BS ISO 13579-4:2013

BSI Standards Publication

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

Part 4: Furnaces with protective or reactive atmosphere

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National foreword

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

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

Part 4: Furnaces with protective or reactive atmosphere

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

Partie 4: Fours à atmosphère contrôlée ou active

Reference number
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Foreword

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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 13579-4 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*

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Introduction

All calculations within this part of ISO 13579 are based on the location of equipment at 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.

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

Part 4: Furnaces with protective or reactive atmosphere

1 Scope

This part of ISO 13579 specifies general methodology for measuring energy balance and calculating the efficiency of the process involving furnaces with protective or reactive atmosphere as designed by the furnace manufacturers. This general methodology includes:

- measurement methods;
- calculations (general calculation);
- evaluation report.

This part of ISO 13579 is not applicable to any efficiencies related to the process itself outside of furnaces with protective or reactive atmosphere.

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.

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3.1 Terms relating 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".

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3.1.4 Total energy output

3.1.4.1
total energy output
E_{output}
total 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
$E_{\text{therm,out}}$
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
$E_{\text{l,jig}}$
enthalpy that jigs for handling the products gained in the area of energy balance measurement

3.1.5.4
sensible heat of exhaust gas
E_{exhaust}
sensible heat of expended gas which is emitted from the area of energy balance measurement

3.1.5.5
heat storage loss by batch furnace
$E_{\text{l,storage}}$
sensible heat which a furnace refractory gains within a batch furnace operation cycle

3.1.5.6
sensible heat loss of atmospheric gas
$E_{\text{s,atm}}$
sensible heat which atmospheric gas for thermal processing gains through the area of energy balance

3.1.5.7
wall loss
$E_{\text{l,wall}}$
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
$E_{\text{l,blowout}}$
sensible heat of blowout gas emitted from the furnace opening

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

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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

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3.1.9 Thermal energy balance

3.1.9.1
thermal energy input from electrical heating source
heat energy being entered 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 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.

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

Symbol	Meaning	Unit
$c_{pm,p2}$	mean specific heat of products between T_{p2} and 273,15 K	kJ/(kg·K)
$c_{pm,ps}$	mean specific heat of products between T_s 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_{fe}	fuel equivalent energy per ton of products	kJ/t
$E_{h,fuel}$	calorific value of fuel per ton of products	kJ/t

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Symbol	Meaning	Unit
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 furnace per ton of products	kJ/t
$E_{l,wall}$	wall loss per ton of products	kJ/t
E_{others}	other energy input 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	
$E_{s,air}$	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
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

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5 Basic principles

5.1 General

The area of energy balance measurement shall be determined.

NOTE Examples of the determination of the area of energy balance measurement of furnaces with protective or reactive atmospheres are shown in Figure 1 and Figure 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 is required to 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).

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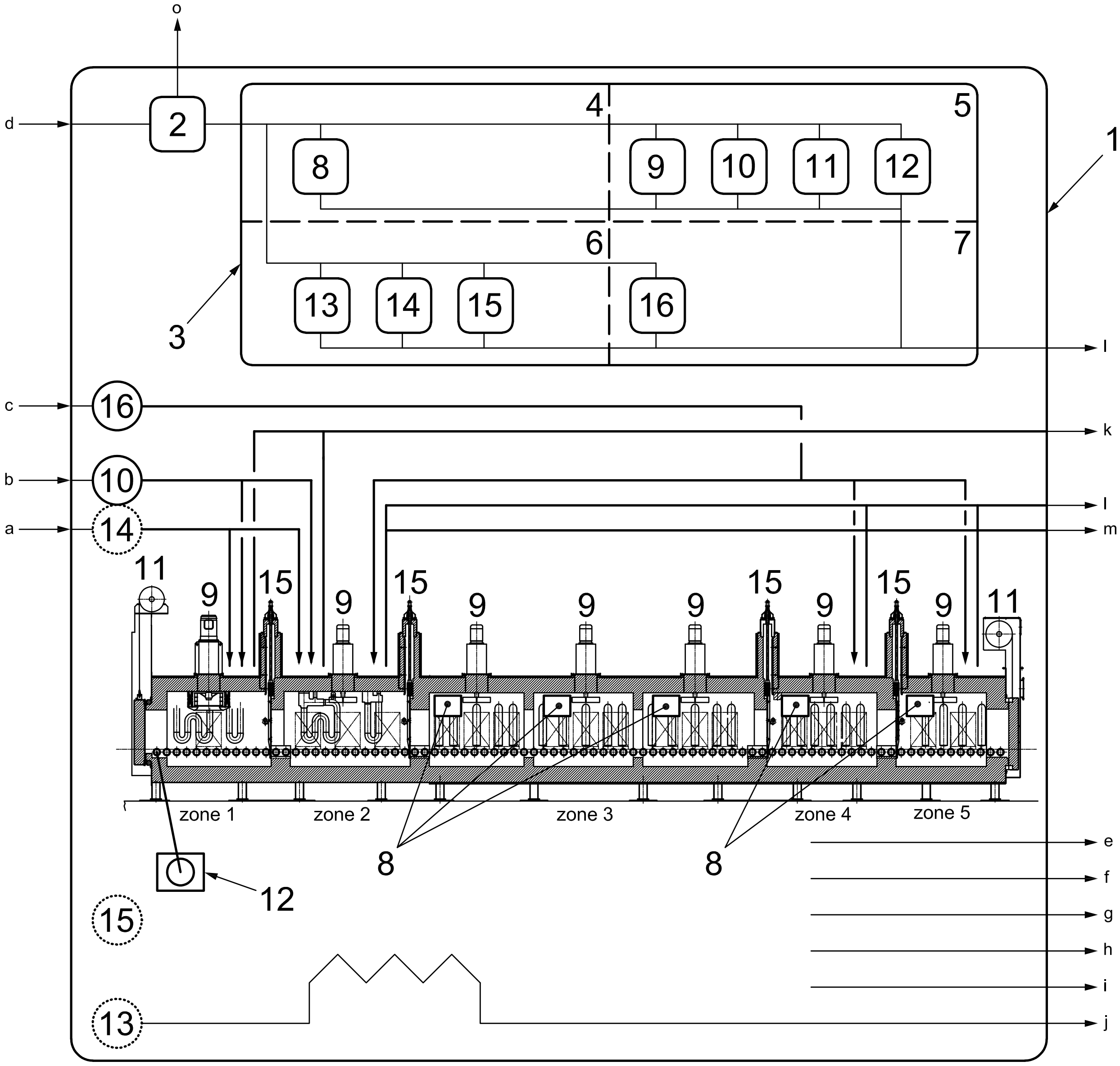

Key

1 area of energy balance
2 electrical generation
3 electrical auxiliary equipment
4 electrical heating equipment
5 installed electrical auxiliary equipment
6 equipment for fluid transfer
7 equipment for generation of utilities
8 electrical heater
9 RC fan
10 combustion blower
11 motor (door)
12 motor (roller hearth drive)
13 cooling water pump
14 fuel transfer equipment
15 compressor and air cylinder for internal door
16 atmospheric gas generator

a Sensible heat of fuel.
b Sensible heat of combustion air.
c Calorific value of source gas of atmospheric gas.
d Fuel equivalent energy of electricity.
e Effective energy.
f Wall loss.
g Heat loss of radiation from furnace opening.
h Heat loss from parts through furnace wall.
i Jig loss.
j Cooling water loss.
k Sensible heat of exhaust gas.
l Calorific value of source gas of atmospheric gas.
m Sensible heat loss of atmospheric gas.
n Energy consumed in electrical auxiliary equipment.
o Electrical generation loss.

Figure 1 — Example of determination of the area of energy balance — Continuous carburizing furnace

