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Industrial furnaces and associated processing equipment — Method of measuring energy balance and calculating energy efficiency —

Part 11: Evaluation of various kinds of efficiency

Fours industriels et équipements associés — Méthode de mesure du bilan énergétique et de calcul de l'efficacité —

Partie 11: Évaluation de différents types d'efficacité

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Foreword

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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).

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For an explanation on the voluntary nature of standards, 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.

This document was prepared by Technical Committee ISO/TC 244, *Industrial furnaces and associated processing equipment*.

A list of all parts in the ISO 13579 series can be found on the ISO website.

Introduction

The Kyoto Protocol of the UN Framework Convention on Climate Change defines a system for emission reduction called the Clean Development Mechanism (CDM). In order for the industrial furnace manufacturers industry to address global warming based on the Kyoto Protocol, it is necessary to have fair guidelines to make use of CDM.

ISO 13579-1 to ISO 13579-4 focus on evaluating the overall efficiency of industrial furnaces and associated processing equipment (TPE) system, including electrical energy consumption as fuel equivalent energy, to help the industry facilitate implementation of CDM.

However, these documents do not define and specify efficiencies of each specific component of TPE (e.g. heat recovery equipment, heating chambers, etc.), which are directly related to and available for energy-saving measures. With this in mind, this document has been developed to specify and provide the following information:

— definitions of the various kinds of efficiency of TPE using designation systems and by defining energy balance boundaries within the TPE based on its elements;

  NOTE The definition for TPE efficiency varies according to region.

— evaluation formulae of energy reduction factors, which are available for actual energy conservation based on the energy balance measurements.

In addition to these evaluations in terms of enthalpy, this document also deals with energy efficiency based on exergy, i.e. efficiency based on availability of fuel energy, for the following reasons.

— The whole amount of "energy" in the "closed" terrestrial system is preserved due to the conservation law of energy while "exergy" inherently decreases. The term "energy" related to energy crisis or energy issue is "exergy". Therefore, it may be said that controlling the degrees of a decrease in exergy (or dissipation of available energy) is the essence of the energy crisis. As such, exergy is one of the indexes to evaluate the energy efficiency of TPE.

— It enables a fair comparison among heating furnaces with different heating conditions or heated materials as a result of a common thermodynamic viewpoint.

— Improvement in exergy efficiency leads to essential efficiency-enhancing measures in energy usage.

Industrial furnaces and associated processing equipment — Method of measuring energy balance and calculating energy efficiency —

Part 11: Evaluation of various kinds of efficiency

1 Scope

This document specifies classifications and designations in the methodology of energy efficiency evaluation of industrial furnaces and associated processing equipment (TPE), including energy efficiency in terms of exergy as well as enthalpy.

This document does not apply to the following types of TPE:

— blast furnaces, basic oxygen furnaces, coke ovens;

— furnaces that generate gases to be used as fuel (including by-product gases);

— special atmosphere gas generators;

— industrial furnaces that are designed for chemical plants or petroleum plants;

— installations where heating or combustion is performed in an open space;

— installations that combust solid fuel;

— waste incinerators.

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 13574:2015, *Industrial furnaces and associated processing equipment — Vocabulary*

ISO 13579-1:2013, *Industrial furnaces and associated processing equipment — Method of measuring energy balance and calculating efficiency — Part 1: General methodology*

ISO 13579-2:2013, *Industrial furnaces and associated processing equipment — Method of measuring energy balance and calculating efficiency — Part 2: Reheating furnaces for steel*

ISO 13579-3:2013, *Industrial furnaces and associated processing equipment — Method of measuring energy balance and calculating efficiency — Part 3: Batch-type aluminium melting furnaces*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13574, ISO 13579-1 and the following apply.

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

— ISO Online browsing platform: available at www.iso.org/obp

— IEC Electropedia: available at www.electropedia.org

3.1 General terms

3.1.1
boundary
enclosed section that is defined for an energy balance evaluation of object(s)

Note 1 to entry: The energy efficiency evaluations are possible once a boundary is set.

