).at various flow rates up to a maximum of 1000 m^3/h as per the procedures discussed above . Uncertainty targeted is about 0.1 %. Using the three ultrasonic meters in parallel, 300 mm turbine flow meter will be calibrated at 2000 m^3/h in the 50 bar closed loop. Subsequently, the turbine meter will be used to calibrate ultrasonic flow meters at 2000 m^3/h. Both ultrasonic and turbine meters can be used as master flow meters to calibrate the custody transfer meters.

A normal flow calibration consists of 6-10 flow rates spread over the range of the flow meter. At each of these flow set points, three (or more) flow measurements are made with the *PVTt* standard. The sets of three measurements can be used to assess repeatability. Fig.7 shows the proposed traceability of measurements

When a flow meter is calibrated, the uncertainty depend on both the uncertainty of the flow standard as well as the uncertainty of the instrumentation associated with absolute pressure, and temperature.

9. UNCERTAINTY IN PVTt SYSTEM AND NOZZLES

The mass flow determinations of a PVTt flow standard rely on accurate measurements of pressure, volume, temperature, and time . Uncertainty components include pressure, temperature measurement, Vessel Volumes, trapped volumes, density determination, time measurement, and data acquisition systems. The largest uncertainties in mass flow can be attributed to the measurement of volumes, temperature, and pressure. However, timing measurements can also play an important role near the maximum flow capacity of a *PVTt* system when collection times are shortest. For these short collections, the largest contribution from timing uncertainties is typically associated with timing errors introduced by the flow diversion processes. On the other hand, at the lower flow capacity the collection times are longer and timing measurements typically play only a minor role in the mass flow uncertainty budget. .In this section, the uncertainty of the various reference parameters and measured quantities are assessed. Reference Parameters are M , *R* , and *Z* [6,7] and listed in Table 3.

The overall uncertainty in the calibration of critical flow venturi nozzle using $PVTt$ method is estimated by combining the uncertainties of actual mass flow measurement and the theoretical flow rate from the nozzle. The Type B Standard uncertainty in the coefficient of discharge, $u_B(C_d)$ is given as the combination of individual component uncertainties and is

$$u_B(C_d) = \pm\sqrt{A+B} \qquad (15)$$

where,

$$\begin{aligned} A = {} & u_c(Me)^2 + u_c(V_v)^2 + u_c(R)^2 + u_c(t)^2 + \\ & u_c(P_{V2})^2 + u_c(Z_{V2})^2 + u_c(T_{V2})^2 + \\ & u_c(P_{V1})^2 + u_c(Z_{V1})^2 + u_c(T_{V1})^2 + \\ & u_c(V_I)^2 + u_c(P_{I2})^2 + u_c(Z_{I2})^2 + u_c(T_{I2})^2 + \\ & u_c(P_{I1})^2 + u_c(Z_{I1})^2 + u_c(T_{I1})^2 \end{aligned} \qquad (16)$$

$$\begin{aligned} B = {} & u_c(d)^2 + u_c(C^*)^2 + u_c(P_o)^2 + u_c(Me)^2 + \\ & u_c(R)^2 + u_c(T_o)^2 \end{aligned}$$

u_c is the standard uncertainty contribution in the particular variable

Type A uncertainty $u_A(C_d)$ is estimated from the standard deviation of results of repeat calibration runs. The overall uncertainty is obtained from

$$U(C_d) = \pm 2\sqrt{u_A(C_d)^2 + u_B(C_d)^2} \quad \% \quad (17)$$

Table 4 gives the uncertainty estimate for the PVTt Standard with assumed values for the process variables.

10. CONCLUSIONS

A unique primary calibration facility based on $PVTt$ method has been designed and being established indigenously. For nozzles designed as per standard ISO 9300, the estimated coefficient of discharge using correlation is associated with an uncertainty of ± 0.2% for smoothly machined nozzle. Calibration activities and process to be performed in the PVTt facility have been discussed. It will establish the traceability of the reference meters installed in the 50 bar loop. The target uncertainty in the actual flow rate determination is better than ± 0.1%

11. REFERENCES

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Table1. PVTt Standards at the Institute

Sl.No	**PVTt Flow Standard**	**Flow Range, m^3/h**	**Gas Type**	**Pressure Range, kPa (a)**	**Expanded Uncertainty (%)**
1	2 m^3	0.8 to 45	Conditioned Air	100	0.1
2*	6.25 m^3	25 to 1000	Dry Air/gas	500 to 5100	0.1
*Discussed in this paper					