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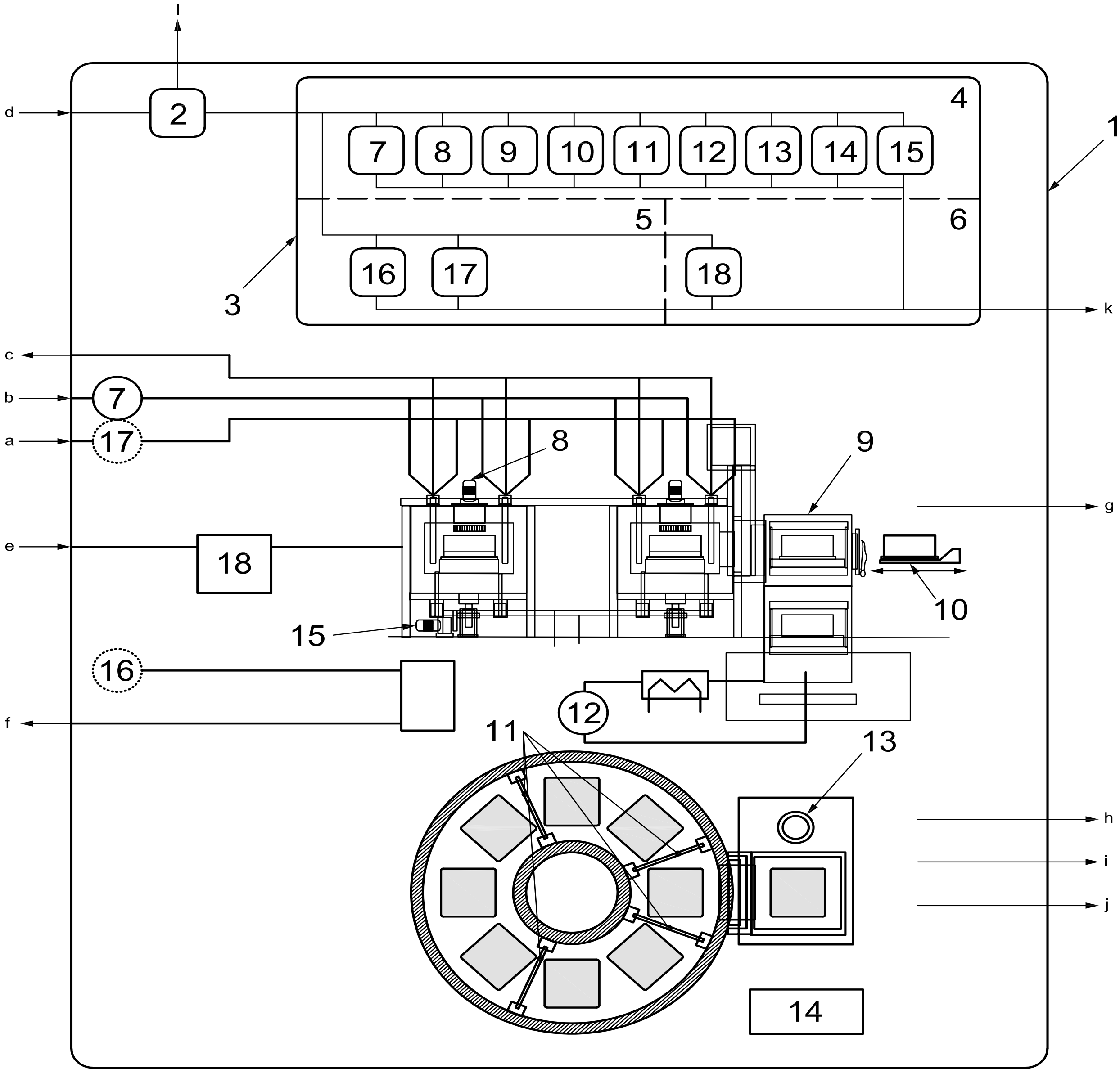

Key

1 area of energy balance
2 electrical generation
3 electrical auxiliary equipment
4 installed electrical auxiliary equipment
5 equipment for fluid transfer
6 equipment for generation of utilities
7 combustion fan
8 recirculation fan
9 elevator drive
10 charging and discharging
11 intermediate door
12 oil pump
13 oil agitator
14 control unit
15 rotary hearth drive
16 cooling water pump
17 fuel transfer equipment
18 atmospheric gas generator

a Sensible heat of fuel.
b Sensible heat of combustion air.
c Sensible heat of exhaust gas.
d Fuel equivalent energy of electricity.
e Calorific value of source gas of atmospheric gas.
f Cooling water loss.
g Calorific value of source gas of atmospheric gas.
h Effective energy.
i Heat loss from furnace (e.g. wall loss).
j Sensible heat loss of process gas.
k Energy consumed in electrical auxiliary equipment.
l Electrical generation loss.

Figure 2 — Example of determination of the area of energy balance — Rotary hearth furnace

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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 as specified in ISO 13579-1:2013, 5.3.

6 Basic conditions of measurement and calculation

6.1 State of furnace

The furnaces subject to measurement shall be prepared under the conditions specified in ISO 13579-1:2013, 6.1.

6.2 Duration of measurement

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

6.3 Unit of specific energy intensity

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

6.4 Reference conditions

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

6.5 Unit of amount of gas

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

6.6 Fuel

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

7 Type of energy used in this part of ISO 13579

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 kilojoule 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.

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Table 1 — Systematization of type of energy used 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 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, $E_{thermal,out}$	Effective energy, E_{effect}	
		Jig loss, $E_{l,jig}$	
		Sensible heat of exhaust gas, $E_{exhaust}$	
		Heat storage loss by batch 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 parts 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 furnace in an unburned state.

The calorific of fuel, $E_{h,fuel}$, consumed in pilot burners for burn-off and flame curtain burners shall be included in the calorific value of fuel if those parts are applied in the furnaces subject to measurement with protective or reactive atmospheres.

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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 furnace subject to the measurement chambers (see Figure 1).

The systematization of thermal energy is described in Table 2.

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Table 2 — Systematization of type of energy used 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, $E_{h,fuel}$	
	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, $E_{them,out}$	Effective energy, $E_{effective}$	
	Jig loss, $E_{l,jig}$	
	Sensible heat of exhaust gas, $E_{exhaust}$	
	Heat storage loss by batch 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 parts through furnace wall, $E_{l,parts}$	
	Cooling water loss, $E_{l,cw}$	
	Other losses, $E_{l,other}$	
The use of thermal energy balance 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.

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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

<table>
<tr><th colspan="4">Type</th></tr>
<tr><th>Energy input/output</th><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="7">Output</td><td rowspan="6">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="3">Generation of utilities, $E_{utility}$</td><td>Oxygen, $E_{u,oxy}$</td></tr>
<tr><td>Steam, $E_{u,steam}$</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 energy balance 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 calculations specified in 9.4.1.

8 Measurement method

8.1 General

Measurement method is specified in ISO 13579-1:2013, 8.1.

8.2 Fuel

8.2.1 Volume

Volume is specified in ISO 13579-1:2013, 8.2.1.

8.2.2 Sampling, test, analysis and measurement of calorific value

Sampling, test, 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.

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8.3 Combustion air and exhaust gas

8.3.1 Combustion air

8.3.1.1 Combustion air volume

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

8.3.1.2 Combustion air pressure and temperature

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

8.3.2 Exhaust gas

8.3.2.1 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, temperature of both the inlet and outlet side of the equipment shall be measured.

The measurement position of exhaust gas shall be at the exit (i.e. lower exhaust gas temperature side) of heat exchanger (i.e. regenerator, in the case of a regenerative burner). In the case of an exhaust system with an eductor type (see Figure 3), the temperature of the exhaust gas temperature shall be measured before suction takes place.

Calculated values using fuel quantity, volumetric ratio of fuel composition and air flow rate may be used as an exhaust gas flow rate.

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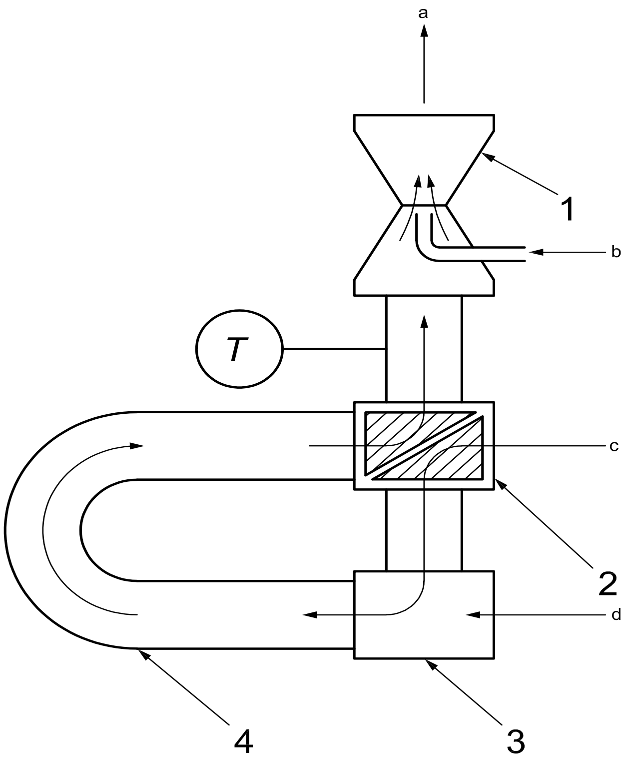

Key

1 eductor
2 recuperator
3 burner
4 radiant tube
T temperature measurement point
[a] Direction of exhaust gas flow.
[b] Flow of high pressure air.
[c] Flow of combustion air.
[d] Fuel intake.

Figure 3 — Measurement point of exhaust gas which is discharged through an eductor

8.3.2.2 Method of exhaust gas analysis

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

8.3.3 Measurement method for burners with recuperative functions

8.3.3.1 Regenerative burners

8.3.3.1.1 Measurement positions

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

8.3.3.1.2 Measurement of exhaust gas temperature

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

8.3.3.2 Recuperative radiant tube burners

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

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8.4 Controlled atmospheric gas

8.4.1 Volume

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

8.4.2 Temperature

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

8.5 Products

8.5.1 Mass

Determine the mass of products using weighing scales.

8.5.1.1 Continuous furnaces

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

8.5.1.2 Batch furnaces

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

8.5.2 Temperature

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

8.6 Temperature of furnace surface

8.6.1 Furnace wall

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

8.6.2 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.

8.7 Furnace inner wall temperature

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

8.8 Inner furnace pressure

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

8.9 Cooling water

8.9.1 Temperature

Temperature is specified in ISO 13579-1:2013, 8.10.1.

8.9.2 Volume

Volume is specified in ISO 13579-1:2013, 8.10.2.

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8.10 Electrical auxiliary equipment

8.10.1 Installed electrical auxiliary equipment

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

8.10.2 Energy for fluid transfer

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

8.11 Generation of utilities

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

8.12 Recycled energy

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

9 Calculations

9.1 General provisions

Calculations 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 Calorific value of waste

Calorific value of waste is specified in ISO 13579-1:2013, 9.2.2.

