INTERNATIONAL STANDARD

ISO 13579-2

First edition
2013-01-15

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

Part 2: Reheating furnaces for steel

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

Partie 2: Fours de réchauffage pour acier

Reference number
ISO 13579-2:2013(E)

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Published in Switzerland

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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 13579-2 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 2: Reheating furnaces for steel*

— *Part 3: Batch-type aluminium melting furnaces*

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

Introduction

All calculations within this part of ISO 13579 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 2: Reheating furnaces for steel

1 Scope

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

— measurement methods;

— calculations (general calculation);

— energy balance and efficiency calculation evaluation report.

This part of ISO 13579 is not applicable to any efficiencies related to the process itself outside of reheating furnaces for steel (e.g. in a rolling mill process, the reheating furnace is 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*

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

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 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

3.1.2.4
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 3.1.5.12.

3.1.5.2
effective energy
E_{effect}
enthalpy that products gain 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
wall loss
$E_{l,wall}$
thermal energy emitted from the surface of industrial furnaces by radiation and convection

3.1.5.8
heat loss of discharged blowout from furnace opening
$E_{l,blowout}$
sensible heat of blowout gas emitted from the furnace opening

3.1.5.9
heat loss of radiation from furnace opening
$E_{l,opening}$
thermal energy emitted from the furnace opening by radiation

3.1.5.10
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.

3.1.5.11
cooling water loss
$E_{l,cw}$
thermal energy brought out by cooling water from the area of energy balance measurement

3.1.5.12
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 into 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

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

NOTE Tons used are metric tons.

Symbol	Meaning	Unit
$c_{pm,p1}$	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)
$c_{pm,oxid}$	mean specific heat of scale between T_{p2} and 273,15 K	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
$E_{aux,installed}$	aggregate of energy used in installed electrical auxiliary equipment 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_{f0}	heat by formation of scale per kilogram of iron	kJ/kg
e_{FeO}	heat by formation of FeO per 1 kg of Fe	kJ/kg
e_{Fe2O3}	heat by formation of Fe_2O_3 per 1 kg of Fe	kJ/kg

Symbol	Meaning	Unit
e_{Fe3O4}	heat by formation of Fe_3O_4 per 1 kg of Fe	kJ/kg
E_{fe}	fuel equivalent energy per ton of products	kJ/t
$E_{fe,el}$	fuel equivalent energy of electricity per ton of products	kJ/t
$E_{h,fuel}$	calorific value of fuel 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_{others}	other energy input 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 oxidant 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
$E_{u,oxy}$	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
M_{loss}	loss of mass per ton of products	kg/t
M_p	mass of products	kg or t
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 extraction from the area of the energy balance	K
η_1	total energy efficiency	—
η_e	regional electrical generation efficiency	—
σ_1	absolute error of thermocouple	°C
σ_2	absolute error of compensation lead wire	°C
σ_3	absolute error of output device of thermocouple	°C
$w_{(FeO)}$	mass fraction of iron oxide	—
$w_{(Fe2O3)}$	mass fraction of Fe_2O_3	—
$w_{(Fe3O4)}$	mass fraction of Fe_3O_4	—
$w_{(T\cdot Fe)}$	mass fraction of iron contained in scale	—

5 Basic principles

5.1 General

The area of energy balance measurement shall be determined.

In principle, exclude table rollers from the area of energy balance.

NOTE Examples of determination of the area of energy balance measurement for reheating furnace for steel are shown in Figures 1 and 2.

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;

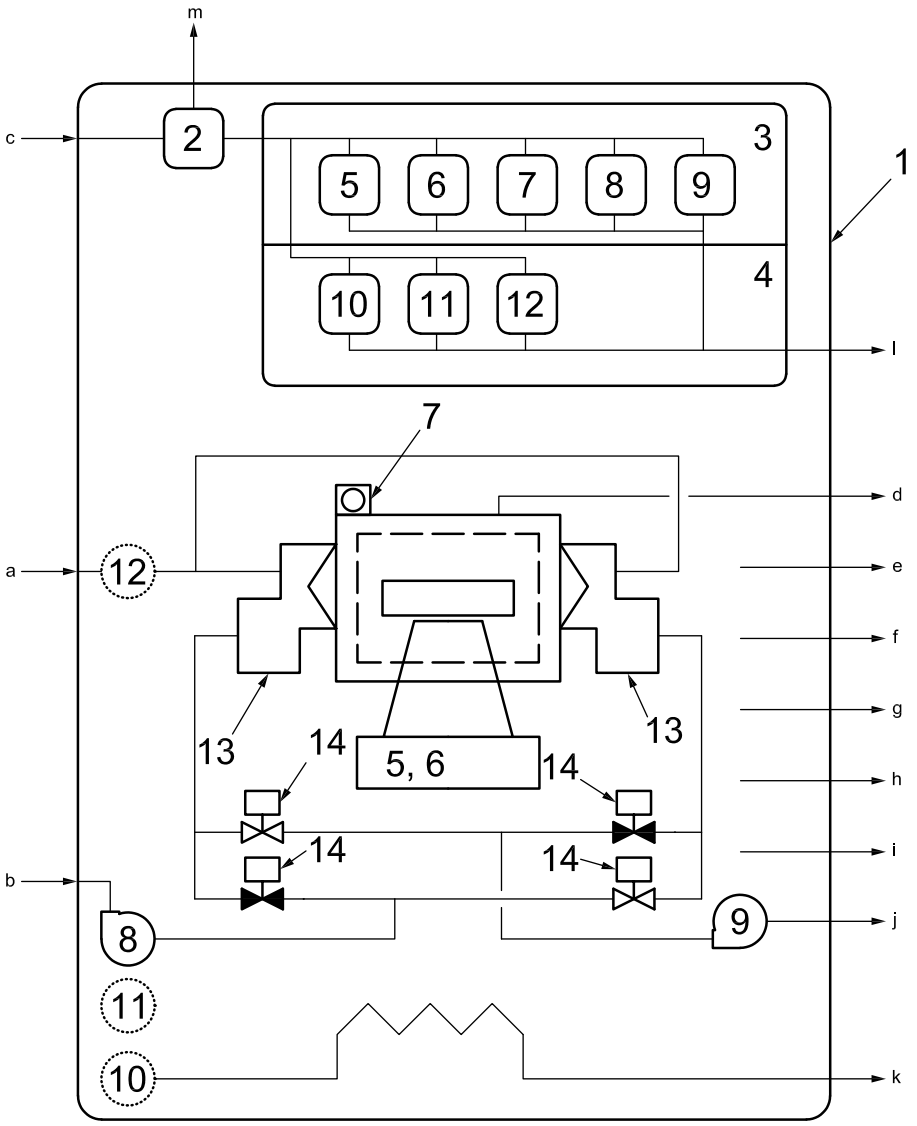
- thermal energy output, $E_{therm,out}$;
- energy consumed in electrical auxiliary equipment, E_{aux};
- energy used for generation of utilities, $E_{utilities}$;
- electrical generation loss, $E_{l,eg}$.