3.1.2
product
item processed in a TPE, including auxiliary material

EXAMPLE Auxiliary material loaded in scrap melting process in addition to the main material (i.e. scraps).

Note 1 to entry: Product does not include by-products formed in the thermo-processing, e.g. formation of oxidized substance such as iron-scale and aluminium oxide.

Note 2 to entry: Product does not include the accessories, e.g. jigs or fixtures that are heated simultaneously with product.

[SOURCE: ISO 13574:2015, 2.134, modified]

3.1.3
energy balance analysis
grouping of energy values into either input energy or output energy, by measuring and calculating provided energy, including by exothermic reaction and outflowing energy, which also includes by endothermic reaction to/from the boundary

Note 1 to entry: The total energy input and the total energy output inherently balance.

3.1.4
energy efficiency
efficiency defined as *specific energy output* (3.1.5) divided by *specific energy input* (3.1.6)

Note 1 to entry: Energy efficiencies are expressed in percentages. Specific energy output and specific energy input are defined in this document.

3.1.5
specific energy output
specific energy defined in this document as effective energy output from the boundary for calculation of an index of efficiency of TPE

EXAMPLE Enthalpy accumulated in product through a TPE process.

3.1.6
specific energy input
amount of supplied energy defined in this document as energy brought to the boundary for calculation of an index of efficiency

3.1.7
available heat
calorific value which is required in a heating chamber of a furnace under specified operating or equipment conditions

Note 1 to entry: Available heat is a form of specific energy output defined in 6.2.5.

Note 2 to entry: “Available energy” in exergy terms has a different concept.

Note 3 to entry: See A.2.5.

3.1.8
available heat ratio
index of efficiency defined as *available heat* (3.1.7) divided by the calorific value of fuel

Note 1 to entry: This term is one of the significant indexes of a combustion furnace.

3.1.9
fuel equivalent energy of electricity
amount of primary energy which is equivalent to the calorific value of fuel input consumed in electrical generation

3.1.10
fuel equivalent energy conversion
conversion of electrical energy consumption to *fuel equivalent energy of electricity* (3.1.9)

Note 1 to entry: The factor for calculation, which is generally available, is not considered loss between the power receiving station to the TPE's power receiving terminal.

Note 2 to entry: The unit kJ/kWh is generally used.

Note 3 to entry: The value for fuel equivalent energy conversion varies depending on governments or regions.

Note 4 to entry: It should be indicated when the conversion is conducted.

3.1.11
energy performance indicator
amount of energy that is consumed per specific production unit of utilities or per specific output of auxiliary equipment

3.1.12
exergy
maximum work which can be extracted under the ambient temperature of a place, which is generally defined as

$$EX = \Delta H - T_0 \Delta S$$

where

EX is the exergy (maximum work);

ΔH is the change in enthalpy;

T_0 is the ambient temperature, in Kelvin;

ΔS is the change in entropy.

Note 1 to entry: There are chemical exergy, pressure exergy, mixing exergy and thermal exergy in a combustion system. But pressure exergy and mixing exergy are negligibly small.

3.1.13
exergy loss
difference between exergy that flows in to and flows out from the targeted *boundary* (3.1.1)

3.1.14
furnace structure
sum of furnace walls, cooling water equipment, furnace opening, etc.

3.2 Balance table

NOTE See Table A.3 and Table A.7 as examples.

3.2.1
energy balance table
table on which breakdowns of energy input and energy output are listed

3.2.2
efficiency evaluation table
reorganized table from an *energy balance table* (3.2.1) to categorize energy groups such as *specific energy input* (3.1.6) or *specific energy output* (3.1.5) to calculate an efficiency index while maintaining the energy balance

