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**Gas analysis — Preparation of  
calibration gas mixtures using  
dynamic methods —**

**Part 6:  
Critical flow orifices**

**iTeh STANDARD PREVIEW**  
*Analyse des gaz — Préparation des mélanges de gaz pour étalonnage  
à l'aide de méthodes volumétriques dynamiques —  
Partie 6: Orifices de débit critiques*  
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# Contents

	Page
Foreword .....	iv
<b>1 Scope</b> .....	<b>1</b>
<b>2 Normative references</b> .....	<b>1</b>
<b>3 Terms and definitions</b> .....	<b>1</b>
<b>4 Symbols</b> .....	<b>4</b>
<b>5 Principle</b> .....	<b>5</b>
<b>6 Calculation of mass flow rate and volume flow rate</b> .....	<b>6</b>
6.1 General .....	6
6.2 Calculation under ideal conditions .....	7
6.2.1 Calculation of mass flow rate .....	7
6.2.2 Calculation of volume flow rates .....	7
6.3 Calculation of mass flow rate using flow calibration with pure nitrogen .....	8
6.4 Flow rate uncertainty calculation .....	9
6.4.1 General .....	9
6.4.2 Sources of uncertainty .....	9
6.4.3 Uncertainty estimation .....	10
<b>7 Calculation of amount of substance fraction and volume fraction and associated uncertainty evaluation</b> .....	<b>10</b>
7.1 General .....	10
7.2 Amount of substance fraction calculation and associated uncertainty .....	10
7.2.1 Case of gases with purity > 99,99 % .....	10
7.2.2 Case of pre-mixtures .....	13
7.3 Remarks about uncertainty for the amount fraction .....	15
<b>8 Application to the preparation of gas mixtures</b> .....	<b>15</b>
8.1 Example of a mixing system .....	15
8.2 Conditions of operation .....	16
<b>9 Calibration and verification</b> .....	<b>17</b>
9.1 General .....	17
9.2 Calibration of the mixing system in the flow rate .....	17
9.3 Calibration of the mixing system with gas mixtures for a specific gas and concentration .....	17
9.4 Verification of the mixing system .....	17
<b>Annex A (informative) Example of calculation of isentropic coefficient, viscosity and critical flow coefficient</b> .....	<b>19</b>
<b>Annex B (informative) Calculation of mass and volume flow rates under real conditions</b> .....	<b>21</b>
<b>Annex C (informative) Example of flow calculation for toroidal critical flow orifices under ideal and real conditions</b> .....	<b>23</b>
<b>Annex D (informative) Calculation of mass flow rate using flow calibration with pure nitrogen: examples</b> .....	<b>25</b>
<b>Bibliography</b> .....	<b>27</b>

## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

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For an explanation on the voluntary nature of standards, on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html). (standards.iteh.ai)

This document was prepared by Technical Committee ISO/TC 158, *Analysis of gases*.

This third edition cancels and replaces the second edition (ISO 6145-6:2003) which has been technically revised.

A list of all parts in the ISO 6145 series can be found on the ISO website.

# Gas analysis — Preparation of calibration gas mixtures using dynamic methods —

## Part 6: Critical flow orifices

### 1 Scope

This document specifies a method for the dynamic preparation of calibration gas mixtures containing at least two gases (usually one of them is a complementary gas) from pure gases or gas pre-mixtures using critical flow orifices systems.

The method applies principally to the preparation of mixtures of non-reactive gases that do not react with any of the materials forming the gas circuit inside the critical flow orifices system or auxiliary equipment. It has the merit of allowing multi-component mixtures to be prepared as readily as binary mixtures if an appropriate number of critical flow orifices are used.

By selecting appropriate combinations of critical flow orifices, a dilution ratio of  $1 \times 10^4$  is achievable.

Although it is more particularly applicable to the preparation of gas mixtures at atmospheric pressure, the method also offers the possibility of preparing calibration gas mixtures at pressures greater than atmospheric. The upstream pressure will need to be at least two times higher than downstream pressure.

The range of flow rates covered by this document extends from 1 ml/min to 10 l/min.