Table 2. PVTt Design Parameters

Design Parameters at 1000 m^3/h			
	Natural Gas	**Air**	
Initial Conditions in Storage Vessels			
Volume	35.40000	35.40000	m^3
Temperature	30.00000	30.00000	^{0}C
Pressure	75.00000	75.00000	bar
Molecular weight/Z	20.00000	29.25727	kg/kmol
Density	59.51176	87.05759	kg/m^3
Mass	2106.71620	3081.83852	kg
Final Conditions in Storage Vessels			
Mass	1765.93700	2583.42296	kg
Density	49.88523	72.97805	kg/m^3
Pressure	62.86811	62.87050	bar
Test Conditions			
Temperature	30.00000	30.00000	^{0}C
Pressure	51.00000	51.00000	bar
Molecular weight/Z	20.00000	29.25727	kg/kmol
Density	40.46799	59.19916	kg/m^3
Volume flowrate	**1000.00000**	**1000.00000**	**m^3/h**
Mass flowrate	40467.99474	59199.15795	kg/h
	11.24111	16.44421	kg/s
PVTt Vessel Initial Conditions			
Vessel Volume	6.25000	6.25000	m^3
Temperature	30.00000	30.00000	^{0}C
Pressure (Vacuum)	0.10000	0.10000	bar
Molecular weight	18.00000	28.96470	kg/kmol
Density	0.07141	0.11492	kg/m^3
Mass	0.44634	0.71823	kg
PVTt Vessel Final Conditions			
Temperature	30.00000	30.00000	^{0}C
Pressure	45.90000	45.90000	bar
Molecular weight/Z	20.00000	29.25727	kg/kmol
Density	36.42120	53.27924	kg/m^3
Mass	227.63247	332.99526	kg
Mass of gas flown	227.18613	332.27704	kg
Time of collection	**20.21029**	**20.20632**	**s**

Table 3. Reference Parameters and Instrumentation

System Components and Parameters	**Quantity**	**Nominal Value/Uncertainty**	**Instrumentation or Reference**
Reference Parameters	Universal Gas Constant, R	8134.472 / 0.01413 J / (kg K)	Reference [7]
	Molecular Mass of dry air/gas, Me	28.9647 g/mol/0.0014772	Reference [6]
	Compressibility Factor (dry-air/gas), Z	Z at P and T	Reference [6]
Collection Vessel	Pressure	up to 5000 kPa /0.016%	Wireless Absolute Pressure Transmitters
	Temperature	20-40°C/0.1°C	Wire Less RTD Transmitters
	Volume, V_V	6.25 m^3/0.05 %	Gravimetric Determination
Inventory Volume	Pressure	up to 5000 kPa /0.016%	Wireless Absolute Pressure Transmitters
	Temperature	20-40°C/0.1°C	Wire Less RTD Transmitters
	Volume, V_I	0.789061 m^3 / 0.05 %	Gravimetric Determination
Time System	Collection Time	20 s to 650 s	Data acquisition card

