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

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

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

Partie 3: Fours dormants de fusion pour l'aluminium

Reference number
ISO 13579-3:2013(E)

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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 13579-3 was prepared by Technical Committee ISO/TC 244, *Industrial furnaces and associated thermal processing equipment*.

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

— *Part 1: General methodology*

— *Part 3: Reheating furnaces for steel*

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

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

Introduction

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.

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

Part 3: Batch-type aluminium melting furnaces

1 Scope

This part of ISO 13579 specifies general methodology for measuring energy balance and calculating the efficiency of the process involving batch-type aluminium melting furnaces 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 batch-type aluminium melting furnaces.

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

EXAMPLE Waste oil on aluminium scrap.

3.1.2.4
fuel equivalent energy of electricity
$E_{fe,el}$
aggregate of fuel equivalent energy of electricity converted from each occurrence of electrical energy consumption 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
$E_{\text{therm,out}}$
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 3.1.5.11.

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

3.1.5.3
sensible heat of oxidized substance
$E_{\text{l,oxid}}$
sensible heat of substances which have reacted with oxygen, formed in the thermal process brought out from the area of energy balance measurement

3.1.5.4
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-type furnace
$E_{\text{l,storage}}$
sensible heat which a furnace refractory gains within a batch-type furnace operation cycle

3.1.5.6
wall loss
$E_{\text{l,wall}}$
thermal energy emitted from the surface of industrial furnaces by radiation and convection

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

3.1.5.8
heat loss of radiation from furnace opening
$E_{\text{l,opening}}$
thermal energy emitted from the furnace opening by radiation

3.1.5.9
heat loss from furnace parts installed through furnace wall
$E_{\text{l,parts}}$
thermal energy emitted through furnace parts which are installed through furnace wall

EXAMPLE As in the case of a roller hearth furnace.

3.1.5.10
cooling water loss
$E_{l,cw}$
thermal energy brought out by cooling water from the area of energy balance measurement

3.1.5.11
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 as specified in ISO 13579-1:2013, 3.1.7.1.

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

3.1.8 Electrical generation loss

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

3.1.9 Thermal energy balance

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

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

3.1.10 Energy balance of electrical generation

3.1.10.1
total consumed electrical energy
$E_{e,total}$
aggregate of electrical energy which is consumed in the area of energy balance and equal to the sum of thermal energy input from electrical heating source, energy consumed in electrical auxiliary equipment and electrical energy used for 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)
$c_{pm,ps}$	mean specific heat of products between T_s and 273,15 K	kJ/(kg·K)
$c_{pm,oxid}$	mean specific heat of scale	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_{Al}	heat by formation of scale per kilogram of scale	kJ/kg
e_{latent}	latent heat of melting per kilogram of aluminium	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
$E_{h,waste}$	calorific value of waste per ton of products	kJ/t

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
$E_{l,opening}$	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 sorage loss by batch-type furnace per square metre 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 oxydant 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_{oxid}	mass of oxidized substance 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 extracting from the area of the energy balance	K
T_s	melting temperature of aluminium	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

5 Basic principles

5.1 General

The area of energy balance measurement shall be determined.

In principle, exclude energy consumed by external product loading vehicles such as forklifts from the area of energy balance.

NOTE An example of determination of the area of energy balance measurement of a batch-type aluminium melting furnace is shown in Figure 1.

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

a) energy input;

— fuel equivalent energy, E_{fe};

— other energy input, E_{others};

b) energy output;

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

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

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

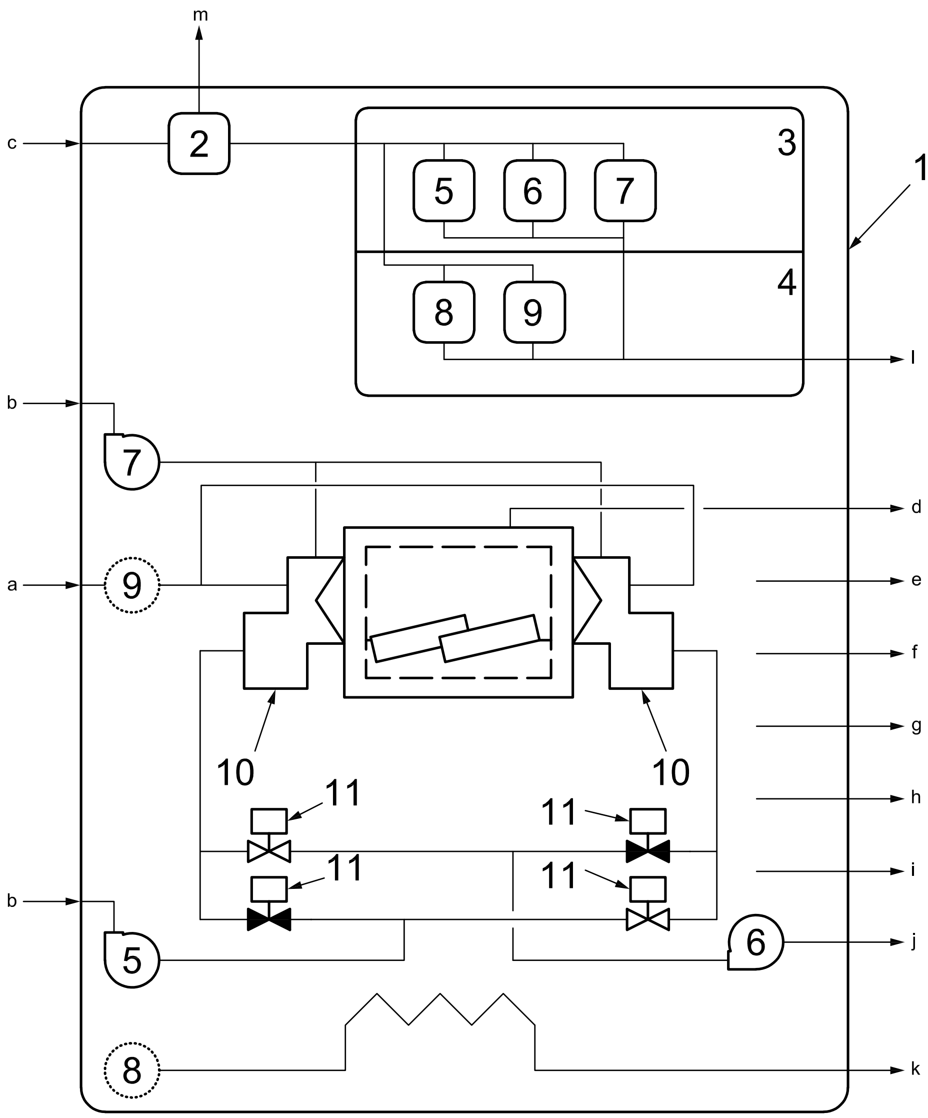
— electrical generation loss, $E_{l,eg}$.