### 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6143, *Gas analysis — Comparison methods for determining and checking the composition of calibration gas mixtures*

ISO 7504, *Gas analysis — Vocabulary*

ISO 9300, *Measurement of gas flow by means of critical flow Venturi nozzles*

ISO 12963, *Gas analysis — Comparison methods for the determination of the composition of gas mixtures based on one- and two-point calibration*

ISO 16664, *Gas analysis — Handling of calibration gases and gas mixtures — Guidelines*

### 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 9300, ISO 7504 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

**3.1  
critical flow orifice**

orifice for which the geometrical configuration and conditions of use are such that the flow rate at the throat is *critical* (3.12)

**3.2  
wall pressure tap**

orifice pierced in a pipework wall in such a way that the orifice edge on the inside pipework wall is flattened off

Note 1 to entry: This pressure tap is set up so that the pressure in the orifice equals the static pressure at this point of the circuit pipework.

**3.3  
static pressure**

actual pressure of a gas stream, which can be measured by connecting a pressure gauge to a wall pressure tap

Note 1 to entry: This document uses only absolute pressure values.

**3.4  
stagnation pressure**

pressure that would be found in a gas if the flowing gas stream was isentropically slowed down to zero velocity

Note 1 to entry: This document uses only absolute pressure values.

**3.5  
stagnation temperature**

temperature that would be found in a gas if the flowing gas stream was isentropically slowed down to zero velocity

Note 1 to entry: This document only uses absolute temperature values.

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**3.6  
mass flow rate**

$q_m$   
mass of gas per unit of time passing through the orifice

**3.7  
molar flow rate**

$q_n$   
amount of substance of gas per unit of time passing through the orifice

**3.8  
volume flow rate**

$q_V$   
volume of gas per unit of time passing through the orifice

**3.9  
throat Reynolds number**

$Re$   
dimensionless parameter calculated from the gas flow rate and dynamic viscosity under critical flow orifice inlet stagnation conditions

Note 1 to entry: The characteristic dimension is taken as the throat diameter at stagnation conditions. The throat Reynolds number is given by the formula:

$$Re = \frac{4(q_m)}{\pi \eta_0 d_N}$$

**3.10****isentropic coefficient** $\gamma$ 

ratio of the relative variation in pressure to the corresponding relative variation in density under elementary reversible adiabatic (isentropic) transformation conditions

Note 1 to entry: In real gases, the forces exerted between molecules as well as the volume occupied by the molecules have a significant effect on the gas behaviour. In an ideal gas, intermolecular forces and the volume occupied by the molecules can be considered as negligible.

**3.11****discharge coefficient** $c$ 

dimensionless ratio of the actual flow rate to the ideal flow rate of a non-viscous gas that would be obtained with one-dimensional isentropic flow for the same upstream stagnation conditions

Note 1 to entry: This coefficient corrects for viscous and flow field curvature effects. For each type of critical flow orifice design and installation conditions specified in this document, this coefficient is solely a function of the throat Reynolds number.

**3.12****critical flow rate**

maximum flow rate through a given orifice under the given upstream conditions

Note 1 to entry: At critical flow, the throat velocity is equal to the local value of the speed of sound (acoustic velocity), the velocity at which small pressure disturbances propagate.

**3.13****critical flow function** $C^*$ 

dimensionless function which characterizes the thermodynamic flow properties of an isentropic one-dimensional flow between the inlet and the throat of a orifice

Note 1 to entry: It is a function of the nature of the gas and of the *stagnation pressure* (3.4) and *stagnation temperature* (3.5).