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 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).

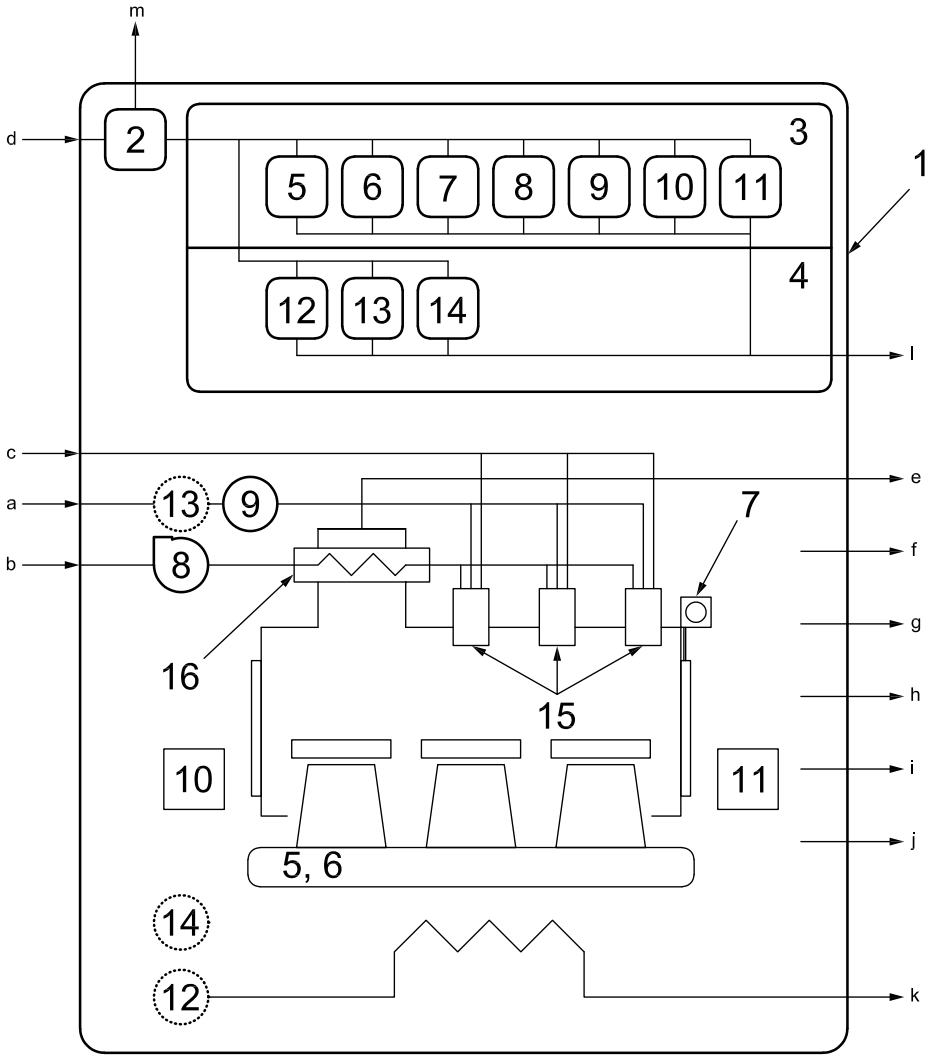


Key

1	area of energy balance	8	fan
2	electrical generation	9	IDF
3	installed electrical auxiliary equipment	10	cooling water pump
4	equipment for fluid transfer	11	air compressor
5	motor for walking beams	12	fuel transfer equipment
6	motor for ball screws	13	regenerative burners
7	motor for furnace door	14	change over valves

a	Sensible heat of fuel.	h	Heat loss of radiation from furnace opening.
b	Sensible heat of combustion air.	i	Other losses.
c	Fuel equivalent energy of electricity.	j	Sensible heat of exhaust gas (regenerative burners).
d	Sensible heat of exhaust gas (auxiliary flue).	k	Cooling water loss.
e	Effective energy.	l	Energy consumed in electrical auxiliary equipment.
f	Sensible heat of oxidized substance.	m	Energy loss in electrical generation.
g	Wall loss.		

Figure 1 — Example of determination of the area of energy balance — Continuous furnace for steel with regenerative burners



Key

1 area of energy balance
2 electrical generation
3 installed electrical auxiliary equipment
4 equipment for fluid transfer
5 motor for walking beams
6 motor for ball screws
7 motor for furnace door
8 fan
9 fuel heater
10 pusher
11 extractor
12 cooling water pump
13 fuel transfer equipment
14 air compressor
15 burner
16 recuperator

a Sensible heat of fuel.
b Sensible heat of combustion air.
c Sensible heat of atomization agent.
d Fuel equivalent energy of electricity.
e Sensible heat of exhaust gas (auxiliary flue).
f Effective energy.
g Sensible heat of oxidized substance.
h Wall loss.
i Heat loss of radiation from furnace opening.
j Other losses.
k Cooling water loss.
l Energy consumed in electrical auxiliary equipment.
m Energy loss in electrical generation.

Figure 2 — Example of determination of the area of energy balance — Continuous furnace for steel with recuperator

5.2 Energy flow diagram

The energy flow diagram or Sankey diagram is as specified in ISO 13579-1:2013, 5.2.

5.3 Process Heating Assessment Survey Tool

The Process Heating Assessment Survey Tool (PHAST) is specified in ISO 13579-1:2013, 5.3.

6 Basic conditions of measurement and calculation

6.1 State of furnace

The state of the furnace is specified in ISO 13579-1:2013, 6.1.

6.2 Duration of measurement

The duration of measurement is specified in ISO 13579-1:2013, 6.2.

6.3 Unit of specific energy intensity

The unit of specific energy intensity is specified in ISO 13579-1:2013, 6.3.

6.4 Reference conditions

The reference conditions are specified in ISO 13579-1:2013, 6.4.

6.5 Unit of amount of gas

The unit of amount of gas is specified in ISO 13579-1:2013, 6.5.

6.6 Fuel

The fuel is specified in ISO 13579-1:2013, 6.6.

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

The systematization of the type 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 grouping**	**Detailed items**
Total energy input, E_{input}	Fuel equivalent energy, E_{fe}	Calorific value of fuel, $E_{h,fuel}$
		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, $E_{l,storage}$
		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 $E_{aux,installed}$ e.g. blowersetc.
		Energy used for fluid transfer $E_{aux,fluid}$ e.g. cooling wateretc.
	Generation of utilities, $E_{utility}$	Oxygen, $E_{u,oxy}$
		Steam, $E_{u,steam}$
	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.

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, $E_{\text{aux,installed}}$, 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, $E_{\text{aux,fluid}}$, shall be applied when energy consumed in auxiliary electrical equipment for fluid transfer, such as 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.

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 reheating furnace chambers under test (see Figure 1).

The systematization of thermal energy is described in Table 2.