9.2.3 Calorific value of source gas of atmospheric gas

Calorific value of source gas of atmospheric gas is specified in ISO 13579-1:2013, 9.2.3.

The specifications for atmospheric gas described in Table A.1 may be used.

9.2.4 Fuel equivalent energy of electricity

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

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9.2.4.1 Sensible heat of fuel

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

9.2.5 Sensible heat of combustion air

9.2.5.1 General

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

9.2.5.2 Gaseous fuel

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

9.2.5.3 Liquid fuel

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

9.2.5.4 Simplified calculation of excess air ratio

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

9.2.6 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

Effective energy is specified in ISO 13579-1:2013, 9.3.1.1.1.

9.3.1.1.2 Sensible heat of products

9.3.1.1.2.1 At the time of loading

Sensible heat of products at the time of loading is specified in ISO 13579-1:2013, 9.3.1.1.2.1.

Tables of heat content with a reference temperature of 273,15 K may be used (for steel products, see Table A.2).

9.3.1.1.2.2 At the time of extraction

The sensible heat of products at the time when products are extracted from the area of energy balance per ton of products is given as Formula (1):

$$E_{\mathrm{p2}} = 1\,000 \times c_{\mathrm{pm,p2}} \times (T_{\mathrm{p2}} - 273{,}15) \tag{1}$$

Tables of heat content with reference a temperature of 273,15 K may be used (for steel products, see Table A.2).

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9.3.1.1.3 Mass of products

Mass of products is specified in ISO 13579-1:2013, 9.3.1.1.3.

9.3.1.2 Jig loss

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

9.3.1.3 Sensible heat of exhaust gas

9.3.1.3.1 General

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

9.3.1.3.2 Gaseous fuel

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

9.3.1.3.3 Liquid fuel

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

9.3.1.4 Heat storage loss by batch furnace

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

9.3.1.5 Sensible heat loss of atmospheric gas

Sensible heat loss of atmospheric gas is specified in ISO 13579-1:2013, 9.3.1.6.

For the volume fraction of atmospheric gas, make reference to Table A.1.

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 — General

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.

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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.

9.3.3.4 Atmospheric gas for heat treatment

9.3.3.4.1 Energy for operation of generator

Energy for operation of generator is specified in ISO 13579-1:2013, 9.3.3.4.1.

9.3.3.4.2 Calorific value of source gas

Calorific value of source gas is specified in ISO 13579-1:2013, 9.3.3.4.2.

For specifications of atmospheric gas, make reference to Table A.1.

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 the heating-up process is specified in ISO 13579-1:2013, 9.4.2.

In the case of protective and reactive furnaces, efficiency should be evaluated during the heating-up process, rather than during the whole process.

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10 Energy balance evaluation report

The energy balance evaluation report for furnaces with protective or reactive atmospheres shall be as specified in ISO 13579-1:2013, Clause 10.

NOTE Examples of an energy balance report are given in Annexes B and C.

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Annex A
(informative)

Reference data

Table A.1 — Types and composition of atmospheric gases — Examples

Type of atmospheric gas	Example of composition volume fraction, %				Application
	CO_2	CO	H_2	N_2	
Exothermic gases	12,5	1,5 to 11	1,5 to12	Balance	Normalization of low-carbon steels or copper alloys
Endothermic gases (sources: LNG and LPG)	0,18	20,9 to 23,9	30,4 to 38,9	Balance	Carburization, normalization of medium- to low-carbon steels
Ammonia cracking gas	-	-	75	Balance	Normalization of stainless steels
Nitrogen gas	<0,05	<0,05	-	Balance	Normalization of low-carbon steels
Hydrogen gas			>99,9		Normalization of low-carbon steels and stainless steels
Cracked gas of drip feed agent (CH_3OH)	-	33,3	66,7	Balance	Carburization
When performing actual calculations, the actual gas composition shall be measured and net calorific value shall be calculated.					
NOTE The values shown in this table are typical examples of the composition of atmospheric gas used in Japan.					

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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.

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Annex B
(informative)

Report of energy balance and efficiency of a continuous gas carburizing furnace (whole process) — Example

B.1 Equipment specification summary

The equipment specification summary for the furnace under evaluation is shown in Table B.1. The schematics of the furnace subject to measurement are shown in Figure B.1.

Table B.1 — Equipment specification summary

1	Company/Plant name			
2	Location		Japan	
3	Manufacturer of reheating furnace			
4	ID number of furnace			
5	Type		batch/ continuous	Continuous
6	Type of heat treatment			Carburizing
7	Cycle time		min	14
8	Loading capacity	Net	kg/tray	150
9		Trays/Jigs	kg/tray	50
10		Gross	kg/tray	200
11	Treatment capacity		t/h	0,643
12	Heat pattern			zone 1: from 20 °C to 700 °C (heat) zone 2: to 930 °C (heat) zone 3: to 950 °C (carburizing) zone 4: to 950 °C (diffusion) zone 5: to 850 °C (quenching)
13	Controlled atmospheric gas		(type)	Endothermic converted gas (Rx gas)
			m^3/h	36
14	Type of transfer system			Roller hearth
15	Type of heat source			Recuperative radiant tube burner (zone 1, 2) Electrical heater (zone 3, 4, 5)

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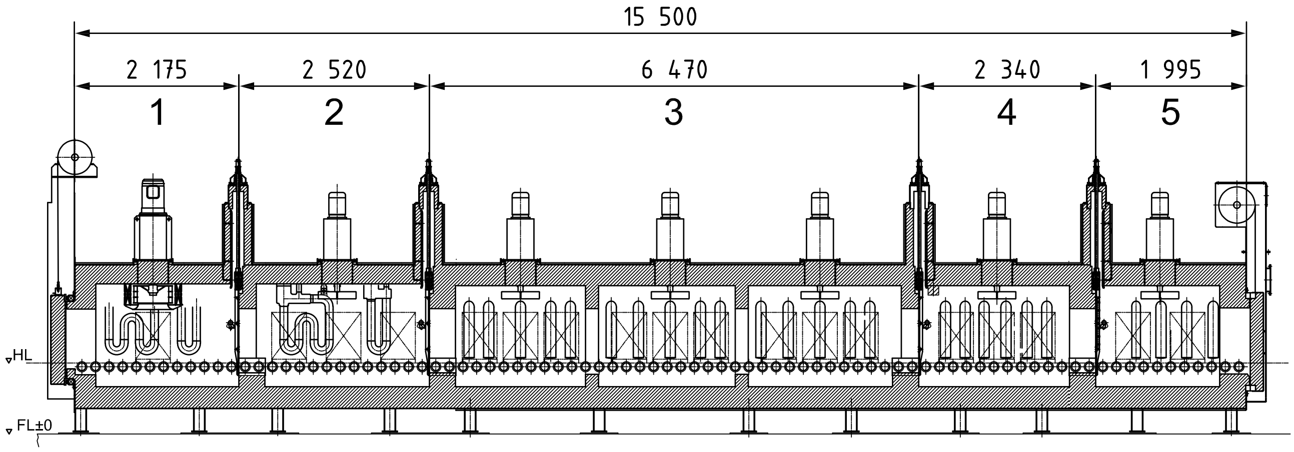
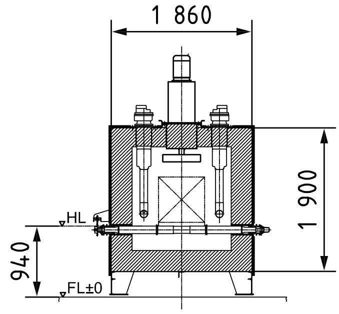
Dimensions in millimetres



a) Longitudinal section



b) Cross-section

Key

1 zone no. 1
2 zone no. 2
3 zone no. 3
4 zone no. 4
5 zone no. 5

Figure B.1 — Outline drawing of the furnace subject to measurement

B.2 Area of energy balance

The area of energy balance is defined as described in Figure B.2.

