

Water-tube boilers and auxiliary installations —

Part 15: Acceptance tests

The European Standard EN 12952-15:2003 has the status of a British Standard

ICS 27.040

National foreword

This British Standard is the official English language version of EN 12952-15:2003. It supersedes BS 2885:1974 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PVE/2, Water-tube boilers, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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Wasserrohrkessel und Anlagenkomponenten - Teil 15:
Abnahmeversuche

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Foreword

This document EN 12952-15:2003 has been prepared by Technical Committee CEN/TC 269 "Shell and water-tube boilers", the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by **March 2004**, and conflicting national standards shall be withdrawn at the latest by **March 2004**.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association. This European Standard is considered as a supporting standard to other application and product standards which in themselves support an essential safety requirement of a New Approach Directive and should appear as a normative reference in them.

The European Standard series EN 12952 concerning water-tube boilers and auxiliary installations consists of the following parts:

- *Part 1: General.*
- *Part 2: Materials for pressure parts of boilers and accessories.*
- *Part 3: Design and calculation for pressure parts.*
- *Part 4: In-service boiler life expectancy calculations.*
- *Part 5: Workmanship and construction of pressure parts of the boiler.*
- *Part 6: Inspection during construction, documentation and marking of pressure parts of the boiler.*
- *Part 7: Requirements for equipment for the boiler.*
- *Part 8: Requirements for firing systems for liquid and gaseous fuels for the boiler.*
- *Part 9: Requirements for firing systems for pulverized solid fuels for the boiler.*
- *Part 10: Requirements for safeguards against excessive pressure.*
- *Part 11: Requirements for limiting devices of the boiler and accessories.*
- *Part 12: Requirements for boiler feedwater and boiler water quality.*
- *Part 13: Requirements for flue gas cleaning systems.*
- *Part 14: Requirements for flue gas DENOX-systems.*
- *Part 15: Acceptance tests.*
- *Part 16: Requirements for grate and fluidized-bed firing systems for solid fuels for the boiler.*

CR 12952 Part 17: Guideline for the involvement of an inspection body independent of the manufacturer.

Although these Parts may be obtained separately, it should be recognized that the Parts are interdependent. As such, the design and manufacture of water-tube boilers requires the application of more than one Part in order for the requirements of the Standard to be satisfactorily fulfilled.

NOTE Part 4 and 15 are not applicable during the design, construction and installation stages.

Annex A is normative.

This document includes a Bibliography.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom.

1 Scope and field of application

1.1 Field of application

This European Standard covers direct-fired steam boilers and hot water generators, including the auxiliaries. For the purposes of this standard, steam boilers and hot water generators are vessels and pipework systems in which:

- steam at a pressure higher than atmospheric pressure is generated for use external to the system;
- water is heated to a temperature higher than the saturation temperature at atmospheric pressure for use external to the system.

A steam generator normally consists of the flue gas-heated evaporator, the superheater, the reheater, the feedwater heater, the air heater, the fuel heater, if any, and the fuel burning equipment.

The term 'direct-fired' relates to equipment by means of which the chemical heat in the fuel of known composition is converted to sensible heat. Such equipment can involve stoker firing, fluidized-bed combustion or burner systems.

The auxiliaries include the fuel feeders, the pulverizer, the FD (forced draught) fan, the ID (induced draught) fan, the facilities for removal of the refuse (combustion residues), the steam air heater, the main air heater, the fuel heater, if any, and the dust collector.

This standard does not cover:

- units fired with special fuels (e.g. refuse);
- pressurized steam generators (e.g. pressurized fluidized-bed combustion (PFBC) boilers);
- steam generators in combined cycle systems.

This standard can be applied by analogy to the acceptance testing of:

- indirect-fired units (e.g. waste heat boilers);
- units operated using other heat carriers (e.g. gases, thermal oils, sodium).

Where this standard is to serve as the basis for the acceptance testing of heat-transfer systems, an agreement should have been reached by the time the contract has been concluded with regard to any special features which may have an effect on the measurements and interpretation of test results.

1.2 Scope

This standard is intended as the basis for the thermal performance (acceptance) testing of direct-fired steam boilers and hot water generators. Such tests are designed to demonstrate that the guarantees with respect to efficiency and output or other parameters have been met.

