INTERNATIONAL STANDARD

ISO 13579-1

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

Part 1: General methodology

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

Partie 1: Méthode générale

Reference number
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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. 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.

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.

ISO 13579-1 was prepared by Technical Committee ISO/TC 244, *Industrial furnaces and associated thermal processing equipment*.

ISO 13579 consists of the following parts, under the general title *Industrial furnaces and associated processing equipment — Method of measuring energy balance and calculating efficiency*:

— *Part 1: General methodology*

— *Part 3: Reheating furnaces for steel*

— *Part 2: Batch-type aluminium melting furnaces*

— *Part 4: Furnaces with protective or reactive atmosphere*

Introduction

Prevention of global warming is a significant issue which needs to be solved on the world scale. For this purpose, it is necessary not only to reduce energy consumption dramatically, but at the same time also ensure a convenient and comfortable daily life for everyone.

It is critical to use energy as efficiently as possible to fulfil these requirements.

Although industrial furnaces play an important role in maintaining everyone's life, on the other hand, they consume a great amount of energy. In order to tackle the above-mentioned issues, it is important to

— establish an International Standard (i.e. the ISO 13579 series), which specifies the energy efficiency of industrial furnaces in a reasonable manner,

— control energy consumption by using the collected measurement data based on ISO 13579 (all parts), and

— improve efficiency.

Furthermore, this part of ISO 13579 can be applied as a fair guideline for utilizing the Clean Development Mechanism (CDM), which was developed under the Kyoto Protocol[24] for measures used to prevent global warming.

All calculations within ISO 13579 (all parts) are based on the location of equipment under reference conditions.

NOTE For equipment intended to be installed above or below sea level, it is expected that the impact of the elevation be calculated for that location.

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

Part 1:
General methodology

1 Scope

This part of ISO 13579 specifies a general methodology for measuring energy balance and calculating the efficiency of the process involving industrial furnaces and associated processing equipment as designed by furnace manufacturers. This general methodology includes:

— measurement methods;

— calculations (general calculation);

— an energy balance evaluation report.

This part of ISO 13579 is not applicable to any efficiencies related to the process itself outside of industrial furnaces and associated processing equipment (e.g. in a rolling mill process, the reheating furnace is intended to be the only part covered by this part of ISO 13579).

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13574, *Industrial furnaces and associated processing equipment — Vocabulary*

3 Terms and definitions

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

3.1 Terms related to type of energy used in this part of ISO 13579

3.1.1 Total energy input

3.1.1.1
total energy input
E_{input}
aggregate of measured energy input brought into the area of energy balance, and which is composed of fuel equivalent energy and other energy input

3.1.2 Fuel equivalent energy

3.1.2.1
fuel equivalent energy
E_{fe}
aggregate of input energy which is composed of calorific value of fuel, calorific value of waste, calorific value of source gas of atmospheric gas and fuel equivalent energy of electricity

3.1.2.2
calorific value of fuel
$E_{h,fuel}$
heat of combustion of fuel which is consumed and used for heating products in the area of energy balance

3.1.2.3
calorific value of waste
$E_{h,waste}$
calorific value of waste which is brought to the area of energy balance with products

EXAMPLE Waste oil on aluminium scrap.

3.1.2.4
calorific value of source gas of atmospheric gas
$E_{fe,atm,cal}$
calorific value of source gas of atmospheric gas which is used as protective and reactive atmospheres

3.1.2.5
fuel equivalent energy of electricity
$E_{fe,el}$
aggregate of fuel equivalent energy of electricity converted from each occurrence of electrical energy consumptions in the area of energy balance

3.1.3 Other energy input

3.1.3.1
other energy input
E_{others}
energy that is composed of sensible heat of fuel, sensible heat of combustion air or other oxidant, sensible heat of atomization agent for liquid fuel, heat of reaction and sensible heat of infiltration air

3.1.3.2
heat of reaction
E_{react}
heat generated by the oxidation reaction of products in the area of energy balance measurement

EXAMPLE The formation of scale of steel products during the oxidation reaction.

3.1.3.3
sensible heat of infiltration air
$E_{s,infilt}$
sensible heat of air that leaks into the furnace through supply/discharge port or gaps in the operating systems of the furnace

Note 1 to entry This term may be replaced with "sensible heat of false air".

3.1.4 Total energy output

3.1.4.1
total energy output
E_{output}
aggregate of measured energy output emitted from or consumed in the area of energy balance, which is composed of thermal energy output, energy consumed in electrical auxiliary equipment, energy used for generation of utility and electrical generation loss

3.1.5 Thermal energy output

3.1.5.1
thermal energy output
$E_{therm,out}$
aggregate of thermal energy which is emitted from the area of energy balance

Note 1 to entry Thermal energy output is composed of energy defined in 3.1.5.2 to 3.1.5.13.

3.1.5.2
effective energy
E_{effect}
enthalpy that products gained in the area of energy balance

3.1.5.3
jig loss
$E_{l,jig}$
enthalpy that jigs for handling the products gained in the area of energy balance measurement

3.1.5.4
sensible heat of oxidized substance
$E_{l,oxid}$
sensible heat of substances which have reacted with oxygen, formed in the thermal process brought out from the area of energy balance measurement

3.1.5.5
sensible heat of exhaust gas
$E_{exhaust}$
sensible heat of expended gas which is emitted from the area of energy balance measurement

3.1.5.6
heat storage loss by batch-type furnace
$E_{l,storage}$
sensible heat which a furnace refractory gains within a batch-type furnace operation cycle

3.1.5.7
sensible heat loss of atmospheric gas
$E_{s,atm}$
sensible heat which atmospheric gas for thermal processing gains through the area of energy balance

3.1.5.8
wall loss
$E_{l,wall}$
thermal energy emitted from the surface of industrial furnaces by radiation and convection

3.1.5.9
heat loss of discharged blowout from furnace opening
$E_{l,blowout}$
sensible heat of blowout gas emitted from the furnace opening

3.1.5.10
heat loss of radiation from furnace opening
$E_{l,opening}$
thermal energy emitted from the furnace opening by radiation

3.1.5.11
heat loss from furnace parts installed through furnace wall
$E_{l,parts}$
thermal energy emitted through furnace parts which are installed through furnace wall

EXAMPLE As in the case of a roller hearth furnace.

3.1.5.12
cooling water loss
$E_{l,cw}$
thermal energy brought out by cooling water from the area of energy balance measurement

3.1.5.13
other losses
$E_{l,other}$
unmeasured thermal energy losses from the area of energy balance

3.1.6 Energy consumed in electrical auxiliary equipment

3.1.6.1
energy consumed in electrical auxiliary equipment
E_{aux}
energy utilized in electrical auxiliary equipment which is composed of energy consumed in installed electrical auxiliary equipment and energy used for fluid transfer

3.1.6.2
energy consumed in installed electrical auxiliary equipment
$E_{aux,installed}$
aggregate of total energy used in installed electrical auxiliary equipment (e.g. fans, pumps) installed in the area of energy balance

3.1.6.3
energy used for fluid transfer
$E_{aux,fluid}$
aggregate of energy for fluid transfer calculated from the property of the fluid

EXAMPLE For cooling water, fuel, etc.

3.1.7 Energy used for generation of utility

3.1.7.1
utility
service other than fuel and electricity provided to the area of energy balance

EXAMPLE Oxygen, steam and atmospheric gas.

3.1.7.2
energy used for generation of utilities
$E_{utility}$
aggregate of energy for the generation of utilities used in the area of energy balance

3.1.8 Electrical generation loss

3.1.8.1
electrical generation loss
$E_{l,eg}$
energy loss in electrical generation which is backcalculated from fuel equivalent energy and total consumed electrical energy

3.1.9 Thermal energy balance

3.1.9.1
thermal energy input from electrical heating source
heat energy entering the process from an electrical heating source, such as an electrical heater emitted to the area of energy balance

3.1.9.2
circulating heat
heat that circulates within equipment or system installed in the area of energy balance

3.1.10 Energy balance of electrical generation

3.1.10.1
total consumed electrical energy
$E_{e,total}$
aggregate of electrical energy which is consumed in the area of energy balance and equal to the sum of thermal energy input from electrical heating source, energy consumed in electrical auxiliary equipment and electrical energy used for the generation of utility

3.1.10.2
electrical energy used for generation of utilities
$E_{e,utility}$
aggregate of electrical energy consumed for generation of utilities (e.g. generation of oxygen) used in the area of energy balance

3.1.11 Recycled energy

3.1.11.1
recycled energy
E_{re}
energy that is regenerated from the wasted thermal energy from the area of energy balance

EXAMPLE Energy reused in waste gas boiler.

4 Symbols used in this part of ISO 13579

For the purposes of this document, the following symbols apply.

NOTE 1 Tons used are metric tons.

NOTE 2 For the units of volume of gas, see 6.5.

Symbol	Meaning	Unit
A	combustion air volume provided per ton of products	m^3(n)/t
A_0	theoretical volume of combustion air required per unit quantity of fuel	m^3(n)/kg or m^3(n)/m^3(n)
C	heat conductivity of hearth material	W/mK

Symbol	Meaning	Unit
$c_{pm,atm1}$	mean specific heat of atmospheric gas between T_{atm1} and 273,15 K	kJ/(kg·K)
$c_{pm,atm2}$	mean specific heat of atmospheric gas between T_{atm2} and 273,15 K	kJ/(kg·K)
$c_{pm,j1}$	mean specific heat of jigs/fixtures between T_{j1} and 273,15 K	kJ/(kg·K)
$c_{pm,j2}$	mean specific heat of jigs/fixtures between T_{j2} and 273,15 K	kJ/(kg·K)
$c_{pm,E}$	mean specific heat of exhaust gas between T_E and 273,15 K	kJ/(kg·K)
$c_{pm,a}$	mean specific heat of combustion air between ambient temperature and 273,15 K	kJ/(m^3(n)·K)
$c_{pm,a1}$	mean specific heat of combustion air between its specified temperature and 273,15 K	kJ/(kg·K) or kJ/m^3(n)·K
$c_{pm,f1}$	mean specific heat of fuel between its provided temperature and 273,15 K	kJ/(kg·K) or kJ/m^3(n)·K
$c_{pm,gf}$	mean specific heat of blowout between $\mathrm{T_{gf}}$ and 273,15K	kJ/m^3(n)·K
$c_{pm,p1}$	mean specific heat of products between T_{p1} and 273,15 K	kJ/(kg·K)
$c_{pm,p2}$	mean specific heat of products between T_{p2} and 273,15 K	kJ/(kg·K)
$c_{pm,ri}$	mean specific heat of refractory of each layer	kJ/(kg·K)
E_{aux}	energy consumed in electrical auxiliary equipment per ton of products	kJ/t
$E_{aux,fluid}$	aggregate of energy used for fluid transfer per ton of products	kJ/t
$E_{aux,fluid,bl}$	energy used for fluid transfer by blowers per ton of products	kJ/t
$E_{aux,fluid,comp}$	energy used for fluid transfer by compressors per ton of products	kJ/t
$E_{aux,fluid,pump}$	energy used for fluid transfer by blowers per ton of products	kJ/t
$E_{aux,installed}$	aggregate of energy used in installed electrical auxiliary equipment per ton of products	kJ/t
$E_{e,utility}$	Electrical energy used for generation of utility per ton of products	kJ/t
E_{effect}	effective energy per ton of products	kJ/t
$E_{exhaust}$	sensible heat of exhaust gas per ton of products	kJ/t
E_{fe}	fuel equivalent energy of electricity per ton of products	kJ/t
$E_{fe,atm,cal}$	calorific value of source gas of atmospheric gas per ton of products	kJ/t
$E_{fe,el}$	fuel equivalent energy per ton of products	kJ/t
$E_{h,fuel}$	calorific value of fuel per ton of products	kJ/t
$E_{h,waste}$	calorific value of waste per ton of products	kJ/t
E_{input}	total energy input per ton of products	kJ/t
$E_{l,blowout}$	heat loss of discharged blowout from furnace opening per ton of products	kJ/t
$E_{l,cw}$	cooling water loss per ton of products	kJ/t
$E_{l,eg}$	energy loss in electrical generation	kJ/t
$E_{l,jig}$	jig loss per ton of products	kJ/t
$E_{l,opening}$	heat loss of radiation from furnace opening per ton of products	kJ/t
$E_{l,other}$	other losses per ton of products	kJ/t
$E_{l,parts}$	Heat loss from furnace parts installed through furnace wall	kJ/t
$E_{l,storage}$	heat storage loss by batch-type furnace per ton of products	kJ/t
$e_{l,storage}$	heat storage loss by batch-type furnace per 1m2 of furnace wall	kJ/m^2
$E_{l,wall}$	wall loss per ton of products	kJ/t
$E_{l,wall,1}$	wall loss from furnace wall and flue per ton of products	kJ/t
$E_{l,wall,2}$	wall loss from hearth per ton of products	kJ/t

Symbol	Meaning	Unit
E_{others}	other energy input per ton of products	kJ/t
E_{output}	total energy output per ton of products	kJ/t
E_{p1}	sensible heat (or enthalpy) of products at the time when products are loaded in the area of energy balance per ton of products	kJ/t
E_{p2}	sensible heat (or enthalpy) of products at the time when products are extracted from the area of energy balance per ton of products	kJ/t
E_{react}	heat of reaction per ton of products	kJ/t
E_{re}	energy regenerated from the wasted thermal energy per ton of products	kJ/t
$E_{s,air}$	sensible heat of combustion air or other oxydant per ton of products	kJ/t
$E_{s,atm}$	sensible heat loss of atmospheric gas per ton of products	kJ/t
$E_{s,atomize}$	sensible heat of atomization agent per ton of products	kJ/t
$E_{s,fuel}$	sensible heat of fuel per ton of products	kJ/t
$E_{s,infilt}$	sensible heat of infiltration air per ton of products	kJ/t
$E_{s,oxid}$	sensible heat of oxidized substance per ton of products	kJ/t
$E_{therm,out}$	thermal (output) energy per ton of products	kJ/t
$E_{utility}$	energy used for generation of utilities per ton of products	kJ/t
$E_{u,atm,gen}$	energy used for generation of atmospheric gas per ton of products	kJ/t
$E_{u,atm,cal}$	calorific value of source gas of atmospheric gas per ton of products	kJ/t
$E_{u,oxy}$	energy for generation of oxygen per ton of products	kJ/t
$E_{u,steam}$	energy for generation of steam per ton of products	kJ/t
G_0	theoretical volume of exhaust gas per unit quantity of fuel	m^3(n)/kg or m^3(n)/m^3(n)
G'_0	theoretical volume of dry exhaust gas per unit quantity of fuel	m^3(n)/kg or m^3(n)/ m^3(n)
H_d	net pump head of pump	M
H_j	net calorific value of component j of gaseous fuel	kJ/m^3(n)
H_h	gross calorific value per unit quantity of fuel	J/kg or kJ/m3(n)
H_l	net calorific value per unit quantity of fuel	J/kg or kJ/ m3(n)
$H_{l,source\ gas}$	net calorific value of source gas	kJ/m^3(n)
H_{wall}	heat storage of multilayer furnace refractory per 1m^2	kJ/m^2
h_{c0}	convection heat transfer coefficient	W/m^2K
h_0	enthalpy of atomization agent at reference temperature	kJ/kg
k_{parts}	heat conductivity of furnace parts of furnace installed through furnace wall	W/mK
L_{th}	theoretical power of compressor	kW
l_1, l_2, l_3	thickness of each refractory layer	M
l_{iw}	inner dimension between sidewalls of furnace	M
l_w	thickness of furnace wall	M
M_j	mass of jigs/fixtures used per ton of products	kg/t
M_{loss}	loss of mass per ton of products	kg/t
M_p	mass of products	kg or t
m	excess combustion air ratio	–
P_d	absolute pressure of fluid at the inlet of furnace	MPa
P_h	static pressure at the inlet	kPa

Symbol	Meaning	Unit
P_s	absolute pressure of atmosphere	MPa
P_{sf}	saturated water vapour pressure	Pa
P_f	absolute pressure of fuel/air	Pa
p_h	static pressure of fluid measured at the inlet of furnaces	kPa
Δ_{po}	difference of pressure at openings	Pa
Q_{blower}	power of blower	kW
Q_{pumps}	power of pump	kW
Q_{comp}	power of compressor	kW
$Q_{aux,installed}$	electrical power consumed in each of installed electrical auxiliary equipment measured per ton of products	kW
$Q_{aux,fluid}$	electrical power used for fluid transfer per ton of products	kW
q_c	heat flux by convection	W/m^2
q_e	energy flux emitted from the furnace surface	W/m^2
q_h	heat energy loss from hearth	W/m^2
q_r	heat flux by radiation	W/m^2
q_t	energy flux through the furnace refractory	W/m^2
R_f	flow rate of fluid at the condition of atmosphere	m^3(n)/min
R	latent heat of water vapour	kJ/kg
r_f	flow rate of fluid measured at the inlet of furnaces	m^3/min
$S_{surface}$	surface area of furnace	m^2
S_{hearth}	surface area of furnace hearth	m^2
$S_{opening}$	area of openings	m^2
S_{parts}	cross-sectional area of furnace parts installed through furnace wall	m^2
T_a	ambient temperature	K
T_{a1}	temperature of combustion air provided	K
T_{atm1}	temperature of atmospheric gas provided	K
T_{atm2}	temperature of atmospheric gas discharged	K
$T_{E,max,i}$	maximum temperature of exhaust gas from regenerative burners in a single cycle	K
$T_{E,min}$	minimum temperature of exhaust gas from regenerative burners in a single cycle	K
T_E	temperature of mean exhaust gas	K
T_{f1}	temperature of fuel provided	K
T_{gf}	temperature of blowout	K
T_h	temperature of hearth surface	K
T_{j1}	temperature of jigs/fixtures at the time of loading to the area of energy balance	K
T_{j2}	temperature of jigs/fixtures at the time of extracting from the area of the energy balance	K
T_{p1}	average temperature of products at the time of loading to the area of energy balance	K
T_{p2}	average temperature of products at the time of extracting from the area of the energy balance	K
T_w	temperature of furnace wall surface	K