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

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

The result of 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 conditions and measurement data.

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



Key

1 area of energy balance
2 electrical generation
3 installed electrical auxiliary equipment
4 equipment for fluid transfer
5 combustion blower
6 induced draft (or draught) fan (IDF)
7 pilot burner blower
8 cooling water pump
9 fuels transfer equipment
10 regenerative burner
11 changeover valve

[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] Heat storage loss by batch-type furnace.
[h] Wall loss.
[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 1 — Example of determination of the area of energy balance measurement of batch-type aluminium melting furnaces

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 in normal operation, and the temperature cycle and throughput shall be as considered in the design calculation.

Normal operating conditions are generally based on nominal conditions stipulated in the specifications. However, in the case of no specified conditions, it may be at the discretion of the supplier, for example two thirds of design throughput.

Melting rate influences efficiency, but in this part of ISO 13579, melting rate is assumed generally to be 300 kg/m^2h to 500 kg/m^2h since furnace temperature is usually around 1 200 °C. As far as the melting rate is in the range, the melting rate does not have a significant effect on energy efficiency. When melting rate is quite different from the range, it should be taken into account and mentioned.

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 products (kJ/t), unless otherwise specified.

7.2 Energy balance

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

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

Type of energy		
Total energy input/output	**Intermediate category**	**Detailed item**
Total energy input, E_{input}	Fuel equivalent energy, E_{fe}	Calorific value of fuel, $E_{h,fuel}$
		Calorific value of waste, $E_{h,waste}$
		Calorific value of source gas of atmospheric gas, $E_{fe,atm,cal}$
		Fuel equivalent energy of electricity, $E_{fe,el}$
	Other energy input, E_{other}	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, $E_{ther,out}$	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, $E_{aux,installed}$, blowers, etc.
		Energy used for fluid transfer, $E_{aux,fluid}$, cooling water, etc.
	Generation of utilities, $E_{utility}$	Oxygen, $E_{u,oxy}$
		Steam, $E_{u,steam}$
	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, $E_{aux,installed}$, 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 the 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 melting furnace chambers (see Figure 1).

The systematization of thermal energy is described in Table 2.

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

Thermal energy input/output	Type of energy 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 $E_{therm,out}$	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 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

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

7.5 Recycled energy

See 3.1.11.

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

8 Measurement method

8.1 General

The 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.

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 are 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

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

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

8.4.3.1.2 Measurement of exhaust gas temperature

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

8.4.3.2 Recuperative radiant tube burners

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

8.5 Products

8.5.1 General

The aluminium products and related by-products are generally described as shown in Table 4.

Table 4 — Aluminium and related by-products generated by aluminium melting furnaces

Material		Description
Input	Load (aluminium scrap)	Aluminium loaded into the furnace for the themal process
	Residual aluminium left in the furnace	Residual aluminium remaining in the furnace from the previous batch
Output	Molten aluminium	Effective amount of aluminium from the furnace
	Scale, dross	Oxidized aluminium which is produced during the thermal process
	Residual aluminium in the furnace	Residual aluminium remaining in the furnace after the batch under measurement

8.5.2 Mass

8.5.2.1 Load (aluminium scrap)

The measurement of the mass of the load aluminium shall be determined using weighing equipment.

The measurement of mass shall be carried out per batch.

8.5.2.2 Molten aluminium

The measurement of the mass of the molten aluminium shall be determined using weighing equipment.

The measurement of mass shall be carried out per batch.

8.5.2.3 Scale and dross

Mass loss due to the formation of scales or dross shall be determined from the measurement of its mass per batch.

NOTE Dross describes impurities separated from molten aluminium by melting.