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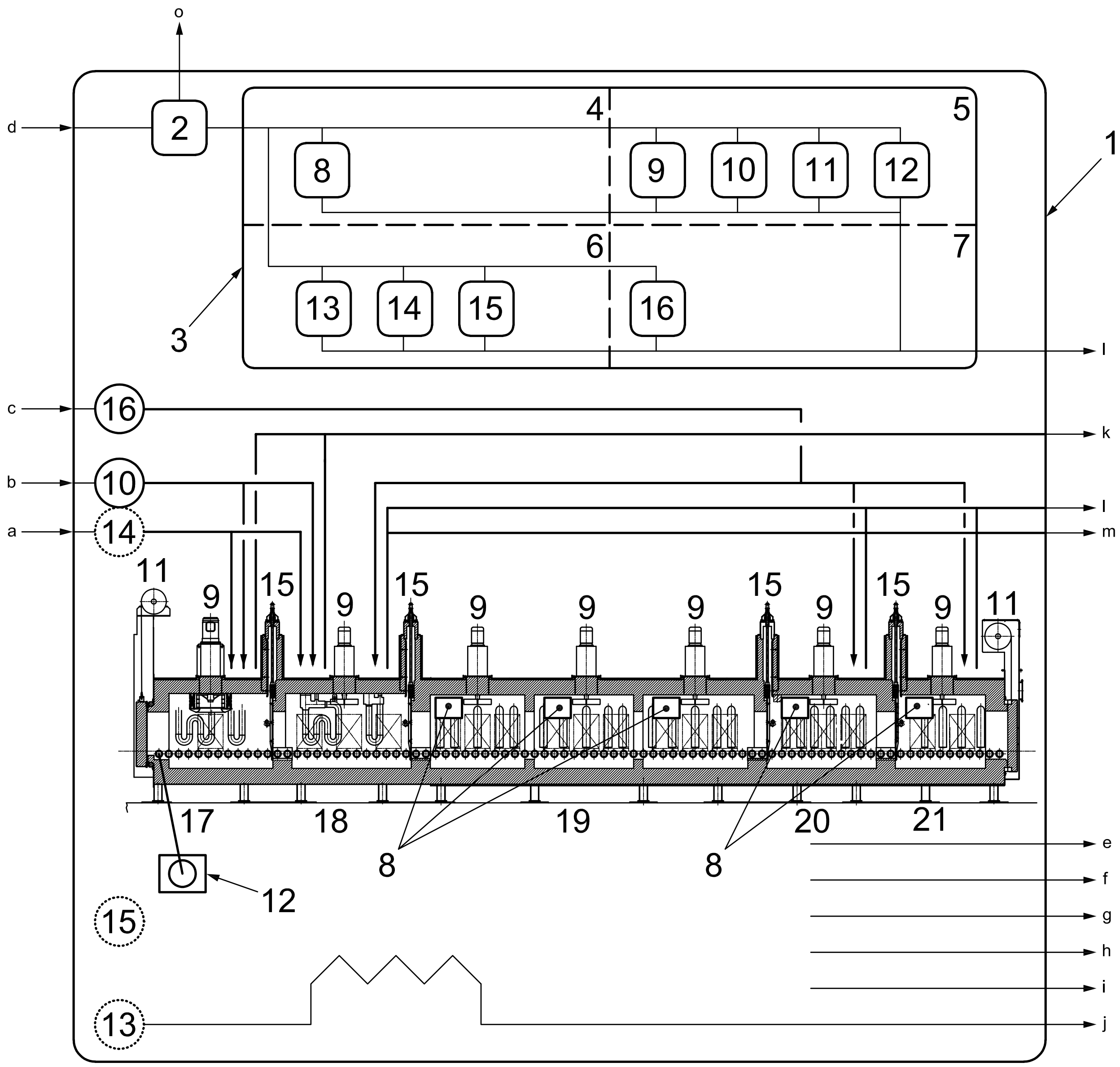

Key

1 area of energy balance
2 electrical generation
3 electrical auxiliary equipment
4 electrical heating equipment
5 installed electrical auxiliary equipment
6 equipment for fluid transfer
7 equipment for generation of utilities
8 electrical heater
9 RC fan
10 combustion blower
11 motor (door)
12 motor (roller hearth drive)
13 cooling water pump
14 fuel transfer equipment
15 compressor and air cylinder for internal door
16 atmospheric gas generator
17 zone 1
18 zone 2
19 zone 3
20 zone 4
21 zone 5

a Sensible heat of fuel.
b Sensible heat of combustion air.
c Calorific value of source gas of atmospheric gas.
d Fuel equivalent energy of electricity.
e Effective energy.
f Wall loss.
g Heat loss of radiation from furnace opening.
h Heat loss from parts through furnace wall.
i Jig loss.
j Cooling water loss.
k Sensible heat of exhaust gas.
l Calorific value of source gas of atmospheric gas.
m Sensible heat loss of atmospheric gas.
n Energy consumed in electrical auxiliary equipment.
o Electrical generation loss.

Figure B.2 — The area of energy balance

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B.3 Measurement data

The measurement data for the energy balance and energy efficiency calculations are shown in Table B.2

Table B.2 — Measurement data

Ambient temperature	20 °C				
Atmospheric pressure	101,2 kPa				
Relative humidity	60 %				
Product	Mass	0,643 t/h			
	Temperature	At the time of loading	20 °C		
		At the time of unloading	850 °C		
	Material	Carbon steel			
	Jig	Carbon steel 0,214 t/h			
Fuel	Type	Natural gas			
	CH_4	89,6 %			
	C_2H_6	5,62 %			
	C_3H_8	3,43 %			
	C_4H_{10}	1,35 %			
Fuel	H_2O	1 % [0,008 kg/m^3(n)]			
	Calorific value	40,63 MJ/m^3(n)			
	Volume	30,0 m^3(n)/t			
	Supply pressure	7 kPa			
	Supply temperature	20 °C			
Atomized agent		None			
Combustion air	Volume	Air to fuel ratio, m = 1,12 is applied to obtain the volume.			
	Temperature	20 °C			
Oxygen enrichment		None			
Infiltration air		None			
Atmospheric gas	Type	Endothermic converted gas (Rx gas)			
	Volume	56 m^3(n)/t			
	Temperature	Zone	2	4	5
		In (°C)	20	20	20
		Out (°C)	930	950	850
		Volume m^3(n)/h)	12	12	12
	Electrical energy consumption of generator	23,8 kW			
	Source gas	Natural gas [40,63 MJ/ m^3(n)]			
	Required source gas volume	9,8 m^3(n)/t			
Exhaust gas	Temperature	300 °C			
	Exhaust gas analysis	CO_2	12,8 %		
		CO	5x10^{-6} m^3(n)/m^3(n)		
		O_2	2,5 %		
		N_2	84,7 %		

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Table B.2 (2 of 2)

Furnace outer wall temperature	Side	60 °C				
	Top	80 °C				
	Bottom	70 °C				
	Front/back	60 °C				
Furnace dimension	Length	15,5 m				
	Width	1,874 m				
	Height	1,91 m				
	Opening width	0,8 m				
	Opening height	0,78 m				
Parts (metallic) through furnace wall	Zone	1	2	3	4	5
	Roller (m^2)	0,042 6	0,049 7	0,128	0,046 2	0,039
	Fan (m^2)	0,005 03	0,002 83	0,005 65	0,002 83	0,002 83
	Piping (m^2)	0,003 22	0,007 44	0,023 8	0,007 56	0,007 56
	Total (m^2)	0,012 9	0,019 4	0,171	0,085	0,068
	Wall thickness (m^2)	0,063 75	0,079 37	0,328 45	0,141 59	0,117 39
Cooling water	Supply temp.	20 °C				
	Discharge temp.	40 °C				
	Volume	2,1 t/h				
	Supply pressure	0,2 MPa				
	Supply piping	100 A				
High-pressure air	Supply pressure.	0,5 MPa				
	Volume	6,71 m^3(n)/min				
Electrical heating		106,5 kW (zone 3, 4, 5)				
Auxiliary electrical equipment	Recirculation fan	24,2 kW NOTE 30 % of the energy used as heat energy				
	Combustion blower	2,35 kW				
	Motor (door)	0,02 kW (average value)				
	Motor (conveyer)	0,02 kW (average value)				

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	%
Total energy input E_{input}	Fuel equivalent energy, E_{fe}	Calorific value of fuel, $E_{h,fuel}$	1 219 378	27,0
		Calorific value of waste, $E_{h,waste}$	-	-
		Calorific value of source gas of atmospheric gas, $E_{u,atm,cal}$	408 177	9,0
		Electricity, $E_{fe,electricity}$	2 887 328	63,8
	Other energy input, E_{others}	Sensible heat of fuel, $E_{s,fuel}$	997	< 0,05
		Sensible heat of combustion air, $E_{s,air}$	9 400	0,2
		Sensible heat of atomization agent, $E_{s,atomize}$	-	-
		Heat of reaction, E_{react}	-	-
		Sensible heat of infiltration air, $E_{s,infilt}$	-	-
		Total	**4 525 280**	100

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Table B.3 (2 of 2)

Type of energy					Specific energy consumption kJ/ton	%
Total energy output E_{output}	Thermal energy, $E_{thermal,out}$	Effective energy, $E_{effective}$			527 286	11,7
		Jig loss, $E_{l,jig}$			175 762	3,9
		Sensible heat of oxidized substance, $E_{s,oxid}$			-	-
		Exhaust gas, $E_{exhaust}$			164 453	3,6
		Heat storage loss by batch furnace, $E_{l,storage}$			-	-
		Sensible heat of atmospheric gas, $E_{s,atm}$			68 277	1,5
		Wall loss, $E_{l,wall}$			436 593	9,7
		Heat loss of radiation from furnace opening, $E_{l,opening}$			20 459	0,5
		Heat loss from parts through furnace wall, $E_{l,parts}$			182 611	4,0
		Cooling water loss, $E_{l,cw}$			273 477	6,0
		Other losses, $E_{l,other}$			17 772	0,4
	Electrical auxiliary equipment, E_{aux}	Energy consumed in installed electrical auxiliary equipment $E_{aux,installed}$		Recirculation fan (other than heat energy)	94 843	2,1
				Combustion blower	13 157	0,3
				Motor (door)	109	< 0,05
				Motor (roller hearth drive)	136	< 0,05
		Energy used for fluid transfer $E_{aux,fluid}$		Cooling water	1 021	< 0,05
				Fuel	490	< 0,05
				Compressed air	249 024	5,5
	Generation of utilities, $E_{utility}$	Oxygen, $E_{u,oxy}$			-	-
		Steam, $E_{u,steam}$			-	-
		Atmospheric gas	electricity for generation, $E_{u,atm,gen}$		133 250	2,9
			calorific value of source gas, $E_{u,atm,cal}$		408 117	9,0
	Electrical generation loss[a], $E_{l,eg}$				1 997 606	38,9
				Total	**4 525 280**	100

[a] The worldwide electrical generation efficiency: η_e = 0,391 is applied to the calculations.