Symbol	Meaning	Unit
$T_{water\ out}$	cooling water temperature at its discharge port	K
$T_{water\ in}$	cooling water temperature at is supply port	K
T_z	temperature of inside furnace	K
t_{open}	time of opening (e.g. charge/discharge door) per ton of products	h/t
t_p	time required to process one ton of product	h/t
T_{r1}, T_{r2}	boundary temperature of refractory	K
U	mean velocity of fluid measured at the supplying point	m/s
V_{atm}	volume of atmospheric gas provided per ton of products	m^3(n)/t
$V_{atomize}$	mass of atomization agent provided per ton of products	kg/t
V_{cw}	quantity of cooling water used per ton of products	kg/t
V_f	fuel consumption per ton of products	kg/t m3(n)/t
V_{gf}	volume of blowout per hour	m^3/h
V_{infilt}	infiltration air volume provided per ton of products	m^3(n)/t
V_{me}	measured combustion air volume per ton of products	m^3(n)/t
V_{oxy}	amount of oxygen used per ton of products	m^3(n)/t
$V_{source\ gas}$	volume of source gas of atmospheric gas used per ton of products	m^3(n)/t
x_j	volume fraction of component j of gaseous fuel	—
z	depth from the water surface	m
φ_{H_2}	volume fraction of hydrogen contained in gaseous fuel	—
φ_{N_2}	volume fraction of nitrogen contained in gaseous fuel	—
φ_{O2}	volume fraction of oxygen contained in gaseous fuel	—
φ_{H_2O}	volume fraction of water contained in gaseous fuel	—
φ_{CO}	volume fraction of carbon monoxide contained in gaseous fuel	—
φ_{CO_2}	volume fraction of carbon dioxide contained in gaseous fuel	—
$\varphi_{C_xH_y}$	volume fraction of carbon hydrate contained in gaseous fuel	—
φ_{H_2S}	volume fraction of hydrogen sulphide contained in gaseous fuel	—
w_C	mass fraction of carbon contained in liquid fuel	—
w_H	mass fraction of hydrogen contained in liquid fuel	—
w_O	mass fraction of oxygen contained in liquid fuel	—
w_S	mass fraction of sulfur contained in liquid fuel	—
w_W	mass fraction of water contained in liquid fuel	—
$\varphi_{(N_2)}$	volume fraction of nitrogen contained in the combustion air	—
$\varphi_{(O_2)}$	volume fraction of oxygen contained in the combustion air	—
$\varphi_{(H_2O)}$	volume fraction of water contained in combustion air	—
$\varphi_{[N_2]}$	volume fraction of nitrogen contained in dry exhaust gas	—
$\varphi_{[O_2]}$	volume fraction of oxygen contained in dry exhaust gas	—
$\varphi_{[CO]}$	volume fraction of carbon monoxide contained in dry exhaust gas	—
$\varphi_{[CO_2]}$	volume fraction of carbon dioxide contained in dry exhaust gas	—
$\varphi_{[CO_2]max}$	maximum volume fraction of carbon dioxide contained in exhaust gas	—
$\varphi_{<N_2>}$	volume fraction of nitrogen contained in exhaust gas per unit quantity of fuel	m^3(n)/kg fuel or m^3(n)/m^3(n) fuel

Symbol	Meaning	Unit
$\varphi_{<O_2>}$	volume fraction of oxygen contained in dry exhaust gas per unit quantity of fuel	m^3(n)/kg fuel or m^3(n)/m^3(n) fuel
$\varphi_{<H_2O>}$	volume fraction of water contained in dry exhaust gas per unit quantity of fuel	m^3(n)/kg fuel or m^3(n)/ m^3(n) fuel
$\varphi_{<CO_2>}$	volume fraction of carbon dioxide contained in dry exhaust gas per unit quantity of fuel	m^3(n)/kg fuel or m^3(n)/ m^3(n) fuel
$\varphi_{<SO_2>}$	volume fraction of sulfur dioxide contained in dry exhaust gas per unit quantity of fuel	m^3(n)/kg fuel or m^3(n)/ m^3(n) fuel
$\varphi_{<H_2S>}$	volume fraction of hydrogen sulfide contained in dry exhaust gas per unit quantity of fuel	m^3(n)/kg fuel or m^3(n)/ m^3(n) fuel
α_f	coefficient of friction	—
α_{hearth}	coefficient determined by the shape of hearth	—
α_m	tolerance of machinery	—
$\alpha_{opening}$	coefficient determined from the shape of openings	—
α_{oxy}	energy consumption rate for production per 1 normal cubic metre of oxygen	kWh/m^3(n)
ε_1	emissivity of furnace surface	—
ε_2	coefficient of determined from the shape of furnace openings	—
η_1	total energy efficiency	—
η_c	overall adiabatic efficiency of compressor	—
η_e	regional electrical generation efficiency	—
η_p	efficiency of pump	—
η_t	overall adiabatic efficiency of compressor	—
η_s	static pressure efficiency of blower	—
κ	ratio of specific heat of fluid	—
λ	heat conductivity of furnace refractory	W/mK
ρ_1, ρ_2, ρ_3	density of each refractory layer	kg/m^3
ρ_f	density of fluid	kg/m^3
σ	Stephen-Boltzmann constant	kJ/m^2 h K^4
ϕ_f	relative humidity	—

5 Basic principles

5.1 General

The area of energy balance measurement shall be determined.

NOTE An example of determination of the area of energy balance measurement is shown in Figure 1.

The following aspects shall be included in the energy balance measurement:

a) energy input;

— fuel equivalent energy, E_{fe};

— other energy input, E_{others};

b) energy output:

— thermal energy output, $E_{therm,out}$;

— energy consumed in electrical auxiliary equipment, E_{aux};

— energy used for generation of utilities, $E_{utilities}$;

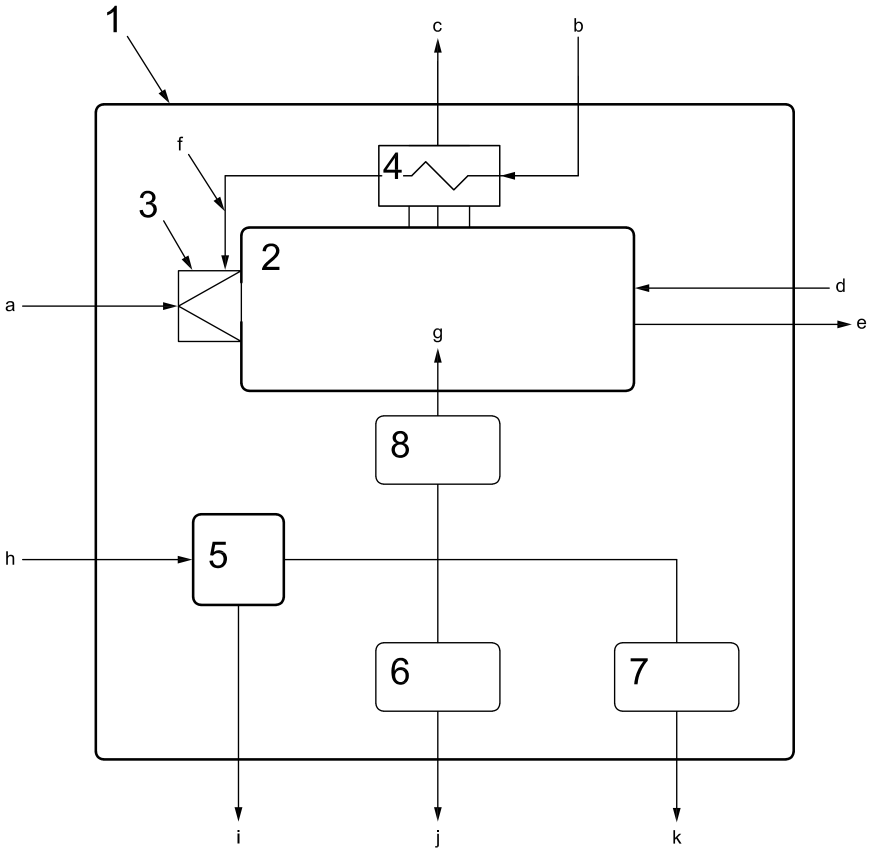
— electrical generation loss, $E_{l,eg}$.

Determine the energy input and energy output which goes into and comes out of the area of energy balance, based on the measurement data.

The total energy input into the area shall balance the total energy output from the area.

The result of the energy balance measurement shall be summarized into energy input and energy output in an energy balance sheet with necessary information, such as equipment summary, measurement condition and measurement data.

Thermal energy balance and electrical generation may be created as subcategories (see 7.3 and 7.4).



Key

1 area of energy balance
2 furnace chamber
3 burner
4 heat exchanger
5 electrical generation
6 electrical auxiliary equipment
7 generation of utilities
8 electrical heating

[a] Calorific value, $E_{h,fuel}$, and sensible heat of fuel, $E_{s,fuel}$.
[b] Sensible heat of combustion air, $E_{s,air}$.
[c] Sensible heat of exhaust gas, $E_{exhaust}$.
[d] Thermal energy input, such as heat of reaction, E_{react}, and sensible heat of infiltration air, $E_{s,infilt}$.
[e] Thermal energy output, such as effective energy, E_{effect}, and heat losses.
[f] Circulating heat plus sensible heat of combustion air.
[g] Thermal energy input from electrical heating sources.
[h] Fuel equivalent energy of electricity, $E_{fe,el}$.
[I] Electrical generation loss, $E_{l,eg}$.
[j] Electrical energy consumption in electrical auxiliary equipment, E_{aux}.
[k] Electrical energy consumption for generation of utilities, $E_{u,atm,gen}$.

Figure 1 — Example of determination of the area of energy balance measurement

5.2 Energy flow diagram

The energy flow diagram is a useful tool to represent input and output energy flow (see Figure 2).

NOTE An energy flow diagram is also known as a Sankey diagram.

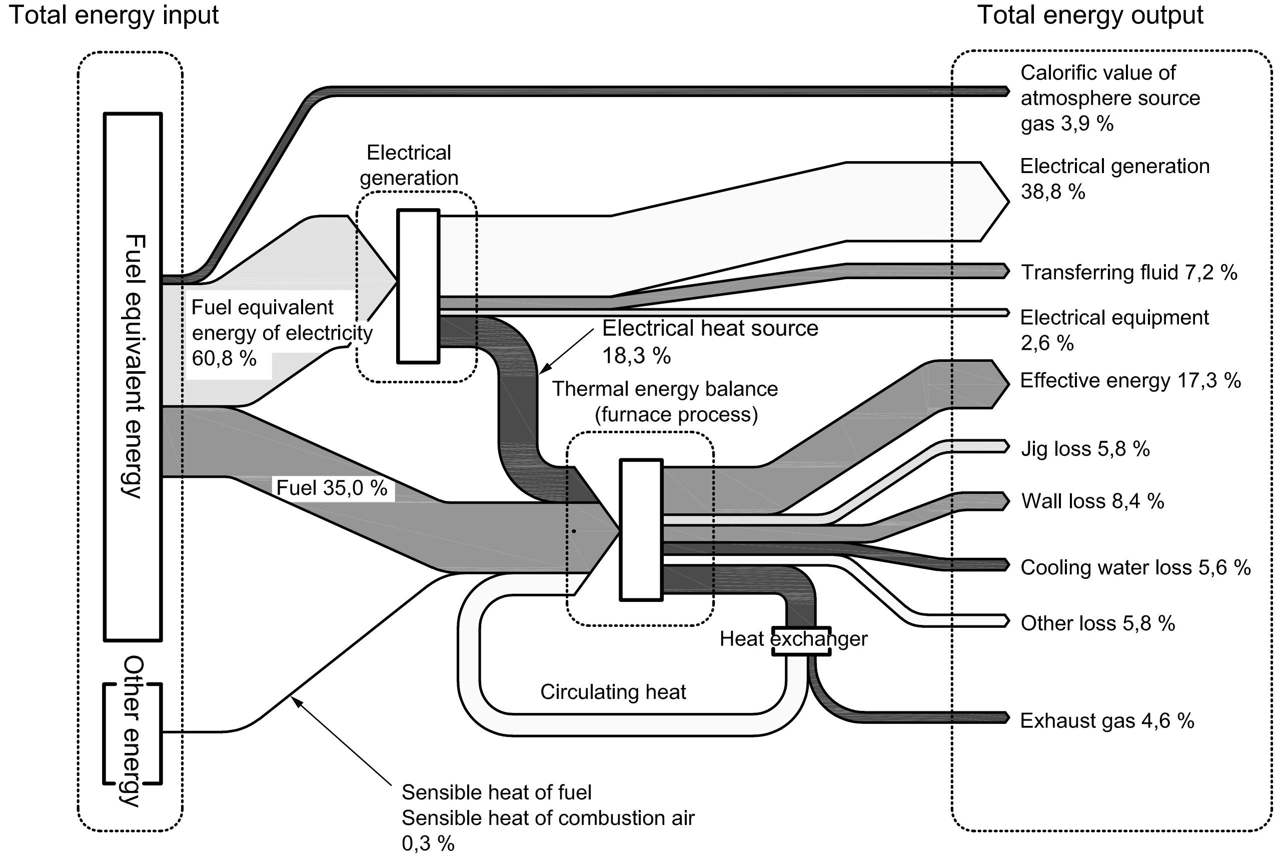


Figure 2 — Example of energy flow diagram (Sankey diagram) of industrial furnace

5.3 Process Heating Assessment Survey Tool

Developed by the U.S. Department of Energy, the software Process Heating Assessment and Survey Tool (PHAST)[25] provides an introduction to process heating methods and tools to improve thermal efficiency of heating equipment. The tool is used to survey process heating equipment that uses fuel, steam or electricity, and identify the most energy-intensive equipment. Users may also perform an energy (heat) balance on selected equipment (furnaces) to identify and reduce non-productive energy use, compare performance of the furnace under various operating conditions and test "what-if" scenarios.

The thermal energy calculation function may be used as a tool which supplements the calculation specified in this part of ISO 13579, such as:

- sensible heat of material (effective energy);
- jig loss:
- calculations related to combustion;
- sensible heat of atmospheric gas;
- wall loss;
- heat loss of radiation from furnace opening;

— cooling water loss;

— exhaust gas losses.

6 Basic conditions of measurement and calculation

6.1 State of furnace

Furnaces subject to measurement shall be operated under normal conditions and

— in the case of continuous furnaces, the temperature and throughput shall be in the steady state considered in the design calculation, and

— in the case of batch-type furnaces, the temperature cycle and throughput shall be as considered in the design calculation.

Normal operating conditions are generally based on nominal conditions stipulated in the specification. But in the case of no specified condition, it may defined by the supplier, e.g. two thirds of design throughput.

6.2 Duration of measurement

In the case of continuous furnaces, the duration of the energy balance measurement should be at least twice as long as the time the products stay in the furnace chamber.

In the case of batch-type furnaces, calculations shall be performed for each batch.

6.3 Unit of specific energy consumption

The basic unit of specific energy consumption shall be one kilo joule per ton (i.e. 1 000 kg) (kJ/t) of product, unless otherwise specified.

6.4 Reference conditions

The reference conditions shall be 0 °C (273,15 K) and 101 325 Pa, unless otherwise specified.

6.5 Unit of amount of gas

The values of amount of gas represented in this part of ISO 13579 shall be expressed in terms of volume under the reference conditions specified in 6.4, unless otherwise specified.

The unit of volume under the reference conditions shall be expressed in normal cubic metres [m^3(n)], unless otherwise specified.

NOTE 2,24 × 10^2 normal cubic metres is equivalent to 1 mol.

6.6 Fuel

The unit quantity of fuel is

— 1 kg in the case of liquid fuel, or

— one normal cubic metre [1 m^3(n)] in the case of gaseous fuel.

In this part of ISO 13579, net calorific value of fuel is used as a calorific value.

7 Type of energy evaluated in this part of ISO 13579 and its systematization

7.1 General

The energy evaluated in this part of ISO 13579 and their symbols are defined in Clause 3.

All energy shall be expressed in kilojoules per ton of product (kJ/t), unless otherwise specified.

7.2 Energy balance

Systematization of energy evaluated in this part of ISO 13579 is described in Table 1.

Table 1 — Systematization of type of energy evaluated in this part of ISO 13579 — Overall energy balance

Type of energy			
Total energy input/output	**Intermediate category**	**Detailed item**	
Total energy input, E_{input}	Fuel equivalent energy, E_{fe}	Calorific value of fuel, $E_{h,fuel}$	
		Calorific value of waste, $E_{h,waste}$	
		Calorific value of source gas of atmospheric gas, $E_{fe,atm,cal}$	
		Fuel equivalent energy of electricity, $E_{fe,el}$	
	Other energy input, E_{others}	Sensible heat of fuel, $E_{s,fuel}$	
		Sensible heat of combustion air, $E_{s,air}$	
		Sensible heat of atomization agent, $E_{s,atomize}$	
		Heat of reaction, E_{react}	
		Sensible heat of infiltration air, $E_{s,infilt}$	
Total energy output, E_{output}	Thermal energy, $E_{therm,out}$	Effective energy, E_{effect}	
		Jig loss, $E_{l,jig}$	
		Sensible heat of oxidized substance, $E_{s,oxid}$	
		Sensible heat of exhaust gas, $E_{exhaust}$	
		Heat storage loss by batch-type furnace, $E_{l,storage}$	
		Sensible heat loss of atmospheric gas, $E_{s,atm}$	
		Wall loss, $E_{l,wall}$	
		Heat loss of discharged blowout from furnace opening, $E_{l,blowout}$	
		Heat loss of radiation from furnace opening, $E_{l,opening}$	
		Heat loss from furnace parts installed through furnace wall, $E_{l,parts}$	
		Cooling water loss, $E_{l,cw}$	
		Other losses, $E_{l,other}$	
	Electrical auxiliary equipment, E_{aux}	Energy consumed in installed electrical auxiliary equipment, $E_{aux,installed}$, blowers, etc.	
		Energy used for fluid transfer, $E_{aux,fluid}$, cooling water, etc.	
	Generation of utilities, $E_{utility}$	Oxygen, $E_{u,oxy}$	
		Steam, $E_{u,steam}$	
		Atmospheric gas	energy for generation, $E_{u,atm,gen}$
			calorific value of source gas, $E_{u,atm,cal}$
	Electrical generation loss, $E_{l,eg}$		

7.2.1 Total energy input

See 3.1.1.