When the batch-by-batch measurement is difficult, other practical methods may also be taken [e.g. adoption of average data determined from the accumulated mass loss for a certain period of time (daily, weekly, etc.)].

8.5.3 Temperature

8.5.3.1 Load (aluminium scrap)

Assume the average temperature of aluminium at the time of loading as it is equal to the ambient temperature.

In the case of aluminium products of which temperature may exceed ambient temperature, it is allowed to estimate the average temperature from the surface temperature.

8.5.3.2 Molten aluminium

Measure the internal temperature of molten aluminium in the furnace at the end of melting cycle.

K thermocouples attached inside the furnace at the tip of the protecting tube, which is submerged in the molten aluminium, are generally used for this measurement.

Molten aluminium shall be properly agitated so as to perform an accurate temperature measurement.

8.5.4 Scale and dross

Assign the temperature data of molten aluminium to the temperature value of scale (dross).

8.5.5 Residual aluminium in the furnace

The furnace should be empty at the beginning of the measurement; otherwise, residual aluminium is considered negligible in most cases. When the residual aluminium in the furnace is not negligible, its mass and temperature shall be determined.

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.

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 Calculation

9.1 General provisions

General provisions for 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.

9.2.4 Fuel equivalent energy of electricity

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

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 atomization agent

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

9.2.7 Heat of reaction

The heat of formation of scale (aluminium oxide) per ton of product is calculated using Formula (1):

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

15,484 kJ/kg may be applied to the heat by the formation of scale per kilogram of scale.

9.2.8 Sensible heat of infiltration air

Sensible heat of infiltration air is specified in ISO 13579-1:2013, 8.2.8.

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, $E_{\text{effective}}$, using Formula (2):

$$E_{\text{effective}} = E_{\text{p2}} - E_{\text{p1}} \tag{2}$$

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, E_{p1}, using Formula (3):

$$E_{\text{p1}} = 1000 \times c_{\text{pm,p1}} \times (T_{\text{p1}} - 273{,}15) \tag{3}$$

The physical properties of purity aluminium are given in Table A.1.

Table A.2 may be used for the specific heat of aluminium alloy.

9.3.1.1.2.2 At the time of extracting

The enthalpy of products at the time when products are extracted from the area of energy balance per ton of aluminium product, E_{p2}, is calculated as,

$$E_{\text{p2}} = \left(1000 - M_{\text{loss}}\right) \times [\{c_{\text{pm,p1}} \times (T_{\text{s}} - 273{,}15)\} + e_{\text{latent}} + \{(c_{\text{pm,p2}} \times (T_{\text{p2}} - T_{\text{s}})\}] \tag{4}$$

where

$$e_{\text{latent}} = 396$$

The mean specific heat before melting, $c_{\text{pm,ps}}$, is calculated as Formula (5):

$$c_{\text{pm,ps}} = 0{,}000\,334 \times \frac{(T_{\text{s}} + 273{,}15)}{2} + 0{,}92 \tag{5}$$

The mean specific heat after melting, $c_{\text{pm,p2}}$, is calculated as Formula (6):

$$c_{\text{pm,p2}} = 0{,}000\,2014 \times \frac{(T_{\text{s}} + T_{\text{p2}})}{2} + 0{,}915 \tag{6}$$

The mean specific heat, melting point and latent heat of melting are shown in Tables A.1 and A.2.

9.3.1.2 Sensible heat of oxidized substance

The sensible heat of scale (aluminium oxide) per ton of product, $E_{\text{s,oxid}}$, is calculated as,

$$E_{\text{s,oxid}} = M_{\text{oxid}} \times c_{\text{pm,oxid}} \times (T_{\text{p2}} - 273{,}15) \tag{7}$$

1,085 (kJ/kg·K) may be applied to the mean specific heat of scale.

NOTE Properties of typical aluminium oxides are shown in Table A.3.

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-type furnace

Heat storage loss by batch-type 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.

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 the 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 the heating-up process

The total energy efficiency limited to the heating-up process, which is specified in ISO 13579-1:2013, 8.4.2, may not be applied to this part of ISO 13579.

10 Energy balanace evaluation report

The energy balance report for batch-type aluminium melting furnaces shall be as specified in ISO 13579-1:2013, Clause 10.

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

Annex A
(informative)

Reference data

Table A.1 — Physical properties of purity aluminium

Property		High-purity aluminium[a]	Purity aluminium[b]
Atomic number		13	-
Atomic mass		26,981 5	-
Grating constant (face-centred cubic lattice) 20 °C (nm)		0,404 96	0,404
Density (mg/m^3)	20 °C	2,698 4	2,1
	700 °C	-	2,373
Melting point (°C)		660,1	~650
Boiling point (°C)		2 520	-
Latent heat of melting (kJ/mol)		10,47	10,3
Combustion heat (kJ/mol)		834	835
Solidification contraction (% mass fraction)		-	6,6
Specific heat 0 °C – 100 °C(J/kg·°C)		917	-
Thermal conductivity 25 °C(W/m·°C)		238	225 (soft)

NOTE Source: Reference [4].

[a] 99,996 mass%.

[b] 99,5 mass%.