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Table B.4 — Thermal energy balance

Type of energy		Specific energy consumption kJ/ton	Specific energy consumption %
Thermal energy input	Calorific value of fuel, $E_{h,fuel}$	1 219 378	65,3
	Thermal energy input from electrical heater	596 267	31,9
	Thermal energy input from recirculation fan	40 647	2,2
	Calorific value of waste, $E_{h,waste}$	-	-
	Sensible heat of fuel, $E_{s,fuel}$	997	0,1
	Sensible heat of combustion air, $E_{s,air}$	9 400	0,5
	Sensible heat of atomization agent, $E_{s,atomize}$	-	-
	Heat of reaction, E_{react}	-	-
	Sensible heat of infiltration air, $E_{s,infilt}$	-	-
	Total	**1 866 690**	100
Thermal energy output, $E_{therm,out}$	Effective energy, $E_{effective}$	527 286	28,3
	Jig loss, $E_{l,jig}$	175 762	9,4
	Sensible heat of oxidized substance, $E_{s,oxid}$	-	-
	Exhaust gas, $E_{exhaust}$	164 453	8,8
	Heat storage loss by batch furnace, $E_{l,storage}$	-	-
	Sensible heat of atmospheric gas, $E_{s,atm}$	68 277	3,7
	Wall loss, $E_{l,wall}$	436 593	24,0
	Heat loss of radiation from furnace opening, $E_{l,opening}$	20 459	1,1
	Heat loss from parts through furnace wall, $E_{l,parts}$	182 611	9,8
	Cooling water loss, $E_{l,cw}$	273 477	14,7
	Other losses, $E_{l,other}$	17 772	1,0
	Total	**1 866 690**	100

Table B.5 — Electrical generation

Type of energy				Specific energy consumption kJ/ton	Specific energy consumption %
Input	Fuel-equivalent energy of electricity			2 887 328	100
Output	Electrical heating			596 267	20,7
	Heat from recirculation fan			40 647	1,4
	Electrical auxiliary equipment, E_{aux}	Energy consumed in installed electrical auxiliary equipment, $E_{aux,installed}$	Recalculation fan (other than heat)	94 843	3,3
			Combustion blower	13 157	0,5
			Motor (door)	109	< 0,05
			Motor (roller hearth drive)	136	< 0,05
		Energy used for fluid transfer, $E_{aux,fluid}$	Cooling water	1 021	< 0,05
			Fuel	490	< 0,05
			Compressed air	249 024	8,6
	Electrical energy used for generation of utilities, $E_{e,utility}$	Oxygen, $E_{u,oxy}$		-	-
		Steam, $E_{u,steam}$		-	-
		Energy used for generation of atmospheric gas, $E_{u,atm,gen}$		133 250	4,6
	Electrical generation loss[a], $E_{l,eg}$			1 758 383	60,9
	Total			**2 887 328**	100

[a] The worldwide electrical generation efficiency: η_e = 0,391 is applied to the calculations.

B.5 Energy efficiency

Based on the energy balance measurement data, which are shown in Tables B.3, B.4 and B.5, the values for the total energy efficiency of the intended furnace, in kilojoules per ton (kJ/ton), are as follows:

$$E_{\text{input}} = 4\ 525\ 280 \qquad \text{(B.1)}$$

$$E_{\text{effective}} = 527\ 286 \qquad \text{(B.2)}$$

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 is calculated using Formula (B.3):

$$\eta_1 = \frac{527\,286}{4\ 525\,280} = 11{,}7 \pm 0{,}2 \qquad \text{(B.3)}$$

NOTE 1 The total energy efficiency is expressed in per cent (%).

NOTE 2 An explanation on the assessment of accuracy of the total energy efficiency is given in Annex D.

B.6 Energy flow diagram

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

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

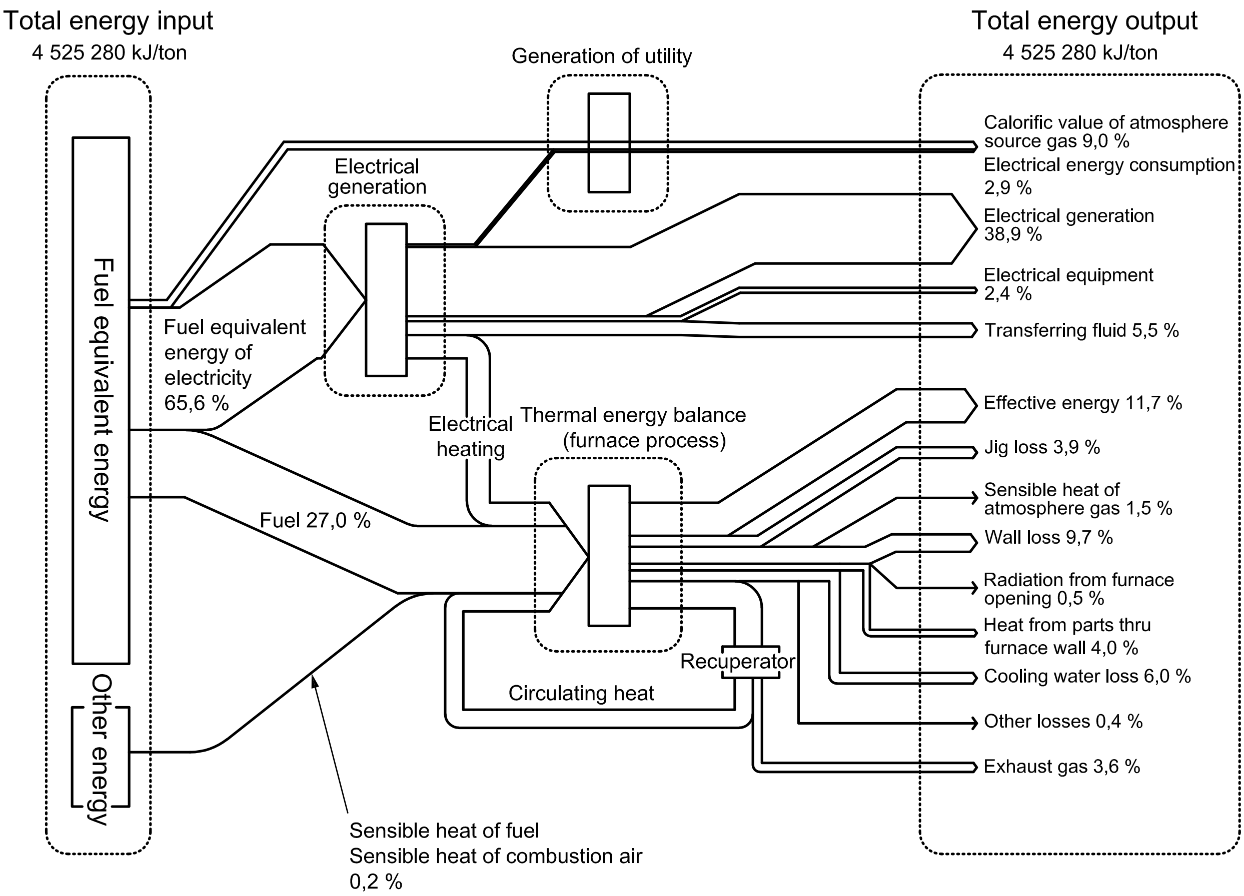

Figure B.3 — The energy flow diagram of the furnace subject to evaluation

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Annex C
(informative)

Report of measurement of energy balance and calculation of efficiency of a continuous gas carburizing furnace — Example

C.1 Equipment specification summary

The equipment specification summary for the continuous gas carburizing furnace is shown in Table C.1. The outline drawing of the furnace is shown in Figure C.1. The measurement of energy balance and calculation of efficiency of this continuous gas carburizing furnace are limited to the heating process (i.e. zones 1 to 3).

Table C.1 — Equipment specification summary

<table>
<tr><th colspan="2">Type</th><th>Batch/ continuous</th><th>Continuous</th></tr>
<tr><td colspan="2">Type of heat treatment</td><td></td><td>Carburizing</td></tr>
<tr><td colspan="2">Products</td><td></td><td>Carbon steel</td></tr>
<tr><td colspan="2">Cycle time</td><td>min</td><td>14</td></tr>
<tr><td rowspan="3">Loading capacity</td><td>Net</td><td>kg/tray</td><td>150</td></tr>
<tr><td>Trays/Jigs</td><td>kg/tray</td><td>50</td></tr>
<tr><td>Gross</td><td>kg/tray</td><td>200</td></tr>
<tr><td colspan="2">Throughput capacity</td><td>t/h</td><td>0.643</td></tr>
<tr><td colspan="2">Type of heat source</td><td></td><td>Recuperative radiant tube burner (zone 1, 2)
Electrical heater (zone 3, 4, 5)</td></tr>
<tr><td rowspan="3">Fuel</td><td>Type</td><td colspan="2">Natural gas</td></tr>
<tr><td>Calorific value</td><td colspan="2">40,63 MJ/m^3(n)</td></tr>
<tr><td>Volume</td><td colspan="2">30,0 m^3(n)/t</td></tr>
<tr><td colspan="2">Electrical heating</td><td></td><td>69,9 Kw (Zone 3)</td></tr>
<tr><td colspan="2">Heat pattern</td><td></td><td>zone 1: from 20 °C to 700 °C (heat)
zone 2: to 930 °C (heat)
zone 3: to 950 °C (carburizing)</td></tr>
<tr><td colspan="2" rowspan="2">Controlled atmospheric gas</td><td>(Type)</td><td>Endothermic converted gas (Rx gas)</td></tr>
<tr><td>Volume</td><td>Zone 2: at 12 m^3(n)/h</td></tr>
<tr><td colspan="2">Type of transfer system</td><td></td><td>Roller hearth</td></tr>
</table>