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

Thermal energy input/output	Type of energy Intermediate category / Detailed items	
Thermal energy input	Calorific value of fuel, $E_{h,fuel}$	
	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, $E_{l,storage}$	
	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 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 — Type of energy used in this part of ISO 13579 — Energy balance of electrical generation

Energy input/output	Type of energy Intermediate category/Detailed items		
Input	Fuel equivalent energy of electricity, $E_{fe,el}$		
Output	Total consumed electrical energy, $E_{e,total}$	Thermal energy output from electrical heating source	
		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.
		Electrical energy used for generation of utilities, $E_{e,utility}$	Oxygen, $E_{u,oxy}$
			Atmospheric gas energy for generation, $E_{u,atm,gen}$
	Electrical generation loss, $E_{l,eg}$		
The use of energy balance sheet of electrical generation is optional.			

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 specified in 9.4.1.

8 Measurement method

8.1 General

The measurement shall be as specified in ISO 13579-1:2013, 8.1

8.2 Fuel

8.2.1 Volume

The measurement of the volume of fuel shall be as specified in ISO 13579-1:2013, 8.2.1.

8.2.2 Sampling, testing, analysis and measurement of calorific value

Sampling, testing, analysis and measurement of calorific value are specified in ISO 13579-1:2013, 8.2.2.

8.2.3 Pressure and temperature

Pressure and temperature are specified in ISO 13579-1:2013, 8.2.3.

8.3 Atomization agent

8.3.1 Volume

Volume is specified in ISO 13579-1:2013, 8.3.1.

8.3.2 Pressure and temperature

Pressure and temperature are specified in ISO 13579-1:2013, 8.3.2.

8.4 Combustion air and exhaust gas

8.4.1 Combustion air

8.4.1.1 Combustion air volume

Combustion air volume is specified in ISO 13579-1:2013, 8.4.1.1.

8.4.1.2 Combustion air pressure and temperature

Combustion air pressure and temperature are specified in ISO 13579-1:2013, 8.4.1.2.

8.4.2 Exhaust gas

8.4.2.1 Temperature

Temperature is specified in ISO 13579-1:2013, 8.4.2.1.

8.4.2.2 Method of exhaust gas analysis

The method of exhaust gas analysis is specified in ISO 13579-1:2013, 8.4.2.2.

8.4.3 Measurement method for burners with recuperative functions

8.4.3.1 Regenerative burners

8.4.3.1.1 Measurement positions

The measurement positions are specified in ISO 13579-1:2013, 8.4.3.1.1.

8.4.3.1.2 Measurement of exhaust gas temperature

The measurement of exhaust gas temperature is specified in ISO 13579-1:2013, 8.4.3.1.2.

8.4.3.2 Recuperative radiant tube burners

Recuperative radiant tube burners are specified in ISO 13579-1:2013, 8.4.3.2.

8.5 Controlled atmospheric gas

8.5.1 Volume

Volume is specified in ISO 13579-1:2013, 8.5.1.

8.5.2 Temperature

Temperature is specified in ISO 13579-1:2013, 8.5.2.

8.6 Products and jigs/fixtures for products handling

8.6.1 Mass

Mass is specified in ISO 13579-1:2013, 8.6.1.

8.6.1.1 Continuous furnaces

Continuous furnaces are specified in ISO 13579-1:2013, 8.6.1.1.

8.6.1.2 Batch-type furnaces

Batch-type furnaces are specified in ISO 13579-1:2013, 8.6.1.2.

8.6.2 Temperature

Temperature is specified in ISO 13579-1:2013, 8.6.2.

8.6.3 Mass loss

The mass due to the formation of scale shall be determined from the measurement of the mass of steel products before loading and after unloading under scale-removed condition. Alternatively, the mass loss due to the formation of scale shall be calculated using the thickness and surface area data of the scale, and its analysis value.

8.7 Temperature of furnace surface

8.7.1 Furnace wall

Furnace wall is specified in ISO 13579-1:2013, 8.7.1.

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

Cross-sectional area of furnace parts installed through furnace wall is specified in ISO 13579-1:2013, 8.7.2.

8.8 Furnace inner wall temperature

Furnace inner wall temperature is specified in ISO 13579-1:2013, 8.8.

8.9 Inner furnace pressure

Inner furnace pressure is specified in ISO 13579-1:2013, 8.9.

8.10 Cooling water

8.10.1 Temperature

As specified in ISO 13579-1:2013, 8.10.1.

8.10.2 Volume

As specified in ISO 13579-1:2013, 8.10.2.

8.11 Electrical auxiliary equipment

8.11.1 Installed electrical auxiliary equipment

Installed electrical auxiliary equipment is specified in ISO 13579-1:2013, 8.11.1.

8.11.2 Energy for fluid transfer

Energy for fluid transfer is specified in ISO 13579-1:2013, 8.11.2.

8.12 Generation of utilities

Generation of utilities is specified in ISO 13579-1:2013, 8.12.

8.13 Recycled energy

Recycled energy is specified in ISO 13579-1:2013, 8.13.

9 Calculation

9.1 General provisions

General provisions are specified in ISO 13579-1:2013, 9.1.

9.2 Total energy input

9.2.1 Calorific value of fuel

9.2.1.1 General

Calorific value of fuel is specified in ISO 13579-1:2013, 9.2.1.1.

9.2.1.2 Gaseous fuel

Gaseous fuel is specified in ISO 13579-1:2013, 9.2.1.2.

9.2.1.3 Liquid fuel

Liquid fuel is specified in ISO 13579-1:2013, 9.2.1.3.

9.2.2 Fuel equivalent energy of electricity

Fuel equivalent energy of electricity is specified in ISO 13579-1:2013, 9.2.4.

9.2.2.1 Sensible heat of fuel

Sensible heat of fuel is specified in ISO 13579-1:2013, 9.2.4.1.

9.2.3 Sensible heat of combustion air

9.2.3.1 General

Sensible heat of combustion air is specified in ISO 13579-1:2013, 9.2.5.1.

9.2.3.2 Gaseous fuel

Gaseous fuel is specified in ISO 13579-1:2013, 9.2.5.2.

9.2.3.3 Liquid fuel

Liquid fuel is specified in ISO 13579-1:2013, 9.2.5.3.

9.2.3.4 Simplified calculation of excess air ratio

Simplified calculation of excess air ratio is specified in ISO 13579-1:2013, 9.2.5.4.

9.2.4 Sensible heat of atomization agent

Sensible heat of atomization agent is specified in ISO 13579-1:2013, 9.2.6.

9.2.5 Heat generated by formation of scale

Heat generated by the formation of scale (heat of reaction) per ton of product is calculated using Formulae (1) and (2):

$$E_{\text{react}} = M_{\text{loss}} \times e_{\text{f0}} \tag{1}$$

$$e_{\text{f0}} = \frac{1}{w_{(\text{T·Fe})}} \times \left(0{,}77 \times e_{\text{FeO}} \times w_{(\text{FeO})} + 0{,}700 \times e_{\text{Fe}_2\text{O}_3} \times w_{(\text{Fe}_2\text{O}_3)} + 0{,}724 \times e_{\text{Fe}_3\text{O}_4} \times w_{(\text{Fe}_3\text{O}_4)}\right) \tag{2}$$

Heat generated by the formation of each scale may be used as shown in Table A.1.