7.2.2 Fuel equivalent energy

See 3.1.2.

The calorific value of source gas of atmospheric gas, $E_{fe,atm,cal}$, shall be added as energy input even though the atmospheric gas is emitted from the furnace in an unburned state.

Regional electrical generation efficiency shall be applied to the convention of fuel equivalent energy of electricity, $E_{fe,el}$.

7.2.3 Other energy input

See 3.1.3.

7.2.4 Total energy output

See 3.1.4.

7.2.5 Thermal energy output

See 3.1.5.

7.2.6 Energy consumed in electrical auxiliary equipment

See 3.1.6.

If part of the energy consumed in electrical auxiliary equipment, $E_{aux,installed}$, is used as thermal energy in the heating process, the thermal energy shall be subtracted from the total energy consumed in the installed electrical auxiliary equipment.

Energy used for fluid transfer, $E_{aux,fluid}$, shall be applied when energy consumed in auxiliary electrical equipment for fluid transfer, such as a pump, cannot be determined from the measurement of electrical energy supplied to the equipment (e.g. cooling water supplied from the factory facilities).

7.2.7 Energy used for generation of utility

See 3.1.7.

Energy used for generation of utilities, $E_{utility}$, other than oxygen, steam and atmospheric gas for heat treatment may be excluded.

Energy for generation of atmospheric gas for heat treatment shall include calorific value of source gas, $E_{u,atm,cal}$, and the energy for generation of the atmospheric gas, $E_{u,atm,gen}$.

7.2.8 Electrical generation loss

See 3.1.8.

7.3 Thermal energy balance

7.3.1 General

Thermal energy balance sheet may be created as a subcategory of total energy balance. The thermal energy balance shall be a part of the total energy balance.

The area of thermal energy balance should be basically equivalent to the industrial furnace chambers subject to measurement (see Figure 1).

The systematization of thermal energy is described in Table 2.

Table 2 — Systematization of type of energy evaluated in this part of ISO 13579 — Thermal energy balance

Type of energy		
Thermal energy input/output	**Intermediate category/detailed item**	
Thermal energy input	Calorific value of fuel, $E_{h,fuel}$	
	Calorific value of waste, $E_{h,waste}$	
	Thermal energy input from electrical heating source	
	Other energy input, E_{others}	Sensible heat of fuel, $E_{s,fuel}$
		Sensible heat of combustion air, $E_{s,air}$
		Sensible heat of atomization agent, $E_{s,atomize}$
		Heat of reaction, E_{react}
		Sensible heat of infiltration air, $E_{s,infilt}$
Thermal energy output, $E_{therm,out}$	Effective energy, E_{effect}	
	Jig loss, $E_{l,jig}$	
	Sensible heat of oxidized substance, $E_{s,oxid}$	
	Sensible heat of exhaust gas, $E_{exhaust}$	
	Heat storage loss by batch-type furnace, $E_{l,storage}$	
	Sensible heat loss of atmospheric gas, $E_{s,atm}$	
	Wall loss, $E_{l,wall}$	
	Heat loss of discharged blowout from furnace opening, $E_{l,blowout}$	
	Heat loss of radiation from furnace opening, $E_{l,opening}$	
	Heat loss from furnace parts installed through furnace wall, $E_{l,parts}$	
	Cooling water loss, $E_{l,cw}$	
	Other losses, $E_{l,other}$	
The use of the thermal energy balance sheet is optional.		

7.3.2 Thermal energy input from electrical heating source

See 3.1.9.1.

Thermal energy input from electrical heating source shall not be the fuel equivalent energy of electricity. Efficiency of heat transfer shall be taken into account if necessary.

7.3.3 Circulating heat

See 3.1.9.2.

When circulating heat is determined, it shall be summarized separately from the thermal energy balance sheet.

7.4 Energy balance of electrical generation

7.4.1 General

Energy balance of electrical generation may be used as a subcategory of total energy balance. This electrical energy balance shall be a part of the total energy balance.

NOTE This category is useful when fuel equivalent energy of electricity, $E_{fe,el}$, is calculated.

The systematization of energy related to electrical generation is described in Table 3.

Table 3 — Systematization of type of energy evaluated in this part of ISO 13579 — Electrical generation

<table>
<tr><th rowspan="2">Energy input/output</th><th colspan="3">Type of energy</th></tr>
<tr><th colspan="3">Intermediate category/detailed item</th></tr>
<tr><td>Input</td><td colspan="3">Fuel equivalent energy of electricity, $E_{fe,el}$</td></tr>
<tr><td rowspan="6">Output</td><td rowspan="5">Total consumed electrical energy, $E_{e,total}$</td><td colspan="2">Thermal energy output from electrical heating source</td></tr>
<tr><td rowspan="2">Electrical auxiliary equipment, E_{aux}</td><td>Energy consumed in installed electrical auxiliary equipment, $E_{aux,installed}$,
blowers, etc.</td></tr>
<tr><td>Energy used for fluid transfer, $E_{aux,fluid}$,
cooling water, etc.</td></tr>
<tr><td rowspan="2">Electrical energy used for generation of utilities, $E_{e,utility}$</td><td>Oxygen, $E_{u,oxy}$</td></tr>
<tr><td>Atmospheric gas energy for generation, $E_{u,atm,gen}$</td></tr>
<tr><td colspan="3">Electrical generation loss, $E_{l,eg}$</td></tr>
<tr><td colspan="4">The use of the energy balance sheet of electrical generation is optional.</td></tr>
</table>

7.5 Recycled energy

See 3.1.11.

The value of this type of energy can be deducted from the total energy input in the total energy efficiency calculation as specified in 9.4.1.

8 Measurement method

8.1 General

The result of the measurement of energy balance should include the indication of accuracy.

To decrease the uncertainty of measurement data, the same measurement should be used multiple times and the average be taken. Personnel carrying out the measurement should check if those data are properly taken after the measurement.

NOTE For information about the assessment of uncertainty, see Annex A.

8.2 Fuel

8.2.1 Volume

The volume of consumed gaseous fuel shall be measured with a flow meter near the furnace. The value shall be corrected according to pressure, temperature, etc. The differential pressure flow meter should preferably be in accordance with ISO 5167-1.

NOTE A regional, national or local equivalent of ISO 5167-1 can apply.

The volume of consumed liquid fuel shall be measured with a volumetric flow meter, etc. The measured value shall be converted to mass with compensated density of fuel temperature.

8.2.2 Sampling, testing, analysis and measurement of calorific value

When the calorific value of fuel is not given by the suppliers, the sampling, testing, analysis and measurement of calorific value of applied fuel shall be performed. Reliability of analysis and measurement shall be maintained by complying with the relevant International Standards .

NOTE 1 The following International Standards are associated with the sampling, testing analysis and measurement of calorific value of fuel applied: ISO 91-1, ISO 649-1, ISO 3104, ISO 3170, ISO 3648, ISO 3733, ISO 3987, ISO 4260, ISO 6326-1, ISO 6327, ISO 6615, ISO 6974-1, ISO 6974-2, ISO 6974-3, ISO 6974-4, ISO 6974-5, ISO 6974-6, ISO 6975, ISO 6976, ISO 8216-99, ISO 8754, ISO 9029 and ISO 10370.

NOTE 2 It is the responsibility of the user to take regional, national or local standards into account for the reliability of analysis and measurement.

8.2.3 Pressure and temperature

The pressure of fuel shall be measured upstream of a flow meter and burners.

The temperature of fuel shall be measured upstream of a flow meter and at the adjacent part of burners.

When fuel is preheated, temperature should be measured at both the inlet and outlet of a preheating device.

8.3 Atomization agent

8.3.1 Volume

The volume of atomization agent shall be measured with a differential pressure flow meter, etc., and shall be corrected for temperature and pressure. However, if the measurement is unable to be performed, the calculated approximate value may be used with a conditional clause.

8.3.2 Pressure and temperature

The pressure and temperature of atomization agent shall be measured upstream of a flow meter and burners.

8.4 Combustion air and exhaust gas

8.4.1 Combustion air

8.4.1.1 Combustion air volume

The amount of combustion air shall be measured near the inlet of combustion equipment with a flow meter (differential pressure flow meter, Pitot tube, blower performance curve and electric power, anemometer, etc.), and the measured value shall be corrected with pressure and temperature.

NOTE The combustion air volume can be obtained by calculation (see 9.2.5).

8.4.1.2 Combustion air pressure and temperature

The pressure of combustion air shall be measured upstream of a flow meter and burners.

The combustion air temperature shall be measured at the inlet of burners and at the adjacent part of burners.

When combustion air is preheated, temperature should be measured at both the inlet and outlet of a preheating device.

8.4.2 Exhaust gas

8.4.2.1 Temperature

The average temperature of exhaust gas shall be measured at the outlet of the area of energy balance. When circulation heat generated by preheating equipment is determined, the temperature of both the inlet and outlet side of the equipment shall be measured.

8.4.2.2 Method of exhaust gas analysis

The volume fraction of CO, CO_2, O_2, (H_2 and other hydrocarbon, if expected) contained in exhaust gas shall be sampled and measured using an analyser.

To ensure the gaseous concentration in the sample exhaust gas stream is representative of that in the flue gas, several factors shall be considered:

a) the heterogeneity of the process stream, such as variations in concentration, temperature or velocity across the duct caused by moisture or gas stratification;

b) gas leakage or air infiltration and continuous gas reactions;

c) random errors due to the finite nature of the sample and the sampling procedure adopted to obtain a representative sample.

A water removal process shall be employed.

The measurement position should be the same as the measurement position of exhaust gas temperature.

Reliability of sampling, analysis and measurement shall be maintained by complying with the relevant International Standards.

NOTE 1 The following International Standards are associated with the sampling, analysis and measurement of exhaust gas: ISO 6326-1, ISO 6327:1981, ISO 6974-1, ISO 6974-2, ISO 6974-3, ISO 6974-4, ISO 6974-5, ISO 6974-6, ISO 6975, ISO 6976 and ISO 10396 (see, in particular, ISO 10396:2007, 5.5.3).

NOTE 2 It is the responsibility of the user to take regional, national or local standards into account for the reliability of analysis and measurement.

8.4.3 Measurement method for burners with recuperative functions

8.4.3.1 Regenerative burners

Combustion air preheated temperature in regenerative burners is generally hard to measure; therefore, specified methods shall apply to this type of product.

8.4.3.1.1 Measurement positions

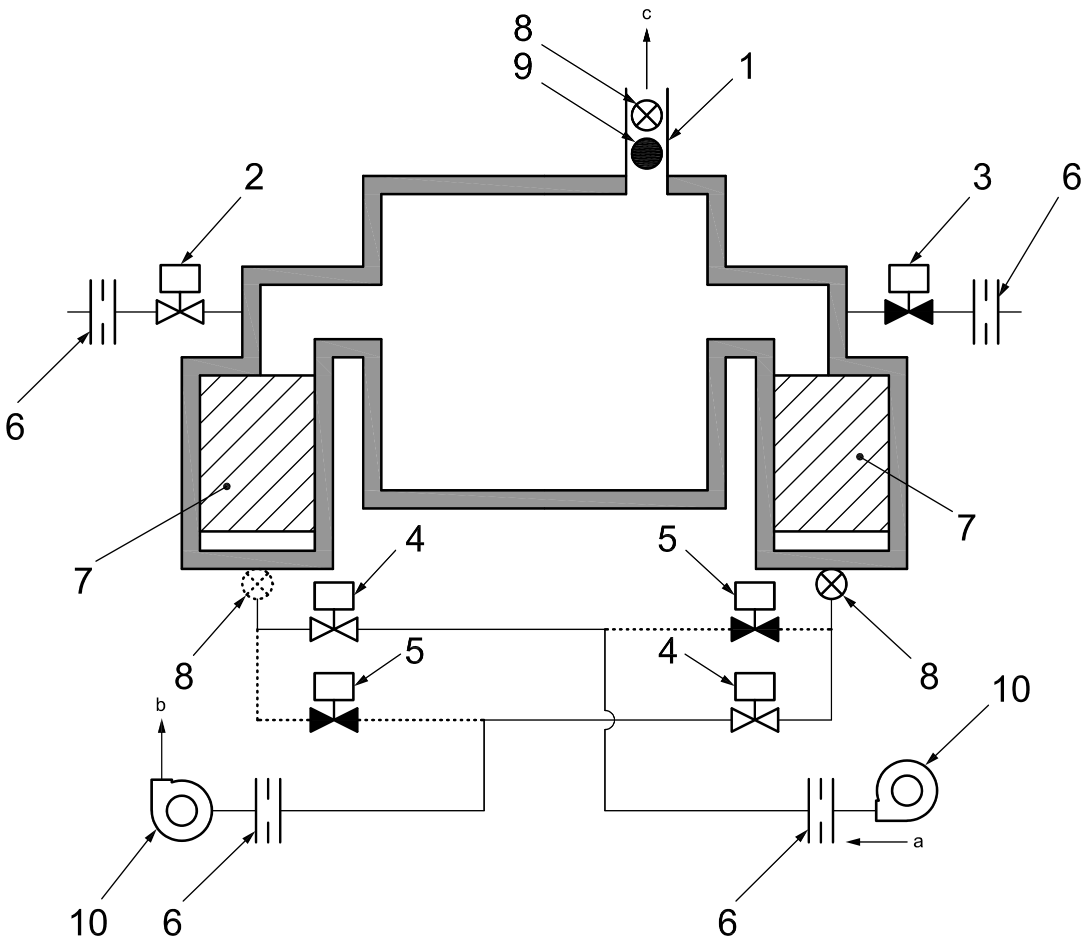
Carry out the measurement of combustion air and exhaust gas for regenerative burners as the following (see Figure 3).

a) The sensible heat of exhaust gas from the furnace shall be measured downstream of the regenerative section of regenerative burners and at the auxiliary flue separately.

b) Temperature of exhaust gas through the regenerative burners shall be measured at the exit of the regenerative burners. The volume of exhaust gas passing through the regenerative burners shall be obtained by measurement.

c) The temperature of exhaust gas through the auxiliary flue shall be measured at the exit of the furnace. The volume of exhaust gas through the auxiliary flue may be obtained by calculation.

NOTE A supplemental comment to this subclause is given in Annex B.



Key

1 auxiliary flue

2 fuel changeover valve (open position)

3 fuel changeover valve (closed position)

4 combustion air/exhaust gas changeover valve (open position)

5 combustion air/exhaust gas changeover valve (closed position)

6 measurement point of flow rate

7 heat exchange media

8 measurement point of temperature

9 measurement point of gas analysis

10 blowers

[a] Direction of flow of combustion air.

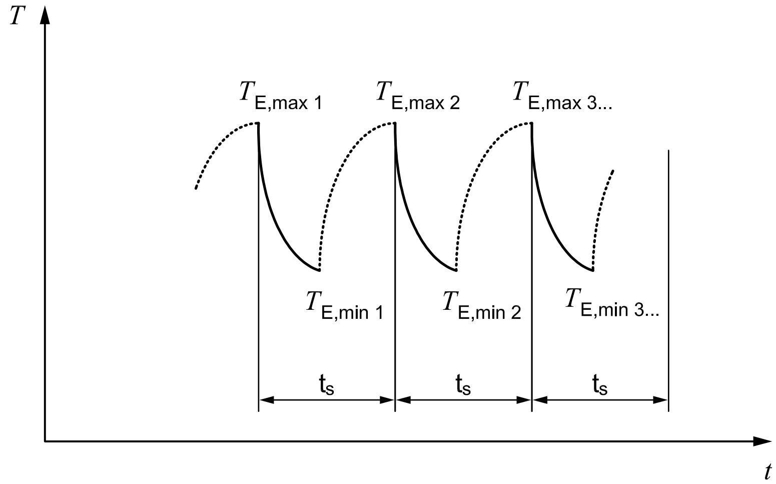
[b] Direction of flow of exhaust gas.

[c] Direction of flow of exhaust gas through auxiliary flue.

Figure 3 — Measurement point of combustion air and exhaust gas to/from regenerative burners

8.4.3.1.2 Measurement of exhaust gas temperature

Determine the temperature under fully stabilized conditions using a thermocouple with satisfactory response. Set the thermocouple on the outlet side of the regenerator, such that it is close to the regenerator, but does not come into contact with it. Perform at least 10 measurement cycles. Figure 4 gives an example of typical temperature curve of exhaust gas from regenerative burners.



Key

$T_{E,max,i}$ maximum temperature of exhaust gas from regenerative burners in a single cycle

$T_{E,min,i}$ minimum temperature of exhaust gas from regenerative burners in a single cycle

t_s cycle time

Figure 4 — Typical temperature curve of exhaust gas from regenerative burners

The average temperature of exhaust gas from regenerative burners is calculated using Formulae (1) and (2):

$$T_E = \frac{\int_{t_0}^{t_0+\Delta t} T(t)dt}{\Delta t} \quad (1)$$

$$\Delta t = Nt_s \quad (2)$$

where N is the number of cycles.