Table 4 : Uncertainty in Mass

Sl.No	Source of uncertainty	Estimate		Expanded uncertainty		Probability distribution		Standard Uncertainty		Sensitivity coefficient		Uncertainty contribution	Degree of freedom
	x_i	x_i		$U(x_i)$		Type	Divisor	$u(x_i)$		c_i		$u_i(y)=c_i*u(x_i)$	ν
		Value	unit	Value	unit			Value	unit	Value	unit	Value	
1	**Vessel Volume**	**6.25000**	**m^3**	**0.003125**	**m^3**	Type B,Normal	2	0.001563	m/s	52.223060	kg/m^3	0.081599	∞
2	**Inventory Volume**	**0.78906**	**m^3**	**0.000395**	**m^3**	Type B,Normal	2	0.000197		-6.964607	kg/m^3	-0.001374	
3	Pressure,P_{V1}	1000	Pa	1.00	Pa	Type B, Normal	2	0.500	Pa	-7.182E-05	$kg/m^3/Pa$	-3.59113E-05	∞
4	Molecular Mass,Mr	28.9647	kg/kmol	0.0014772	kg/kmol	Type B, Rectangular	1.7321	0.000853	kg/kmol	11.079	$kmole/m^3$	0.009448816	∞
5	Compressibility,Z_{V1}	1	-	0.0001	-	Type B, Rectangular	1.7321	0.000058	-	-0.072	kg/m^3	-4.14667E-06	∞
6	Universal gas constant,R	8314.4	J/kmol/K	0.014134	J/kmol/K	Type B, Rectangular	1.7321	0.008161	J/kmol/K	-0.039	kg/m3/(J/kmol/K)	-0.000314961	∞
7	Temperature,T_{V1}	303.15	K	0.10	K	Type B, Rectangular	2	0.050000	K	0.00024	$kg/m^3/K$	1.1846E-05	∞
8	Pressure,P_{V2}	4500000	Pa	1600.00	Pa	Type B, Normal	2	800.000	Pa	7.255E-05	$kg/m^3/Pa$	0.05803839	∞
9	Compressibility,Z_{V2}	0.99	-	0.000495	-	Type B, Rectangular	1.7321	0.000286	-	-329.764	kg/m^3	-0.0942426	∞
10	Temperature,T_{V2}	303.15	K	0.10	K	Type B, Rectangular	2	0.050000	K	-1.077	$kg/m^3/K$	-0.053845612	∞
11	Pressure,P_{I1}	5100000	Pa	1600.00	Pa	Type B, Normal	2	800.000	Pa	-9.159E-06	$kg/m^3/Pa$	-0.007327333	∞
12	Compressibility,Z_{I1}	0.99	-	0.000495	-	Type B, Rectangular	1.7321	0.000286	-	47.184	kg/m^3	0.01348452	∞
13	Temperature,T_{I1}	303.15	K	0.10	K	Type B, Rectangular	2	0.050000	K	0.154	$kg/m^3/K$	0.007704395	∞
14	Pressure,P_{I2}	4500000	Pa	1600.00	Pa	Type B, Normal	2	800.000	Pa	9.159E-06	$kg/m^3/Pa$	0.007327333	∞
15	Compressibility,Z_{I2}	0.99	-	0.000495	-	Type B, Rectangular	1.7321	0.000286	-	-41.633	kg/m^3	-0.011898106	∞
16	Temperature,T_{I2}	303.15	K	0.10	K	Type B, Rectangular	2	0.050000	K	-0.136	$kg/m^3/K$	-0.006797996	∞
17	**Mass (net)**	**320.89862**	**kg**	**0.29956908**	**0.1**	**%**							