In case the analysis of scale is not performed, the following value may be applied.

$$e_{\text{f0}} = 5\,558{,}4 \text{ (kJ/kg Fe)} \tag{3}$$

9.2.6 Sensible heat of infiltration air

Sensible heat of infiltration air is specified in ISO 13579-1:2013, 9.2.8.

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 (4):

$$E_{\text{effect}} = E_{\text{p2}} - E_{\text{p1}} \tag{4}$$

9.3.1.1.2 Sensible heat of products

9.3.1.1.2.1 At the time of loading

Calculate the sensible heat of products at the time when products are loaded in the area of energy balance per ton of products using Formula (5):

$$E_{p1} = 1\,000 \times c_{pm,p1} \times (T_{p1} - 273{,}15) \tag{5}$$

Tables of heat content with reference temperature of 273,15 K may be used as shown in Table A.2.

9.3.1.1.2.2 At the time of extraction

Calculate the sensible heat of products at the time when products are extracted from the area of energy balance per ton of products using Formula (6):

$$E_{p2} = \left(1\,000 - M_{loss}\right) \times c_{pm,p2} \times (T_{p2} - 273{,}15) \tag{6}$$

Tables of heat content with reference temperature of 273,15 K may be used as shown in Table A.2.

NOTE Mass loss is weight loss from forming an oxidized substance in the thermoprocess, for instance.

9.3.1.1.3 Mass of products

In the case of continuous furnaces, calculate the sum of mass of products processed within the duration of measurement using Formula (7):

$$\sum M_{p} = \frac{\left(\sum M_{p2} + \sum M_{p3}\right)}{2} \tag{7}$$

9.3.1.2 Jig loss

Jig loss iss specified in ISO 13579-1:2013, 9.3.1.2.

9.3.1.3 Sensible heat of oxidized substance

The sensible heat of scale per ton of products is calculated using Formula (8):

$$E_{s,oxid} = M_{loss} \times \frac{100}{w_{(T\cdot Fe)}} \times c_{pm,oxid}\left(T_{p2} - 273{,}15\right) \tag{8}$$

where

M_{loss} is the mass of scale loss per ton of product;

$w_{(T\cdot Fe)}$ is the mass fraction of iron contained in the scale;

$C_{pm,oxid}$ is the mean specific heat of scale between T_{p2} and 273,15 K.

The specific heat of scale may be 0,900 (kJ/kg·K).

$w_{(T\cdot Fe)}$, the mass fraction of iron (Fe) contained in the scale can be 75,5 %, if scale analysis is not performed.

9.3.1.4 Sensible heat of exhaust gas

9.3.1.4.1 General

Sensible heat of exhaust gas is specified in ISO 13579-1:2013, 9.3.1.4.1.

9.3.1.4.2 Gaseous fuel

Gaseous fuel is specified in ISO 13579-1:2013, 9.3.1.4.2.

9.3.1.4.3 Liquid fuel

Liquid fuel is specified in ISO 13579-1:2013, 9.3.1.4.3.

9.3.1.5 Heat storage loss by batch-type furnace

Heat storage loss by batch-type furnace is specified in ISO 13579-1:2013, 9.3.1.5.

9.3.1.6 Wall loss

Wall loss is specified in ISO 13579-1:2013, 9.3.1.7.

9.3.1.7 Heat loss of discharged blowout from furnace opening

Heat loss of discharged blowout from furnace opening is specified in ISO 13579-1:2013, 9.3.1.8.

9.3.1.8 Heat loss of radiation from furnace opening

Heat loss of radiation from furnace opening is specified in ISO 13579-1:2013, 9.3.1.9.

9.3.1.9 Heat loss from furnace parts installed through furnace wall

Heat loss from furnace parts installed through furnace wall is specified in ISO 13579-1:2013, 9.3.1.10.

9.3.1.10 Cooling water loss

Cooling water loss is specified in ISO 13579-1:2013, 9.3.1.11.

9.3.2 Energy consumed in electrical auxiliary equipment

9.3.2.1 Energy consumed in electrical auxiliary equipment

Energy consumed in electrical auxiliary equipment is specified in ISO 13579-1:2013, 9.3.2.1.

9.3.2.2 Energy consumed in installed electrical auxiliary equipment

Energy consumed in installed electrical auxiliary equipment is specified in ISO 13579-1:2013, 9.3.2.2.

9.3.2.3 Energy used for fluid transfer

Energy used for fluid transfer is specified in ISO 13579-1:2013, 9.3.2.3.

9.3.3 Energy used for generation of utilities

9.3.3.1 General

Energy used for generation of utilities is specified in ISO 13579-1:2013, 9.3.3.1.

9.3.3.2 Oxygen

Oxygen is specified in ISO 13579-1:2013, 9.3.3.2.

9.3.3.3 Steam

Steam is specified in ISO 13579-1:2013, 9.3.3.3.

9.3.4 Electrical generation loss

Electrical generation loss is specified in ISO 13579-1:2013, 9.3.4.

9.4 Total energy efficiency

9.4.1 General

Total energy efficiency is specified in ISO 13579-1:2013, 9.4.1.

9.4.2 Total energy efficiency limited to heating-up process

Total energy efficiency limited to heating-up process is specified in ISO 13579-1:2013, 9.4.2.

10 Energy balance evaluation report

The energy balance and efficiency evaluation report shall be as specified in ISO 13579-1:2013, Clause 10.

NOTE An example of an energy balance and efficiency report is given in Annex B.

Annex A
(informative)

Reference data

Table A.1 — Heat generated by iron-scale formation

Reaction	Reaction heat per unit quantity of iron	
	kJ/mol	kJ/mol
$Fe + \frac{1}{2}O_2 = FeO$	268,954	4,8140
$2Fe + \frac{3}{2}O_2 = Fe_2O_3$	817,117	7,3172
$3Fe + 2O_2 = Fe_3O_4$	1 117,257	6,6684
NOTE Source: JIS G 0702.		

Table A.2 — Specific heat content of steels

Calorific value required to elevate temperature of steel from 0 °C to the target temperature			
Target temperature	**Killed steel** 0,08 %[a]	**Soft steel** 0,23 %[a]	**Carbon steel** 0,4 %[a]
°C	KJ/kg		
0	0,0	0,0	0,0
50	23,44	23,44	23,44
100	47,72	47,72	47,72
150	72,84	72,84	72,84
200	98,79	98,79	98,37
250	126,00	125,58	124,74
300	153,63	153,21	152,37
350	182,09	182,09	180,84
400	211,81	211,81	210,14
450	243,21	243,21	240,70
500	276,28	276,28	273,35
550	311,02	311,44	307,67
600	348,28	348,69	343,25
650	387,62	388,04	379,67
700	430,32	430,32	418,18
750	487,25	501,90	497,30
800	535,39	549,62	528,27
850	578,51	586,46	553,81
900	619,11	618,69	581,02
950	651,76	651,34	612,41
1 000	684,41	683,57	643,39
1 050	717,48	716,22	675,20
1 100	750,55	748,46	706,60
1 150	783,62	781,53	738,83
1 200	816,69	814,60	771,48
1 250	849,76	848,50	804,97
1 300	883,25	882,83	839,29

NOTE Source: JIS G 0702.

