BS ISO 13579-11:2017

BSI Standards Publication

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

Part 11: Evaluation of various kinds of efficiency

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# National foreword

This British Standard is the UK implementation of ISO 13579-11:2017.

The UK participation in its preparation was entrusted to Technical Committee RHE/13, Oil burning equipment.

A list of organizations represented on this committee can be obtained on request to its secretary.

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INTERNATIONAL STANDARD

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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

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).

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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.

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# 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.


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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

## 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

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— 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.


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**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);

$\Delta H$ is the change in enthalpy;

$T_0$ is the ambient temperature, in Kelvin;

$\Delta S$ 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.

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**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 |


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| 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) |

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| 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 |
| $\Delta H$ | change in enthalpy per tonne of product, in kJ/t |
| $L$ | latent heat of vaporization of water, in kJ/kg |
| $m$ | air ratio |
| $m_{\mathrm{I}}$ | air ratio of baseline |
| $m_{\mathrm{II}}$ | 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 |
| $\Delta S$ | 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 $i$ |
| $\alpha_{es}$ | energy saving ratio (%) |


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| Symbol | Definition |
|---|---|
| $\eta$ | specific energy efficiency of enthalpy |
| $\eta_1$ | overall efficiency in accordance with ISO 13579-1 |
| $\eta_2$ | heat efficiency on the whole calorific value basis |
| $\eta_3$ | heat efficiency on the supplied calorific value basis |
| $\eta_5$ | combusted fuel ratio |
| $\eta_7$ | ratio of waste heat recovery in combustion furnace |
| $\eta^*$ | available heat ratio |
| $\eta^*_{\mathrm{I}}$ | available heat ratio of the baseline |
| $\eta^*_{\mathrm{II}}$ | estimated available heat ratio after energy saving measure |
| $\eta^*_0$ | converted available heat ratio where waste heat recovery is not considered |
| $\eta_{\mathrm{e}}$ | electrical generation efficiency |
| $\eta_{\mathrm{exh}}$ | ratio of waste heat of combustion exhaust gas to calorific value of fuel |
| $\eta_{\mathrm{ex}}$ | specific exergy efficiency |
| $\eta_{\mathrm{ex}}^*$ | ratio of exergy in available heat to the input exergy |
| $\eta_{\mathrm{ex1}}$ | overall exergy efficiency in accordance with ISO 13579-1 using Gibbs free energy of fuel |
| $\eta_{\mathrm{ex2}}$ | heat exergy efficiency on the whole calorific value basis using Gibbs free energy of fuel |
| $\eta_{\mathrm{exh}}$ | ratio of waste heat of combustion exhaust gas to calorific value of fuel |
| $\eta_{\mathrm{R}}$ | effective ratio of waste heat recovery in combustion furnace |
| $\eta_{\mathrm{R\,I}}$ | effective ratio of waste heat recovery in combustion furnace of the baseline |
| $\eta_{\mathrm{R\,II}}$ | effective waste heat recovery ratio in combustion furnace after energy saving measure |
| $\eta_{\mathrm{rcy,steam}}$ | 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.

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**Table 1 — Classification of boundary**

| Symbol | Classification of boundary | Description |
|---|---|---|
| EB1 | Overall process of TPE | As specified in ISO 13579-1.<br>Electric generator[a] can be excluded when fuel equivalent energy conversion is not considered.<br>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.<br>Auxiliary equipment[b] and utility generator[c] shall be excluded.<br>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.<br>Auxiliary equipment[b] and utility generator[c] shall be excluded.<br>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].<br>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.