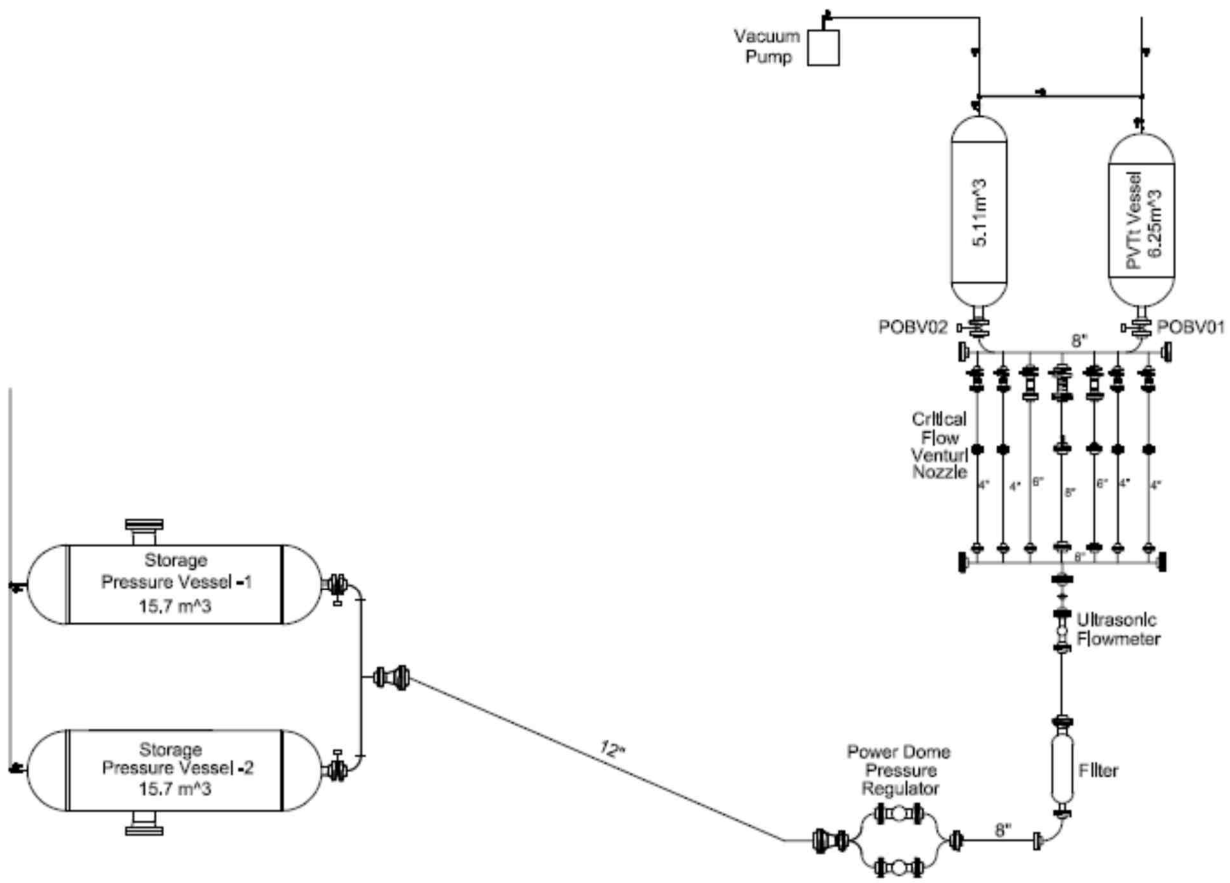

Fig.1 Schematic of PVTt Standard

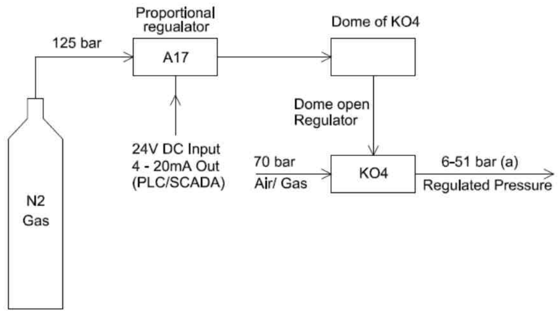

Fig.2 Scheme of Pressure Regulation

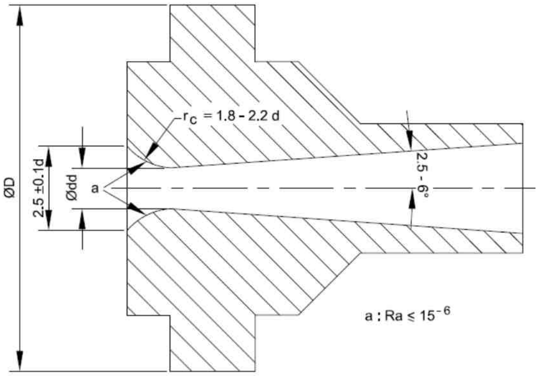

Fig.3. Geometry of Nozzles

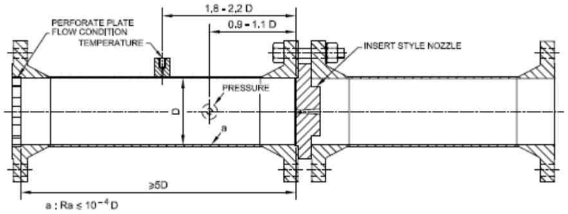

Fig.4 Installation requirements for Nozzles