[a] Mass concentration of carbon.

Annex B
(informative)

Report of energy balance and efficiency of a reheating furnace for steel — Example

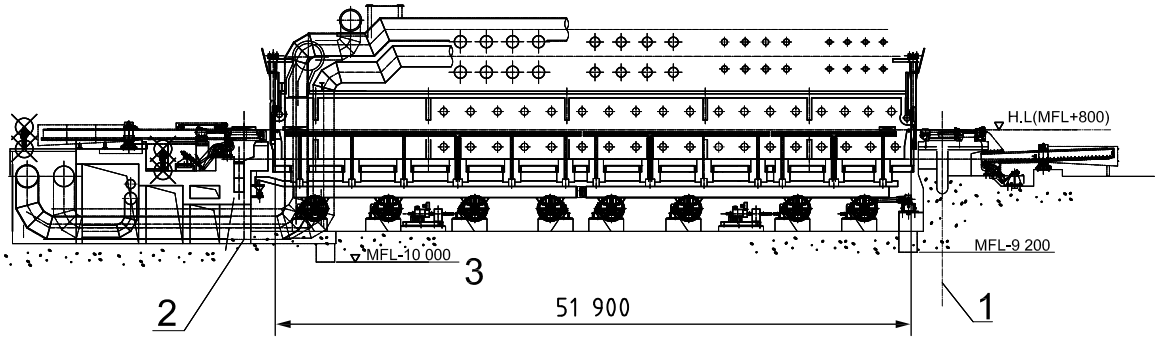
B.1 Equipment specification summary

The equipment specification summary of the furnace is shown in Table B.1. The outline drawings are in Figure B.1.

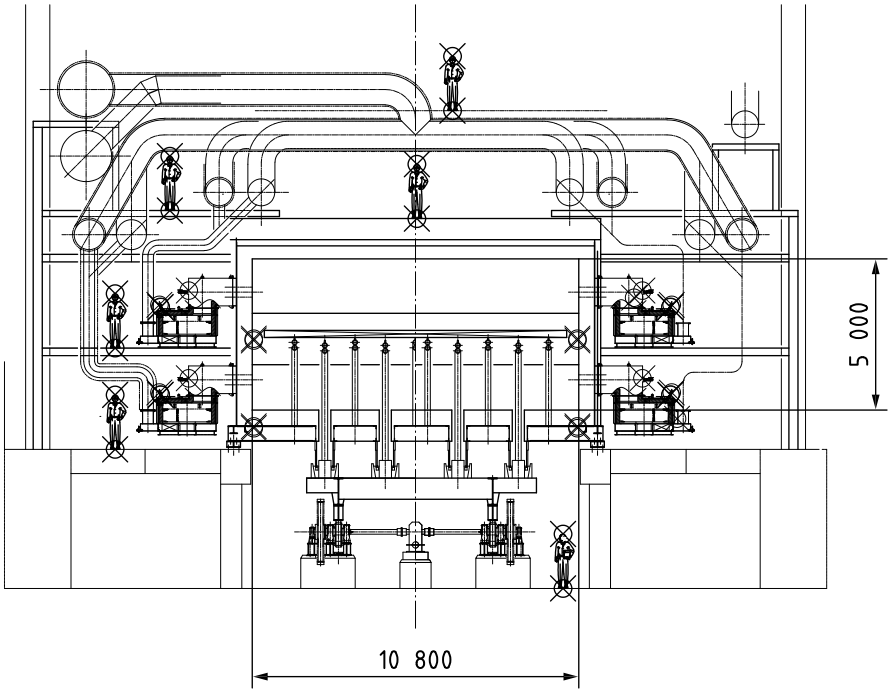
Table B.1 — Equipment specification summary

Company/Plant name		
Location		
Maker of reheating furnace		
Serial number		
Type		Continuous reheating furnace
Nominal capacity	t/h	300 t/h
Effective length times width of furnace	mm	50 600 × 11 840
Dimension and material of furnace refractory and lagging material		see attached
Type of transfer of products		Walking beam
Type of fuel		COG
Type, capacity and quantity of burners		Regenerative burners 36 pairs
Type and capacity of fans		Turbo blower of single suction
Material of products		Carbon steel slab
Dimension and mass of nominal products	mm kg	250 × 1250 × 100 000 24 400
Nominal loading temperature of products	°C	20
Nominal extraction temperature of products	°C	1 250

Dimensions in millimetres



a) Longitudinal section



b) Cross-section

Key

1 discharge table
2 charge table
3 drain pit

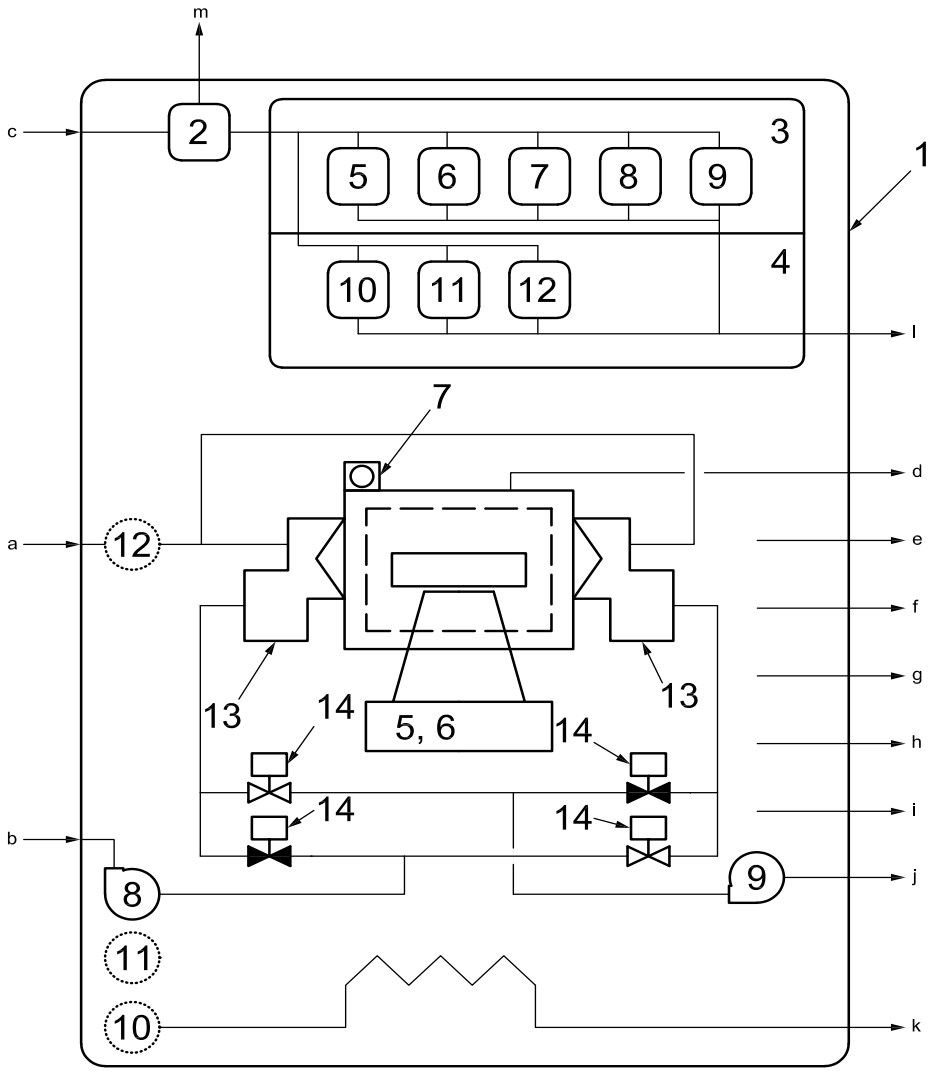
Figure B.1 — Outline drawing of the continuous furnace for steel