Since the integral calculation as defined is difficult to obtain algebraically, it is permissible to calculate the mean temperature using Formulae (3), (4) and (5):

$$T_E = \frac{1}{2} \times \left(\overline{T_{E,max,i}} + \overline{T_{E,min,i}} \right) \quad (3)$$

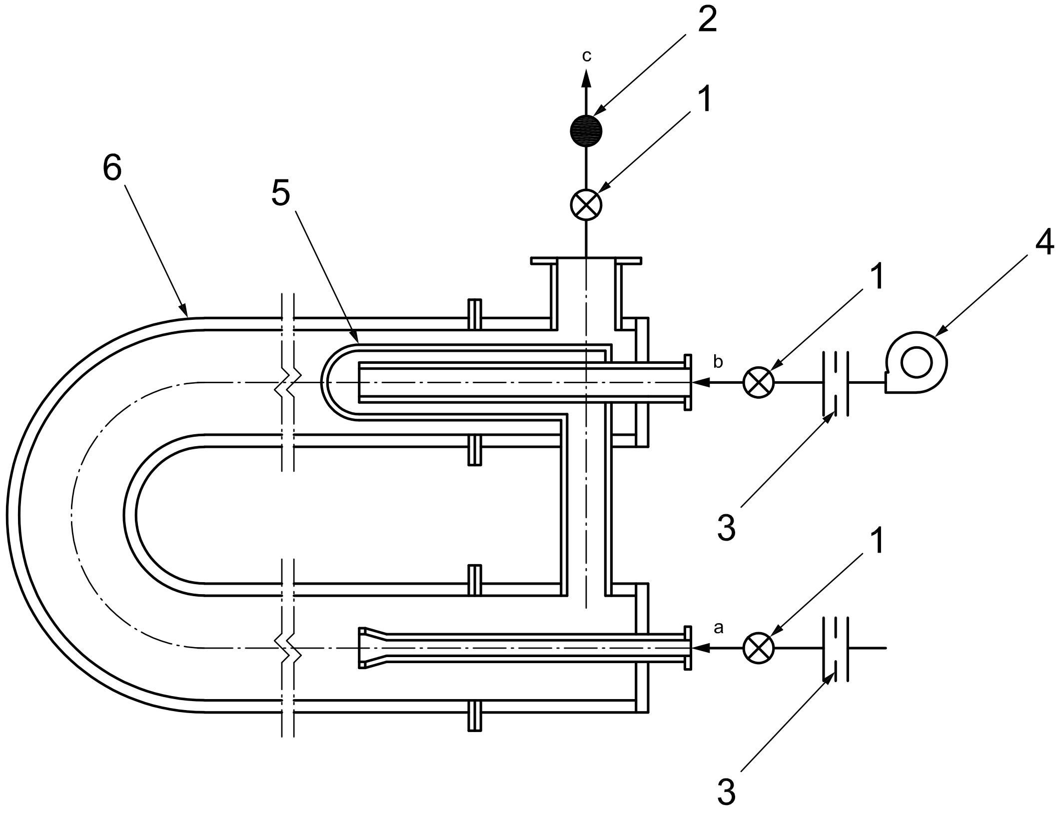
$$\overline{T_{E,max,i}} = \frac{\sum_{i=1}^{N} T_{E,max,i}}{N} \quad (4)$$

$$\overline{T_{E,min,i}} = \frac{\sum_{i=1}^{N} T_{E,min,i}}{N} \quad (5)$$

8.4.3.2 Recuperative radiant tube burners

In case of recuperative radiant tube burners, as shown in Figure 5, it is difficult to measure the temperature of preheated combustion air. Examples of the measurement positions for combustion air, exhaust gas and fuel for recuperative radiant tube burners are given in Figure 5.

NOTE In the case of a furnace with a great number of this type of burner (e.g. continuous annealing line), the measurement positions can be at a represented burner in a control section.



Key

1 measurement point of temperature

2 measurement point of gas analysis

3 measurement point of flow rate

4 blower

5 recuperator

6 radiant tube

[a] Direction of flow of fuel.

[b] Direction of flow of combustion air.

[c] Direction of flow of exhaust gas.

Figure 5 — Measurement point of combustion air, exhaust gas to/from and preheated fuel of recuperative radiant tube burners

8.5 Controlled atmospheric gas

8.5.1 Volume

The volume of controlled atmospheric gas shall be measured with a flow meter (differential pressure flow meter, Pitot tube, etc.). The measured value shall be corrected by pressure and temperature.

8.5.2 Temperature

Controlled atmospheric gas shall be measured at its feeding port to furnace.

8.6 Products and jigs/fixtures for product handling

8.6.1 Mass

Determine the mass of products and jigs per fixture with weighing equipment.

8.6.1.1 Continuous furnaces

In the case of continuous furnaces, determine the mass of products and jigs per fixture, both loaded and unloaded, during the period of measurement.

8.6.1.2 Batch-type furnaces

In the case of batch-type furnaces, determine the mass of products and jigs per fixture per batch.

8.6.2 Temperature

The surface and internal temperature across the width of unloaded products shall be measured just before unloading. The acquired average temperature data are regarded as the temperature of the unloaded products. It is recommended to obtain conversion factors to estimate the internal temperature distribution across the width of the products. In the case of calculations using conversion factors, the background data of conversion factors shall be attached. If temperature measurement is unable to be performed, estimation of the temperature of products at downstream processes or the calculated temperature used in the computer control system for furnace operations may be used.

8.6.3 Mass loss

For steel products processed with reheating furnaces for steel, use ISO 13579-2:2013, 8.6.3.

For aluminium products processed with batch-type aluminium melting furnaces, use ISO 13579-3:2013, 8.5.2.3.

For products specified in ISO 13579-4, mass loss is generally not applicable.

8.7 Temperature of furnace surface

8.7.1 Furnace wall

The measurement of furnace wall surface temperature shall be performed at each separate area (i.e. side, top, bottom, front and back). When there are varieties of temperature zones within a furnace, the temperature of each furnace zone shall be measured. Thermocouples, contact thermometers, radiation thermometers and thermo viewers shall be used.

8.7.2 Cross-sectional area of furnace parts installed through furnace wall

The cross-sectional area of furnace parts with good heat conductivity which are installed through furnace wall (e.g. heath rollers) shall be obtained by actual measurement or calculation using drawings.

8.8 Furnace inner wall temperature

The temperature of the furnace inner wall may be substituted by temperature data gathered from the furnace temperature control unit.

8.9 Inner furnace pressure

Use the indicated values from furnace pressure instrumentation, if installed. Otherwise, measurement of the inner furnace pressure shall be performed and recorded.

8.10 Cooling water

8.10.1 Temperature

Cooling water temperature shall be measured at a supply port and discharge port of furnace.

8.10.2 Volume

Cooling water volume shall be measured at a supply port and/or discharge port of furnace.

8.11 Electrical auxiliary equipment

8.11.1 Installed electrical auxiliary equipment

Determine the electrical energy consumed in installed electrical auxiliary equipment which is necessary for the operation of industrial furnaces within the duration of measurement and convert the electrical energy consumed to fuel-equivalent energy.

Energy used in auxiliary equipment may be obtained from nominal capacity of each equipment if it is reasonable.

NOTE Electrical energy generation conversion factors in Table C.1 can be used.

8.11.2 Energy for fluid transfer

Unless fluid is transferred by auxiliary electrical equipment within the area of total energy efficiency calculation, determine the following in order to obtain the energy for the fluid transfer:

— static pressure of the fluid measured at its supply port;

— volume used within the duration of measurement.

8.12 Generation of utilities

Determine the amount of utilities for the operation of industrial furnaces within the duration of measurement.

8.13 Recycled energy

When recycled energy is regenerated from the waste thermal energy of furnaces under test, determine the amount of energy generated within the duration of the overall measurement of energy balance.

9 Calculation

9.1 General provisions

The conditions of calculation are as specified in Clause 6.

The moisture content of gas shall be considered in the calculations specified in Clause 9, if not otherwise specified.

The composition of the combustion air shall be treated as Formula (6):

$$\varphi_{(N_2)} + \varphi_{(O_2)} + \varphi_{(H_2O)} = 1 \quad (6)$$

The ratio of nitrogen and oxygen contained in the atmosphere shall be treated as 79:21.

Calculations for combustion air and exhaust gas specified in 9.2.5 and 9.3.1.4 are only applied to combustion with excess combustion air ratio 1,0 or more.

NOTE When excess combustion air ratio is less than 1,0, it is necessary to perform chemical equilibrium calculation assuming that the following water gas reaction is realized:

$$\varphi_{\langle CO \rangle} + \varphi_{\langle H_2O \rangle} = \varphi_{\langle CO_2 \rangle} + \varphi_{\langle H_2 \rangle} \quad (7)$$

For symbols used in the calculations, together with their meanings and units, see Clause 4.

9.2 Total energy input

9.2.1 Calorific value of fuel

9.2.1.1 General

Calculate the calorific value of fuel per ton of products, $E_{\mathrm{h,fuel}}$, using Formula (8):

$$E_{\mathrm{h,fuel}} = V_{\mathrm{f}} \times H_{\mathrm{l}} \quad (8)$$

9.2.1.2 Gaseous fuel

Calculate the net calorific value per normal cubic metre from the volume fraction of each component of gaseous fuel using Formula (9):

$$H_{\mathrm{l}} = \sum x_{\mathrm{j}} H_{\mathrm{j}} \quad (9)$$

NOTE The calorific value of components is given in Table C.2.

9.2.1.3 Liquid fuel

Calculate the net calorific value per kilogram of liquid fuel, H_{l}, from measured gross calorific value and the volume fraction of each component of liquid fuel using Formula (10):

$$H_{\mathrm{l}} = \left[H_{\mathrm{h}} - r \times \left(8{,}94 \times h + w \right) \right] \times 1\,000 \quad (10)$$

NOTE Latent heat of water at 0 °C is equivalent to 2 502 kJ/kg.

Or, the net calorific value per kilogram of liquid fuel, H_{l}, may be calculated from the volume fraction of each component of liquid fuel using Formula (11):

$$H_{\mathrm{l}} = (33{,}8 \times c + 122{,}5 \times h - 18{,}2 \times o + 9{,}42 \times s - 2{,}44 \times w) \times 1\,000 \quad (11)$$

H_{l}, the approximate net calorific value per kilogram of liquid fuel, may be calculated sing Formula (11), with the value of w, mass fraction of water contained in fuel, being 0.

For the calorific value of a typical liquid fuel, Table C.3 may be used.

9.2.2 Calorific value of waste

Calorific value of waste attached to the products shall be calculated according to the specification of waste material.

9.2.3 Calorific value of source gas of atmospheric gas

Calculate the calorific value of source gas of atmospheric gas, $E_{\text{u,atm,cal}}$, using Formula (12):

$$E_{\text{u,atm,cal}} = V_{\text{source gas}} \times H_{\text{l,source gas}} \tag{12}$$

The calculation for the calorific value of source gas shall be referred to 9.2.1.2.

9.2.4 Fuel equivalent energy of electricity

Calculate the fuel equivalent energy of electricity, $E_{\text{fe,el}}$, using Formula (13):

$$E_{\text{fe,el}} = \frac{1}{\eta_{\text{e}}} \times E_{\text{e,total}} \tag{13}$$

where η_{e} = 0,391 the world electrical generation efficiency.

For regional electrical generation, Table C.1 may be used.

9.2.4.1 Sensible heat of fuel

Calculate the sensible heat of fuel provided per ton of product, $E_{\text{s,fuel}}$, using Formula (14):

$$E_{\text{s,fuel}} = V_{\text{f}} \times c_{\text{pm,f1}} \times \left(T_{\text{f1}} - 273{,}15\right) \tag{14}$$

The value of 1,88 (kJ/kg·K) may be applied to the mean specific heat of heavy crude oil. Sensible heat of gaseous fuel shall be calculated from the volume fraction of its components.

Moisture content shall be considered when the volume fraction of each component is determined.

Table C.4 may be used for the mean specific heat of gaseous fuel.

Table C.5 may be used for the mean specific heat of liquid fuel.

For the calculation to determine the moisture content from the relative humidity of gaseous fuel, see Annex D.

9.2.5 Sensible heat of combustion air

9.2.5.1 General

Calculate the sensible heat of combustion air provided per ton of product, $E_{\text{s,air}}$, using Formula (15):

$$E_{\text{s,air}} = A \times c_{\text{pm,a1}} \times (T_{\text{a1}} - 273{,}15) \tag{15}$$

Moisture content shall be taken into consideration when the volume fraction of each component is determined.

For the calculation to determine the moisture content from the relative humidity of air, see Annex D.

9.2.5.2 Gaseous fuel

Calculate the volume of combustion air provided per ton of product, A, using Formula (16):

$$A = m \times A_0 \times V_f \tag{16}$$

The theoretical volume of combustion air, A_0, theoretical volume of dry exhaust gas, G'_0, and excess air ratio, m, are calculated using Formulae (17), (18) and (19):

$$A_0 = \frac{1}{\varphi_{(O_2)}} \times \left[\frac{1}{2} \times \varphi_{(H_2 + \varphi_{CO})} + \sum \left(x + \frac{y}{4} \right) \varphi_{CxHy} + \frac{3}{2} \times \varphi_{H_2S} - \varphi_{O\boldsymbol{OK}} \right] \tag{17}$$

$$G'_0 = \left[1,0 - \varphi_{(O_2)} - \varphi_{(H_2O)} \right] \times A_0 + \varphi_{CO} + \sum x \times \varphi_{C_xH_y} + \varphi_{H_2S} + \varphi_{CO_2} + \varphi_{N_2} \tag{18}$$

$$m = 1 + \frac{\varphi_{[O_2]}}{\varphi_{(O_2)} - \varphi_{[O_2]} \times \left[1 - \varphi_{(H_2O)} \right]} \times \frac{G'_0}{A_0} \tag{19}$$

9.2.5.3 Liquid fuel

Calculate the volume of dry combustion air provided per ton of product, A, using Formula (20):,

$$A = m \times A_0 \times V_f \tag{20}$$

The theoretical volume of combustion air, A_0, theoretical volume of dry exhaust gas, G'_0, and excess air ratio, m, are calculated using Formulae (21), (22) and (23):

$$A_0 = \frac{22,4}{\varphi_{(O_2)}} \times \left[\frac{c}{12} + \frac{1}{4} \times \left(h - \frac{o}{8} \right) + \frac{s}{32} \right] \tag{21}$$

$$G'_0 = \left[1,0 - \varphi_{(O_2)} - \varphi_{(H_2O)} \right] \times A_0 + 22,4 \left(\frac{c}{12} + \frac{s}{32} + \frac{n}{28} \right) \tag{22}$$

$$m = 1 + \frac{\varphi_{[O_2]}}{\varphi_{(O_2)} - \varphi_{[O_2]} \times \left(1 - \varphi_{(H_2O)} \right)} \times \frac{G'_0}{A_0} \tag{23}$$

9.2.5.4 Simplified calculation of excess air ratio

When approximate calculation of excess air ratio is used, calculate the excess combustion air ratio, m, using Formula (24):

$$m \approx \frac{\varphi_{(O_2)}}{\varphi_{(O_2)} - \varphi_{[O_2]}} = \frac{\varphi_{[CO_2]max}}{\varphi_{[CO_2]}} \tag{24}$$

The maximum volume fraction of carbon dioxide contained in exhaust gas, $\varphi_{[CO2]max}$, shall be calculated using Formulae (25) and (26):

for gaseous fuel:

$$\varphi_{[CO_2]max} = \frac{\varphi_{CO} + \sum x \times \varphi_{C_xH_y} + \varphi_{CO_2}}{G'_0} \quad (25)$$

for liquid fuel:

$$\varphi_{[CO_2]max} = \frac{1}{G'_0} \times \frac{22{,}4 \times c}{12} \quad (26)$$

9.2.6 Sensible heat of atomization agent

Calculate the sensible heat of atomization agent provided per ton of products, $E_{s,atomize}$, using Formula (27):

$$E_{s,atomize} = V_{atomize} \times (h - h_0) \quad (27)$$

NOTE The Steam Table is given in Table C.6.

9.2.7 Heat of reaction

The heat of reaction should be taken into account if it is not negligible in the heat processes under evaluation.

9.2.8 Sensible heat of infiltration air

Calculate the sensible heat of infiltration air per ton of products, $E_{s,infilt}$, using Formula (28):

$$E_{s,infilt} = V_{infilt} \times c_{pm,p1} \times (T_a - 273{,}15) \quad (28)$$

Calculate the infiltration air volume, V_{infilt}, per a unit of fuel using Formula (29):

$$V_{infilt} = A - V_{me} \quad (29)$$

9.3 Total energy output

9.3.1 Thermal energy output

9.3.1.1 Effective energy

9.3.1.1.1 General

Calculate the effective energy, E_{effect}, using Formula (30):

$$E_{effect} = E_{p2} - E_{p1} \quad (30)$$

9.3.1.1.2 Sensible heat of products

9.3.1.1.2.1 At the time of loading

Calculate the sensible heat (or enthalpy) of products at the time when products are loaded in the area of energy balance per ton of products using Formula (31):

$$E_{p1} = 1\,000 \times c_{pm,p1} \times (T_{p1} - 273{,}15) \quad (31)$$

9.3.1.1.2.2 At the time of extraction

Calculate the sensible heat (or enthalpy) of products at the time when products are extracted from the area of energy balance per ton of products using Formula (32):

$$E_{p2} = \left(1\,000 - M_{loss}\right) \times c_{pm,p2} \times \left(T_{p2} - 273{,}15\right) \quad (32)$$

Tables of heat content with a reference temperature of 273,15 K may be used.

In the case of melting furnaces, 9.3.1.1.2.2 of ISO 13579-3:2013 shall be used for the calculations.

NOTE The loss of mass is any mass loss arising from the formation of oxidized substances during the thermoprocess.

9.3.1.2 Jig loss

Calculate the heat loss of jigs/fixtures for product handling per ton of products, $E_{l,jig}$, using Formula (33):

$$E_{l,jig} = M_J \times \left[c_{pm,j2} \times \left(T_{j2} - 273{,}15\right) - c_{pm,j1} \times \left(T_{j1} - 273{,}15\right)\right] \quad (33)$$

9.3.1.3 Sensible heat of oxidized substance

ISO 13579-2:2013, 9.3.1.3 and ISO 13579-3:2013, 9.3.1.3 shall be used for the calculation of the sensible heat of oxidized substances, expressed in kilojoules per ton.

9.3.1.4 Sensible heat of exhaust gas

9.3.1.4.1 General

Calculate the sensible heat of exhaust gas discharged per ton of products, $E_{exhaust}$, using Formula (34):

$$E_{exhaust} = \left[G_0 + (m-1) \times A_0\right] \times c_{pm,E} \times \left(T_E - 273{,}15\right) \times V_f \quad (34)$$

For the specific heat of each component contained in exhaust gas, make reference to Table C.4.