Table A.2 — Specific heat of aluminium alloy

Temperature °C	Solid state kJ/kg°C	Liquid state kJ/kg°C
0	0,920 92	-
100	0,961 524	-
200	0,993 756	-
300	1,025 989	-
400	1,058 639	-
500	1,090 872	-
600	1,123 104	-
660	1,141 522	1,047 337
700	-	1,056 128
800	-	1,076 221
900	-	1,095 476
1 000	-	1,116 406

NOTE Extracted from Reference [4].

Table A.3 — Properties of aluminium oxide[a]

Material	Temperature K	Density kg/m^3	Specific heat kJ/(kg·K)	Thermal conductivity W/(m·K)	Thermal dispersion mm^2/s
Alumina, Al_2O_3	300	3890	0,779	36,0	11,89
	500	3870	1,040	20,2	5,02
	800	3850	1,181	10,4	2,29
	1 300	3790	1,271	6,13	1,27
	1 800	3740	1,323	5,59	1,13

NOTE Source: Reference [5].

[a] Based on 2 % porosity.

Annex B
(informative)

Measurement of energy balance and calculation of efficiency of a batch-type aluminium melting furnace sample report

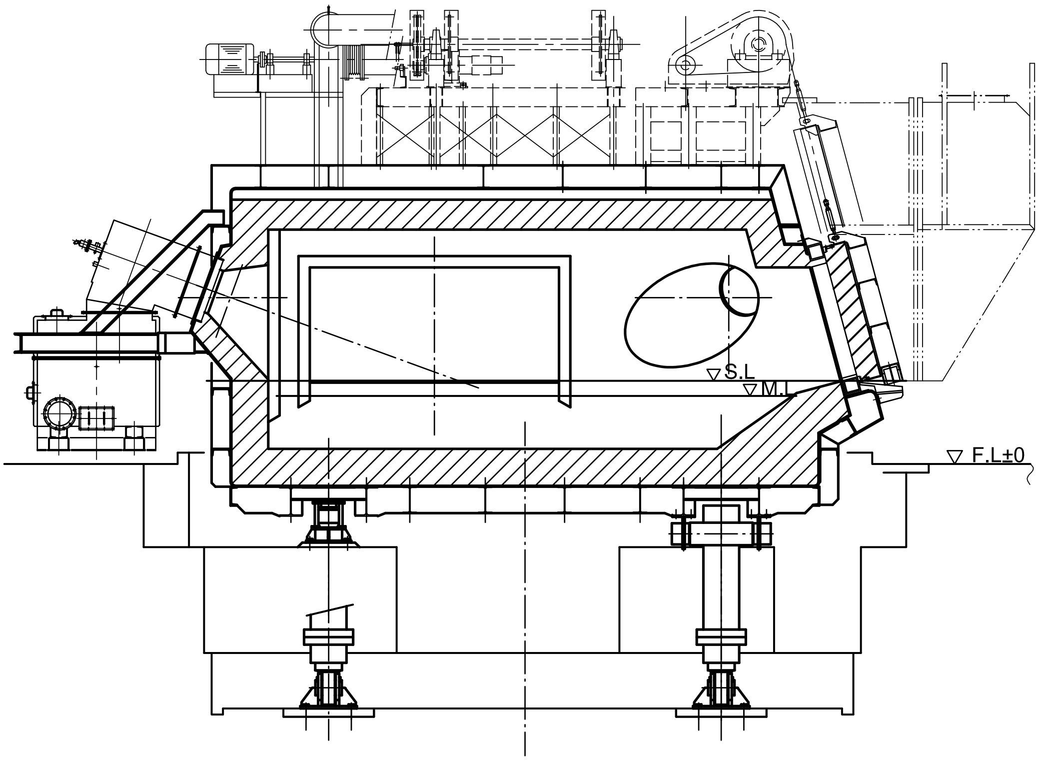
B.1 Equipment specification summary

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

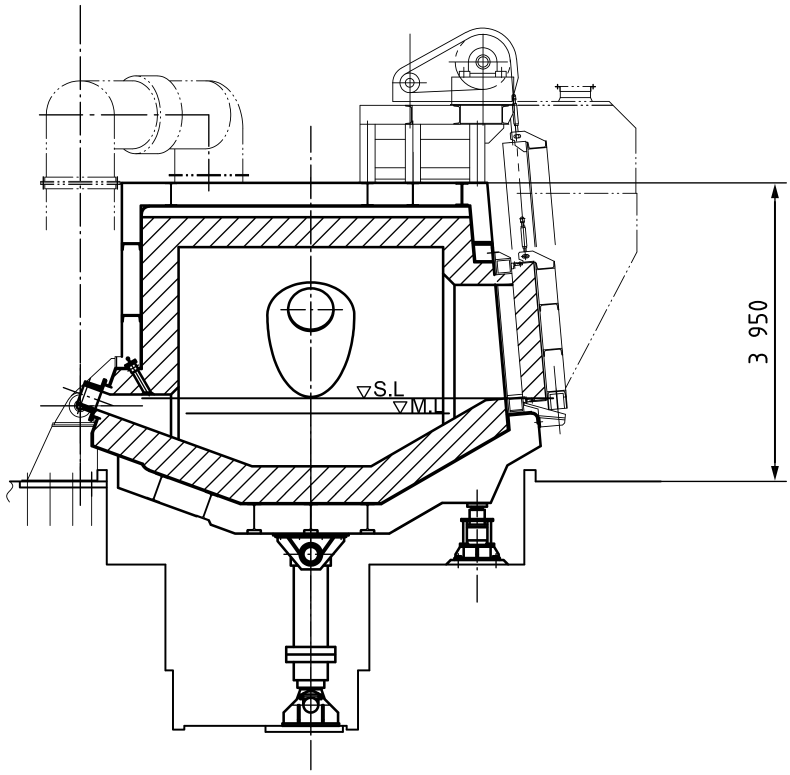
Table B.1 — Equipment specification summary