**3.14****critical flow coefficient of a real gas** $C_R$ 

alternative form of the critical flow function, more convenient for gas mixtures

Note 1 to entry: This coefficient can be deduced from critical flow function via the formula:

$$C_R = C^* \sqrt{z_0}$$

**3.15****critical pressure ratio** $r^*$ 

ratio of the static pressure at the critical flow orifice throat to the stagnation pressure for which the gas mass flow rate through the critical flow orifice is maximal

Note 1 to entry: This ratio is calculated according to the formula given in [Clause 5](#).

$$r^* = \left( \frac{p_{\text{out}}}{p_{\text{in}}} \right)_{\text{crit}} = \left( \frac{2}{\gamma + 1} \right)^{\frac{\gamma}{\gamma - 1}}$$

**3.16 compressibility factor**

$Z_0$   
correction factor numerically expressing the fact that the behaviour of a real gas deviates from the ideal gas law at stagnation pressure and temperature

Note 1 to entry: It is defined by the following formula:

$$Z_0 = \frac{p_0 M}{\rho_0 R T_0}$$

where  $R$ , the universal gas constant, equals 8,314 4621 J/(mol·K)

**4 Symbols**

Symbol	Definition	SI unit
$A$	critical flow orifice throat area	m <sup>2</sup>
$a, b$	coefficients of the discharge coefficient equation	—
$C$	discharge coefficient calculated for the critical flow orifice	—
$C^*_i$	critical flow function for the gas under ideal conditions dependent on $p$ and $T$	—
$C_i$	sensitivity coefficient	—
$C_R$	critical flow coefficient for the gas under real conditions dependent on $p$ and $T$	—
$C_p$	molar specific heat capacity of the gas at constant pressure	J/(mol·K)
$C_V$	molar specific heat capacity of the gas at constant volume	J/(mol·K)
$d_N$	critical flow orifice throat diameter	m
$d_t$	conduit diameter upstream of the critical flow orifice	m
$M$	molar mass of the gas	kg/mol
$n$	coefficient $n$ of the critical flow orifice discharge coefficient equation	—
$p_{\text{in}}$	absolute static pressure measured upstream of the critical flow orifice	Pa
$p_n$	absolute pressure under normal conditions (101,325 kPa)	Pa
$p_{\text{out}}$	absolute static pressure measured downstream of the critical flow orifice	
$p_0$	absolute stagnation pressure dependent on $p_{\text{in}}$ , $T_{\text{in}}$ and $q_m$	
$q_m$	mass flow rate	kg/s
$q_n$	molar flow rate	mol/s
$q_V$	volume flow rate	m <sup>3</sup> /s
$r^*$	critical pressure ratio	—
$R$	universal gas constant	J/(mol.K)
$Re$	critical flow orifices throat Reynolds number	—
$T_{\text{in}}$	temperature measured upstream of the critical flow orifice	K
$T_n$	temperature under normal conditions (273,15 K)	K
$T_0$	absolute stagnation temperature dependent on $P_{\text{in}}$ , $T_{\text{in}}$ and $q_m$	K
$v_g$	speed of gas through the critical flow orifices	m/s
$v_s$	velocity of sound at the throat	m/s
$Z_n$	compressibility factor under normal conditions ( $T_n$ , $P_n$ )	—

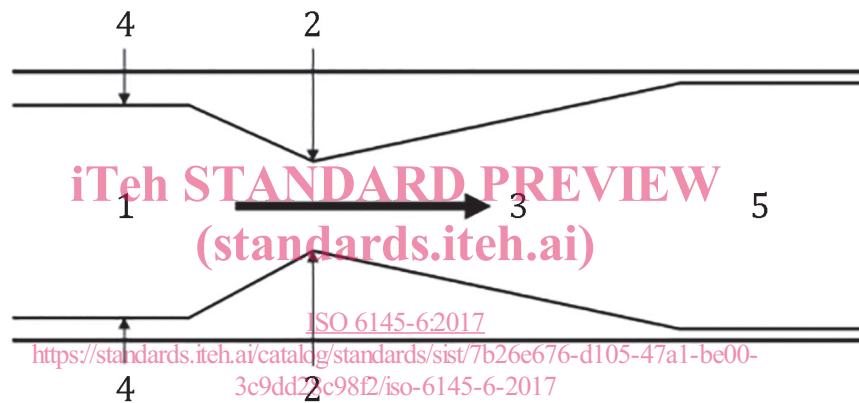


Symbol	Definition	SI unit
$Z_0$	compressibility factor at $P_0, T_0$	—
$\gamma$	isentropic coefficient dependent on $P$ and $T$	—
$\eta_0$	dynamic viscosity calculated for the gas at $P_0$ and $T_0$	Pa.s
$\rho_{in}$	gas density upstream of the critical flow orifice	kg/m <sup>3</sup>
$\rho_n$	gas density at the critical flow orifices throat	kg/m <sup>3</sup>
$\rho_0$	gas density at stagnation condition	kg/m <sup>3</sup>

