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Measurement of gas flow by means of critical flow Venturi nozzles

Measurement of gas flow by means of critical flow Venturi nozzles (ISO 9300:1990)

Durchflußmessung von Gasen mit Venturidüsen bei kritischer Strömung (ISO 9300:1990)

Mesure de débit de gaz au moyen de Venturi-tuyeres en régime critique (ISO 9300:1990)

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CEN

European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Central Secretariat: rue de Stassart,36 B-1050 Brussels

Foreword

This European Standard has been taken over by CEN from the work of ISO/TC 30 "Measurement of fluid flow in closed conduits" of the International Organization for Standardization (ISO).

This European Standard shall be given the status of a National Standard, either by publication of an identical text or by endorsement, at the latest by September 1995, and conflicting national standards shall be withdrawn at the latest by September 1995.

According to CEN/CENELEC Internal Regulations, the following countries are bound to implement this European Standard: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom.

Endorsement notice

The text of the International Standard ISO 9300:1990 has been approved by CEN as a European Standard without any modification.

INTERNATIONAL STANDARD

ISO 9300

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Measurement of gas flow by means of critical flow Venturi nozzles

Mesure de débit de gaz au moyen de Venturi-tuyères en régime critique

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Contents

Page

Annexes

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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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 9300 was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits.*

Annexes A, B and C form an integral part of this International Standard. Annexes D and E are for information only.

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INTERNATIONAL STANDARD ISO 9300 : 1990 (E)

Measurement of gas flow by means of critical flow Venturi nozzles

1 Scope

This International Standard specifies the geometry and method of use (installation in a system and operating conditions) of critical flow Venturi nozzles used to determine the mass flow-rate of a gas flowing through a system. It also gives the information necessary for calculating the flow-rate and its associated uncertainty.

It applies to Venturi nozzles in which the gas flow accelerates to the critical velocity at the throat (this being equal to the local sonic velocity). At the critical velocity, the mass flow-rate of the gas flowing through the Venturi nozzle is the maximum possible for the existing upstream conditions.

This International Standard is applicable only where there is steady flow of single-phase gases. The critical flow Venturi nozzles dealt with can only be used within specified limits, e.g. limits for the nozzle throat to inlet diameter ratio and throat Reynolds number. It deals with Venturi nozzles for which direct calibration experiments have been made in sufficient number and quantity to enable inherent systems of application to be based on their results and to enable coefficients to be given with certain predictable limits of uncertainty.

The Venturi nozzles specified in this International Standard are called "primary devices". The other instruments necessary for the measurement of the flow-rate are known as "secondary devices". This International Standard principally covers primary devices; secondary devices are discussed only occasionally.

Information is given in this International Standard for cases where

a) the pipeline upstream of the Venturi nozzle is of circular cross-section, or

b) it can be assumed that there is a large space upstream of the Venturi nozzle.

2 Definitions and symbols

2.1 Definitions

For the purposes of this International Standard, the following definitions apply.

2.1.1 Pressure measurement

2.1.1.1 wall pressure tapping: Hole drilled in the wall of a conduit in such a way that the edge of the hole is flush with the internal surface of the conduit. The tapping is achieved such that the pressure within the hole is the static pressure at that point in the conduit.

2.1.1.2 static pressure of a gas: Actual pressure of the flowing gas which can be measured by connecting a pressure gauge to a wall pressure tapping.

NOTE — Only the value of the absolute static pressure is used in this International Standard.

2.1.1.3 stagnation pressure of a gas: Pressure which would exist in the gas in a flowing gas stream if the stream were brought to rest by an isentropic process.

NOTE — Only the value of the absolute stagnation pressure is used in this International Standard.

2.1.2 Temperature measurement

2.1.2.1 static temperature of a gas: Actual temperature of the flowing gas.

NOTE — Only the value of the absolute static temperature is used in this International Standard.

2.1.2.2 stagnation temperature of a gas: Temperature which would exist in the gas in a flowing gas stream if the stream were brought to rest by an isentropic process.

NOTE — Only the value of the absolute stagnation temperature is used in this International Standard.