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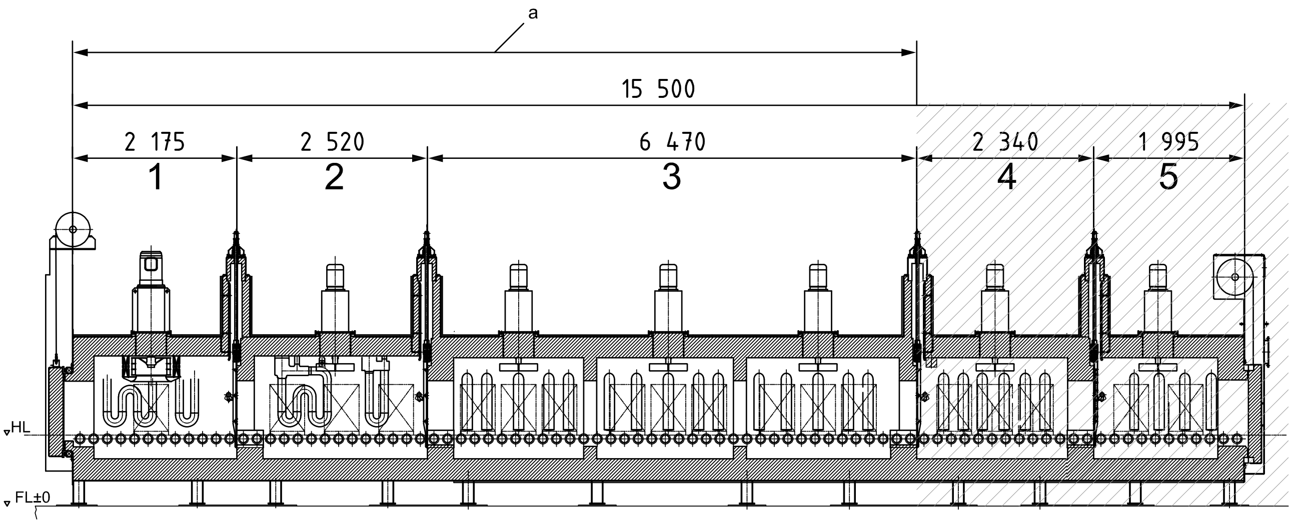
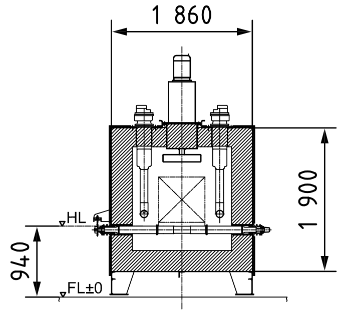
Dimensions in millimetres



a) Longitudinal section



b) Cross-section

Key

1 zone no. 1
2 zone no. 2
3 zone no. 3
4 zone no. 4
5 zone no. 5

[a] Heating process.

Figure C.1 — Outline drawing of the furnace subject to measurement

C.2 Area of energy balance

The area of energy balance is defined as descibed in Figure C.2.

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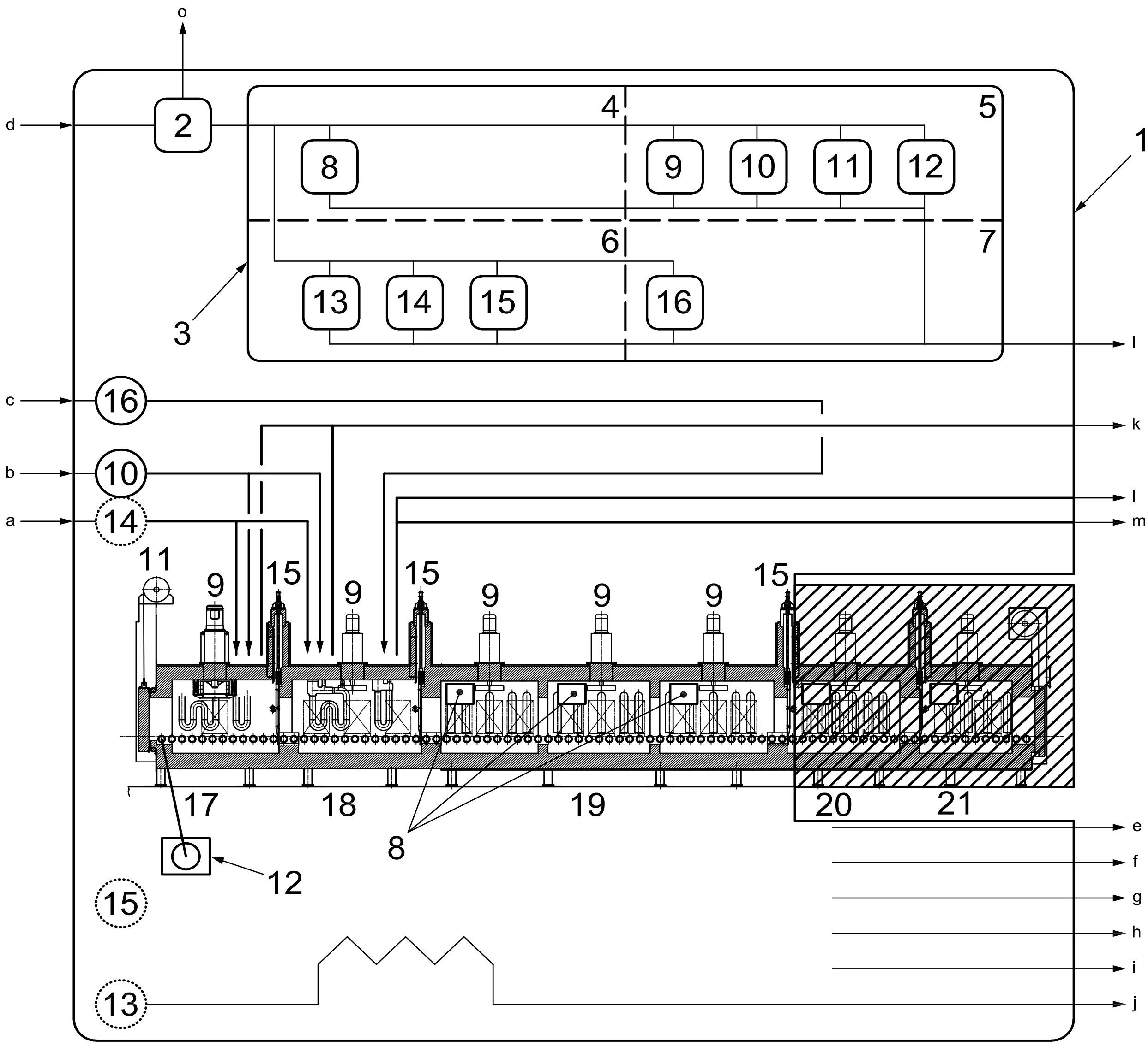

Key

1 area of energy balance
2 electrical generation
3 electrical auxiliary equipment
4 electrical heating equipment
5 installed electrical auxiliary equipment
6 equipment for fluid transfer
7 equipment for generation of utilities
8 electrical heater
9 RC fan
10 combustion blower
11 motor (door)
12 motor (roller hearth drive)
13 cooling water pump
14 fuel transfer equipment
15 compressor and air cylinder for internal door
16 atmospheric gas generator
17 zone 1
18 zone 2
19 zone 3
20 zone 4
21 zone 5

[a] Sensible heat of fuel.
[b] Sensible heat of combustion air.
[c] Calorific value of source gas of atmospheric gas.
[d] Fuel equivalent energy of electricity.
[e] Effective energy.
[f] Wall loss.
[g] Heat loss of radiation from furnace opening.
[h] Heat loss from parts through furnace wall.
[i] Jig loss.
[j] Cooling water loss.
[k] Sensible heat of exhaust gas.
[l] Calorific value of source gas of atmospheric gas.
[m] Sensible heat loss of atmospheric gas.
[n] Energy consumed in electrical auxiliary equipment.
[o] Electrical generation loss.

Figure C.2 — The area of energy balance

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C.3 Measurement data

The measurement data for the energy balance and energy efficiency calculations are shown in Table C.2.