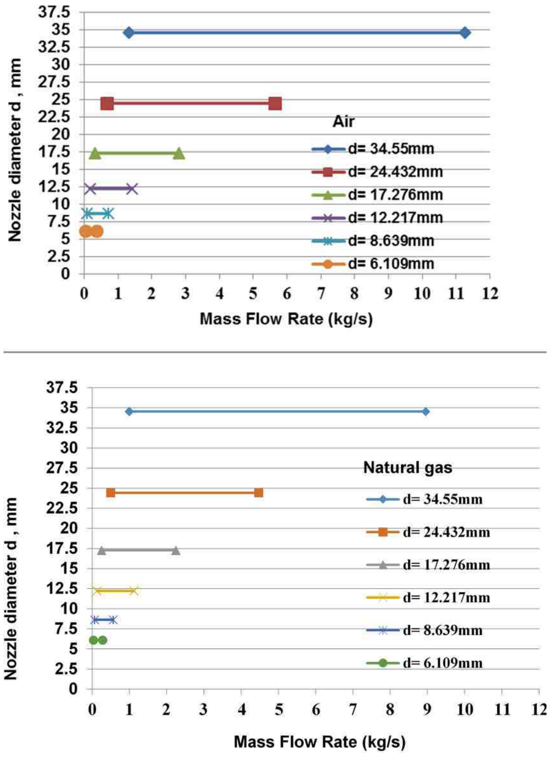

Fig.5 Flow Rate Ranges of PVTt Standard

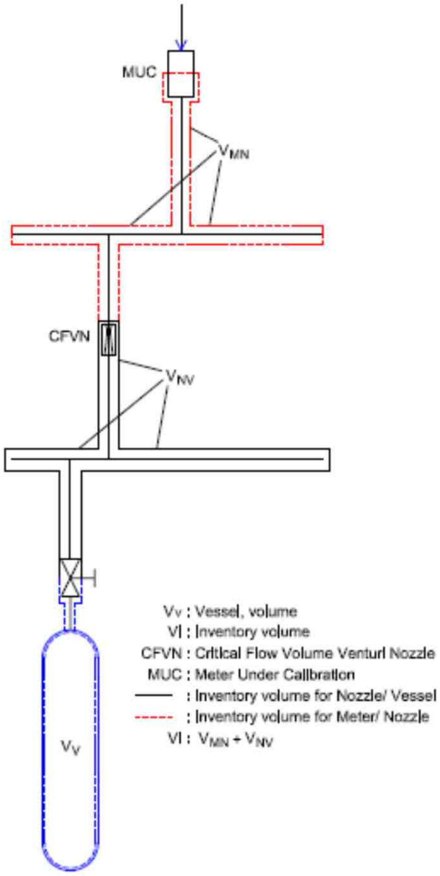

Fig.6 Control Volume

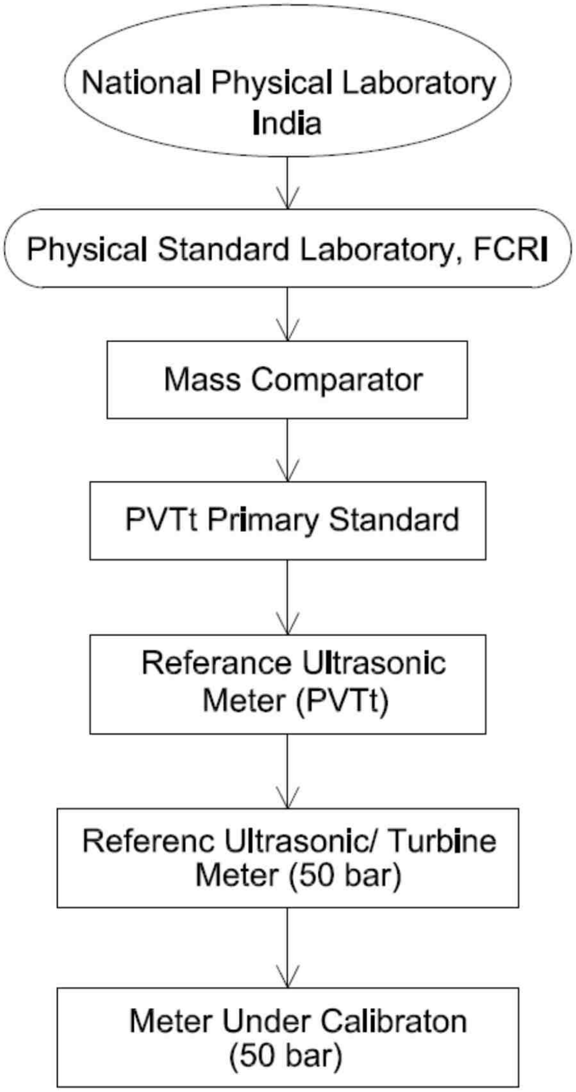

Fig.7a Traceability of Calibration in 50 bar Loop

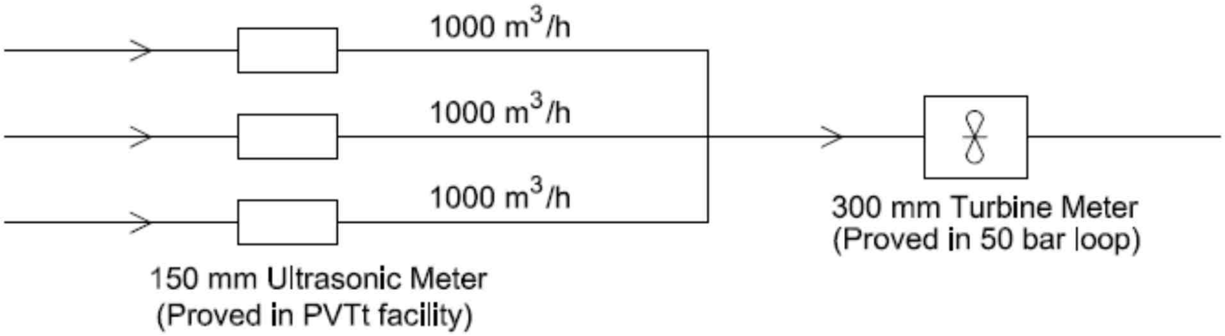

Fig.7b Traceability of Calibration in 50 bar Loop