4 Symbols

4.1 Symbols for energy/exergy

Symbol	Definition
E_{aux}	energy consumed in auxiliary equipment per tonne of product
$E_{available}$	available heat per tonne of product
$E_{available\ I}$	available heat of the baseline, in MJ/t
$E_{available\ II}$	available heat after energy saving measure, in MJ/t
E_{ex}	sensible heat of exhaust gas per tonne of product
$E_{ex,ir}$	sensible heat of exhaust gas from fuel at the inlet of heat recovery equipment per tonne of product
$E_{ex,oc}$	sensible heat of exhaust gas from fuel at the outlet of combustion chamber per tonne of product
$E_{ex,or}$	sensible heat of exhaust gas from fuel at the outlet of heat recovery equipment per tonne of product
$E_{exrm,ir}$	sensible heat of exhaust gas from raw materials at the inlet of heat recovery equipment per tonne of product
$E_{exrm,oc}$	sensible heat of exhaust gas from raw materials at the outlet of combustion chamber per tonne of product
$E_{exrm,or}$	sensible heat of exhaust gas from raw materials at the outlet of heat recovery equipment per tonne of product
$E_{fe,el}$	fuel equivalent energy of electricity per tonne of product
E_{h}	energy input to the heating chamber per tonne of product
$E_{h,el}$	heat energy by electroheating per tonne of product
$E_{h,fuel}$	calorific value of fuel per tonne of product
$E_{h,fuel\ I}$	energy consumption (calorific value of fuel) of the baseline, in MJ/t
$E_{h,fuel\ II}$	estimated energy consumption after energy saving measure, in MJ/t
$E_{h,re}$	recovery heat per tonne of product
$E_{h,reex}$	recovery heat from sensible heat of exhaust gas per tonne of product
$E_{h,repr}$	recovery heat from sensible heat of product per tonne of product
E_{l}	thermal energy loss per tonne of product
$E_{l,atm}$	energy loss by atmosphere gas per tonne of product
$E_{l,eg}$	electrical generation loss per tonne of product
$E_{l,eh}$	electrical energy loss in electroheating per tonne of product
$E_{l,exrm}$	energy loss by exhaust gas from raw material
$E_{l,fs}$	energy loss from furnace structure per tonne of product
$E_{l,j}$	energy required for heating jigs and other substance per tonne of product
$E_{l,hs}$	energy required for heat storage of furnace structure per tonne of product
$E_{l,other}$	other energy loss per tonne of product
$E_{l,uc}$	energy loss by uncombusted content per tonne of product
E_{p1}	enthalpy of product at the time of loading into the boundary per tonne

Symbol	Definition
E_{p2}	enthalpy of product at the time of extraction from the boundary per tonne
E_{pr}	energy required for process per tonne of product
$E_{pr,en}$	enthalpy change in product per tonne
$E_{pr,ev}$	energy required for drying and evaporation per tonne of product
$E_{pr,re}$	energy required for endothermic reaction for heated material (product)
E_{rcy}	recycled energy per tonne of product
$E_{s,air}$	sensible heat of combustion air or other oxidant which is not preheated per tonne of product
$E_{s,atomize}$	sensible heat of atomization agent per tonne of product
$E_{s,fuel}$	sensible heat of fuel per tonne of product
$E_{s,fluid}$	sensible heat of fluid at the inlet per tonne of product
$E_{s,infilt}$	sensible heat of infiltration air per tonne of product
$E_{sp\text{-}in}$	specific energy input per tonne of product
$E_{sp\text{-}out}$	specific energy output per tonne of product
$E_{react,exo}$	heat of exothermic reaction per tonne of product
$E_{u,gen}$	energy consumed in generation of utilities per tonne of product
EX_{aux}	exergy consumed in auxiliary equipment per tonne of product
$EX_{available}$	available exergy per tonne of product
$EX_{ex,ir}$	exergy of exhaust gas at the inlet of heat recovery equipment per tonne of product
$EX_{ex,oc}$	exergy of exhaust gas at the outlet of combustion chamber per tonne of product
$EX_{ex,or}$	exergy of exhaust gas at the outlet of heat recovery equipment per tonne of product
$EX_{h,el}$	exergy input from electrical source per tonne of product
$EX_{h,fuel}$	exergy of fuel per tonne of product
$EX_{h,re}$	recovery exergy per tonne of product
$EX_{l,atm}$	exergy in given enthalpy to atmosphere gas per tonne of product
$EX_{l,eh}$	exergy loss in electroheating per tonne of product
$EX_{l,fs}$	exergy in heat loss from furnace structure per tonne of product
$EX_{l,hs}$	exergy in energy required for heat storage of furnace structure per tonne of product
$EX_{l,j}$	exergy in required for heating jigs and other substance per tonne of product
$EX_{l,other}$	exergy in other energy loss per tonne of product
$EX_{pr,en}$	exergy in given enthalpy to product per tonne
$EX_{pr,ev}$	exergy in energy required for drying and evaporation per tonne of product
$EX_{pr,re}$	exergy required for endothermic reaction for heated material
$EX_{react,exo}$	exergy of exothermic reaction per tonne of product
$EX_{sp\text{-}in}$	specific exergy input per tonne of product
$EX_{sp\text{-}out}$	specific exergy output per tonne of product
$EX_{s,fluid}$	exergy of sensible heat of fluid at the inlet
EX_{rcy}	exergy of recycled energy per tonne of product
$EX_{u,gen}$	exergy consumed in generation of utilities per tonne of product
EX_{v}	recovery of exergy as steam