B.2 Area of energy balance

The area of energy balance is defined as described in Figure B.2 (see key item 1).

B.3 Measurement data

The measurement data are shown in Table B.2.



Key

1	area of energy balance	8	fan
2	electrical generation	9	IDF
3	installed electrical auxiliary equipment	10	cooling water pump
4	equipment for fluid transfer	11	air compressor
5	motor for walking beams	12	fuel transfer equipment
6	motor for ball screws	13	regenerative burners
7	motor for furnace door	14	change over valves

[a] Sensible heat of fuel.
[b] Sensible heat of combustion air.
[c] Fuel equivalent energy of electricity.
[d] Sensible heat of exhaust gas (auxiliary flue).
[e] Effective energy.
[f] Sensible heat of oxidized substance.
[g] Wall loss.
[h] Heat loss of radiation from furnace opening.
[i] Other losses.
[j] Sensible heat of exhaust gas (regenerative burners).
[k] Cooling water loss.
[l] Energy consumed in electrical auxiliary equipment.
[m] Energy loss in electrical generation.

Figure B.2 — The area of energy balance

Table B.2 — Measurement data

Ambient temperature	20 °C		
Atmospheric pressure	101,2 kPa		
Relative humidity	60 %		
Product	Mass	300 t/h	
	Temperature	At the time of loading	20 °C
		At the time of unloading	1250 °C
	Material	Low carbon steel	
	Oxidized substance	5kg/t	
Fuel	Type	COG (coke oven gas)	
	CO_2	2,38 %	
	C_2H_2	2,42 %	
	O_2	0,1 %	
	CO	7,06 %	
	H_2	57,39 %	
	CH_4	24,55 %	
	N_2	6,1 %	
	Volume	65,95 m^3(n)/t	
	Calorific value	17,23 MJ/ m^3(n)	
	Supply pressure	7 kPa	
	Supply temperature	20 °C	
Atomized agent		None	
Combustion air	Volume	Excess air ratio, m=1,15, is obtained by calculation.	
	Temperature	20 °C	
Oxygen enrichment		None	
Infiltration air		None	
Atmospheric gas		None	
Exhaust gas	Regenerative burner	200 °C	80 %
	Auxiliary flue	900 °C	20 %
	Exhaust gas analysis	CO_2	11,8 %
		CO	0 %
		O_2	3,0 %
		N2	85,2 %
Furnace outer wall temperature	Side	110 °C	
	Top	120 °C	
	Bottom	120 °C	
	Front/back	110 °C	
Furnace dimension	Length	51,9 m	
	Width	11,8 m	
	Height	7,9 m	
	Opening width	10 m	
	Opening height	3 m	
Cooling water	Indirect	Supply temp.	35 °C
		Discharge temp.	49 °C
		Volume	450 t/h
		Supply pressure	0,5 MPa
	Direct	Supply temp.	35 °C
		Discharge temp.	49 °C
		Volume	70 t/h
		Supply pressure	0,5 MPa
	Supply piping	500A (Diameter 0,5 m)	
High-pressure air	Supply pressure	0,5 MPa	
	Volume	20 m^3(n)/min	
Auxiliary electrical equipment	Fan	550 kW	
	IDF	800 kW	
	Motor – walking beam	400 kW actual operation time: 1/8	
	Motor – ball screw	55 kW actual operation time: 1/8	
	Motor – furnace door	30 kW actual operation time: 1/24	

B.4 Energy balance sheet

Energy balance sheets are shown in Tables B.3, B.4 and B.5.

Table B.3 — Overall energy balance

Type of energy				Specific energy consumption	
				kJ/ton	%
Energy input, E_{input}	Fuel equivalent energy, E_{fe}	Calorific value of fuel, $E_{h,fuel}$		1 136 229	92,5
		Calorific value of waste, $E_{h,waste}$		0	—
		Calorific value of source gas of atmospheric gas, $E_{u,atm,cal}$		0	—
		Electricity, $E_{fe,el}$		53 582	4,4
	Other energy E_{others}	Sensible heat of fuel, $E_{s,fuel}$		1 800	0,2
		Sensible heat of combustion air, $E_{s,air}$		8 305	0,7
		Sensible heat of atomization agent, $E_{s,atomize}$		0	—
		Heat of reaction, E_{react}		27 942	2,3
		Sensible heat of infiltration air, $E_{s,infilt}$		0	—
	Total			1 227 858	100
Energy output, E_{output}	Thermal energy $E_{therm,out}$	Effective energy, E_{effect}		834 882	68,0
		Jig loss, $E_{l,jig}$		0	—
		Sensible heat of oxidized substance, $E_{s,oxid}$		7 331	0,6
		Exhaust gas (regenerative burner), $E_{exhaust}$		79 917	14,5
		Exhaust gas (auxiliary flue), $E_{exhaust}$		97 746	
		Sensible heat of atmospheric gas, $E_{s,atm}$		0	—
		Wall loss, $E_{l,wall}$		41 597	3,4
		Heat loss of radiation from furnace opening, $E_{l,opening}$		8 235	0,7
		Heat loss from furnace parts installed through furnace wall, $E_{l,parts}$		—	—
		Cooling water loss, $E_{l,cw}$		101 580	8,3
		Other losses, $E_{l,other}$		2 988	0,2
	Electrical auxiliary equipment, E_{aux}	Energy consumed in installed electrical auxiliary equipment, $E_{aux,installed}$	Motor — walking beam	600	0,05
			Motor — ball screw	68	< 0.05
			Motor — furnace door	15	< 0.05
			Fan	6 600	0,5
			IDF	9 600	0,8
		Energy used for fluid transfer, $E_{aux,fluid}$	Cooling water	1 536	0,1
			Fuel	1 080	0,1
			Compressed air	1 632	0,1
	Generation of utilities, $E_{utility}$	Oxygen, $E_{u,oxy}$		0	—
		Steam, $E_{u,steam}$		0	—
		Atmospheric gas	electricity for generation, $E_{u,atm,gen}$	0	—
			calorific value of source gas, $E_{u,atm,cal}$	0	—
	Electrical generation loss, $E_{l,eg}$			32 631	2,7
	Total			1 232 297	100
The regional electrical generation efficiency: η_e = 0,391 is applied to the calculations.					