9.3.1.4.2 Gaseous fuel

Calculate the theoretical volume of exhaust gas per normal cubic metre of gaseous fuel, G_0, using Formula (35):

$$G_0 = G'_0 + \varphi_{H_2} + \sum\left(\frac{y}{2}\right) \times \varphi_{C_xH_y} + \varphi_{H_2S} + \varphi_{H_2O} + mA_0 \times \varphi_{(H_2O)} \quad (35)$$

Calculate each component contained in exhaust gas per cubic metre of gaseous fuel using Formulae (36), (37), (38), (39) and (40):

$$\varphi_{\langle CO_2 \rangle} = \varphi_{CO} + x\varphi_{C_xH_y} + \varphi_{CO_2} - G' \times \varphi_{[CO]} \quad (36)$$

$$\varphi_{\langle N_2 \rangle} = \varphi_{N_2} + mA_0 \times \left[1 - \varphi_{(O_2)} - \varphi_{(H_2O)}\right] \quad (37)$$

$$\varphi_{\langle O_2 \rangle} = \left[G'_0 + (m-1) \times A_0 \times \left(1 - \varphi_{(H_2O)}\right)\right] \times \varphi_{[O_2]} \quad (38)$$

$$\varphi_{\langle H_2O\rangle} = \varphi_{H_2} + \frac{y}{2}\varphi_{C_xH_y} + \varphi_{H_2S} + \varphi_{H_2O} + \varphi_{(H_2O)} \times mA_0 \quad (39)$$

$$\varphi_{\langle H_2S\rangle} = \varphi_{H_2S} \quad (40)$$

9.3.1.4.3 Liquid fuel

Calculate the theoretical volume of exhaust gas per kilogram of liquid fuel, G_0, using Formula (41):

$$G_0 = G'_0 + \frac{22,4}{2} \times h + \frac{22,4}{18} \times w + A_0 \times \varphi_{(H_2O)} \quad (41)$$

Calculate each component contained in exhaust gas per kilogram kg of liquid fuel using Formulae (42), (43), (44), (45) and (46):

$$\varphi_{\langle CO_2\rangle} = \frac{22,4}{12} \times c \quad (42)$$

$$\varphi_{\langle N_2\rangle} = mA_0 \times \left(1 - \varphi_{(O_2)} - \varphi_{(H_2O)}\right) \quad (43)$$

$$\varphi_{\langle O_2\rangle} = \left[G'_0 + (m-1) \times A_0 \times \left(1 - \varphi_{(H_2O)}\right)\right] \times \varphi_{[O_2]} \quad (44)$$

$$\varphi_{\langle SO_2\rangle} = \frac{22,4}{32} \times s \quad (45)$$

$$\varphi_{\langle H_2O\rangle} = \frac{22,4}{4} \times h + \varphi_{(H_2O)} \times mA_0 \quad (46)$$

9.3.1.5 Heat storage loss by batch-type furnace

The heat storage loss by batch-type furnace wall may be calculated as specified in Annex E.

9.3.1.6 Sensible heat loss of atmospheric gas

Calculate the sensible heat of atmospheric gas discharged from furnace per ton of product, $E_{s,atm}$, using Formula (47):

$$E_{s,atm} = V_{atm} \times \left(c_{pm,\,atm2}T_{atm2} - c_{pm,\,atm1}T_{atm1}\right) \quad (47)$$

The specific heat of atmospheric gas may be calculated using the components of atmospheric gas.

For the specific heat of each component, reference may be made to Table C.4.

9.3.1.7 Wall loss

Temperature data collected from furnace walls which are separated at each area (side, top, bottom, front and back) shall be averaged in each area. When determination of surface area is difficult, projected surface areas may be used.

F.1 may be used for the calculation of the heat loss of radiation from furnace wall.

9.3.1.8 Heat loss of discharged blowout from furnace opening

Calculate the heat loss of discharged blowout from furnace opening per ton of products, $E_{\mathrm{l,blowout}}$, using Formula (48):

$$E_{\mathrm{l,blowout}} = t_{\mathrm{p}} \times V_{\mathrm{gf}} \times c_{\mathrm{pm,gf}} \times \left(T_{\mathrm{gf}} - 273{,}15\right) \quad (48)$$

F.2 may be used for the calculation of blowout volume.

9.3.1.9 Heat loss of radiation from furnace opening

F.3 may be used for the calculation of radiation from opening.

9.3.1.10 Heat loss from furnace parts installed through furnace wall

When heat loss from furnace parts installed through furnace wall, $E_{\mathrm{l,parts}}$, is not negligible (e.g. roller hearth furnaces), calculate the loss using Formula (49):

$$E_{\mathrm{l,parts}} = 0{,}8 \times \frac{k_{\mathrm{parts}}}{l_{\mathrm{w}}} \times S_{\mathrm{parts}} \times \left(T_{\mathrm{z}} - T_{\mathrm{a}}\right) \times t_{\mathrm{p}} \quad (49)$$

9.3.1.11 Cooling water loss

Calculate the cooling water loss, $E_{\mathrm{l,cw}}$, using Formula (50):

$$E_{\mathrm{l,cw}} = 4{,}186 \times V_{\mathrm{cw}} \times \left(T_{\mathrm{water,out}} - T_{\mathrm{water,in}}\right) \quad (50)$$

9.3.2 Energy consumed in electrical auxiliary equipment

9.3.2.1 Energy consumed in electrical auxiliary equipment

The energy consumed in electrical auxiliary equipment, E_{aux}, is determined as Formula (51):

$$E_{\mathrm{aux}} = E_{\mathrm{aux,installed}} + E_{\mathrm{aux,fluid}} \quad (51)$$

9.3.2.2 Energy consumed in installed electrical auxiliary equipment

Accumulate the energy consumed in installed electrical auxiliary equipment, $E_{\mathrm{aux,installed}}$, using Formula (52):

$$E_{\mathrm{aux,installed}} = \sum 3\,600 \times t_{\mathrm{p}} \times Q_{\mathrm{aux,installed}} \quad (52)$$

If part of energy consumed in installed electrical auxiliary equipment used as thermal energy in the heating process, the thermal energy shall be subtracted from the total energy consumed in the installed electrical auxiliary equipment.

9.3.2.3 Energy used for fluid transfer

Accumulate the energy used for fluid transfer, $E_{\mathrm{aux,fluid}}$, using Formula (53):

$$E_{\mathrm{aux,fluid}} = \sum 3\,600 \times t_{\mathrm{p}} \times Q_{\mathrm{aux,fluid}} \quad (53)$$

$Q_{\mathrm{aux,fluid}}$ may be determined by the calculations specified in Annex G.

9.3.3 Energy used for generation of utilities

9.3.3.1 General

Determine the energy used for the generation of utilities according to its usage per ton of product.

The method of the determination of specific consumption of energy shall comply with each process.

This category may be limited to oxygen for combustion air, steam (boiler) and atmospheric gas for heat treatment, as specified in 7.2.7.

9.3.3.2 Oxygen

In the case of oxygen for combustion air and other oxidant, the calculations in Fomula (54) may be applied.

$$E_{\text{u,oxy}} = 3\,600 \times \alpha_{\text{oxy}} \times V_{\text{oxy}} \tag{54}$$

α_{oxy}=0,5 kWh per normal cubic metre [m^3(n)] may be used.

Table C.1 may be used for regional conversion factors.

9.3.3.3 Steam

Determine the consumed energy for generation of steam used per ton of products.

9.3.3.4 Atmospheric gas for heat treatment

9.3.3.4.1 Energy for operation of generator

Determine the consumed energy for the operation of atmospheric gas generator per ton of products.

9.3.3.4.2 Calorific value of source gas

Determine the calorific value of source gas for atmospheric gas for heat treatment used per ton of products when the atmospheric gas is discharged in unburned state. Calculation shall be as specified in 9.2.3.

9.3.4 Electrical generation loss

Calculate the electrical generation loss, $E_{\text{l,eg}}$, using Formulae (55) and (56):

$$E_{\text{l,eg}} = E_{\text{fe,el}} - E_{\text{e,total}} \tag{55}$$

$$E_{\text{fe,el}} = \frac{1}{\eta_{\text{e}}} \times E_{\text{e,total}} \tag{56}$$

where η_e = 0,391 of the world's electrical generation efficiency.

Table C.1 may be used for regional electrical generation efficiency.

9.4 Total energy efficiency

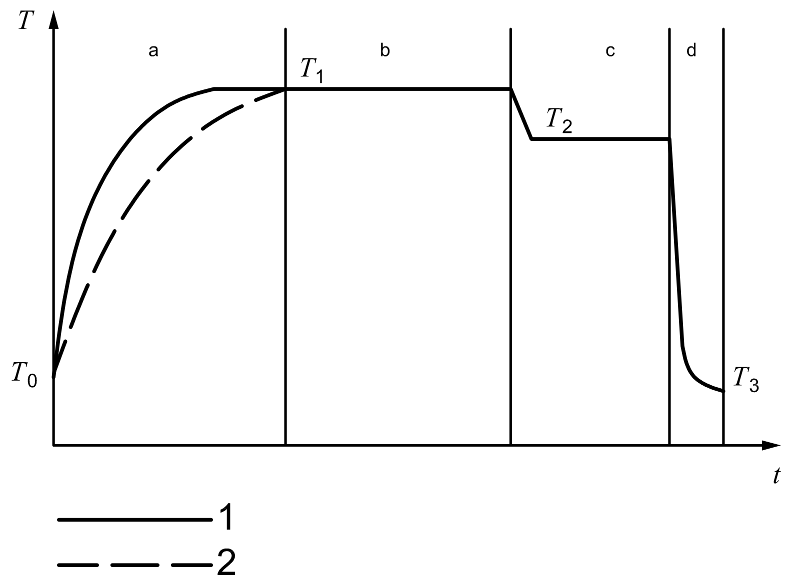
9.4.1 General

Calculate the total energy efficiency, η_1, using Formula (57):

$$\eta_1 = \frac{E_{\text{effect}}}{E_{\text{input}} - E_{\text{re}}} \tag{57}$$

9.4.2 Total energy efficiency limited to heating-up process

In the case of thermal processes, such as case hardening, the calculation of total energy efficiency may be limited to the heating-up process which is followed by other processes (e.g. soaking process for diffusion). It is defined that the heating-up process ends when the minimum temperature within the products reaches the designed heat-up temperature (see Figure 6).



Key

T temperature

t time

1 surface temperature of products

2 Minimum temperature within products (inner temperature)

T_0 temperature at t = 0

T_1 temperature at the end of heating up process and soaking process 1

T_2 temperature at soaking process 2

T_3 temperature at the end of cooling process

[a] Heating-up process.

[b] Soaking process 1.

[c] Soaking process 2.

[d] Cooling process.

Figure 6 — Example of division of heat profile

In this case, the calculation of total energy efficiency and measurement of heat balance should be carried out separately divided into process-by-process or zone-by-zone within the whole process of the furnace.

10 Energy balance evaluation report

Create an energy balance evaluation sheet that comprises input and output energy.

Every item of input or output energy shall be summarized in the energy balance sheet with the energy value and percentage of each to its total amount of energy.

The report of energy balance measurement shall include at least the following information:

a) schematic diagrams/drawings of the area of energy balance;

b) the measurement data;

c) the energy efficiency data as specified in 9.4;

Addition of the following information to the reports can be useful to the user/reader for better understanding:

— an equipment specification summary;

— outline drawings of the area under test;

— energy flow or Sankey diagrams.

NOTE Examples of an energy balance report are given in Annex H and ISO 13579-2, ISO 13579-3 and ISO 13579-4.

Annex A
(informative)

Assesment of uncertainty of the total energy efficiency

A.1 General

The absolute error of the total energy efficiency specified in 9.4.1 is generally given by Formula (A.1):

$$\delta\eta_1{}^2 = \left(\frac{\partial\eta_1}{\partial E_{\text{effect}}}\right)^2 \left(\delta E_{\text{effect}}\right)^2 + \left(\frac{\partial\eta_1}{\partial\left(E_{\text{input}} - E_{\text{re}}\right)}\right)^2 \left[\delta\left(E_{\text{input}} - E_{\text{re}}\right)\right]^2 \quad \text{(A.1)}$$

where

η_1 is the total energy efficiency specified in 9.4.1;

E_{re} is the recycled energy specified in 7.5.

NOTE Other symbols are specified in Clause 4.

Since the effective energy is a function of temperature, mass of products and mass loss, and the total input energy is a summation of sorts of energy (calorific value of fuel, electrical energy, etc.), Formula (A.1) can be described as:

$$\delta\eta_1{}^2 = \left(\frac{\partial\eta_1}{\partial f(T_{\text{p2}},T_{\text{p1}},M_{\text{p}},M_{\text{loss}})}\right)^2 \left(\delta f(T_{\text{p2}},T_{\text{p1}},M_{\text{p}},M_{\text{loss}})\right)^2 + \left(\frac{\partial\eta_1}{\partial g\left(E_{\text{h,fuel}},E_{\text{fe,el}},\ldots,E_{\text{re}}\right)}\right)^2 \left[\delta g\left(E_{\text{h,fuel}},E_{\text{fe,el}},\ldots,E_{\text{re}}\right)\right]^2 \quad \text{(A.2)}$$

Since the total energy efficiency and the effective energy are given by:

$$\eta_1 = \frac{E_{\text{effect}}}{E_{\text{input}} - E_{\text{re}}} = \frac{E_{\text{effect}}}{\sum\left[E_{\text{h,fuel}},E_{\text{fe,el}},\cdots\left(-E_{\text{re}}\right)\right]} = \frac{f\left(T_{\text{P2}},T_{\text{P1}},M,M_{\text{loss}}\right)}{\sum E_i} \quad \text{(A.3)}$$

$$f\left(T_{\text{p1}},T_{\text{p2}},M_{\text{p}},M_{\text{loss}}\right) = c_{\text{pmp2}}T_{\text{p2}}\left(M_{\text{p}} - M_{\text{loss}}\right) - c_{\text{pm,p1}}T_{\text{p1}}M_{\text{p}} \quad \text{(A.4)}$$

where

$\sum Ei$ is the comprehensive total energy input including regenerated energy per ton of product.

Therefore, absolute error of the total energy efficiency is described as:

$$\delta\eta_1{}^2 = \left(\frac{1}{\sum E_i}\right)^2 \left[\delta f(T_{\text{p2}},T_{\text{p1}},M_{\text{p}},M_{\text{loss}})\right]^2 + E_{\text{effect}}{}^2\left(\delta\frac{1}{\sum E_i}\right)^2 \quad \text{(A.5)}$$

$$= \left\{ \frac{\left(c_{\text{pm,p1}} M_{\text{p}} \delta T_{\text{p1}}\right)^2 + \left[c_{\text{pm,p2}}\left(M_{\text{p}} - M_{\text{loss}}\right)\delta T_{\text{p2}}\right]^2 + \left(c_{\text{pm,p2}} T_{\text{p2}} - c_{\text{pm,p1}} T_{\text{p1}}\right)^2 \left(\delta M_{\text{p}}\right)^2 + \left(c_{\text{pm,p2}} T_{\text{p2}} \delta M_{\text{loss}}\right)^2}{\sum E_i} \right\}^2$$

$$+ E_{\text{effect}}{}^2 \left[\left(\frac{1}{\sum E_i} \right)^2 \sum \delta E_i \right]^2 \tag{A.6}$$

$$= \left\{ \frac{\left(c_{\text{pm,p1}} M_{\text{p}} \delta T_{\text{p1}}\right)^2 + \left[c_{\text{pm,p2}}\left(M_{\text{p}} - M_{\text{loss}}\right)\delta T_{\text{p2}}\right]^2 + \left(c_{\text{pm,p2}} T_{\text{p2}} - c_{\text{pm,p1}} T_{\text{p1}}\right)^2 \left(\delta M_{\text{p}}\right)^2 + \left(c_{\text{pm,p2}} T_{\text{p2}} \delta M_{\text{loss}}\right)^2}{E_{\text{input}} - E_{\text{re}}} \right\}^2$$

$$+ \eta_1{}^2 \left(\frac{\sum \delta E_i}{E_{\text{input}} - E_{\text{re}}} \right)^2 \tag{A.7}$$

NOTE Mean specific heat values are assumed not to have error.

Annex B
(informative)

Measurement method concerning regenerative burners

When measurement for calculations of circulating heat to determine the efficiency of burners which use preheated combustion air is performed, the temperature of preheated combustion air should normally be measured directly using temperature probes such as thermocouples. However, in the case of regenerative burners, the temperature of preheated combustion air reaches around 90 % of that of exhaust gas. Therefore, temperature measurement is greatly affected by the radiation from heat exchange media which surround combustion air, and furnace atmosphere which exists in burner throats or around burners and inner wall of furnace. Due to these reasons, suction pyrometer is required for the measurement in order to avoid the effect of radiation. However, this method may be subject to significant measurement error due to the heat capacity of probe when a typically large section pyrometer probe is used with compact regenerative burners.

Since the measurement of preheated combustion air of regenerative burners is difficult as described above, temperature of combustion air is defined as an ambient temperature and temperature of exhaust gas is defined as that measured at just after the heat exchange media independent of furnace temperature as specified in this part of ISO 13579.

However, calculation of the circulating heat of regenerative burners may be performed if measurement error range is small enough to perform the evaluation reasonably (e.g. using a small-size suction pyrometer).

Annex C
(informative)

Reference data

Table C.1 — Regional electrical generation efficiency

Region	Fuel input[abcde]	Electricity generated[ab]	Electrical generation efficiency %
Japan	231	96,6	41,8
China	744	282	37,9
Korea	96,9	36,6	37,8
USA	963	372	38,6
UK	81	34	41,8
Germany	146	54	37,1
France	137	48,5	35,4
Europe — OECD	747	308	41,2
ASEAN 9	128	49	38,2
World	4 353	1 700	39,1

[a] Source: Handbook of statistics of energy and economy[23].

