INTERNATIONAL STANDARD

ISO 1217

Fourth edition
2009-07-01

AMENDMENT 1
2016-04-15

Displacement compressors — Acceptance tests

AMENDMENT 1: Calculation of isentropic efficiency and relationship with specific energy

Compresseurs volumétriques — Essais de réception

AMENDEMENT 1: Calcul du rendement isentropique et relation avec l'énergie spécifique

Reference number
ISO 1217:2009/Amd.1:2016(E)

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Amendment 1 to ISO 1217:2009 was prepared by Technical Committee ISO/TC 118, *Compressors and pneumatic tools, machines and equipment*, Subcommittee SC 6, *Air compressors and compressed air systems*.

Displacement compressors — Acceptance tests

AMENDMENT 1: Calculation of isentropic efficiency and relationship with specific energy

Page 6, 3.5.1

Replace the term and definition with the following:

isentropic power

power that is theoretically required to compress an ideal gas under constant entropy, from given inlet conditions to a given discharge pressure

Note 1 to entry The term “ideal gas” is used to indicate any gas in a condition or state so that it follows closely the ideal gas law.

Page 6, 3.6.1

Replace the term and definition with the following:

isentropic efficiency

ratio of the required isentropic power to measured power for the same specified boundaries with the same gas and the same inlet conditions and outlet pressure

$$\eta_{\text{isen}} = \frac{P_{\text{isen}}}{P_{\text{real}}}$$

Note 1 to entry Examples of specified boundaries may be shaft power of bare compressor or motor power of the package including inlet and discharge losses or total input power of the package.

Note 2 to entry In many turbo compressor textbooks, the adiabatic stage gas power $P_i = \Delta h \cdot q_m = \left(h_2 - h_1\right) \cdot q_m$ is taken as P_{real}. Isentropic efficiency is then defined as $\eta_{\text{isen}} = \frac{P_{\text{isen}}}{\Delta h \cdot q_m} = \frac{\Delta h_{\text{isen}}}{\Delta h}$. In this special case, the most narrow boundaries are used which are enclosing only the gas volume. In this sense, it corresponds with the formula for isentropic efficiency given in ISO 5389:2005, Formula (E.101).

Page 64, Annex G

Add a new Annex H as follows.

Annex H
(informative)

Isentropic efficiency and its relation to specific energy requirement

H.1 General

This annex provides general derivation of isentropic power and calculations for the relationship between isentropic efficiency as defined in this annex and specific energy requirement in accordance with this International Standard.

No additional data or measurements are required for the calculation of isentropic power and isentropic efficiency.

This annex also provides calculations for the relative tolerances between specific power and isentropic efficiency.

H.2 Symbols and subscripts

Table H.1 — Symbols

Symbol	Term	SI unit	Other practical units
c_p	specific heat at constant pressure	J/(kg·K)	—
h	specific enthalpy	J/kg	kJ/kg
Δh	specific enthalpy difference	J/kg	kJ/kg
P	power	W	MW, kW
p	pressure	Pa	MPa, bar, mbar
Δp	pressure difference	Pa	MPa, bar, mbar
R	gas constant	J/(kg·K)	
T	absolute temperature	K	
q_m	mass rate of flow	kg/s	kg/h
q_V	volume flow rate	m^3/s	m^3/h, m^3/min, L/s
K	isentropic exponent (ratio of specific heats)		min^{-1}
L	lower limit		
η	efficiency		
ρ	density	kg/m^3	
U	upper limit		

Table H.2 — Subscripts

Subscript	Term	Remark
isen	isentropic	
η	efficiency	
m	mass	Characterizes the mass-specific rates of flow, energies and volumes
P	power	
real	real	

Table H.2 *(continued)*

Subscript	Term	Remark
spec	specific	
V	volume	Characterizes the volume-specific rates of flow and energy
1,2	states	

H.3 Derivation of isentropic power

The power required for isentropic compression can be derived from basic relationships:

$$P_{\text{isen}} = \Delta h_{\text{isen}} \cdot q_m \quad \text{with} \quad q_m = q_V \cdot \rho = \frac{p_1}{RT_1} \quad \text{(ideal gas)} \tag{H.1}$$