Table B.4 — Thermal energy balance

Type of energy		Specific energy consumption	
		kJ/ton	%
Thermal energy input	Calorific value of fuel, $E_{h,fuel}$	1 136 229	96,8
	Thermal energy input from electrical heating source	0	—
	Calorific value of waste, $E_{h,waste}$	0	—
	Sensible heat of fuel, $E_{s,fuel}$	1 800	0,2
	Sensible heat of combustion air, $E_{s,air}$	8 305	0,7
	Sensible heat of atomization agent, $E_{s,atomize}$	0	—
	Heat of reaction, E_{react}	27 942	2,4
	Sensible heat of infiltration air, $E_{s,infilt}$	0	—
	Total	1 174 276	100
Thermal energy output, $E_{therm,out}$	Effective energy, E_{effect}	834 882	71,10
	Jig loss, $E_{l,jig}$	0	—
	Sensible heat of oxidized substance, $E_{s,oxid}$	7 331	0,6
	Exhaust gas (regenerative burner), $E_{exhaust}$	79 917	15,1
	Exhaust gas (Auxiliary flue), $E_{exhaust}$	97 746	
	Sensible heat of atmospheric gas, $E_{s,atm}$	0	—
	Wall loss, $E_{l,wall}$	41 597	3,5
	Heat loss of radiation from furnace opening, $E_{l,opening}$	8 235	0,7
	Heat loss from furnace parts installed through furnace wall, $E_{l,parts}$	—	—
	Cooling water loss, $E_{l,cw}$	101 580	8,7
	Other losses, $E_{l,other}$	2 988	0,3
	Total	1 174 276	100

Table B.5 — Electrical generation

Type of energy				Specific energy consumption	
				kJ/ton	%
Input	Fuel-equivalent energy of electricity, $E_{fe,el}$			53 582	100
Output	Thermal energy output from electrical heat source			0	—
	Electrical auxiliary equipment, E_{aux}	Energy consumed in installed electrical auxiliary equipment, $E_{aux,installed}$	Motor — walking beams	600	1,1
			Motor — ball screw	68	0,1
			Motor — furnace door	15	< 0.05
			Fan	6 600	12,3
			IDF	9 600	17,9
		Energy used for fluid transfer, $E_{aux,fluid}$	Cooling water	1 536	2,5
			Fuel	1 080	2,0
			Compressed air	1 632	3,0
	Electrical energy used for generation of utilities, $E_{e,utility}$	Oxygen, $E_{u,oxy}$		0	—
		Steam, $E_{u,steam}$		0	—
		energy used for generation of atmospheric gas, $E_{u,atm,gen}$		0	—
	Electrical generation loss, $E_{l,eg}$			32 631	60,9
	Total			53 582	100
The regional electrical generation efficiency: η_e = 0,391 is applied to the calculations.					

B.5 Energy efficiency

Based on the energy balance sheets, the total energy efficiency, η_1, of the furnace, in kilojoules per ton (kJ/ton), is calculated as follows:

$$E_{\text{input}} = 1\ 227\ 858 \tag{B.1}$$

$$E_{\text{effective}} = 834\ 882 \tag{B.2}$$

Therefore, according to Formula (57) specified in ISO 13579-1:2013, 9.4.1, the total energy efficiency, η_1, of the furnace subject to measurement, as a percentage, is calculated as given by Formula (B.3):

$$\eta_1 = \frac{834\ 882}{1\ 227\ 858} = 68{,}0 \pm 0{,}7 \tag{B.3}$$

NOTE An explanation on the assessment of accuracy of the total energy efficiency is given in Annex C.

B.6 Energy flow diagram

The energy flow diagram is shown in Figure B.3, and is based on the energy balance analyses shown in Tables B.3, B.4 and B.5.

NOTE For an energy flow or Sankey diagram, see ISO 13579-1:2013, 5.2.