Company/Plant name	--
Location	--
Manufacturer of the furnace	--
Serial number	--
Type	Aluminium melting furnace: batch-type
Nominal capacity	29,5 per ton per charge
Type of fuel	LNG 13A
Type, capacity and quantity of burners	Regenerative burner: one pair
Material of products	Aluminium
Nominal loading temperature of products	20 °C
Nominal extracting temperature of products	750 °C
Melting temperature	660 °C

Dimensions in millimetres

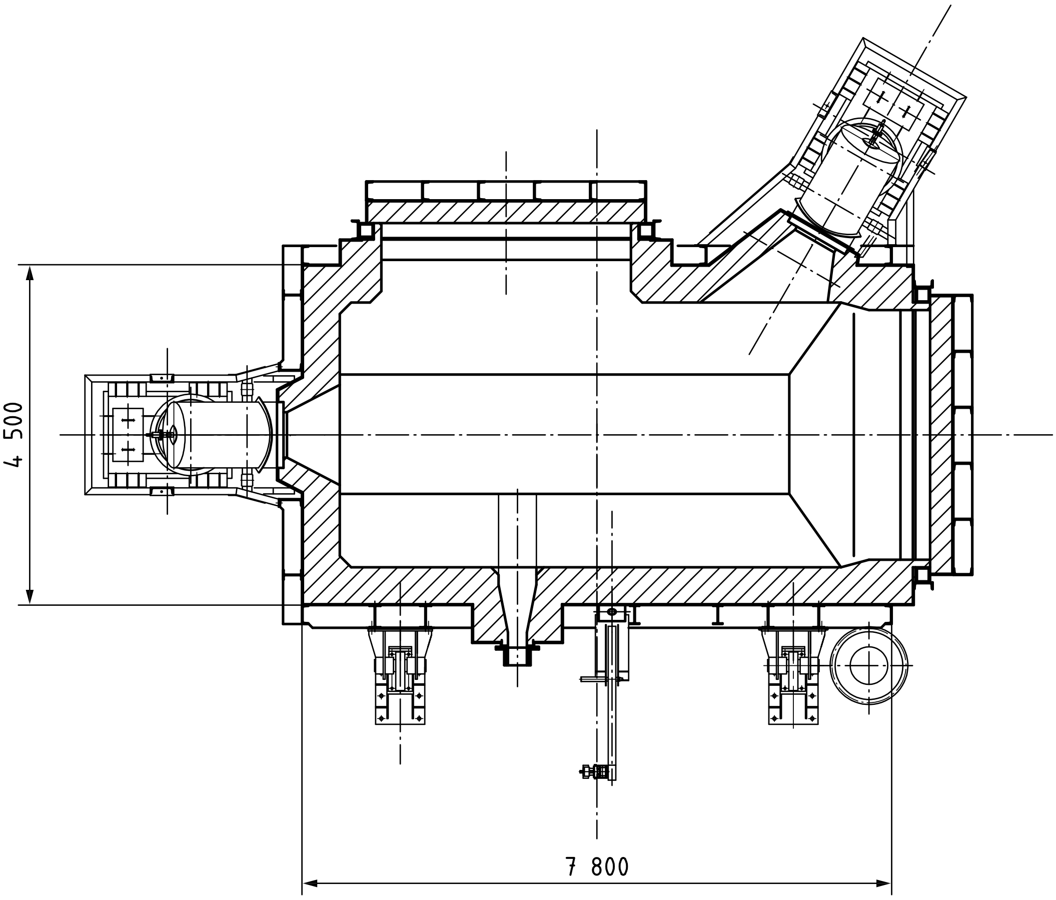


a) Longitudinal section



b) Cross-section

Dimensions in millimetres

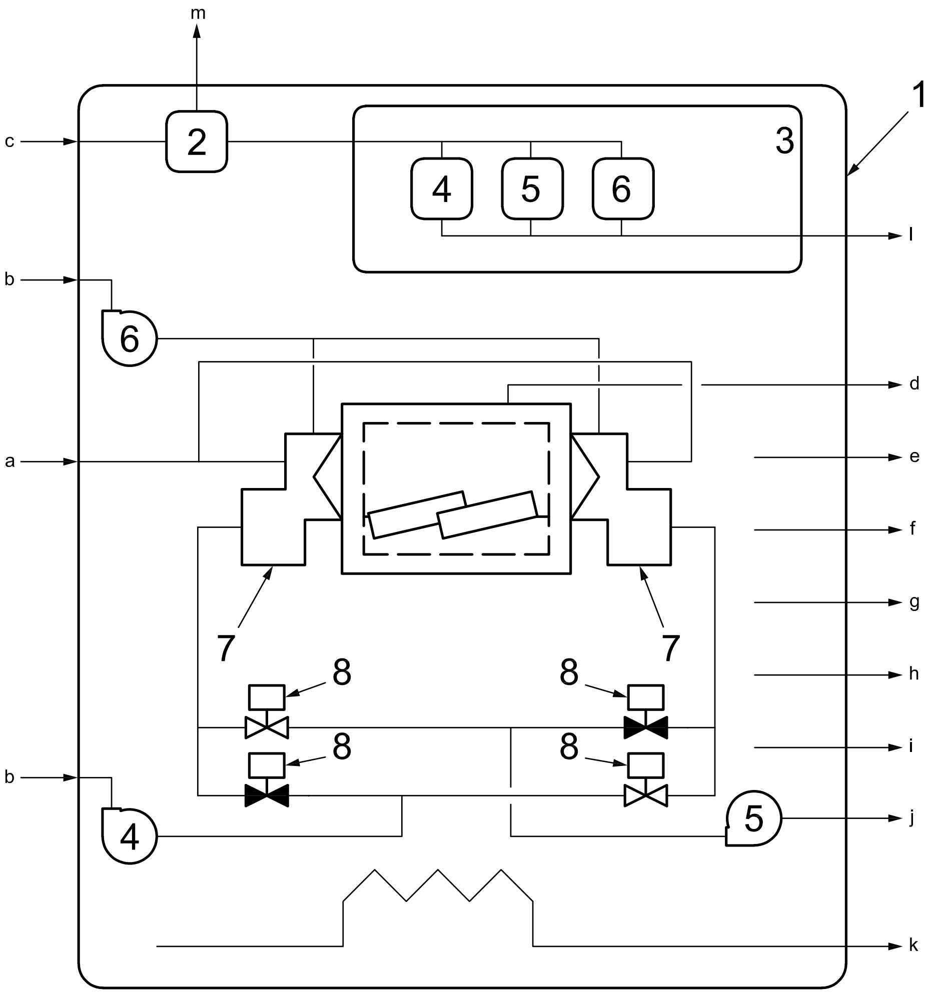


c) Horizontal section

Figure B.1 — Outline drawing of the intended furnace

B.2 Area of energy balance

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



Key

1 area of energy balance
2 electrical generation
3 installed electrical auxiliary equipment
4 combustion blower
5 IDF
6 pilot burner blower
7 regenerative burner
8 changeover valve

[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] Heat storage loss by batch-type furnace.
[h] Wall loss.
[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.

NOTE The energy used for fluid transfer is neglected.

Figure B.2 — The area of energy balance

B.3 Measurement data