2.1.3 Critical flow nozzles

2.1.3.1 Venturi nozzle: Convergent/divergent restriction inserted in a system, intended for the measurement of flow-rate.

2.1.3.2 throat: Section of minimum diameter of a Venturi nozzle.

2.1.3.3 critical Venturi nozzle: Venturi nozzle for which the nozzle geometrical configuration and conditions of use are such that the flow-rate is critical.

2.1.4 Flow

2.1.4.1 mass flow-rate, q_m: Mass of gas per unit time passing through the Venturi nozzle.

NOTE — In this International Standard, the term flow-rate always refers to mass flow-rate.

2.1.4.2 throat Reynolds number, Re_d: Dimensionless parameter calculated from the gas velocity, the gas density at the nozzle throat and the gas dynamic viscosity at nozzle inlet stagnation conditions. The characteristic dimension is taken as the throat diameter at working conditions. The throat Reynolds number is given by the formula

$$Re_d = \frac{4q_m}{\pi d \mu_0}$$

2.1.4.3 isentropic exponent, κ: Ratio of the relative variation in pressure to the corresponding relative variation in density under elementary reversible adiabatic (isentropic) transformation conditions:

$$\kappa = \frac{\varrho}{p}\left(\frac{\partial p}{\partial \varrho}\right)_{\mathrm{S}} = \frac{\varrho c^2}{p}$$

where

p is the absolute static pressure of the gas;

ϱ is the density of the gas;

c is the local speed of sound;

the subscript S means "at constant entropy".

For an ideal gas[1], κ is equal to the ratio of specific heat capacities γ and is equal to 5/3 for monatomic gases, 7/5 for diatomic gases, 9/7 for triatomic gases, etc.

2.1.4.4 discharge coefficient, C: Dimensionless ratio of the actual flow-rate to the ideal flow-rate that would be obtained with one-dimensional isentropic flow for the same upstream stagnation conditions. This coefficient corrects for viscous and flow field curvature effects. For the nozzle design and installation conditions specified in this International Standard, it is a function of the throat Reynolds number only.

2.1.4.5 critical flow: Maximum flow-rate for a particular Venturi nozzle which can exist for the given upstream conditions. When critical flow exists the throat velocity is equal to the local value of the speed of sound (acoustic velocity), the velocity at which small pressure disturbances propagate.

2.1.4.6 critical flow function, C_*: Dimensionless function which characterizes the thermodynamic flow properties of an isentropic and one-dimensional flow between the inlet and the throat of a Venturi nozzle. It is a function of the nature of the gas and of stagnation conditions (see 3.2).

2.1.4.7 real gas critical flow coefficient, C_{R}: Alternative form of the critical flow function, more convenient for gas mixtures. It is related to the critical flow function as follows:

$$C_{\mathrm{R}} = C_* Z^{1/2}$$

2.1.4.8 critical pressure ratio, r_*: Ratio of the absolute static pressure of the gas at the nozzle throat to the absolute stagnation pressure for which the gas mass flow-rate through the nozzle is a maximum.

2.1.4.9 back-pressure ratio: Ratio of the absolute nozzle exit static pressure to the absolute nozzle upstream stagnation pressure at which the flow becomes critical.

2.1.4.10 Mach number, Ma_1 (at nozzle upstream static conditions): Ratio of the mean axial fluid velocity to the velocity of sound at the inlet of the Venturi nozzle.

2.1.4.11 compressibility factor, Z: Correction factor expressing numerically the deviation from the ideal gas law of the behaviour of a real gas at given pressure and temperature conditions. It is defined by the formula

$$Z = \frac{pM}{\varrho RT}$$

where R, the molar gas constant, equals 8,314 3 J/(mol·K).

2.1.5 uncertainty: Estimate characterizing the range of values within which the true value of a measurand lies, at 95 % probability.

In some cases, the confidence level which can be attached to this range of values will be greater than 95 %, but this will be so only where the value of a quantity used in the calculation of flow-rate is known with a confidence level in excess of 95 %; in such a case, reference should be made to ISO 5168.

2.2 Symbols

The symbols used in this International Standard are specified in table 1.