4.2 Other symbols

Symbol	Definition
A_0	theoretical volume of combustion air per unit fuel consumption, in $m^3(n)$
c	weight fraction of carbon contained in liquid fuel
C_a	mean specific heat of air, in kJ/(kg·K)

Symbol	Definition
C_g	mean specific heat of exhaust gas, in kJ/(kg·K)
$c_{pm,ex}$	mean specific heat of exhaust gas, in kJ/(kg·K)
$c_{pm,fl}$	mean specific heat of fluid (fuel or combustion air), in kJ/(kg·K)
$c_{pm,c}$	mean specific heat of combustion gas, in kJ/(kg·K)
$c_{pm,w}$	mean specific heat of liquid water, in kJ/(kg·K)
$c_{pm,ph}$	mean specific heat of preheated item (e.g. product, fluid), in kJ/(kg·K)
$c_{pm,v}$	mean specific heat of water vapour, in kJ/(kg·K)
$e_c{}^0$	chemical exergy per unit quantity of fuel, in kJ/m^3(n)
G_0	theoretical volume of exhaust gas per unit fuel consumption, in m^3(n)
h	weight fraction of hydrogen contained in liquid fuel
H_{ex}	sensible heat of exhaust gas at the outlet of combustion chamber per unit fuel consumption, in MJ/ m^3(n) or MJ/kg
H_h	gross calorific value of fuel per unit quantity of fuel, in kJ/kg or kJ/m^3(n)
H_l	net calorific value of fuel per unit quantity of fuel, in J/kg or kJ/m^3(n)
H_r	sensible heat of preheated combustion air per unit fuel consumption, in MJ/ m^3(n) or MJ/kg
H_v	recovered enthalpy by generation of steam per tonne of product, in kJ/t
ΔH	change in enthalpy per tonne of product, in kJ/t
L	latent heat of vaporization of water, in kJ/kg
m	air ratio
$m_{\ I}$	air ratio of baseline
$m_{\ II}$	air ratio after energy saving measure
m_{ex}	mass of exhaust gas per tonne of product, in kg/t
m_{fl}	mass of fluid (fuel or combustion air) per tonne of product, in kg/t
$m_{fl,c}$	summation of mass of fluid provided per tonne of product and mass of theoretical combustion air corresponding to the amount of fuel, in kg/t
m_{ph}	mass of preheated item (e.g. product, fluid) per tonne of product, in kg/t
m_{v1}	mass of steam as atomization agent required per tonne of product, in kg/t
m_{v2}	mass of steam recycled from exhausted energy required per tonne of product, in kg/t
O	weight fraction of oxygen contained in liquid fuel
R	gas constant
s	weight fraction of sulfur contained in liquid fuel
ΔS	change in entropy per tonne of product, in kJ/K/t
t_a	temperature of preheated combustion air, in K
t_{gout}	temperature of exhaust gas at the outlet of combustion chamber, in K
T_{ad}	adiabatic flame temperature, in K
T_0	ambient temperature, in K
T_{ex}	temperature of exhaust gas at defined location in K
T_{fc}	temperature inside furnace, in K
T_{fl}	temperature of fluid (fuel or combustion air), in K
T_{ph}	temperature of preheated item (e.g. product, fluid), in K
T_{v1}	temperature of water vapour as atomization agent, in K
T_{v2}	temperature of water vapour recycled from exhausted energy, in K
V_f	fuel consumption per tonne of product, in m^3(n)/t or kg/t
x_i	volume fraction of fuel component i
α_{es}	energy saving ratio (%)