The measurement data 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	29,5t/charge	
	Temperature	At the time of loading	20 °C
		Melting temperature	660 °C
		At the time of unloading	750 °C
	Material	Aluminium	
	Oxidized substance	10 kg/t	
Fuel	Type	LNG 13A	
	CH_4	89,6 %	
	C_2H_6	5,62 %	
	C_3H_8	3,43 %	
	C_4H_{10}	1,35 %	
	H_2O	0,008 kg/m^3	
	Volume	44,9 m^3(n)/t	
	Calorific value	40,63 MJ/m^3	
	Supply pressure	2,5 kPa	
	Supply temperature	20 °C	
Combustion air	Volume	Excess air ratio, m = 1,1, is obtained by calculation	
	Supply pressure	4,5 kPa	
	Supply temperature	20 °C	
	Preheated temperature	943 °C (Calculated value)	
Exhaust gas	Regenerative burner	200 °C	80 %
	Auxiliary flue	1 150 °C	20 %
	Exhaust gas analysis	CO_2	12,8 %
		CO	0 % (5 × 10^{-4} %)
		O_2	2,5 %
		N_2	84,7 %
Furnace outer wall temperature	Side	70 °C	
	Top	76 °C	
	Bottom	120 °C	
	Door	78 °C	
Furnace dimension	Side	95 m^2	
	Top	35 m^2	
	Bottom	45 m^2	
	Door	19 m^2	
	Structure (side wall)	50 m^2	
Cooling water	Supply temp.	20 °C	
	Discharge temp.	27,8 °C	
	Volume	6 t/h	
	Supply pressure	0,2 MPa	
	Supply piping	100 A	
Auxiliary electrical equipment	Combustion blower	27 kw × 2P × 440V, 60Hz (valuable voltage valuable frequency drive (VVVF))	
	IDF	37 kw × 2P × 440V, 60Hz (VVVF)	
	Pilot blower	3,7 kw × 2P × 440V, 60Hz	