Isentropic enthalpy difference:

$$\Delta h_{\text{isen}} = c_p \cdot \left[T_{2,\text{isen}} - T_1 \right] \quad \text{(ideal gas)} \tag{H.2}$$

with

$$c_p = R \cdot \frac{K}{(K-1)} \tag{H.3}$$

follows:

$$\Delta h_{\text{isen}} = \frac{K}{K-1} RT_1 \cdot \left[\frac{T_{2,\text{isen}}}{T_1} - 1 \right] \tag{H.4}$$

With the isentropic relation $\frac{T_{2,\text{isen}}}{T_1} = \left(\frac{p_2}{p_1} \right)^{\frac{K-1}{K}}$ follows

$$\Delta h_{\text{isen}} = \frac{K}{K-1} RT_1 \cdot \left[\left(\frac{p_2}{p_1} \right)^{\frac{K-1}{K}} - 1 \right] \tag{H.5}$$

and for the power required for isentropic compression:

$$P_{\text{isen}} = q_m \Delta h_{\text{isen}} = q_{V1} \cdot \frac{p_1}{RT_1} \Delta h_{\text{isen}}$$

$$P_{\text{isen}} = q_{V1} \cdot \frac{p_1}{RT_1} \frac{K}{K-1} RT_1 \cdot \left[\left(\frac{p_2}{p_1} \right)^{\frac{K-1}{K}} - 1 \right]$$

$$P_{\text{isen}} = q_{V1} \cdot p_1 \frac{K}{K-1} \cdot \left[\left(\frac{p_2}{p_1} \right)^{\frac{K-1}{K}} - 1 \right] \tag{H.6}$$

which is the most widely used version of the formula for isentropic power.

The formulae above show that no additional data have to be measured for the calculation of isentropic power and isentropic efficiency.

Where performance guarantee values are to be determined, then the correction factors to be applied shall be done in accordance with C.4.

H.4 Relationship between isentropic efficiency and specific energy requirement

“Specific energy requirement” (SER) or more precisely “specific power requirement” is defined as

$$P_{\mathrm{spec}} = \frac{P_{\mathrm{real}}}{q_{V1}} \tag{H.7}$$

The relation of “isentropic efficiency” to “specific power requirement” can be derived using

$$\frac{1}{\eta_{\mathrm{isen}}} = \frac{P_{\mathrm{real}}}{P_{\mathrm{isen}}} \text{ and } P_{\mathrm{isen}} = q_{V1} \cdot p_1 \frac{K}{K-1} \cdot \left[\left(\frac{p_2}{p_1} \right)^{\frac{K-1}{K}} - 1 \right] \tag{H.8}$$

to build

$$\frac{1}{\eta_{\mathrm{isen}}} = \frac{\left(\frac{P_{\mathrm{real}}}{q_{V1}} \right)}{P_{\mathrm{spec}}} \cdot \frac{1}{p_1 \frac{K}{K-1} \cdot \left[\left(\frac{p_2}{p_1} \right)^{\frac{K-1}{K}} - 1 \right]} \tag{H.9}$$

$$\frac{1}{\eta_{\mathrm{isen}}} = P_{\mathrm{spec}} \cdot \frac{1}{p_1 \frac{K}{K-1} \cdot \left[\left(\frac{p_2}{p_1} \right)^{\frac{K-1}{K}} - 1 \right]} \tag{H.10}$$

or alternatively

$$\eta_{\mathrm{isen}} = \frac{1}{P_{\mathrm{spec}}} \cdot p_1 \frac{K}{K-1} \cdot \left[\left(\frac{p_2}{p_1} \right)^{\frac{K-1}{K}} - 1 \right] \tag{H.11}$$

Therefore, if the operating conditions are known, the calculation of isentropic efficiency from specific energy requirement and vice versa is unambiguous.