Table C.2 — Measurement data

Ambient temperature	20 °C				
Atmospheric pressure	101,2 kPa				
Relative humidity	60 %				
Product	Mass	0,643 t/h			
	Temperature	At the time of loading	20 °C		
		At the time of unloading	850 °C		
	Material	Carbon steel			
	Jig	Carbon steel 0,214 t/h			
Fuel	Type	Natural gas			
	CH_4	89,6 %			
	C_2H_6	5.62 %			
	C_3H_8	3,43 %			
	C_4H_{10}	1,35 %			
	H_2O	1 % [0,008 kg/m^3(n)]			
	Calorific value	40,63 MJ/m^3(n)			
	Volume	30,0 m^3(n)/t			
	Supply pressure	7 kPa			
	Supply temperature	20 °C			
Atomized agent		None			
Combustion air	Volume	Air to fuel ratio, m = 1,12 is applied to obtain the volume			
	Temperature	20 °C			
Oxygen enrichment		None			
Infiltration air		None			
Atmospheric gas	Type	Rx gas			
	Volume	56 m^3(n)/t			
	Temperature	Zone	2		
		In (°C)	20		
		Out (°C)	930		
		Volume [m^3(n)/h]	12		
	Electrical energy consumption of generator	7,9 kW			
	Source gas	Natural gas [40,63 MJ/ m^3(n)]			
	Required volume of source gas	3,3 m^3(n)/t			
Exhaust gas	Temperature	300 °C			
	Exhaust gas analysis	CO2	12,8 %		
		CO	5x10^{-6} m^3(n)/m^3(n)		
		O2	2,5 %		
		N2	84,7 %		
Furnace outer wall temperature	Side	60 °C			
	Top	80 °C			
	Bottom	70 °C			

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Table C.2 (2 of 2)

	Front/back	60 °C				
Furnace dimension	Length	11,2 m				
	Width	1,874 m				
	Height	1,91 m				
	Opening width	0,8 m				
	Opening height	0,78 m				
Parts through furnace wall	Zone	1	2	3		
	Roller (m^2)	0,042 6	0,049 7	0,128		
	Fan (m^2)	0,005 03	0,002 83	0,005 65		
	Piping (m^2)	0,003 22	0,007 44	0,023 8		
	Total (m^2)	0,012 9	0,019 4	0,171		
	Wall thickness (m^2)	0,063 75	0,079 37	0,328 45		
Cooling water	Supply temp.	20 °C				
	Discharge temp.	40 °C				
	Volume	1,5 t/h				
	Supply pressure	0,2 MPa				
	Supply piping	100 A				
High-pressure air	Supply pressure.	0,5 MPa				
	Volume	6,71 m^3(n)/min				
Electrical heating		69,9 kW (zone 3)				
Auxiliary electrical equipment	Recirculation fan	19,8 kW NOTE 30 % of the energy used as heat energy				
	Combustion blower	2,35 kW				
	Motor (door)	0,02 kW (average value)				
	Motor (conveyer)	0,02 kW (average value)				

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C.4 Energy balance sheet

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

Table C.3 — Overall energy balance

Type of energy				Specific energy consumption kJ/ton	Specific energy consumption %
Total energy input, E_{input}	Fuel equivalent energy, E_{fe}	Calorific value of fuel, $E_{h,fuel}$		1 219 378	35,5
		Calorific value of waste, $E_{h,waste}$		-	-
		Calorific value of source gas of atmospheric gas, $E_{u,atm,cal}$		136 059	4,0
		Electricity, $E_{fe,electricity}$		2 073 051	60,3
	Other energy, E_{others}	Sensible heat of fuel, $E_{s,fuel}$		997	< 0,05
		Sensible heat of combustion air, $E_{s,air}$		9 400	0,3
		Sensible heat of atomization agent, $E_{s,atomize}$		-	-
		Heat of reaction, E_{react}		-	-
		Sensible heat of infiltration air, $E_{s,infilt}$		-	-
		Subtotal		10 397	
	Total			**3 438 885**	100
Total energy output, E_{output}	Thermal energy, $E_{thermal,out}$	Effective energy, $E_{effective}$		602 893	17,5
		Jig loss, $E_{l,jig}$		200 966	5,8
		Sensible heat of oxidized substance, $E_{s,oxid}$		-	-
		Exhaust gas, $E_{exhaust}$		164 453	4,8
		Heat storage loss by batch furnace, $E_{l,storage}$		-	-
		Sensible heat of atmospheric gas, $E_{s,atm}$		23 295	0,7
		Wall loss, $E_{l,wall}$		309 987	9,0
		Heat loss of radiation from furnace opening, $E_{l,opening}$		9 337	0,3
		Heat loss from furnace parts installed through furnace wall, $E_{l,parts}$		118 962	3,5
		Cooling water loss, $E_{l,cw}$		195 341	5,7
		Other losses, $E_{l,other}$		29 151	0,9
	Electrical auxiliary equipment, E_{aux}	Energy consumed in installed electrical auxiliary equipment, $E_{aux,installed}$	RC fan (other than heat)	77 599	2,26
			Combustion blower	13 157	0,4
			Motor (door)	109	< 0,05
			Motor (roller hearth drive)	136	< 0,05
		Energy used for fluid transfer, $E_{au,fluid}$	Cooling water	1 021	< 0,05
			Fuel	490	< 0,05
			Compressed air	249 024	7,2
	Generation of utilities $E_{utility}$	Oxygen, $E_{u,oxy}$		-	-
		Steam, $E_{u,steam}$		-	-
		Atmospheric gas	electricity for generation, $E_{u,atm,gen}$	44 417	1,3
			calorific value of source gas, $E_{u,atm,cal}$	136 059	4,0
	Fluid transfer E_{fluid}	Cooling water		1 021	< 0,05
		Fuel		490	< 0,05
		Compressed air		249 024	7,2
	Electrical generation loss[a], $E_{l,eg}$			1 262 488	36,7
	Total			**3 438 885**	100

[a] The worldwide electrical generation efficiency: η_e = 0,391 is applied.

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Table C.4 — Thermal energy balance

Type of energy		Specific energy consumption kJ/ton	%
Thermal energy input	Calorific value of fuel, $E_{h,fuel}$	1 219 378	73,7
	Thermal energy input from electrical heater	391 353	23,7
	Thermal energy input from recirculation fan	33 257	2,0
	Calorific value of waste, $E_{h,waste}$	-	-
	Sensible heat of fuel, $E_{s,fuel}$	997	0,1
	Sensible heat of combustion air, $E_{s,air}$	9 400	0,6
	Sensible heat of atomization agent, $E_{s,atomize}$	-	-
	Heat of reaction, E_{react}	-	-
	Sensible heat of infiltration air, $E_{s,infilt}$	-	-
	Total	**1 654 385**	100
Thermal energy output, $E_{thermal,out}$	Effective energy, E_{effect}	602 893	36,4
	Jig loss, $E_{l,jig}$	200 966	12,2
	Sensible heat of oxidized substance, $E_{s,oxid}$	-	-
	Exhaust gas, $E_{exhaust}$	164 453	10,0
	Heat storage loss by batch furnace, $E_{l,storage}$	-	-
	Sensible heat of atmospheric gas, $E_{s,atm}$	23 295	1,4
	Wall loss, $E_{l,wall}$	309 987	18,7
	Heat loss of radiation from furnace opening, $E_{l,opening}$	9 337	0,7
	Heat loss from parts through furnace wall, $E_{l,parts}$	118 962	7,2
	Cooling water loss, $E_{l,cw}$	195 341	11,8
	Other losses, $E_{l,other}$	29 151	1,8
	Total	**1 654 385**	100

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Table C.5 — Electrical generation

Type					Specific energy consumption kJ/ton	Specific energy consumption %
Input	Fuel-equivalent energy of electricity				2 073 051	
Output	Electrical heating			$E_{h,electricity}$	391 353	18,9
Output	Heat from RC fan			$E_{h,rc}$	33 257	1,6
Output	Electrical auxiliary equipment	Energy consumed in installed electrical auxiliary equipment $E_{aux,installed}$	RC fan (other than heat)		77 599	3,74
Output	Electrical auxiliary equipment	Energy consumed in installed electrical auxiliary equipment $E_{aux,installed}$	Combustion blower		13 157	0,63
Output	Electrical auxiliary equipment	Energy consumed in installed electrical auxiliary equipment $E_{aux,installed}$	Motor (door)		109	< 0,05
Output	Electrical auxiliary equipment	Energy consumed in installed electrical auxiliary equipment $E_{aux,installed}$	Motor (roller hearth drive)		136	< 0.05
Output	Electrical auxiliary equipment	Energy consumed in installed electrical auxiliary equipment $E_{aux,installed}$	Subtotal		91 001	
Output	Electrical auxiliary equipment	Energy used for fluid transfer $E_{aux,fluid}$	Cooling water		1 021	0,05
Output	Electrical auxiliary equipment	Energy used for fluid transfer $E_{aux,fluid}$	Fuel		490	< 0.05
Output	Electrical auxiliary equipment	Energy used for fluid transfer $E_{aux,fluid}$	Compressed air		249 024	12,0
Output	Electrical auxiliary equipment	Energy used for fluid transfer $E_{aux,fluid}$	Subtotal		250 535	
Output	Generation of utilities	Oxygen		$E_{u,oxy}$	-	-
Output	Generation of utilities	Steam		$E_{u,steam}$	-	-
Output	Generation of utilities	Atmospheric gas	electricity for generation	$E_{u,atm,gen}$	44 417	2,1
Output	Electrical generation loss[a]			$E_{l,eg}$	1 262 488	60,9
Output				Total	**2 073 051**	100

[a] The worldwide electrical generation efficiency: η_e = 0,391 is applied.

C.5 Energy efficiency

Based on the energy balance measurement data, the energy efficiency limited to the heating process is, in kilojoules per ton (kJ/ton), as follows:

$$E_{\text{input}} = 3\,438\,885 \quad \text{(C.1)}$$

$$E_{\text{effective}} = 602\,893 \quad \text{(C.2)}$$

Therefore, using Formula (57) specified in ISO 13579-1:2013, 9.4.1, the total energy efficiency of the furnace is calculated as given by Formula (C.3):

$$\eta_1 = \frac{602\,893}{3\,438\,885} = 17{,}5 \pm 0{,}3 \quad \text{(C.3)}$$

NOTE 1 The total energy efficiency is expressed in per cent (%).