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	Specific energy consumption %
Total energy input, E_{input}	Fuel equivalent energy, E_{fe}	Calorific value of fuel, $E_{h,fuel}$		1 824 287	89,1
		Calorific value of waste, $E_{h,waste}$		–	–
		Calorific value of source gas of atmospheric gas, $E_{u,atm,cal}$		–	–
		Electricity, $E_{fe,el}$		52 490	2,56
		Subtotal		1 886 777	
	Other energy, E_{others}	Sensible heat of fuel, $E_{s,fuel}$		1 841	0,09
		Sensible heat of combustion air, $E_{s,air}$		13 899	0,68
		Sensible heat of atomization agent, $E_{s,atomize}$		–	–
		Heat of reaction, E_{react}		154 840	7,56
		Sensible heat of infiltration air, $E_{s,infilt}$		–	–
		Subtotal		170 580	
	Total			**2 047 357**	100
Total energy output, E_{output}	Thermal energy, $E_{therm,out}$	Effective energy, E_{effect}		1 209 016	59,1
		Jig loss, $E_{l,jig}$		-	-
		Sensible heat of oxidized substance, $E_{s,oxid}$		7 921	0,4
		Exhaust gas, $E_{exhaust}$		331 895	16,2
		Heat storage loss by batch-type furnace, $E_{l,storage}$		122 363	6,0
		Sensible heat of atmospheric gas, $E_{s,atm}$		-	-
		Wall loss, $E_{l,wall}$		62 995	3,1
		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, $E_{l,cw}$		25 036	1,2
		Other losses, $E_{l,other}$		235 641	11,5
	Electrical auxiliary equipment, E_{aux}	Energy consumed in installed electrical auxiliary equipment, $E_{aux,installed}$	Combustion blower	8 097	0,4
			IDF	10 894	0,5
			Pilot burner blower	1 532	0,1
		Energy used for fluid transfer, $E_{aux,fluid}$	Cooling water	–	–
			Fuel	–	–
	Generation of utilities, $E_{utility}$	Oxygen, $E_{u,oxy}$		–	–
		Steam, $E_{u,steam}$		–	–
		Atmospheric gas	electricity for generation, $E_{u,atm,gen}$	–	–
			calorific value of source gas, $E_{u,atm,cal}$	–	–
	Electrical generation loss, $E_{l,eg}$			31 966	1,6
	Total			**2 047 357**	100
The regional electrical generation efficiency: η_e = 0,391 is applied.					

Table B.4 — Thermal energy balance

Type of energy		Specific energy consumption	
		kJ/ton	%
Thermal energy input	Calorific value of fuel, $E_{h,fuel}$	1 824 287	91,4
	Thermal energy input from electrical heating source	–	–
	Calorific value of waste, $E_{h,waste}$	–	–
	Sensible heat of fuel, $E_{s,fuel}$	1 841	0,1
	Sensible heat of combustion air, $E_{s,air}$	13 899	0,7
	Sensible heat of atomization agent, $E_{s,atomize}$	–	–
	Heat of reaction, E_{react}	154 840	7,8
	Sensible heat of infiltration air, $E_{s,infilt}$	–	–
	Total	**1 994 867**	100
Thermal energy output, $E_{threm,out}$	Effective energy, E_{effect}	1 209 018	60,6
	Jig loss, $E_{l,jig}$	–	–
	Sensible heat of oxidized substance, $E_{s,oxid}$	7 921	0,4
	Exhaust gas, $E_{exhaust}$	331 895	16,6
	Heat storage loss by batch-type furnace, $E_{l,storage}$	122 363	6,1
	Sensible heat of atmosphere gas, $E_{s,atm}$	–	–
	Wall loss, $E_{l,wall}$	62 995	3,2
	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, $E_{l,cw}$	25 036	1,3
	Other losses, $E_{l,other}$	235 639	11,8
	Total	**1 994 867**	100

Table B.5 — Electrical generation

Type of energy				Specific energy consumption	
				kJ/ton	%
Input	Fuel-equivalent energy of electricity, $E_{fe,el}$			**52 490**	
Output	Thermal energy output from electrical heat source			–	–
	Electrical auxiliary equipment, E_{aux}	Energy consumed in installed electrical auxiliary equipment, $E_{aux,installed}$	Combustion blower	8 097	15,4
			IDF	10 894	20,8
			Pilot burner blower	1 532	2,9
		Energy used for fluid transfer, $E_{aux,fluid}$	Cooling water	–	–
			Fuel	–	–
	Generation of utilities, $E_{e,utility}$	Oxygen, $E_{u,oxy}$		–	–
		Steam, $E_{u,steam}$		–	–
		Energy used for generation of atmospheric gas, $E_{u,atm,gen}$		–	–
	Electrical generation loss, $E_{l,eg}$			31 966	60,9
	Total			**52 490**	100
The regional electrical generation efficiency: η_e = 0,391 is applied.					

B.5 Energy efficiency

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

$$E_{\text{input}} = 2\,047\,357 \qquad \text{(B.1)}$$

$$E_{\text{effective}} = 1\,209\,016 \qquad \text{(B.2)}$$

Therefore, according to Formula (57) specified in ISO 13579-1:2013, 9.4.1, the total energy efficiency, η_1, of the furnace, as a percentage (%), is calculated as:

$$\eta_1 = \frac{1209016}{2047357} = 59{,}1 \pm 0{,}7 \qquad \text{(B.3)}$$

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, based on the energy balance analyses shown in Tables B.3, B.4 and B.5.