3 Basic equations

3.1 State equation

The behaviour of a real gas can be described by the formula

$$p/\varrho = (R/M)\ TZ$$

3.2 Flow-rate under ideal conditions

For ideal critical flow-rates to exist, three main conditions are necessary:

a) the flow is one-dimensional;

b) the flow is isentropic;

c) the gas is perfect (i.e. $Z = 1$ and $\kappa = \gamma$).

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[1] 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 neglected.

Table 1 — Symbols

Symbol	Quantity	Dimensions[1]	SI unit
A_2	Cross-sectional area of Venturi nozzle exit	L^2	m^2
A_*	Cross-sectional area of Venturi nozzle throat	L^2	m^2
C	Discharge coefficient	dimensionless	
C_R	Real gas critical flow coefficient (for one-dimensional flow of a real gas)	dimensionless	
C_*	Critical flow function (for one-dimensional flow of a real gas)	dimensionless	
C_{*i}	Critical flow function (for one-dimensional isentropic flow of a perfect gas)	dimensionless	
D	Diameter of upstream conduit	L	m
d	Diameter of Venturi nozzle throat	L	m
E	Relative uncertainty	dimensionless	
e	Absolute uncertainty	[2]	
M	Molar mass	M	$kg\ kmol^{-1}$
Ma_1	Mach number at nozzle inlet static conditions	dimensionless	
p_1	Absolute static pressure of the gas at nozzle inlet	$ML^{-1}\ T^{-2}$	Pa
p_2	Absolute static pressure of the gas at nozzle exit	$ML^{-1}\ T^{-2}$	Pa
p_0	Absolute stagnation pressure of the gas at nozzle inlet	$ML^{-1}\ T^{-2}$	Pa
p_*	Absolute static pressure of the gas at nozzle throat	$ML^{-1}\ T^{-2}$	Pa
p_{*i}	Absolute static pressure of the gas at nozzle throat for one-dimensional isentropic flow of a perfect gas	$ML^{-1}\ T^{-2}$	Pa
$(p_2/p_0)_i$	Ratio of nozzle exit static pressure to nozzle inlet stagnation pressure for one-dimensional isentropic flow of a perfect gas	dimensionless	
q_m	Mass flow-rate	MT^{-1}	$kg \cdot s^{-1}$
q_{mi}	Mass flow-rate for one-dimensional isentropic flow of an inviscid gas	MT^{-1}	$kg \cdot s^{-1}$
R	Universal gas constant	$ML^2\ T^{-2}\ \Theta^{-1}$	$J \cdot kmol^{-1}\ K^{-1}$
Re_d	Nozzle throat Reynolds number	dimensionless	
r_c	Radius of curvature of nozzle inlet	L	m
r_*	Critical pressure ratio p_*/p_0	dimensionless	
T_0	Absolute stagnation temperature of the gas at nozzle inlet	Θ	K
T_1	Absolute static temperature of the gas at nozzle inlet	Θ	K
T_*	Absolute static temperature of the gas at nozzle throat	Θ	K
v_*	Throat sonic flow velocity; critical flow velocity at the throat	LT^{-1}	$m \cdot s^{-1}$
Z	Compressibility factor	dimensionless	
β	Diameter ratio d/D	dimensionless	
γ	Ratio of the specific heat capacity at constant pressure c_p to the specific heat capacity at constant volume c_V	dimensionless	
κ	Isentropic exponent	dimensionless	
μ_0	Dynamic viscosity of the gas at stagnation conditions at nozzle inlet	$ML^{-1}\ T^{-1}$	$Pa \cdot s$
μ_*	Dynamic viscosity of the gas at nozzle throat	$ML^{-1}\ T^{-1}$	$Pa \cdot s$
ϱ_0	Gas density at stagnation conditions at nozzle inlet	ML^{-3}	$kg \cdot m^{-3}$
ϱ_*	Gas density at nozzle throat	ML^{-3}	$kg \cdot m^{-3}$

1) M = mass; L = length; T = time; Θ = temperature.

2) The dimension of this parameter is the dimension of the quantity to which it relates.