Symbol	Definition
η	specific energy efficiency of enthalpy
η_1	overall efficiency in accordance with ISO 13579-1
η_2	heat efficiency on the whole calorific value basis
η_3	heat efficiency on the supplied calorific value basis
η_5	combusted fuel ratio
η_7	ratio of waste heat recovery in combustion furnace
η^*	available heat ratio
η^*_{I}	available heat ratio of the baseline
η^*_{II}	estimated available heat ratio after energy saving measure
η^*_0	converted available heat ratio where waste heat recovery is not considered
η_e	electrical generation efficiency
η_{exh}	ratio of waste heat of combustion exhaust gas to calorific value of fuel
η_{ex}	specific exergy efficiency
η_{ex}^*	ratio of exergy in available heat to the input exergy
η_{ex1}	overall exergy efficiency in accordance with ISO 13579-1 using Gibbs free energy of fuel
η_{ex2}	heat exergy efficiency on the whole calorific value basis using Gibbs free energy of fuel
η_{exh}	ratio of waste heat of combustion exhaust gas to calorific value of fuel
η_R	effective ratio of waste heat recovery in combustion furnace
$\eta_{R\,I}$	effective ratio of waste heat recovery in combustion furnace of the baseline
$\eta_{R\,II}$	effective waste heat recovery ratio in combustion furnace after energy saving measure
$\eta_{rcy,steam}$	ratio of enthalpy which is recovered in the generated steam to the whole enthalpy provided to the steam generator

5 Boundary and energy (enthalpy)

5.1 Configuration of the area of evaluation

The general configuration of the area of evaluation under the scope of this document consists of the following:

— heating chamber (key 1);

— burner (key 2);

— heat recovery equipment (preheating equipment using exhaust gas) (key 3);

— electrical generation (key 4);

— electrical auxiliary equipment (e.g. fan motor, compressor) (key 5);

— generation of utilities (e.g. endothermic gas generator) (key 6);

— electrical heating (key 7).

NOTE For keys, see Figure 1.

5.2 Classification of boundary

The codes for each classification of boundaries drawn for the evaluation of energy efficiency of TPE specified in Table 1 apply.

Table 1 — Classification of boundary

Symbol	Classification of boundary	Description
EB1	Overall process of TPE	As specified in ISO 13579-1. Electric generator[a] can be excluded when fuel equivalent energy conversion is not considered. See 6.2.2 for typical efficiency applicable to this boundary.
EB2a	Heating chamber with heat recovery equipment	Recovery heat shall be considered as internal circulating heat. Auxiliary equipment[b] and utility generator[c] shall be excluded. See 6.2.4, 6.2.5 and 6.2.7 for typical efficiency applicable to this boundary.
EB2b	Heating chamber and cooling zone with heat recovery equipment	
EB3a	Heating chamber	Heat recovery equipment shall be outside the boundary. Auxiliary equipment[b] and utility generator[c] shall be excluded. See 6.2.3, 6.2.5 and 6.2.7 for typical efficiency applicable to this boundary.
EB3b	Heating chamber and cooling zone	
EB4	Heat recovery equipment	Boundary shall be set adjacent to the heat recovery equipment[d]. See 6.2.6 for typical efficiency applicable to this boundary.
EB4a	Combustion air preheating equipment	
EB4f	Fuel preheating equipment	
EB4p	Product preheating equipment	
EB5	Auxiliary equipment	Auxiliary equipment[b] shall explicitly be specified[e].
EB6	Utility generator	Utility generator[c] shall explicitly be specified[f].