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

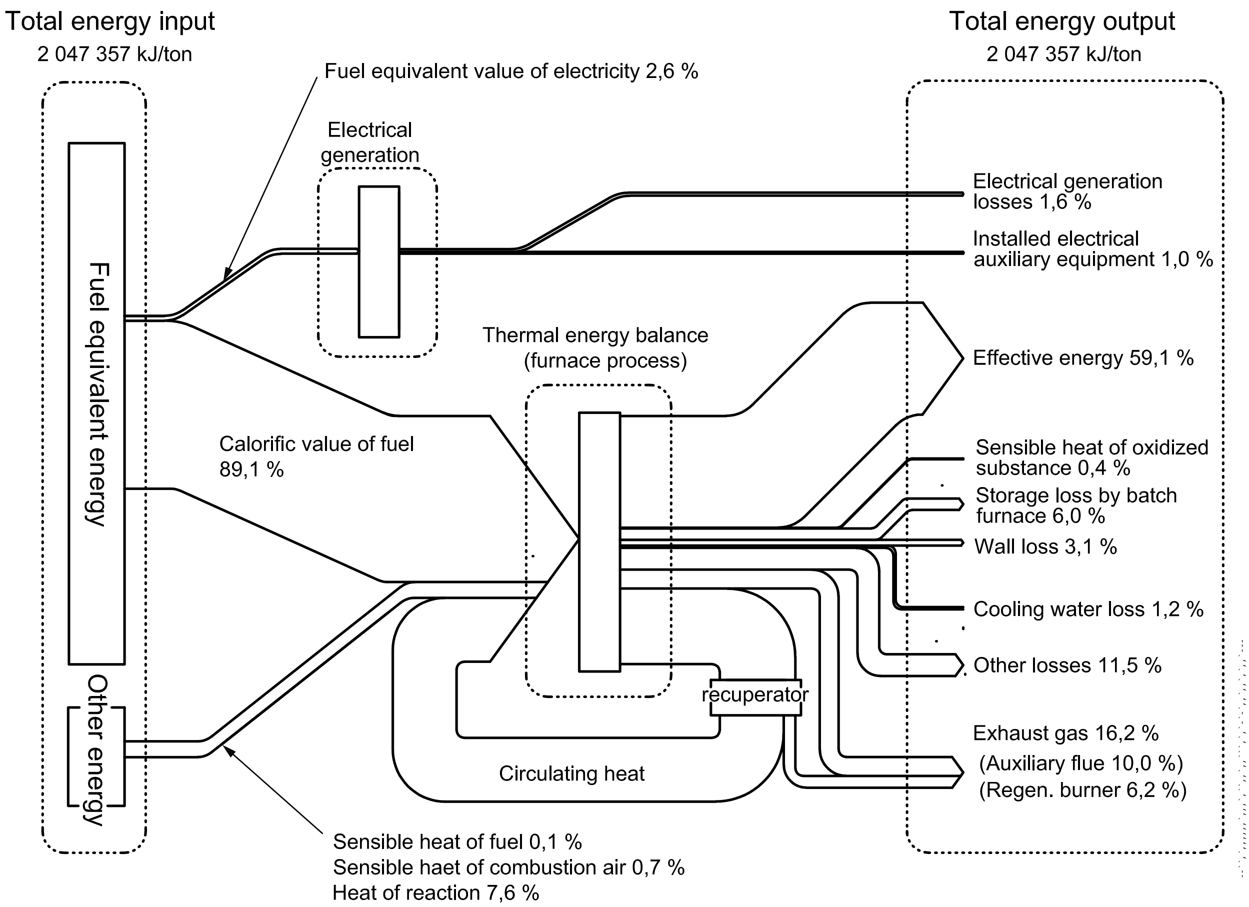


Figure B.3 — Energy flow diagram of the energy flow of the furnace

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 A .

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

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 as:

$$\delta\eta_1{}^2 = \left\{\frac{\left(C_{\text{pm,p1}}M_{\text{p}}\delta T_{\text{p1}}\right)^2 + \left[C_{\text{pm,p2}}\left(M_{\text{p}} - M_{\text{loss}}\right)\delta T_{\text{p2}}\right]^2 + \left(C_{\text{pm,p2}}T_{\text{p2}} - C_{\text{pm,p1}}T_{\text{p1}}\right)^2\left(\delta M_{\text{p}}\right)^2 + \left(C_{\text{pm,p2}}T_{\text{p2}}\delta M_{\text{loss}}\right)^2}{E_{\text{input}} - E_{\text{re}}}\right\}^2 + \eta_1{}^2\left(\frac{\sum\delta E_i}{E_{\text{input}} - E_{\text{re}}}\right)^2 \quad \text{(C.1)}$$

C.1.1 Assessment

C.1.2 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)	±5,6 (°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 products	Weighing equipment	±1 (kg) at 1 000 kg[a]
Electrical power	Electrical power meter	±3 (%)[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 in account in the assessment of uncertainty:

— mass loss of products during the thermo-process is assumed to be negligible,

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

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

C.1.3 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.1), the each absolute error of temperature is estimated as:

$$\delta T_1 = 0{,}5\ ^{\circ}\text{C} \tag{C.3}$$

$$\delta T_2 = 6{,}4\ ^{\circ}\text{C} \tag{C.4}$$

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

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

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;

$\frac{\delta M_{\text{s}}}{M_{\text{s}}}$ 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 into Formula (C.5), the absolute error of the total energy efficiency of the continuous carburizing furnace is estimated as:

$$\delta\eta_1 = 0{,}007 \quad \text{(C.6)}$$

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

$$\eta_1 = 59{,}1 \pm 0{,}7 \quad \text{(C.7)}$$

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