[b] Dimensions in 1 000 000 ton of oil equivalent (1 ton of oil equivalent = 4,19 x 10^7 kJ).

[c] Fuel input is equivalent to oil converted from coal, oil, natural gas, etc.

[d] Conversion factor used for atomic power generation: 10 919 kJ/kWh.

[e] Conversion factor used for hydraulic power generation: 3 603 kJ/kWh.

Table C.2 — Net calorific value of common fuel gases

Fuel gas		Net calorific value MJ/m^3(n)[a]	Fuel gas		Net calorific value MJ/m^3(n)[a]
Methane	CH_4	35,82	1-Pentene	C_5H_{10}	140,80
Ethane	C_2H_6	63,76	cis-2-Pentene	C_5H_{10}	140,60
Propane	C_3H_8	91,18	trans-2-Pentene	C_5H_{10}	140,40
n-Butane	C_4H_{10}	118,61	2-Methyl-1-Butene	C_5H_{10}	140,20
2-Methylpropane	C_4H_{10}	118,18	3-Methyl-1-Butene	C_5H_{10}	140,50
Ethylene	C_2H_4	59,04	2-Methyl-2-Butene	C_5H_{10}	139,90
Propylene	C_3H_6	85,94	Cyclopentane	C_5H_{10}	138,34
1-Butene	C_4H_8	113,18	Benzene	C_6H_6	141,42
cis-2-Butene	C_4H_8	113,08	Toluene	C_7H_8	168,31
trans-2-Butene	C_4H_8	112,91	Hydrogen	H_2	10,78
Acetylene	C_2H_2	56,07	Hydrogen sulfide	H_2S	23,20
n-Pentane	C_5H_{12}	146,00	Ammonia	NH_3	14,14
2-Methylbutane	C_5H_{12}	145,69	Carbon monoxide	CO	12,62
2,2-Dimethylpropane	C_5H_{12}	145,06			

NOTE 1 Source: ISO 6976.

NOTE 2 Reference temperature and pressure for combustion are the reference condition [0 °C (273,15 Kelvin) and 0,101 325 MPa], as specified in 6.4.

[a] The unit used is megajoule per normal cubic metre. For the unit(s) of the amount of gas [m^3(n)], see 6.4.

Table C.3 — Net calorific value of common liquid fuels (Japan)

Liquid fuel		Fuel oil C	Fuel oil B	Fuel oil A	Kerosene
Chemical component expressed in percentage of mass fraction	carbon	85,83	86,00	86,58	86,70
	hydrogen	10,48	11,34	11,83	13,00
	oxygen	0,48	0,36	0,70	-
	nitrogen	0,29	0,18	0,03	-
	sulfur	2,85	2,10	0,85	0,004
Net calorific value	MJ/kg	40,92	42,40	42,73	43,15
	MJ/l	38,06	37,74	36,75	34,52
NOTE 1 Values given in this table are examples from the Japanese market.					
NOTE 2 Source: Energy Conservation Handbook 2009[22].					

Table C.4 — Mean specific heat of gas at constant pressure

Temp-erature	H_2	N_2	N_2 in the air	O_2	CO	H_2O	H_2S	CO_2	SO_2	Air	CH_4	C_2H_4	C_2H_6	C_2H_2	C_3H_6	C_3H_8	C_4H_8 1-Butane	C_4H_8 2-Butane	C_4H_{10} *n*-Butane	C_4H_{10} i-Butane
°C	kJ/(m[3](n)·K)[a]																			
0	1,277	1,302	1,293	1,306	1,302	1,427	1,532	1,620	1,775	1,298	1,549	1,884	1,913	1,804	2,662	3,039	3,700	3,713	4,123	3,998
100	1,285	1,302	1,298	1,319	1,306	1,440	1,561	1,725	1,863	1,302	1,670	2,122	2,076	2,022	3,052	3,537	4,270	4,240	4,739	4,663
200	1,293	1,306	1,302	1,340	1,310	1,457	1,595	1,808	1,942	1,306	1,771	2,344	2,206	2,139	3,395	3,973	4,751	4,701	5,283	5,207
300	1,293	1,310	1,306	1,360	1,319	1,473	1,628	1,884	2,013	1,319	1,896	2,549	2,315	2,240	3,721	4,387	5,203	5,136	5,798	5,777
400	1,298	1,323	1,319	1,381	1,331	1,494	1,666	1,951	2,068	1,331	2,022	2,742	2,399	2,332	4,019	4,768	5,618	5,538	6,275	6,275
500	1,302	1,335	1,327	1,398	1,344	1,520	1,700	2,009	2,122	1,344	2,147	2,913	2,474	2,411	4,295	5,115	5,994	5,911	6,714	6,727
600	1,306	1,344	1,340	1,419	1,360	1,545	1,741	2,064	2,168	1,356	2,269	3,073	2,545	2,495	4,579	5,479	6,384	6,287	7,158	7,196
700	1,310	1,360	1,356	1,436	1,377	1,570	1,779	2,110	2,206	1,373	2,386	3,215	2,608	2,545	4,785	5,735	6,647	6,559	7,493	7,518
800	1,314	1,377	1,369	1,453	1,390	1,595	1,817	2,156	2,240	1,386	2,495	3,370	2,667	2,604	4,998	6,007	6,932	6,848	7,836	7,861
900	1,323	1,386	1,381	1,469	1,402	1,620	1,850	2,189	2,269	1,398	2,595	3,474	2,721	2,654	5,195	6,254	7,187	7,108	8,154	8,179
1 000	1,327	1,398	1,394	1,482	1,415	1,645	1,884	2,227	2,294	1,415	2,696	3,592	2,771	2,700	5,379	6,484	7,614	7,351	8,447	8,468
1 100	1,335	1,415	1,406	1,490	1,427	1,674	1,913	2,260	2,319	1,420	2,788			2,746	5,546	6,698	7,702	7,572	8,715	8,732
1 200	1,344	1,420	1,415	1,503	1,440	1,700	1,942	2,290	2,340	1,436	2,872			2,792	5,706	6,894	8,904	7,778	8,962	8,979
1 300	1,352	1,432	1,427	1,515	1,448	1,720	1,972	2,315	2,357	1,444										
1 400	1,360	1,444	1,440	1,524	1,457	1,750	1,993	2,340	2,373	1,457										
1 500	1,365	1,453	1,448	1,532	1,469	1,771	2,018	2,365	2,386	1,465										
1 600	1,373	1,465	1,457	1,540	1,478	1,792	2,043	2,386	2,399	1,478										
1 700	1,381	1,469	1,465	1,549	1,486	1,813	2,064	2,407	2,415	1,482										
1 800	1,390	1,478	1,473	1,557	1,494	1,838	2,085	2,424	2,424	1,490										
1 900	1,398	1,482	1,482	1,566	1,499	1,854	2,101	2,440	2,432	1,499										
2 000	1,407	1,490	1,486	1,574	1,507	1,875	2,118	2,457	2,440	1,503										

NOTE 1 Source: JIS G 0702.

NOTE 2 Values are at the pressure of 101 325Pa.

[a] The unit used is kilojoule per normal cubic metre kelvin. For unit of the amount of gas [m[3](n)], see 6.4.

Table C.5 — Approximate specific heat of liquid fuel (Japan)

Type	Specific heat
Coal	1,05 kJ/(kg·K)
Heavy crude oil	1,9 kJ/(kg·K)
Kerosene, Diesel oil, Crude oil	2,0 to 2,1 kJ/(kg·K)
NOTE Source: Energy Conservation Center, Japan.	

Table C.6 — Steam Table

Type °C	Saturation pressure kPa	Specific volume m^3/kg		Specific enthalpy kJ/kg			Specific entropy kJ/kg·K	
		water	vapour	water	vapour	Latent heat	water	vapour
		$v' \times 10^3$	v''	h'	h''	$r= h''- h'$	s'	s''
0,01	0,611 2	1,000 22	206,163	0,001	2 501,6	2 501,6	0,000 00	9,157 46
4	0,812 9	1,000 03	157,272	16,803	2 508,9	2 492,1	0,061 06	9,052 58
6	0,934 5	1,000 04	137,779	25,208	2 512,6	2 487,4	0,091 28	9,001 45
8	1,072 0	1,000 12	120,966	33,605	2 516,2	2 482,6	0,121 26	8,951 25
10	1,227 0	1,000 25	106,430	41,994	2 519,9	2 477,9	0,150 99	8,901 96
12	1,401 4	1,000 44	93,835 4	50,377	2 523,6	2 473,3	0,180 49	8,853 55
14	1,597 3	1,000 69	82,899 7	58,754	2 527,2	2 468,5	0,209 76	8,806 02
16	1,816 8	1,000 99	73,384 2	67,127	2 530,9	2 463,8	0,238 82	8,759 33
18	2,062 4	1,001 33	65,087 3	75,496	2 534,5	2 459,0	0,267 66	8,713 46
20	2,336 6	1,001 72	57,838 3	83,862	2 538,2	2 454,3	0,296 30	8,668 40
22	2,642 2	1,002 16	51,492 3	92,225	2 541,8	2 449,6	0,324 73	8,624 13
24	2,982 1	1,002 64	45,926 0	100,587	2 545,5	2 444,9	0,352 96	8,580 62
26	3,359 7	1,003 16	41,034 3	108,947	2 549,1	2 440,2	0,381 00	8,537 87
28	3,778 2	1,003 71	36,727 6	117,305	2 552,7	2 435,4	0,408 85	8,495 86
30	4,241 5	1,004 31	32,928 9	125,664	2 556,4	2 430,7	0,436 51	8,454 56
32	4,753 4	1,004 94	29,572 4	134,021	2 560,0	2 425,9	0,463 99	8,413 96
34	5,318 0	1,005 61	26,601 3	142,379	2 563,6	2 421,2	0,491 28	8,374 05
36	5,940 0	1,006 31	23,967 1	150,736	2 567,2	2 416,4	0,518 40	8,334 80
38	6,624 0	1,007 04	21,627 5	159,094	2 570,8	2 411,7	0,545 35	8,296 21
40	7,375 0	1,007 81	19,546 1	167,452	2 574,4	2 406,9	0,572 12	8,258 26
45	9,582 0	1,009 87	15,276 2	188,351	2 583,3	2 394,9	0,638 32	8,166 07
50	12,335	1,012 11	12,045 7	209,256	2 592,2	2 382,9	0,703 51	8,077 57
55	15,741	1,014 54	9,578 87	230,168	2 601,0	2 370,8	0,767 72	7,992 55
60	19,920	1,017 14	7,678 53	251,091	2 609,7	2 358,6	0,830 99	7,910 81
65	25,009	1,019 91	6,202 28	272,025	2 618,4	2 346,3	0,893 34	7,832 17
70	31,162	1,022 85	5,046 27	292,972	2 626,9	2 334,0	0,954 82	7,756 47
75	38,549	1,025 94	4,134 10	313,936	2 635,4	2 321,5	1,015 44	7,683 53

Table C.6 (2 of 2)

Type °C	Saturation pressure kPa	Specific volume m3/kg		Specific enthalpy kJ/kg			Specific entropy kJ/kg·K	
		water	vapour	water	vapour	Latent heat	water	vapour
		v' x 10^3	v''	h'	h''	$r= h''- h'$	s'	s''
80	47,360	1,029 19	3,409 09	334,916	2 643,8	2 308,8	1,075 25	7,613 22
85	57,803	1,032 59	2,828 81	355,917	2 652,0	2 296,1	1,134 27	7,545 37
90	70,109	1,036 15	2,361 30	376,939	2 660,1	2 283,2	1,192 53	7,479 87
95	84,526	1,039 85	1,982 22	397,988	2 668,1	2 270,2	1,250 05	7,416 58
100	101,32	1,043 7	1,673 00	419,064	2 676,0	2 256,9	1,306 87	7,355 38
110	143,27	1,051 87	1,209 94	461,315	2 691,3	2 230,0	1,418 49	7,238 80
120	198,54	1,060 63	0,891 524	503,719	2 706,0	2 202,2	1,527 59	7,129 28
130	270,13	1,070 02	0,668 136	546,305	2 719,9	2 173,6	1,634 36	7,026 06
140	361,38	1,080 06	0,508 493	589,104	2 733,1	2 144,0	1,738 99	6,928 44
150	476,00	1,090 78	0,392 447	632,149	2 745,4	2 113,2	1,841 64	6,835 78
160	618,06	1,102 23	0,306 756	675,474	2 756,7	2 081,3	1,942 47	6,747 49
170	792,02	1,114 46	0,242 553	719,116	2 767,1	2 047,9	2,041 64	6,663 03
180	1 002,7	1,127 52	0,193 800	763,116	2 776,3	2 013,1	2,139 29	6,581 89
190	1 225,1	1,141 51	0,156 316	807,517	2 784,3	1 976,7	2,235 58	6,503 61
200	1 554,9	1,156 50	0,127 160	852,371	2 790,9	1 938,6	2,330 66	6,427 76
210	1 907,7	1,172 60	0,104 239	897,734	2 796,2	1 898,5	2,424 67	6,353 93
220	2 319,8	1,189 96	0,086 037 8	943,673	2 799,9	1 856,2	2,517 79	6,281 72
230	2 797,6	1,208 72	0,071 449 8	990,265	2 802,0	1 811,7	2,610 17	6,210 74
240	3 347,8	1,229 08	0,059 654 4	1 037,60	2 802,2	1 764,6	2,702 00	6,140 59
250	3 977,6	1,251 29	0,050 037 4	1 085,78	2 800,4	1 714,7	2,793 48	6,070 83
260	4 694,3	1,275 63	0,042 133 8	1 134,94	2 796,4	1 661,5	2,884 85	6,000 97
270	5 505,8	1,302 50	0,035 588 0	1 185,23	2 789,9	1 604,6	2,976 35	5,930 45
280	6 420,2	1,332 39	0,030 126 0	1 236,84	2 780,4	1 543,6	3,068 30	5,858 63
290	7 446,1	1,365 95	0,025 535 1	1 290,01	2 767,6	1 477,6	3,161 08	5,784 78
300	8 592,7	1,404 06	0,021 648 7	1 345,05	2 751,0	1 406,0	3,255 17	5,708 12
310	9 870,0	1,447 97	0,018 333 9	1 402,39	2 730,0	1 327,6	3,351 19	5,627 76
320	11 289	1,499 50	0,015 479 8	1 462,60	2 703,7	1 241,1	3,450 00	5,542 33
330	12 863	1,561 47	0,012 989 4	1 526,52	2 670,2	1 143,6	3,552 83	5,449 01
340	14 605	1,638 72	0,010 780 4	1 595,47	2 626,2	1 030,7	3,661 62	5,342 74
350	16 535	1,741 12	0,008 799 1	1 671,94	2 567,7	895,7	3,780 04	5,217 66
360	18 675	1,895 9	0,006 939 8	1 764,2	2 485,4	721,3	3,921 02	5,060 03
370	21 054	2,213 6	0,004 972 8	1 890,2	2 342,8	452,6	4,110 80	4,814 39
374,15	22 120	3,170 0	0,003 170 0	2 107,4	2 107,4	0,0	4,442 86	4,442 86

NOTE Source: Steam Table[29].

Table C.7 — Emissivity — Non-metal

Material	Temperature °F	Temperature °C	Emissivity
Cement	32 – 392	0 – 200	0,96
Cement, red	2 500	1 371	0,67
Cement, white	2 500	1 317	0,65
Slate	68	20	0,72
Brick			
Red, rough	70	21	0,93
Gault cream	2 500 – 5 000	1 371 – 2 760	0,26 – 0,30
Fire clay	2 500	1 371	0,75
Lime clay	2 500	1 371	0,43
Fire brick	1 832	100	0,75 – 0,80
Magnesite, refractory	1 832	1 000	0,38
Grey brick	2 021	1 100	0,75
Silica, glazed	2 000	1 093	0,88
Silica, unglazed	2 000	1 093	0,8
Sandlime	2 500 – 5 000	1 371 – 2 760	0,59 – 0,63
Carborundum	1850	1010	0,92
Ceramic			
Alumina on Inconel[1]	800-2 000	427-1093	0,69-0,45
Earthenware, glazed	70	21	0,9
Earthenware, matte	70	21	0,93
Greens No. 5210-2C	200-750	93-399	0,89-0,82
Coating No. C20A	200-750	93-399	0,73-0,80
Porcelain	72	22	0,92
White Al_2O_3	200	93	0,9
Zirconia on Inconel[1)]	800-2 000	427-1093	0,62-0,45
Clay	68	20	0,39
Clay, fired	158	70	0,91
Clay, shale	68	20	0,69
Clay tiles, light red	2 500-5 000	1 371-2 760	0,32-0,34
Clay tiles, dark purple	2 500-5 000	1 371-2 760	0,78
Concrete			
Rough	32-2000	0-1093	0,94
Tiles, natural	2500-5000	1371-2760	0,63-0,62
Tiles, brown	2500-5000	1371-2760	0,87-0,83
Tiles, black	2500-5000	1371-2760	0,94-0,91
Cotton cloth	68	20	0,77
Dolomite lime	68	20	0,41
Emery corundum	176	80	0,86

1 Inconel is the trademark of a product supplied by the Special Metals family of companies. This information is given for the convenience of users of this part of ISO 13579 and does not constitute an endorsement by ISO of this product. Equivalent products may be used if they can be shown to lead to the same results.