NOTE 2 An explanation on the assessment of accuracy of the total energy efficiency is given in Annex D, particularly in D.2.2.

C.6 Energy flow diagram

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

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

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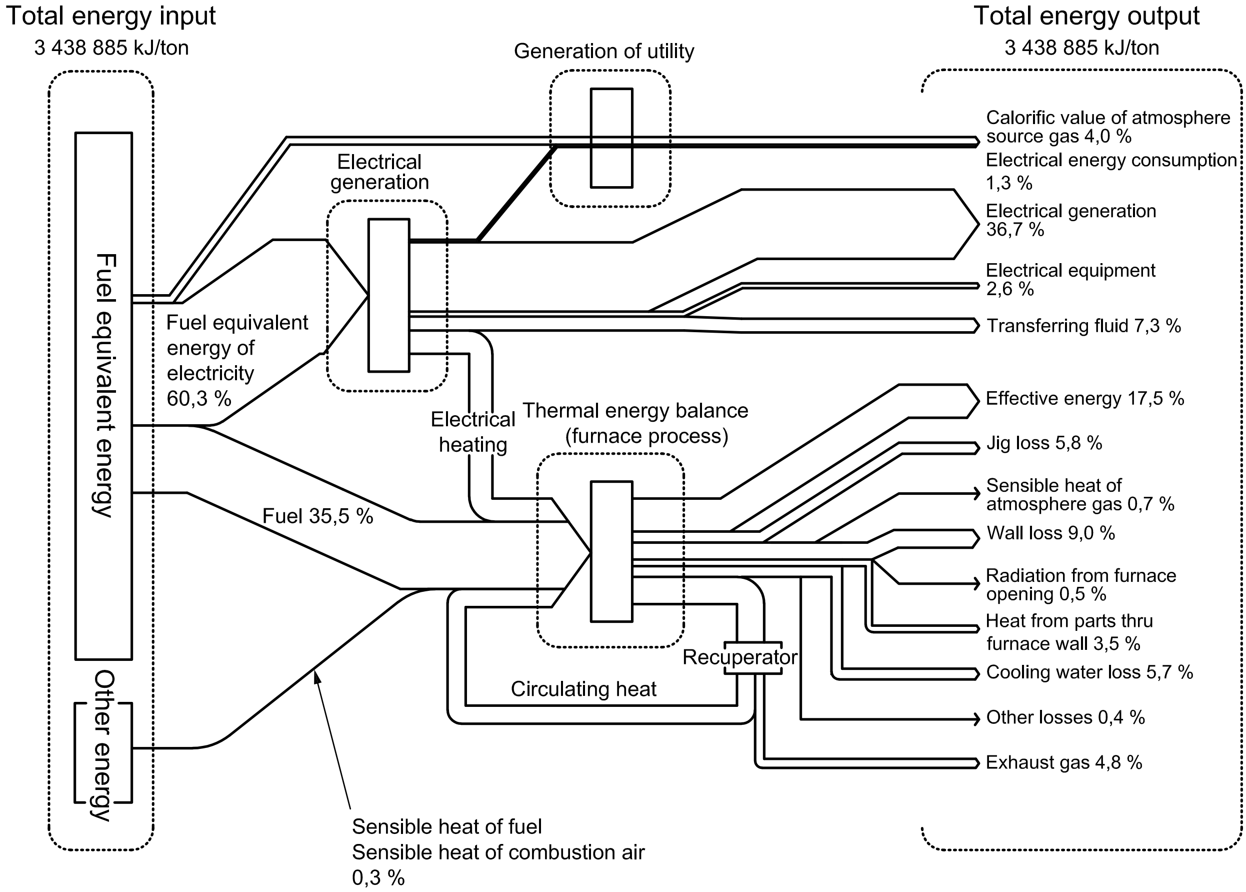

Figure C.3 — Energy flow diagram of the furnace subject to evaluation

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Annex D
(informative)

Assessment of uncertainty of total energy efficiency

D.1 Introduction

This annex gives an explanation of the assessment of uncertainty of the total energy efficiency calculated in Annex B (the whole process of the gas carburizing furnace) and Annex C (the heating process).

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

According to the basic principle, given in Annex A of ISO 13579-1:2013, the absolute error of the total energy efficiency is generally described using Formula (D.1):

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

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

D.2 Assessment

D.2.1 Whole process (Annex B)

D.2.1.1 Measurement condition

Measurement conditions are given in Table D.1:

Table D.1 — Measurement conditions

Item	Measurement device	Measurement accuracy (relative error)
Temperature of product	Thermocouple (type K)	±6,4 (°C) at 850 °C T_{p2} ±1,5 (°C) at 20 °C T_{p1}
	Compensating lead wire	±3 (°C) at 850 °C T_{p2} ±0,5 (°C) at 20 °C T_{p1}
	Output device	±0,1 (%)[a]
Mass of product	Weighing equipment	±1 (kg) at 1000kg[a]
Electrical power	Electrical power meter	±2 (%)[a]
Calorific value of fuel	Given by supplier	±0,5 (%)
Volume of fuel	Turbine flowmeter	±1,0 (%)

[a] This represents the accuracy of the measurement device.

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

— mass lost by products during the thermoprocessing is assumed to be negligible in this assessment;

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

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

D.2.1.2 Calculations

The absolute error of the measurement data of temperature of products is estimated using Formula (D.2):

$$\delta T = \sqrt{\delta\sigma_1^2 + \delta\sigma_2^2 + \delta\sigma_3^2} \quad \text{(D.2)}$$

When measurement accuracy provided in Table D.1 is substituted into Formula (D.2), the absolute error of each temperature is estimated as:

$$\delta T_{\text{p1}} = 0{,}5\ ^\circ\text{C} \quad \text{(D.3)}$$

$$\delta T_{\text{p2}} = 7{,}1\ ^\circ\text{C} \quad \text{(D.4)}$$

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

$$\delta\eta_1 = \left[\frac{\left(C_{\text{pm1}} M \delta T_{\text{p1}}\right)^2 + \left(C_{\text{pm2}} M \delta T_{\text{p2}}\right)^2 + \left(C_{\text{pm2}} T_{\text{p2}} - C_{\text{pm1}} T_{\text{p1}}\right)^2 \left(\delta M\right)^2}{E_{\text{h,fuel}} + E_{\text{fe,el}} + E_{\text{u,atm,cal}}}\right]^2$$
$$+\eta_1^2 \left[\frac{\sqrt{\left(\frac{\delta H_{\text{l}}}{H_{\text{l}}}\right)^2 + \left(\frac{\delta V_{\text{fuel}}}{V_{\text{fuel}}}\right)^2}\left(E_{\text{h,fuel}} + E_{\text{u,atm,cal}}\right) + \left(\frac{\delta E_{\text{fe,el}}}{E_{\text{fe,el}}}\right) E_{\text{fe,el}}}{E_{\text{h,fuel}} + E_{\text{fe,el}} + E_{\text{u,atm,cal}}}\right]^2 \quad \text{(D.5)}$$

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;

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

NOTE Other symbols are specified in Clause 4.

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

$$\delta\eta_1 = 0{,}002 \quad \text{(D.6)}$$

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

$$\eta_1 = 11{,}7 \pm 0{,}2 \qquad \text{(D.7)}$$

D.2.2 Heating process (Annex C)

D.2.2.1 Measurement condition

Measurement conditions are given in Table D.2:

Table D.2 — Measurement conditions

Item	Measurement device	Measurement accuracy (relative error)
Temperature of products	Thermocouple (type K)	±7,1 (°C) at 950 °C T_{p2} ±1,5 (°C) at 20 °C T_{p1}
	Compensating lead wire	±3 (°C) at 950 °C T_{p2} ±0,5 (°C) at 20 °C 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	Turbine flowmeter	±1,0 (%)

[a] Accuracy of measurement device.

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

— mass lost by products during the thermoprocessing is assumed to be negligible in this assessment;

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

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

D.2.2.2 Calculations

When measurement accuracy provided in Table D.2 is substituted to Formula (D.2), the absolute error of each temperature is estimated as:

$$\delta T_{p1} = 0{,}5\ ^{\circ}\mathrm{C} \qquad \text{(D.8)}$$

$$\delta T_{p2} = 7{,}8\ ^{\circ}\mathrm{C} \qquad \text{(D.9)}$$

When values estimated in Formulae (D.8) and (D.9) and values given in Table C.3 and Table D.2 are substituted to Formula (D.5), the absolute error of the total energy efficiency of the continuous carburizing furnace is estimated as:

$$\delta \eta_1 = 0{,}003 \qquad \text{(D.10)}$$

Therefore, the uncertainty of total energy efficiency estimated in Formula (D.5) can be described, as a percentage (%), as:

$$\eta_1 = 17{,}5 \pm 0{,}3 \qquad \text{(D.11)}$$

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Bibliography

[1] JIS G 0702:1995, Method of heat balance for continuous reheating furnace for steel

[2] JIS Z 9202:1991, *General rules for heat balance*

[3] VDMA 24206 *Acceptance and ordering of thermoprocessing equipment for the steel, iron and non-ferrous metals industry*

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