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**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. | | | |

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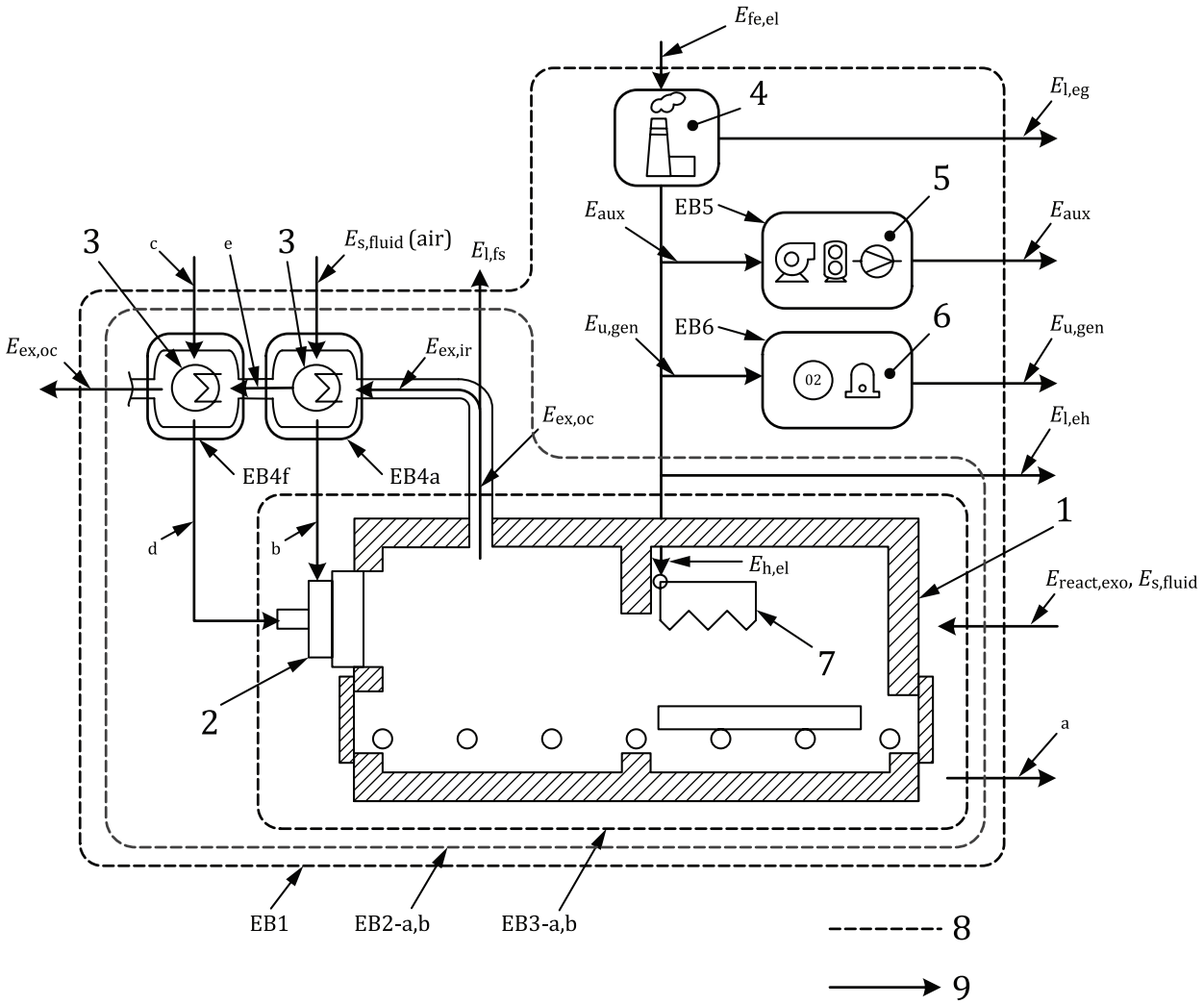


**Key**

1 heating chamber/combustion chamber
2 burner
3 heat recovery equipment
4 electrical generation
5 electrical auxiliary equipment
6 generation of utilities
7 electrical heating
8 boundary of efficiency evaluation
9 energy flow

a Energy required for process ($E_{pr}$) and thermal energy losses ($E_l$).
b $E_{s,fluid}$ (air) + $E_{h,re}$.
c $E_{h,fuel}$ + $E_{s,fluid}$ (fuel).
d $E_{h,fuel}$ + $E_{s,fluid}$ (fuel) + $E_{h,re}$.
e $E_{ex,or}$ or $E_{ex,ir}$.