Table C.7 (2 of 4)

Material	Temperature °F	Temperature °C	Emissivity
Glass			
Convex D	212	100	0,8
Convex D	600	316	0,82
Convex D	932	500	0,76
Nonex[2]	212	100	0,82
Nonex[2)]	939	500	0,76
Smooth	32-200	0-93	0,92-0,94
Granite	70	21	0,45
Gravel	100	38	0,28
Gypsum	68	20	0,80-0,90
Ice, smooth	32	0	0,97
Ice, rough	32	0	0,98
Lacquer			
Black	200	93	0,96
Blue, on aluminium foil	100	38	0,78
Clear, on aluminium foil (two coats)	200	93	0,08 (0,09)
Clear, on bright copper	200	93	0,66
Clear, on tarnished copper	200	93	0,64
Red, on aluminium foil (two coats)	200	93	0,61 (0,74)
White	200	930	0,95
White, on aluminium foil (two coats)	100	38	0,69 (0,88)
Yellow, on aluminium foil (two coats)	100	38	0,57 (0,79)
Lime mortar	100-500	38-260	0,90-0,92
Limestone	100	38	0,95
Marble, white	100	38	0,95
Marble, smooth, white	100	38	0,56
Marble, polished grey	100	38	0,75
Mica	100	38	0,75
Oil on nickel			
0,001 film	72	22	0,27
0,002 film	72	22	0,46
0,005 film	72	22	0,72
Thick film	72	22	0,82
Oil, linseed			
On aluminium foil, uncoated	250	121	0,09
On aluminium foil, one coat	250	121	0,56
On aluminium foil, two coats	250	121	0,56
On polished iron, 0,001 film	100	38	0,22

[2] Nonex is the trademark of a product supplied by E.I. du Pont de Nemours and Company (DuPont). This information is given for the convenience of users of this part of ISO 13579 and does not constitute an endorsement by ISO of this product. Equivalent products may be used if they can be shown to lead to the same results.

Table C.7 (3 of 4)

Material	Temperature °F	Temperature °C	Emissivity
On polished iron, 0,002 film	100	38	0,45
On polished iron, 0,004 film	100	38	0,65
On polished iron, thick film	100	38	0,83
Paints			
Blue, Cu_2O_3	75	24	0,94
Black, CuO	75	24	0,96
Green, Cu_2O_3	75	24	0,92
Red, Fe_2O_3	75	24	0,91
White, Al_2O_3	75	24	0,94
White, Y_2O3	75	24	0,9
White, ZnO	75	24	0,95
White, $MgCO_3$	75	24	0,91
White, ZrO_2	75	24	0,95
White, ThO_2	75	24	0,9
White, MgO	75	24	0,91
White, $PbCO_3$	75	24	0,93
Yellow, PbO	75	24	0,9
Yellow, $PbCrO_4$	75	24	0,93
Paints, aluminium	100	38	0,27-0,67
10% Al	100	38	0,52
26% Al	100	38	0,3
Dow XP-310	200	93	0,22
Paints, Bronze	low	low	0,34-0,80
Gum varnish (two coats)	70	21	0,53
Gum varnish (three coats)	70	21	0,5
Cellulose binder (two coats)	70	21	0,34
Paints, oil			
All colours	200	93	0,92-0,96
Black	200	93	0,92
Black gloss	70	21	0,9
Camouflage green	125	52	0,85
Flat black	80	27	0,88
Flat white	80	27	0,91
Grey-green	70	21	0,95
Green	200	93	0,95
Lamp black	209	98	0,96
Red	200	93	0,95
White	200	93	0,94
Quartz, rough, fused	70	21	0,93
Glass, 1,98 mm	540	282	0,9
Glass, 1,98 mm	1540	838	0,41
Glass, 6,88 mm	540	282	0,93

Table C.7 (4 of 4)

Material	Temperature °F	Temperature °C	Emissivity
Glass, 6,88 mm	1540	838	0,47
Opaque	570	299	0,92
Opaque	1540	838	0,68
Red lead	212	100	0,93
Rubber, hard	74	23	0,94
Rubber, soft, grey	76	24	0,86
Silica,glazed	1832	1000	0,85
Silica, unglazed	2012	1100	0,75
Silicon carbide	300-1200	149-649	0,83-0,96
Slate	100	38	0,67-0,80
Soot			
Acetylene	75	24	0,97
Camphor	75	24	0,94
Candle	250	121	0,95
Coal	68	20	0,95
Water	100	38	0,67
Waterglass	68	20	0,96
Aluminium			
Unoxidized	212	100	0,03
Unoxidized	932	500	0,06
Oxidized	392	200	0,11
Oxidized	1,112	600	0,19
Monel, Ni-Cu			
Unoxidized	392	200	0,41
Unoxidized	1,112	600	0,46
Nickel			
Polished	104	40	0,05
Oxidized	104	40	0,31
Oxidized	482	250	0,46
Steel			
Unoxidized	212	100	0,08
Oxidized	212	100	0,8
Stainless steel			
Polished	212	100	0,22
Polished	797	425	0,45

Annex D
(informative)

Calculation of moisture content of fuel and air

The moisture content in gaseous fuel, w, can be obtained using Formula (D.1):

$$w = \frac{\varphi_f \times P_{sf}}{100 \times P_f - \varphi_f \times P_{sf}} \quad (D.1)$$

In the case of by-product gaseous fuel, the value of relative humidity should be 100 (%). “By-product gaseous fuel” includes blast furnace gas, converter gas and coke oven gas.

If the volume fraction of water contained in gaseous fuel is actually measured, the volume of water vapour contained in gaseous fuel used per ton of product shall be calculated using the measured volume fraction of water.

NOTE ISO 6326-1, ISO 6327, ISO 6974-1, ISO 6974-2, ISO 6974-3, ISO 6974-4, ISO 6974-5, ISO 6974-6, ISO 6975 and ISO 6976 can be used for the measurement of the volume fraction of water contained in gaseous fuel.

Annex E
(informative)

Calculations of heat storage of furnace wall, furnace wall temperature profile and heat loss by furnace wall in serial batch-type furnace process

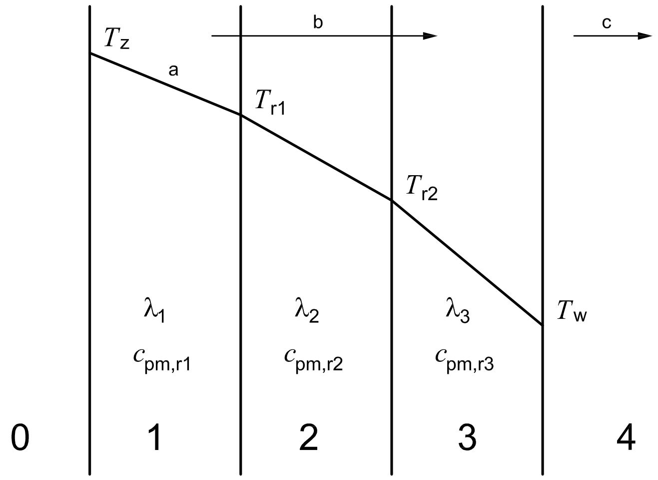
E.1 Applicable conditions

In this annex, the calculations of heat storage of furnace wall and furnace wall temperature profile are defined under conditions of heat flow penetrating a wide multilayer flat furnace wall under steady-state conditions.

Under these conditions, though it is difficult to determine accurate values of heat loss by the furnace wall due to the difficulties in accurate measurement of heat transfer coefficient, transformation of refractory during its use, deposition of dust, etc., it is possible to calculate these values in sufficient accuracy for the practical use of industrial furnaces.

E.2 Calculation of emitted calorific value and temperature profile of furnace wall

As shown in Figure E.1, under perfect contact conditions between layers, the heat transfer coefficients of furnace wall at layers 1, 2 and 3 are defined as λ_1, λ_2, and λ_3, respectively, and the thicknesses of the furnace wall at layers 1, 2 and 3 are defined as l_1, l_2, and l_3, respectively. In addition, the inner wall surface temperature (hot surface) is defined as T_z, and the first boundary temperature is defined as T_{r1}; the second boundary temperature is defined as T_{r2}, and the outer furnace wall surface temperature (cold surface) is defined as T_w.



Key

0	space inside furnace
1	furnace refractory layer 1
2	furnace refractory layer 2
3	furnace refractory layer 3
4	space outside furnace
T_z	temperature of inside furnace
T_{r1}, T_{r2}	boundary temperature of refractory
T_w	temperature of outer furnace wall surface
λ_i	heat conductivity of furnace refractory of each layer
$c_{pm,ri}$	mean specific heat of refractory of each layer

[a] Temperature profile of furnace wall layer.

[b] Direction of heat flux by heat transfer.

[c] Direction of heat flux by heat emission from the surface of furnace.

Figure E.1 — Static state heat transfer through multilayer furnace wall

The heat transfer coefficient at average temperature in the temperature range of furnace refractory shall be determined from the temperature-heat transfer coefficient curve.

E.3 Basic formula to determine heat loss by furnace walls

E.3.1 Heat transfer through furnace walls

Calculate the heat transfer through the furnace walls, Q_t, using Formula (E.1):

$$Q_t = \frac{\lambda}{l_w}\left(T_z - T_w\right) \tag{E.1}$$

In the case of multilayer furnace walls, when each thickness of layers is defined as l_i and the heat transfer coefficient of each layer is defined as λ_i, total furnace wall thickness l_w, and its total heat transfer coefficient, λ, are calculated as:

$$\frac{l_w}{\lambda} = \sum_{i=1}^{n} \frac{l_i}{\lambda_i} \tag{E.2}$$

NOTE Informative data of thermal conductivity of refractory are given in Table E.3.

E.3.2 Heat emission from furnace wall surface

Calculate the convection and radiation heat emission from furnace wall surface, Q_e, using Formula (E.3):

$$Q_e = q_r + q_c$$

$$= \sigma\varepsilon_1\left(T_w{}^4 - T_a{}^4\right) + h_{C0}\left(T_w - T_a\right)^{5/4} \quad \text{(E.3)}$$

NOTE 1 $\sigma = 5{,}67 \times 10^{-8}$ W/(m²·K⁴): Stephan-Boltzmann constant.

Table C.7 includes the emissivity data of a variety of materials. Since heat flux within the furnace wall and emitted from the furnace surface are equivalent under steady-state conditions, the balance of energy flux is described as Formula (E.4):

$$Q_t = Q_e \quad \text{(E.4)}$$

Therefore, Formula (E.4) can be transformed into Formula (E.5):

$$\frac{\lambda}{l_w}\left(T_z - T_w\right) = \sigma\varepsilon_1\left(T_w{}^4 - T_a{}^4\right) + h_{c0}\left(T_w - T_a\right)^{5/4} \quad \text{(E.5)}$$

NOTE 2 $\sigma = 5{,}67 \times 10^{-8}$ W/(m²·K⁴): Stephan-Boltzmann constant.

When furnace inner wall temperature T_a and the constant term of convection heat transfer coefficient h_{c0} are given, unknown term is outer furnace wall surface temperature T_w. Therefore, T_z may be determined from Formula (E.5).

Convection heat transfer coefficient, h_{c0} ,may be as follows:

— furnace upper wall: h_{c0} = 3,26 W/(m²·K);

— furnace side wall: h_{c0} = 2,56 W/(m²·K);

— furnace bottom wall: h_{c0} = 1,74 W/(m²·K).

NOTE 3 Source of Formula (E.5): JIS G 0702.

E.4 Formula to determine heat loss by storage in furnace wall

Calculate the heat storage of multilayer furnace refractory per 1 m², H_{wall}, using Formula (E.6):

$$H_{wall} = l_1 \times \rho_1 \times c_{pm,r1}\left(\frac{T_z + T_{r1}}{2} - T_a\right) + l_2 \times \rho_2 \times c_{pm,r2}\left(\frac{T_{r1} + T_{r2}}{2} - T_a\right) + l_3 \times \rho_3 \times c_{pm,r3}\left(\frac{T_{r2} + T_w}{2} - T_a\right) \quad \text{(E.6)}$$

NOTE Informative data of mean specific heat of refractory are given in Table E.1.

E.5 Heat storage loss of batch-type furnace process

Formula (E.7) may be used to obtain the heat storage loss of batch-type furnace per square metre of furnace wall, $E_{l,storage}$:

$$E_{l,storage} = \frac{1}{3} \times H_{wall} \qquad (E.7)$$

Table E.1 — Mean specific heat of refractory

Refractory	**Mean specific heat** (20~t°C)			
	t = 500 °C	t = 700 °C	t = 900 °C	t = 1 050 °C
	kJ/(kg·K)			
Clay 1	0,056 14	0,059 01	0,060 92	0,061 87
Clay 2	0,054 47	0,058 53	0,061 16	0,062 35
Clay 3	0,053 51	0,057 57	0,060 68	0,062 35
Silica stone	0,057 34	0,059 49	0,061 40	0,062 59
China clay	0,054 95	0,059 00	0,061 64	0,062 83
Bonded sillimanite	0,055 42	0,059 00	0,061 88	0,063 07
Mullite	0,057 57	0,060 68	0,063 07	0,064 50
Alumina (95 %)	0,058 53	0,061 88	0,064 03	0,064 98
Magnesite	0,062 83	0,064 98	0,067 13	0,068 33
Molten magnesia	0,063 31	0,065 94	0,068 09	0,069 28
Molten forsterite	0,060 44	0,063 07	0,065 46	0,066 89
Chrome brick	0,049 21	0,051 12	0,052 80	0,054 23
Chrome magnesite brick	0,053 51	0,056 14	0,058 53	0,059 73
Dolomite brick	0,056 62	0,059 01	0,061 16	0,062 35
Zirconia brick	0,039 42	0,064 98	0,042 52	0,043 24
Vermiculite brick	0,055 90	0,059 49	0,062 11	0,063 31
Diatomite brick	0,055 42	0,058 53	0,060 68	0,061 88
NOTE Source: Refractories Handbook[28].				

Table E.2 — Composition of refractory listed in Table E.1

Refractory	Component								
	SiO_2	TiO_2	ZrO_2	Al_2O_2	Cr_2O_3	Fe_2O_3	CaO	MgO	Alkaline
	% by mass								
Clay 1	60,6	1,1	-	30,5	-	6,0	0,3	0,3	0,9
Clay 2	60,0	1,5	-	32,3	-	2,4	0,4	0,7	2,3
Clay 3	58,0	1,2	-	35,0	-	1,6	0,9	0,3	3,1
Silica stone	95,2	0,5	-	1,2	-	0,6	2,0	0,1	0,4
China clay	54,9	0,4	-	40,9	-	0,9	0,5	0,5	1,8
Bonded sillimanite	39,7	1,5	-	55,4	-	0,8	0,5	0,3	1,3
Mullite	26,6	0,7	-	70,1	-	0,6	1,6	0,4	0,3
Alumina (95%)	4,4	-	-	95,3	-	0,1	-	-	0,1
Magnesite	2,9	-	-	1,2	-	7,8	2,0	86,5	-
Molten magnesia	-	-	-	-	-	-	-	-	-
Molten forsterite	42,6	-	-	-	-	-	-	57,4	-
Chrome brick	5,2	-	-	21,3	39,6	10,9	1,6	21,2	-
Chrome magnesite brick	7,2	-	-	17,3	25,4	14,2	-	35,3	-
Dolomite brick	15,1	-	-	2,2	-	3,3	40,0	39,2	-
Zirconia brick	34,0	-	65,2	-	-	-	-	-	-
Vermiculite brick	50,1	-	-	27,3	0,1	4,0	1,2	12,2	3,7
Diatomite brick	79,3	-	-	12,7	-	3,3	1,5	0,9	1,3
NOTE Source: Refractories Handbook[28].									

Table E.3 — Thermal conductivity of refractory

Name	Clay			Silicon carbide					Silica			High-alumina			Magnesia			
Bulk specific gravity	1,83	1,77	1,90	2,19	2,36	2,32	2,58	2,63	2,04	1,95	1,77	2,4	2,72	2,16	2,01	2,34	2,6-3,0	2,35
Mass content	SiO_2 63,2 %	SiO_2 71,2 %	SiO_2 73,7 %	SiC 49 %	SiC 77 %	SiC 90 %	SiC 92 %	SiC 92,5 %	SiO_2 96,9 %	SiO_2 94 %	SiO_2 96 %	Al_2O_3 60-70 %	Al_2O_3 81,5 %	Al_2O_3 60 %	MgO 54 %	MgO 86 %	MgO 86-90 %	MgO 88,9 %
	Al_2O_3 30,4 %	Al_2O_3 24,3 %	Al_2O_3 25,0 %															
Temperature (°C)	W/(m·K)																	
0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
100	-	-	-	3,70	-	16,3	-	-	-	0,89	-	0,73-1,23	-	-	2,0	3,6	4,3-6,9	-
200	0,34	0,28	0,65	-	-	-	-	-	0,40	-	-	-	-	-	-	-	-	0,37
300	-	-	-	3,53	9,63	13,3	17,2	22,8	-	0,90	1,00	0,73-1,20	1,7	-	1,72	3,4	4,3-6,0	-
400	0,43	0,28	0,74	-	-	-	-	-	0,50	-	-	-	-	-	-	-	-	0,34
500	-	-	-	3,35	8,51	11,3	14,2	18,1	-	0,97	1,05	0,73-1,16	1,6	0,86	1,5	3,3	3,4-5,2	-
600	0,46	0,37	0,83	-	-	-	-	-	0,52	-	-	-	-	-	-	-	-	0,40
700	-	-	-	3,23	7,57	9,6	12,5	15,5	-	1,09	1,16	0,73-1,12	1,5	0,88	1,3	3,0	3,0-4,3	-
800	0,58	0,40	0,83	-	-	-	-	-	0,52	-	-	-	-	-	-	-	-	0,52
900	-	-	-	3,10	6,71	8,3	11,3	13,8	-	1,20	1,24	0,73-1,08	1,5	0,89	1,16	2,58	2,2-3,4	-
1 000	0,65	-	0,83	-	-	-	-	-	0,56	-	-	-	-	-	-	-	-	0,43
1 100	-	-	-	2,83	5,93	7,4	10,5	12,9	-	-	1,31	0,67-1,03	1,5	-	-	-	1,7-2,6	-
1 200	-	-	0,83	-	-	-	-	-	0,65	-	-	-	-	-	-	-	-	0,43

NOTE Source: Refractories Handbook[28].