H.5 Tolerances

As isentropic efficiency can be calculated from specific power requirement without additional data to be measured and vice versa (see above), their relative tolerances are directly related as well. As isentropic efficiency is proportional to the reciprocal of specific power requirement [see Formulae (H.9) or (H.10)], the algebraic signs of the tolerance values change and the values have to be converted.

Let P_{spec} have a lower limit L_P and an upper limit U_P, both given as relative values in percentage.

Then, P_{spec} can have values between

$$\frac{\left(100-\left(L_P\left[\%\right]\right)\right)}{100}\times P_{\text{spec}} \quad \text{and} \quad \frac{\left(100+\left(U_P\left[\%\right]\right)\right)}{100}\times P_{\text{spec}} \tag{H.12}$$

Due to the inverse relation between isentropic efficiency and specific power requirement, η_{isen} can then have values between

$$\frac{100}{\left(100+\left|U_P\left[\%\right]\right|\right)}\cdot\eta_{\text{isen}} \quad \text{and} \quad \frac{100}{\left(100-\left|L_P\left[\%\right]\right|\right)}\cdot\eta_{\text{isen}} \tag{H.13}$$

Introducing a lower limit, L_η, and an upper limit, U_η, for η_{isen}, both given as relative values in percentage, it is obviously as well true that η_{isen} can then have values between

$$\frac{\left(100-\left|L_\eta\left[\%\right]\right|\right)}{100}\cdot\eta_{\text{isen}} \quad \text{and} \quad \frac{\left(100-\left|U_\eta\left[\%\right]\right|\right)}{100}\cdot\eta_{\text{isen}} \tag{H.14}$$

From the last two equations, it follows that

$$\frac{\left(100-\left|L_\eta\left[\%\right]\right|\right)}{100}=\frac{100}{\left(100+\left|U_P\left[\%\right]\right|\right)} \quad \text{and} \quad \frac{\left(100+\left|U_\eta\left[\%\right]\right|\right)}{100}=\frac{100}{\left(100-\left|L_P\left[\%\right]\right|\right)} \tag{H.15}$$

which can be solved to

$$\left|L_\eta\left[\%\right]\right|=100-\frac{10000}{\left(100+\left|U_P\left[\%\right]\right|\right)} \quad \text{and} \quad \left|U_\eta\left[\%\right]\right|=\frac{10000}{\left(100-\left|L_P\left[\%\right]\right|\right)}-100 \tag{H.16}$$

For example, the tolerances of P_{spec} from Annex C are therefore converted as shown in Table H.3.

Table H.3 — Tolerances on isentropic efficiency

Volume flow rate at specified conditions (m^3/s)·10^{-3}	P_{spec} **tolerances** (%)		**Corresponding** η_{isen} **tolerances as percentage of the efficiency value** (%)	
	U_P	L_P	L_η	U_η
$0 < q_V \leq 8{,}3$	+8	−8	−7,4	8,7
$8{,}3 < q_V \leq 25$	+7	−7	−6,5	7,5
$25 < q_V \leq 250$	+6	−6	−5,7	6,4
$q_V > 250$	+5	−5	−4,8	5,3

The tolerances on isentropic efficiency in Table H.3 are percentages of percentages. To calculate the tolerance on the isentropic efficiency in percentage points, the tolerance percentage is multiplied with the percentage value of the isentropic efficiency.

EXAMPLE

A specific energy requirement of 402 kW/(m^3/s) is given for a compressor that compresses dry air (K = 1,4) from 101 300 Pa to 750 000 Pa. Using Formula (H.15), an isentropic efficiency of 68,1 % is calculated.

The specific energy requirement of a second compressor for the same compression task is 7 % higher, therefore 430,14 kW/(m^3/s). Using Formula (H.15), an isentropic efficiency of 63,7 % is calculated. This efficiency is 6,54 % (or, in this case, 4,4 percentage-points) lower than that of the first compressor.

The specific energy requirement of a third compressor for the same compression task is 7 % lower, therefore 373,86 kW/(m^3/s). Using Formula (H.15), an isentropic efficiency of 73,2 % is calculated. This efficiency is 7,53 % (or, in this case, 5,1 percentage-points) higher than that of the first compressor.