**Figure 1 — Example configuration of TPE and boundaries of efficiency evaluation**


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## 5.4 Calculation of energy (enthalpy)

### 5.4.1 Energy input to the heating chamber ($E_h$)

#### 5.4.1.1 General

Calculate energy input to the heating chamber per tonne of product using Formula (1):

$$E_h = \sum E_{h\,i} \tag{1}$$

where $E_{h\,i}$ is the individual applicable energy input to the heating chamber per tonne of product.

Calculate each applicable energy, as appropriate, in accordance with the following:

— energy input from electrical source ($E_{h,el}$), as defined in 5.4.1.2;

— calorific value of fuel ($E_{h,fuel}$), as defined in 5.4.1.3;

— heat of exothermic reaction ($E_{react,exo}$), as defined in 5.4.1.4;

— sensible heat of fluid at the inlet ($E_{s,fluid}$), as defined in 5.4.1.5.

#### 5.4.1.2 Energy input from electrical source ($E_{h,el}$)

This classification is for energy supplied for electroheating as energy source. This includes resistance heating, induction heating, arc heating, dielectric heating and microwave heating. Fuel equivalent energy conversion is necessary depending on the condition of energy evaluation (e.g. in the case of EB1).

#### 5.4.1.3 Calorific value of fuel ($E_{h,fuel}$)

This classification is for energy that is generated by combustion reaction of gaseous and/or liquid fuel. Sensible heat of fuel or air is not included.

Calculate calorific value of fuel according to ISO 13579-1:2013, 9.2.1, if applicable.

#### 5.4.1.4 Heat of exothermic reaction ($E_{react,exo}$)

This classification is for energy that is generated by exothermic reactions such as oxidation reaction of product and calorific value by reactions such as exothermic reaction of auxiliary material or oxidation reaction of the electrode. Heat of exothermic reaction may be excluded from calculation of energy required for product depending on the condition of energy evaluation.

Calculate heat generated by the formation of scale of steel product according to ISO 13579-2:2013, 9.2.5, if applicable.

Calculate heat generated by the formation of aluminium oxide according to ISO 13579-3:2013, 9.2.7, if applicable.

#### 5.4.1.5 Sensible heat of fluid at the inlet ($E_{s,\,fluid}$)

This classification is for summation of sensible heat of fluid and/or air at the inlet of heating chamber excluding recovery heat. This classification of energy includes sensible heat of infiltration air and atomization agent. When water/moisture is provided, its sensible heat and latent heat of vaporizing (as negative value) shall be taken into account. This item may be omitted when the value is small enough to neglect comparing to the entire energy input.

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Calculate sensible heat input from fluid per tonne of product using Formula (2):

$$E_{\text{s, fluid}} = \sum E_{\text{s, fluid i}} \tag{2}$$

where $E_{\text{s, fluid i}}$ is the individual applicable sensible heat of fluid per tonne of product, e.g. sensible heat of fuel, sensible heat of combustion air, sensible heat of atomization agent, sensible heat of infiltration air, etc.

Calculate sensible heat of each fluid in accordance with the following references, where applicable:

— ISO 13579-1:2013, 9.2.4.1 for fuel ($E_{\text{s,fuel}}$);

— ISO 13579-1:2013, 9.2.5 for combustion air ($E_{\text{s,air}}$);

— ISO 13579-1:2013, 9.2.6 for atomization agent ($E_{\text{s,atomize}}$);

— ISO 13579-1:2013, 9.2.8 for infiltration air ($E_{\text{s,infilt}}$).

### 5.4.2 Energy required for process ($E_{\text{pr}}$)

#### 5.4.2.1 General

This classification is for the net energy required for the intended process itself. Energy required for the process is the summation of any combination of the following three classifications of energy:

— energy required for drying and evaporation ($E_{\text{pr,ev}}$), as defined in 5.4.2.2;

— energy required for endothermic reaction for heated material ($E_{\text{pr,re}}$), as defined in 5.4.2.3;

— enthalpy change in product ($E_{\text{pr,en}}$), as defined in 5.4.2.4.

#### 5.4.2.2 Energy required for drying and evaporation ($E_{\text{pr,ev}}$)

This classification is for energy required for drying and evaporation in the thermo processing.