Annex F
(informative)

Calculation of wall loss and heat loss of discharged blowout from furnace opening

F.1 Wall loss

F.1.1 Wall loss from furnace wall and flue

Calculate the heat loss by radiation from furnace wall and flue per ton of products, $E_{\mathrm{l,wall,1}}$, using Formula (F.1):

$$E_{\mathrm{l,wall,1}} = 3600 \times t_{\mathrm{p}} \times S_{\mathrm{surface}} \times (q_{\mathrm{r}} + q_{\mathrm{c}}) \quad \text{(F.1)}$$

Calculate the heat flux by radiation, q_{r}, using Formula (F.2):

$$q_{\mathrm{r}} = \sigma \times \varepsilon_1 \times \left(T_{\mathrm{w}}{}^4 - T_{\mathrm{a}}{}^4\right) \quad \text{(F.2)}$$

where

$\sigma = 5{,}67 \times 10^{-8}$ (W/m^2·K^4): Stephan-Boltzmann constant;

NOTE 1 Table C.7 includes emissivity data of variety of materials.

Calculate the heat flux by convection, q_{c}, using Formula (F.3):

$$q_{\mathrm{c}} = h_{\mathrm{C0}} \times \left(T_{\mathrm{w}} - T_{\mathrm{a}}\right)^{5/4} \quad \text{(F.3)}$$

When furnace inner wall temperature, T_{a}, and the constant term of convection heat transfer coefficient, h_{C0}, are given, the unknown term is the outer furnace wall surface temperature T_{w}. Therefore, T_{w} may be determined using Formulae (F.1), (F.2) and (F.3). The Secant method, modified by the Newton method, is used as a numerical solution method.

NOTE 2 The convection heat transfer coefficient, h_{C0}, may be as follows:

— Furnace upper wall: h_{C0} = 3,26 (W/m^2 K)

— Furnace side wall: h_{C0} = 2,56 (W/m^2 K)

— Furnace bottom wall; h_{C0} = 1,74 (W/m^2 s K)

NOTE 3 Source of Formula (F.3): JIS G 0702.

F.1.2 Wall loss from hearth

Calculate the wall loss from hearth which is directly built on the concrete floor per ton of products, $E_{\mathrm{l,wall,2}}$, using Formula (F.4):

$$E_{\mathrm{l,wall,2}} = 3\,600 \times t_{\mathrm{p}} \times S_{\mathrm{hearth}} \times q_{\mathrm{h}} \quad \text{(F.4)}$$

where

$$q_h = \alpha_{hearth} \times C \times \frac{T_h - T_a}{l_{iw}} \quad \text{(F.5)}$$

α_{hearth} is the coefficient determined by the shape of the hearth, and is defined as follows:

— 4,1: circle,

— 4,5: square,

— 3,8: long rectangle.

Formula (F.4) is defined on the condition that the thickness of wall is equivalent to $l_{iw}/6$. When the thickness of the wall is equivalent to, $l_{iw}/4$, the value q_h shall be 95 % of the calculated value. When the thickness of the wall is equivalent to $l_{iw}/8$, the value q_h shall be 110 % of the calculated value. For other dimensions of wall thickness, the conversion ratio is to be estimated from the ratio given in this subclause.

F.2 Heat loss of discharged blowout from furnace opening

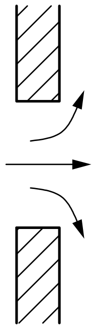
Calculate the blowout volume, V_{gf}, indicated in 9.3.1.8, using Formula (F.6):

$$V_{gf} = 4\ 467 \times \sqrt{\frac{273}{T_{gf}}} \times \alpha_{opening} \times \sqrt{\Delta p_0} \times S_{opening} \quad \text{(F.6)}$$

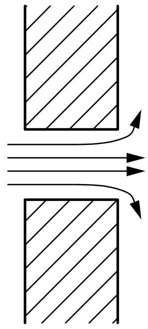
$\alpha_{opening}$ is the coefficient determined from the shape of openings, and expressed as:

$$\alpha_{opening} = \frac{1}{1 + \alpha_f} \quad \text{(F.7)}$$

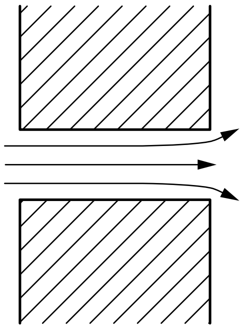
$\alpha_{opening}$ is determined in accordance with the shape of openings described in Figure F.1.



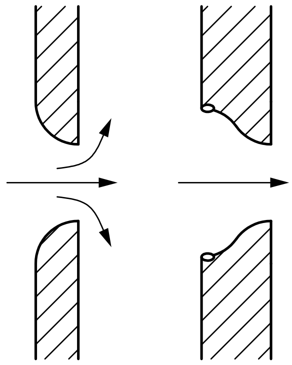
a) $\alpha_{opening}$ = 0,38 ($\alpha_f = 1{,}6$), when furnace wall thickness is a half of the diameter or less than the diameter of openings (in the case of an opening shape other than a rounded shape, the hydraulic diameter shall be used).



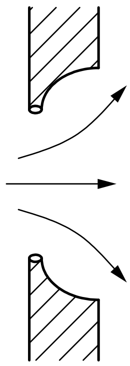
b) $\alpha_{opening}$ = 0,67 ($\alpha_f = 0{,}5$), when furnace wall thickness is two and a half to three times greater than the diameter of openings. In the case wall thickness is a half to two and a half times greater than the diameter of openings, the value $\alpha_{opening}$ shall be equivalent to the intermediate value of subfigures a) and b).



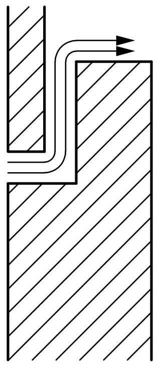
c) When furnace wall thickness is three times the diameter or greater than the diameter of openings, the coefficient of friction, α_f, is defined as 0,5 for the first part, where the opening inlet to the depth is up to three times the furnace wall, and then only the friction loss of the inner wall of openings shall be considered in the calculation for the latter part of openings. Therefore, $\alpha_{opening} < 0{,}67$.



d) $\alpha_{opening}$ = 0,9 to 0,95 α_f = 0,1 to 0,05, when inlet for gas is open. $\alpha_{opening}$ = 0,9 (α_f = 0,1), when melted material is accumulated as shown at the right-hand side of subfigure d).



e) Intermediate value of subfigures a) and b) shall be applied.



f) General gap configuration of a door. Pressure loss at the corner shall be added to the value obtained in subfigures b) or c).

Figure F.1 — Coefficient determined from the shape of openings

F.3 Heat loss by radiation from furnace opening

Calculate the heat loss by radiation from furnace opening per ton of products, $E_{\text{l,opening}}$, using Formula (F.8):

$$E_{\text{l,opening}} = t_{\text{p}} \times S_{\text{opening}} \times q_{\text{r}} \quad \text{(F.8)}$$

Calculate the heat flux by radiation, q_{r}, using Formula (F.9):

$$q_{\text{r}} = \sigma \times \varepsilon_2 \left(T_{\text{z}}^{\,4} - T_{\text{a}}^{\,4} \right) \quad \text{(F.9)}$$

where

$\sigma = 5{,}67 \times 10^{-8}$ (W/m^2·K^4): Stephan-Boltzmann constant;

ε_2 is the coefficient which is listed in Table F.1, and is determined from the shape of furnace openings.

Table F.1 — Coefficient of heat flux by radiation

Shape of openings	Diameter or shortest side length divided by wall thickness							
	0,01	**0,1**	**0,2**	**0,5**	**1**	**2**	**4**	**6**
Circle	0,02	0,10	0,18	0,35	0,52	0,67	0,80	0,86
Square	0,02	0,11	0,20	0,36	0,53	0,69	0,82	0,87
Rectangular (2:1)	0,03	0,13	0,24	0,43	0,60	0,75	0,86	0,90
Extremely narrow shape	0,05	0,22	0,34	0,54	0,68	0,81	0,89	0,92
NOTE Source: JIS G 0702.								

Annex G
(informative)

Calculation of energy for fluid transfer

G.1 Blowers

When fluid is supposed to be transferred by blowers (i.e. in the case that the supply pressure is relatively low), calculate the energy consumption of fluid transfer using Formulae (G.1) and (G.2):

$$E_{\text{aux,fluid,bl}} = Q_{\text{blower}} \times t_{\text{p}} \quad \text{(G.1)}$$

$$Q_{\text{blower}} = \frac{P_{\text{h}} \times r_{\text{f}}}{60} \times \frac{1+\alpha_{\text{m}}}{\eta_{\text{s}}} \quad \text{(G.2)}$$

The tolerances and the static pressure efficiency of blowers given in Table G.1 may be used or applied.

Table G.1 — Efficiency and tolerance of blowers

Type	Static pressure efficiency η_{s}	Tolerance α_{m}
Propeller fan	50 to 75 %	30 %
Sirocco fan	45 to 60 %	20 to 30 %
Plate fan	50 to 70 %	15 to 25 %
Turbo-fan	55 to 75 %	15 to 25 %
Single-stage turbo blower	60 to 80 %	10 to 20 %
Multistage turbo blower	50 to 70 %	10 to 70 %
NOTE Source: Energy Conservation Handbook 2009[22].		

G.2 Pumps

When fluid is supposed to be transferred by pumps, calculate the energy consumption of fluid transfer using Formulae (G.3), (G.4) and (G.5):

$$E_{\text{aux,fluid,pump}} = Q_{\text{pump}} \times t_{\text{p}} \quad \text{(G.3)}$$

$$Q_{\text{pump}} = \frac{\rho_{\text{f}} \times r_{\text{f}} \times H_{\text{d}}}{6,12} \times \frac{1+\alpha_{\text{m}}}{\eta_{\text{p}}} \quad \text{(G.4)}$$

$$H_{\text{d}} = z + \frac{p_{\text{h}}}{9,8 \times \rho_{\text{f}}} + \frac{U^2}{19,6} \quad \text{(G.5)}$$

The tolerance of pumps may be as given in Table G.2.

Table G.2 — Tolerance of pumps

Dimensions in per cent

Type	Tolerance α_m
Centrifugal pump (high pump head)	20
Centrifugal pump (middle/low pump head)	15
Diagonal flow pump	20
Axial flow pump	25
NOTE Source: Energy Conservation Handbook 2009[22].	

Pump efficiency may be determined from Figure G.1.

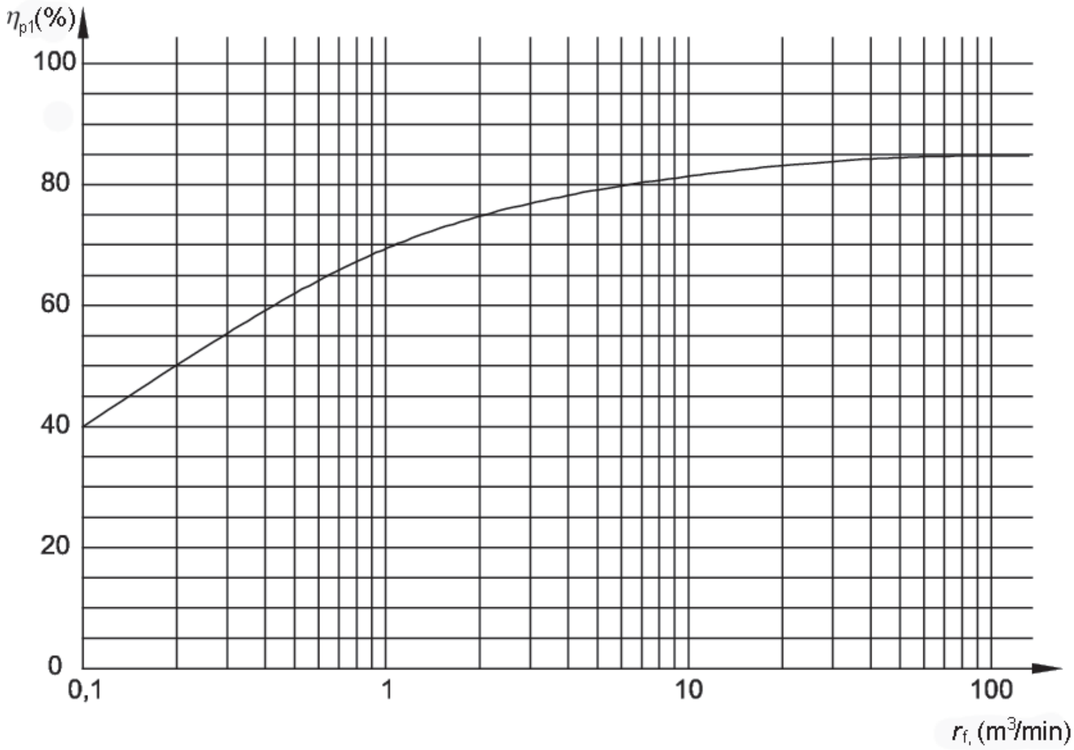


Figure G.1 — Efficiency of general pumps

G.3 Compressors

When fluid is supposed to be transferred by compressors, calculate the energy consumption of fluid transfer using Formulae (G.6), (G.7) and (G.8):

$$E_{\text{aux,fluid,comp}} = Q_{\text{comp}} \times t_p \quad \text{(G.6)}$$

$$L = L_{\text{th}} \times \frac{\alpha_m}{\eta_c \times \eta_t} \quad \text{(G.7)}$$

$$L_{\text{th}} = \frac{\kappa}{\kappa - 1} \times \frac{P_{\text{s}} \times r_{\text{f}}}{0,06} \times \left[\left(\frac{P_{\text{d}}}{P_{\text{s}}} \right)^{\frac{\kappa-1}{\kappa}} - 1 \right] \quad \text{(G.8)}$$

The value of α_{m} shall be the following,

- reciprocating compressor: 1,10;
- oilless screw compressor: 1,15;
- lubricated screw compressor: 1,10;
- turbo compressor: 1,20.

Annex H
(informative)

Example of energy balance sheet

H.1 Energy balance sheet

Examples of energy balance sheets are shown in Tables H.1, H.2 and H.3.

Table H.1 — Overall energy balance

Type of energy				Specific energy consumption kJ/t	Specific energy consumption %
Energy input, E_{input}	Fuel equivalent energy, E_{fe}	Calorific value of fuel, $E_{h,fuel}$			
		Calorific value of waste, $E_{h,waste}$			
		Calorific value of source gas of atmospheric gas, $E_{u,atm,cal}$			
		Electricity, $E_{fe,el}$			
	Subtotal				
	Other energy, E_{others}	Sensible heat of fuel, $E_{s,fuel}$			
		Sensible heat of combustion air, $E_{s,air}$			
		Sensible heat of atomization agent, $E_{s,atomize}$			
		Heat of reaction, E_{react}			
		Sensible heat of infiltration air, $E_{s,infilt}$			
	Subtotal				
	Total				100
Energy output, E_{output}	Thermal energy, $E_{therm,out}$	Effective energy, E_{effect}			
		Jig loss, $E_{l,jig}$			
		Sensible heat of oxidized substance, $E_{s,oxid}$			
		Exhaust gas (regenerative burner), $E_{exhaust}$			
		Exhaust gas (auxiliary flue), $E_{exhaust}$			
		Sensible heat of atmospheric gas, $E_{s,atm}$			
		Wall loss, $E_{l,wall}$			
		Heat loss of radiation from furnace opening, $E_{l,opening}$			
		Heat loss from furnace parts installed through furnace wall, $E_{l,parts}$			
		Cooling water loss, $E_{l,cw}$			
		Other losses, $E_{l,other}$			
	Electrical auxiliary equipment, E_{aux}	Energy consumed in installed electrical auxiliary equipment, $E_{aux,installed}$	Motor — WB		
			Fan		
			Induced draft (or draught) fan (IDF)		
		Energy used for fluid transfer, $E_{aux,fluid}$	Cooling water		
			Fuel		
			Compressed air		
	Generation of utilities, $E_{utility}$	Oxygen, $E_{u,oxy}$			
		Steam, $E_{u,steam}$			
		Atmospheric gas	electricity for generation, $E_{u,atm,gen}$		
			calorific value of source gas, $E_{u,atm,cal}$		
	Electrical generation loss, $E_{l,eg}$				
	Total				100

Table H.2 — Thermal energy balance

Type of energy			Specific energy consuption	
			kJ/t	%
Thermal energy input	Calorific value of fuel, $E_{h,fuel}$			
	Thermal energy input from electrical heating source			
	Calorific value of waste, $E_{h,waste}$			
	Other energy, E_{others}	Sensible heat of fuel, $E_{s,fuel}$		
		Sensible heat of combustion air, $E_{s,air}$		
		Sensible heat of atomization agent, $E_{s,atomize}$		
		Heat of reaction, E_{react}		
		Sensible heat of infiltration air, $E_{s,infilt}$		
	Total			100
Thermal energy output, $E_{therm,out}$	Effective energy, E_{effect}			
	Jig loss, $E_{l,jig}$			
	Sensible heat of oxidized substance, $E_{s,oxid}$			
	Exhaust gas (regenerative burner), $E_{exhaust}$			
	Exhaust gas (auxiliary flue), $E_{exhaust}$			
	Sensible heat of atmospheric gas, $E_{s,atm}$			
	Wall loss, $E_{l,wall}$			
	Heat loss of radiation from furnace opening, $E_{l,opening}$			
	Heat loss from furnace parts installed through furnace wall, $E_{l,parts}$			
	Cooling water loss, $E_{l,cw}$			
	Other losses, $E_{l,other}$			
	Total			100

Table H.3 — Electrical generation

Type of energy				Specific energy consumption	
				kJ/t	%
Input	Fuel-equivalent energy of electricity, $E_{fe,el}$				100
Output	Thermal energy output from electrical heat source				—
	Electrical auxiliary equipment E_{aux}	Energy consumed in installed electrical auxiliary equipment, $E_{aux,installed}$	Motor		
			Fan		
			IDF		
		Energy used for fluid transfer $E_{aux,fluid}$	Cooling water		
			Fuel		
			Compressed air		
	Electrical energty used for generation of utilities $E_{e,utility}$	Oxygen, $E_{u,oxy}$			
		Steam, $E_{u,steam}$			
		Energy used for generation of atmospheric gas, $E_{u,atm,gen}$			
	Electrical generation loss, $E_{l,eg}$				
	Total				100

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