## 5 Principle

When passed through a critical orifice at increasing upstream pressure  $p_{in}$ , the volume flow rate of gas passing through the orifice will increase. When the ratio of the gas pressure downstream  $p_{out}$  and the gas pressure upstream  $p_{in}$  of the orifice has reached the critical value, the volume flow rate of the gas becomes independent with respect to  $p_{out}$  and is proportional to  $p_{in}$ .

An example of a critical flow orifice is illustrated in [Figure 1](#).



### Key

- 1 inlet
- 2 critical flow orifice throat diameter ( $d_N$ )
- 3 direction of flow
- 4 conduit diameter upstream of the critical flow orifice ( $d_t$ )
- 5 outlet

NOTE 1 The temperature  $T_{in}$  and the pressure  $p_{in}$  are measured in point 4 and the pressure  $p_{out}$  in point 5.

NOTE 2 The temperature  $T_0$  and the pressure  $p_0$  are calculated in point 2 (see 5.2).

**Figure 1 — Example of a critical flow orifice**

For a given gas at constant temperature, the critical pressure ratio, ( $r^*$ ), is:

$$r^* = \left( \frac{p_{out}}{p_{in}} \right)_{crit} = \left( \frac{2}{\gamma + 1} \right)^{\frac{\gamma}{\gamma - 1}} \quad (1)$$

Different methods for calculating the isentropic coefficient  $\gamma$  are described in [A.1](#).

For monatomic, diatomic and triatomic gases, this critical pressure ratio will be around 0,5, but it is dependent on pressure and temperature conditions as shown in [Table 1](#).

**Table 1 — Influence of the pressure and type of gas on the critical pressure ratio**

Gas	Temperature $T_{in}$ °C	Pressure $p_{in}$ bar	Pressure $p_{out}$ bar	$\gamma = C_p/C_V$	Critical pressure ratio $r^*$
Argon	20,0	2,1	1,0	1,669 7	0,49
	20,0	10,3	5,0	1,681 7	0,49
	20,0	20,7	10	1,696 9	0,49
Nitrogen	20,0	1,9	1,0	1,401 4	0,53
	20,0	9,5	5,0	1,408 6	0,53
	20,0	19,0	10	1,417 7	0,53
Carbon dioxide	20,0	1,8	1,0	1,296 7	0,55
	20,0	9,2	5,0	1,322 2	0,54
	20,0	18,7	10	1,358 9	0,54

NOTE The  $\gamma$  values were calculated for  $p = p_{out}$  using the data from the NIST REFPROP V 9.0 database.

To prepare calibration gas mixtures, the gas blender mixes the complementary gas flowing at a known rate out of one or several critical flow orifice(s) and the gas to be diluted flowing out of one or several critical flow orifice(s). The resulting mixture is generally homogenized in a mixing chamber.

This method is not absolute, as each critical flow orifice system should be calibrated for each gas used, to obtain optimal accuracy with minimal uncertainty (traceable flow calibration or analytical comparison). This is because the formula for the volume flow rate of a gas includes its molar mass. If a different calibration gas is used, a correction factor shall be applied and allowance shall be only made for its associated uncertainty.

The temperatures of all critical flow orifices shall be the same in order to avoid any effects on the flow rates.

To obtain a flow rate below 10 l/min, the throat diameter should be less than 0,2 mm.

## 6 Calculation of mass flow rate and volume flow rate

### 6.1 General

Mass and volume flow rates in critical flow orifices are directly proportional to stagnation pressure upstream of critical flow orifices and inversely proportional to the square root of absolute stagnation temperature.

The flow rates through a critical flow orifice running at sonic conditions (below critical pressure ratio) can be calculated under ideal and real conditions using ISO 9300. The flow rate in real conditions is given in [Annex B](#) and examples of the calculation of the flow rates under ideal and real conditions in [Annex C](#).