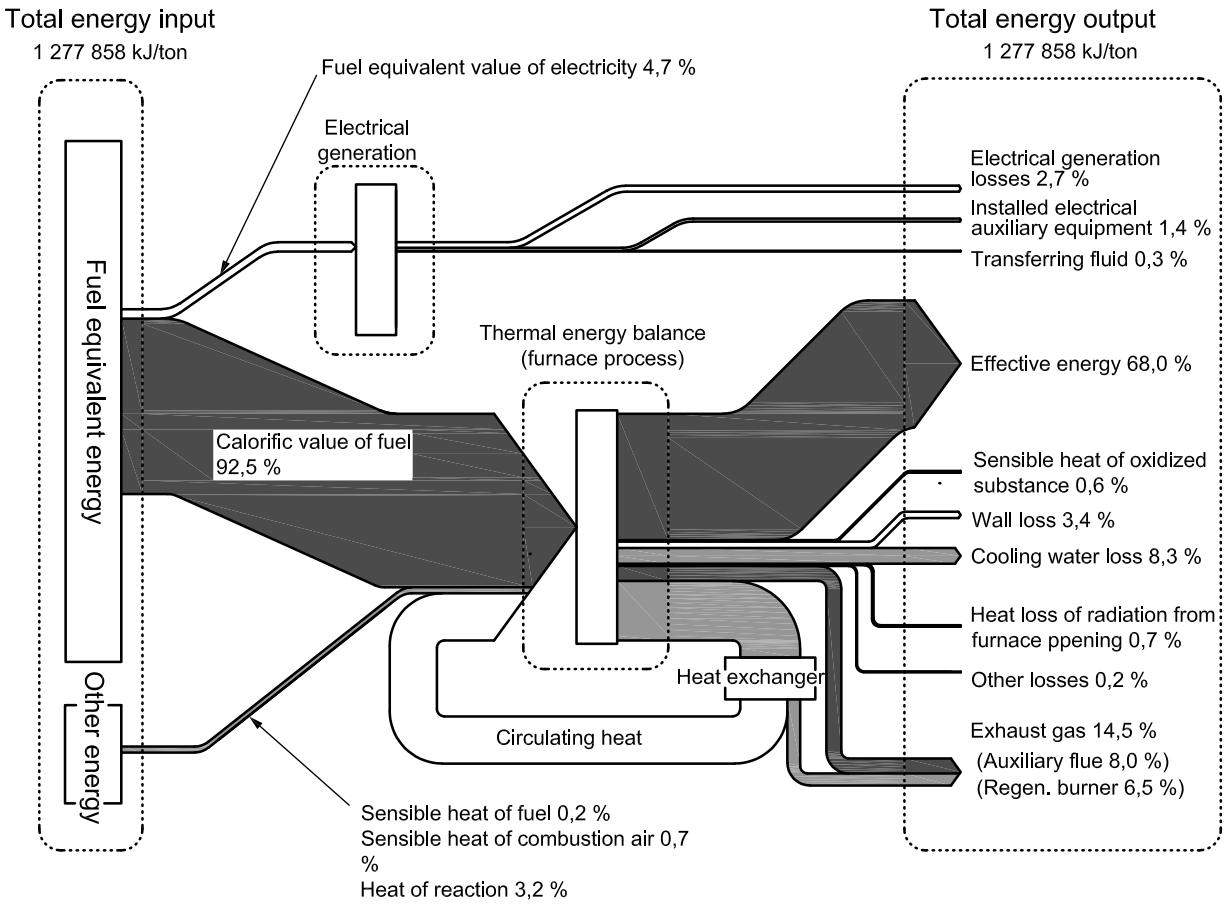


Figure B.3 — Energy flow diagram of the energy flow of the furnace — energy flow (Sankey) diagram

Annex C
(informative)

Assessment of uncertainty of the total energy efficiency

C.1 General

This annex gives an explanation on the assessment of uncertainty of the total energy efficiency calculated in Annex B.

The explanation of the basic principle of this assessment is given in ISO 13579-1:2013, Annex A.

According to the basic principle, given in the ISO 13579-1:2013, Annex A, the absolute error of the total energy efficiency is generally described as:

$$\delta\eta_1{}^2 = \left(\frac{\left(c_{\mathrm{pm,p1}} M_{\mathrm{p}} \delta T_{\mathrm{p1}}\right)^2 + \left(c_{\mathrm{pm,p2}} \left(M_{\mathrm{p}} - M_{\mathrm{loss}}\right) \delta T_{\mathrm{p2}}\right)^2 + \left(c_{\mathrm{pm,p2}} T_{\mathrm{p2}} - c_{\mathrm{pm,\,p1}} T_{\mathrm{p1}}\right)^2 \left(\delta M_{\mathrm{p}}\right)^2 + \left(c_{\mathrm{pm,p2}} T_{\mathrm{p2}} \delta M_{\mathrm{loss}}\right)^2}{E_{\mathrm{input}} - E_{\mathrm{re}}} \right)^2$$

$$+\eta_1{}^2 \left(\frac{\sum \delta E_i}{E_{\mathrm{input}} - E_{\mathrm{re}}} \right)^2 \qquad \text{(C.1)}$$

C.2 Assessment

C.2.1 Measurement conditions

The measurement conditions are given in Table C.1:

Table C.1 — Measurement conditions

Item	Measurement device	Measurement accuracy (relative error)
Temperature of products	Thermocouple (type K)	±9,3 ºC at 850ºC, T_{P2} ±1,5 ºC at 20ºC T_{P1}
	Compensating lead wire	±3 (ºC) at 850ºC T_{P2} ±0,5 (ºC) at 20ºC T_{P1}
	Output device	±0,1 (%)[a]
Mass of products	Weighing equipment	±1 (kg) at 1 000 kg[a]
Electrical power	Electrical power meter	±2 (%)[a]
Calorific value of fuel	Given by supplier	±0,5 (%)
Volume of fuel	Differential pressure type flowmeter	±0,5 (%)

[a] Accuracy of measurement device.

In addition, the following aspects are taken in account in the assessment of uncertainty:

— recycled energy is not involved in the energy balance measurement;

— uncertainty of other energy input, E_{others}, in Table B.3 are neglected.

C.2.2 Calculation

The absolute error of the measurement data of the temperature of products, δT, is estimated by:

$$\delta T = \sqrt{\delta\sigma_1{}^2 + \delta\sigma_2{}^2 + \delta\sigma_3{}^2} \tag{C.2}$$

When measurement accuracy provided in Table C.1 is substituted in Formula (C.2), the absolute errors of T_{p1} and T_{p2} are estimated as:

$$\delta T_{\text{p1}} = 0{,}5\ ^{\circ}\text{C} \tag{C.3}$$

$$\delta T_{\text{p2}} = 9{,}9\ ^{\circ}\text{C} \tag{C.4}$$

According to the result of energy balance measurement given in Annex B, Formula (C.1) can be described as:

$$\delta\eta_1{}^2 = \left\{ \frac{\left(c_{\text{pm,p1}} M_{\text{p}} \delta T_{\text{P1}}\right)^2 + \left[c_{\text{pm,p2}}\left(M_{\text{p}} - M_{\text{loss}}\right)\delta T_{\text{p2}}\right]^2 + \left(c_{\text{cm,p2}} T_{\text{p2}} - c_{\text{pm,p1}} T_{\text{p1}}\right)^2 \left(\delta M_{\text{p}}\right)^2 + \left(c_{\text{pm,p2}} T_{\text{p2}} \delta M_{\text{loss}}\right)^2}{E_{\text{input}}} \right\}^2 + \eta_1{}^2 \left[\frac{\sqrt{\left(\frac{\delta H_{\text{l}}}{H_{\text{l}}}\right)^2 + \left(\frac{\delta V_{\text{fuel}}}{V_{\text{fuel}}}\right)^2} E_{\text{h,fuel}} + \left(\frac{\delta M_{\text{loss}}}{M_{\text{loss}}}\right) E_{\text{react}} + \left(\frac{\delta E_{\text{fe,el}}}{E_{\text{fe,el}}}\right) E_{\text{fe,el}}}{E_{\text{input}}} \right]^2 \tag{C.5}$$

where

$\frac{\delta H_{\text{l}}}{H_{\text{l}}}$ is the relative measurement error of calorific value of fuel or source gas for atmospheric gas;

$\frac{\delta V_{\text{fuel}}}{V_{\text{fuel}}}$ is the relative measurement error of volume of fuel or source gas for atmospheric gas;

$\frac{\delta M_{\text{loss}}}{M_{\text{loss}}}$ is the relative measurement error of the mass of oxidized substance;

$\frac{\delta E_{\text{fe,el}}}{E_{\text{fe,el}}}$ is the relative measurement error of watt-hour-meter.

NOTE Other symbols are specified in Clause 4.

When values estimated in Formulae (C.3) and (C.4) and values given in Table B.3 and C.1 are substituted to Formula (C.5), the absolute error of the total energy efficiency of the reheating furnace is estimated as:

$$\delta\eta_1 = 0{,}007 \tag{C.6}$$

Therefore, the uncertainty of total energy efficiency estimated in Formula (B.3) can be described, as a percentage (%), as:

$$\eta_1 = 68{,}0 \pm 0{,}7 \quad \text{(C.7)}$$

Bibliography

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ICS 25.180.01

Price based on 34 pages