NOTE Keys mentioned are found in Figure 1.

[a] See key 4.

[b] See key 5.

[c] See key 6.

[d] See key 3.

[e] For example, blower.

[f] For example, O_2 generator.

5.3 Classification of energy (enthalpy)

The classification of energy types and symbols specified in Table 2 apply.

The basic unit of energy specified in Table 2 is 1 kJ per tonne (i.e. 1 000 kg) of product, unless otherwise specified.

For calculation of each classification of energy, see 5.4.

Table 2 — Classification of energy

Classification		Symbol	Description
Energy input to the heating chamber	Energy input from electrical source	E_h	5.4.1
		$E_{h,el}$	5.4.1.2
	Calorific value of fuel	$E_{h,fuel}$	5.4.1.3
	Heat of exothermic reaction	$E_{react,exo}$	5.4.1.4
	Sensible heat of fluid at the inlet	$E_{s,fluid}$	5.4.1.5

NOTE See Figure 1.

Table 2 *(continued)*

Classification		Symbol	Description
Energy required for process	Energy required for drying and evaporation	E_{pr}	5.4.2
		$E_{pr,ev}$	5.4.2.2
	Energy required for endothermic reaction for heated material (product)	$E_{pr,re}$	5.4.2.3
	Enthalpy change in product	$E_{pr,en}$	5.4.2.4
Sensible heat of exhaust gas at the outlet of combustion chamber	Sensible heat of exhaust gas from fuel	$E_{ex,oc}$	5.4.3.1
	Sensible heat of exhaust gas from raw materials	$E_{exrm,oc}$	5.4.3.2
Sensible heat of exhaust gas at the outlet of heat recovery equipment	Sensible heat of exhaust gas from fuel	$E_{ex,or}$	5.4.4.1
	Sensible heat of exhaust gas from raw materials	$E_{exrm,or}$	5.4.4.2
Sensible heat of exhaust gas at the inlet of heat recovery equipment	Sensible heat of exhaust gas from fuel	$E_{ex,ir}$	5.4.5.1
	Sensible heat of exhaust gas from raw materials	$E_{exrm,ir}$	5.4.5.2
Recovery heat	Recovery heat	$E_{h,re}$	5.4.6
	Recovery heat from sensible heat of exhaust gas	$E_{h,reex}$	5.4.6.2
	Recovery heat from sensible heat of product	$E_{h,repr}$	5.4.6.3
Thermal energy loss	Energy loss by uncombusted content	E_{l}	5.4.7
		$E_{l,uc}$	5.4.7.2
	Energy required for heating jigs and other substance	$E_{l,j}$	5.4.7.3
	Energy loss from furnace structure	$E_{l,fs}$	5.4.7.4
	Energy required for heat storage of furnace structure	$E_{l,hs}$	5.4.7.5
	Energy loss by atmosphere gas	$E_{l,atm}$	5.4.7.6
	Energy loss by exhaust gas from raw material	$E_{l,exrm}$	5.4.7.7
	Other energy loss	$E_{l,other}$	5.4.7.8
Electrical energy loss in electroheating	Electrical energy loss in electroheating	$E_{l,eh}$	5.4.8
Additional energy consumption	Energy consumed in auxiliary equipment	E_{aux}	5.4.9
	Energy consumed in generation of utilities	$E_{u,gen}$	5.4.10
Electrical generation loss	Electrical generation loss	$E_{l,eg}$	5.4.11
Fuel equivalent energy of electricity	Fuel equivalent energy of electricity	$E_{fe,el}$	5.4.12
Energy to be used outside TPE	Recycled energy	E_{rcy}	5.4.13

NOTE See Figure 1.