To calculate mass flow rate under real conditions, additional parameters shall be taken into account (viscosity, surface roughness, flow field curvature, installation conditions). Due to the complexity for calculating the flow rate in real conditions, this document presents the flow rate calculation in ideal conditions only.

The calculation using ideal and real conditions can result in flow rates which could be different. This could influence the accuracy of the generated gas mixtures. By calibrating the device with each used gas, this effect will become negligible.

The conversion of mass flow rate to volume flow rate is presented in [6.2.2](#).

## 6.2 Calculation under ideal conditions

### 6.2.1 Calculation of mass flow rate

The mass flow rate of a gas through a critical flow orifice under ideal conditions is given by [Formula \(2\)](#):

$$q_m = \frac{AC_{*i}p_0}{\sqrt{\frac{T_0R}{M}}} \quad (2)$$

where

$q_m$  is the mass flow rate;

$A$  is the critical orifice throat area;

$C_{*i}$  is the critical flow function for the gas, calculated as follows:

$$C_{*i} = \sqrt{\gamma \left( \frac{2}{\gamma + 1} \right)^{\frac{\gamma+1}{\gamma-1}}} \quad (3)$$

$R$  is the universal gas constant;

$M$  is the molar mass of the gas.

NOTE 1 The critical flow orifice throat area is dependent on the critical flow orifice thermal expansion coefficient. It is consequently advisable to use the critical flow orifice within the manufacturer's stated temperature range.

NOTE 2 At under a millimetre, getting a dimensional measurement of the throat diameter becomes particularly difficult. This makes it difficult to obtain an accurate throat area figure.

$\gamma$  is the isentropic coefficient which can be calculated using different methods described in [Annex A](#):

$p_0$  is the absolute stagnation pressure, in these conditions:

$$p_0 = p_{in} \quad (4)$$

$T_0$  is the absolute stagnation temperature, in these conditions:

$$T_0 = T_{in} \quad (5)$$

### 6.2.2 Calculation of volume flow rates

Dividing mass flow rate by density  $\rho_n = \frac{p_n \times M}{R \times T_n}$  gives the volume flow rate:

$$q_V = \frac{q_m}{\rho_n} = A \times C_{*i} \times \frac{p_0 \times T_n}{p_n} \times \sqrt{\frac{R}{M \times T_0}} \quad (6)$$

### 6.3 Calculation of mass flow rate using flow calibration with pure nitrogen

For practical use, the flow calibration of the device is usually done with pure nitrogen. For the use of the devices with another gas G, it is necessary to calculate a ratio *K* between the other gas G and nitrogen N<sub>2</sub>. These calculations are accurate if the temperature of all critical flow orifices is homogeneous. In this case, calibration could be performed at any temperature. For simplification, the following formula is used under ideal conditions:

$$K = \frac{(q_m)_G}{(q_m)_{N_2}} \tag{7}$$

where

$(q_m)_G$  is the mass flow of gas G;

$(q_m)_{N_2}$  is the mass flow of nitrogen.

$$(q_m)_{N_2} = \frac{A \times C^*_{in2} \times p_{in}(N_2)}{\sqrt{\frac{T_{in}(N_2) \times R}{M_{N_2}}}} \tag{8}$$

$$(q_m)_G = \frac{A \times C^*_{iG} \times p_{in}(G)}{\sqrt{\frac{T_{in}(G) \times R}{M_G}}} \tag{9}$$

Assuming that  $T_0$  and  $p_0$  are the same for both gases and  $A$  and  $R$  are constant, [Formula \(7\)](#) becomes:

$$K = \frac{C^*_{iG} \times \sqrt{M_G}}{C^*_{iN_2} \times \sqrt{M_{N_2}}} \tag{10}$$

The calculation of  $C^*_{iG}$  and  $C^*_{iN_2}$  is done using the following formulae:

$$C^*_{iG} = \sqrt{\gamma_G \times \left(\frac{2}{\gamma_G + 1}\right)^{\frac{\gamma_G + 1}{\gamma_G - 1}}} \tag{11}$$