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

Part 1:
General methodology

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

Partie 1: Méthode générale

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

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

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

— *Part 1: General methodology*

— *Part 3: Reheating furnaces for steel*

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

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

Introduction

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

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

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

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

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

— improve efficiency.

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

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

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

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

Part 1: General methodology

1 Scope

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

— measurement methods;

— calculations (general calculation);

— an energy balance evaluation report.

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

2 Normative references

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

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

3 Terms and definitions

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

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

3.1.1 Total energy input

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

3.1.2 Fuel equivalent energy

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

3.1.2.2
calorific value of fuel
$E_{\mathrm{h,fuel}}$
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
$E_{\mathrm{h,waste}}$
calorific value of waste which is brought to the area of energy balance with products

EXAMPLE Waste oil on aluminium scrap.

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

3.1.2.5
fuel equivalent energy of electricity
$E_{\mathrm{fe,el}}$
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
$E_{\mathrm{s,infilt}}$
sensible heat of air that leaks into the furnace through supply/discharge port or gaps in the operating systems of the furnace

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

3.1.4 Total energy output

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

3.1.5 Thermal energy output

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

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

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

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

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

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

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

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

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

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

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

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

EXAMPLE As in the case of a roller hearth furnace.

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

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

3.1.6 Energy consumed in electrical auxiliary equipment

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

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

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

EXAMPLE For cooling water, fuel, etc.

3.1.7 Energy used for generation of utility

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

EXAMPLE Oxygen, steam and atmospheric gas.

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

3.1.8 Electrical generation loss

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

3.1.9 Thermal energy balance

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

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

3.1.10 Energy balance of electrical generation

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

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

3.1.11 Recycled energy

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

EXAMPLE Energy reused in waste gas boiler.

4 Symbols used in this part of ISO 13579

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

NOTE 1 Tons used are metric tons.

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

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

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

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

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

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