#### 5.4.2.3 Energy required for endothermic reaction for heated material (product) ($E_{\text{pr,re}}$)

This classification is for energy required for chemical reaction for heated material in the thermo processing. The energy is absorbed energy by chemical reactions, e.g. $CaCO_3 + E_{\text{pr,re}} \rightarrow CaO + CO_2$.

#### 5.4.2.4 Enthalpy change in product ($E_{\text{pr,en}}$)

This classification is for the amount of change in the enthalpy of a product in the boundary.

Calculate enthalpy change in a product using Formula (3):

$$E_{\text{pr,en}} = E_{\text{p2}} - E_{\text{p1}} \tag{3}$$

Calculate enthalpy of a product at the time of the loading into the boundary per tonne ($E_{\text{p1}}$) according to ISO 13579-1:2013, 9.3.1.1.2.1.

Calculate enthalpy of a product at the time of extraction from the boundary per tonne ($E_{\text{p2}}$) according to ISO 13579-1:2013, 9.3.1.1.2.2.

### 5.4.3 Sensible heat of exhaust gas at the outlet of combustion chamber

#### 5.4.3.1 Sensible heat of exhaust gas from fuel ($E_{\text{ex,oc}}$)

This classification is for sensible heat of exhaust gas from fuel at the outlet of combustion chamber.


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Calculate sensible heat of exhaust gas according to ISO 13579-1:2013, 9.3.1.4, if applicable.

#### 5.4.3.2 Sensible heat of exhaust gas from raw materials ($E_{exrm,oc}$)

This classification is for sensible heat of exhaust gas from raw materials at the outlet of combustion chamber.

Calculate sensible heat of exhaust gas according to ISO 13579-1:2013, 9.3.1.4, if applicable.

### 5.4.4 Sensible heat of exhaust gas at the outlet of heat recovery equipment

#### 5.4.4.1 Sensible heat of exhaust gas from fuel ($E_{ex,or}$)

This classification is for sensible heat of exhaust gas at the outlet of heat recovery equipment. In this case, the heat recovery equipment is integrally structured within the combustion chamber. Indication that describes the structure of the heat recovery equipment is necessary.

Calculate sensible heat of exhaust gas according to ISO 13579-1:2013, 9.3.1.4, if applicable.

#### 5.4.4.2 Sensible heat of exhaust gas from raw materials ($E_{exrm,or}$)

This classification is for sensible heat of exhaust gas at the outlet of heat recovery equipment. In this case, the heat recovery equipment is integrally structured with the combustion chamber. An indication that describes the structure of the heat recovery equipment is necessary.

Calculate sensible heat of exhaust gas according to ISO 13579-1:2013, 9.3.1.4, if applicable.

### 5.4.5 Sensible heat of exhaust gas at the inlet of heat recovery equipment

#### 5.4.5.1 Sensible heat of exhaust gas from fuel ($E_{ex,ir}$)

This classification is for sensible heat of exhaust gas at the inlet of heat recovery equipment which is located well apart from combustion chamber. This classification is used for evaluation of the heat recovery equipment unit.

Calculate sensible heat of exhaust gas according to ISO 13579-1:2013, 9.3.1.4, if applicable.

#### 5.4.5.2 Sensible heat of exhaust gas from raw materials ($E_{exrm,ir}$)

This classification is for sensible heat of exhaust gas at the inlet of heat recovery equipment which is located well apart from combustion chamber. This classification is used for evaluation of the heat recovery equipment unit.

Calculate sensible heat of exhaust gas according to ISO 13579-1:2013, 9.3.1.4, if applicable.

### 5.4.6 Recovery heat ($E_{h,re}$)

#### 5.4.6.1 General

This classification is for available recovery heat which is recovered from exhaust energy (e.g. heat of exhaust gas). Recovery heat is used for preheating of fuel, combustion air and/or product provided to the boundary.

#### 5.4.6.2 Recovery heat from sensible heat of exhaust gas ($E_{h,reex}$)

This classification is for available recovery heat which is recovered from exhaust gas.

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