This standard includes (among other things):

- recommendations for the performance of acceptance tests (see clause 6);
- a definition of the envelope boundary of the steam generating unit and of the efficiency (see clause 8);
- details on the uncertainty of measurement (see clause 10).

1.3 General information

The standard provides information on agreements relating to the type and scope of acceptance tests. Such agreements should be made prior to testing or at the time when the steam or hot water generator is ordered.

The agreements can refer to the following:

- scope of supply, envelope boundary, reference temperature;
- method of determining thermal efficiency, direct (input-output) method or indirect (heat loss) method;
- additional measurements;
- test conditions, such as degree of cleanliness, time to reach steady-state condition and test duration;
- any deviating test conditions;
- blowdown and sootblowing;
- functional use of instrumentation other than specified in clause 6;
- steam table and tables for other thermodynamic properties to be used;
- any special correction methods;
- location and position of measuring points.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN 837-1, *Pressure gauges — Part 1: Bourdon tube pressure gauges — Dimensions, metrology, requirements and testing*.

EN 12952-1:2001, *Water-tube boilers and auxiliary installations — Part 1: General*.

EN 26801, *Rubber or plastics hoses — Determination of volumetric expansion (ISO 6801:1983)*.

EN 60584-1, *Thermocouples — Part 1: Reference tables (IEC 60584-1:1995)*.

EN 60584-2, *Thermocouples — Part 2: Tolerances (IEC 60584-2:1982 + A1:1989)*.

EN 60751, *Industrial platinum resistance thermometer sensors (IEC 60751:1983 + A1:1986)*.

EN ISO 3170, *Petroleum liquids — Manual sampling (ISO 3170:1988, including Amendment 1:1998)*.

EN ISO 3993, *Liquefied petroleum gas and light hydrocarbons — Determination of density or relative density — Pressure hydrometer method (ISO 3993:1984)*.

EN ISO 5167-1, *Measurement of fluid flow by means of pressure differential devices — Part 1: Orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full (ISO 5167-1:1991)*.

ISO 157, *Coal — Determination of forms of sulfur*.

ISO 334, *Solid mineral fuels — Determination of total sulfur — Eschka method*.

ISO 589, *Hard coal — Determination of total moisture.*

ISO 609, *Solid mineral fuels — Determination of carbon and hydrogen — High temperature combustion method.*

ISO 625, *Solid mineral fuels — Determination of carbon and hydrogen — Liebig method.*

ISO 1217, *Displacement compressors — Acceptance tests.*

ISO 1928, *Solid mineral fuels — Determination of gross calorific value by the bomb calorimetric method, and calculation of net calorific value.*

ISO 1988, *Hard coal — Sampling.*

ISO 5389, *Turbocompressors — Performance test code.*

3 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in EN 12952-1 and the following apply.

3.1

direct method

input-output method

efficiency is determined as the ratio of heat absorbed by the working fluids (water and steam) to the heat input (chemical heat plus heat credits added to the steam generator)

3.2

indirect method

heat loss method

determination of all accountable heat losses, heat credits and the heat in the fuel. The efficiency is then equal to 100 minus the ratio of the sum of all heat losses to the sum of heat in the fuel plus heat credits

3.3

standard condition

embraces the condition at $p_n = 1,01325$ bar and $t_n = 0$ °C

3.4

refuse

combustion residues that are obtained in the form of flue dust or in the molten and/or agglomerated solid state (slag), including the fuel contained in them

4 Symbols and abbreviations and coefficients

4.1 Symbols and abbreviations

For the purpose of this part, the symbols given in EN 12952-1:2001, Table 4-1 and those given in Table 4.1-1 and Table 4-1-2 shall apply.

Table 4.1-1 — Latin Letters

Symbol	Description	Unit
A	Ash content of fuel related to daf-based fuel	—
A_U	Influence factor	—
c	Specific heat capacity ^a	kJ/(kgK)
$\bar{c}$	Integral specific heat capacity ^a	kJ/(kgK)
f	factor (transient fraction of heat output)	—
f	Limit of (permissible) error	—
H	Calorific value (CV)	kJ/kg
h	Specific enthalpy	kJ/kg
i	Number of samples	—
J	Enthalpy of flue gas or combustion air related to fuel mass flow	kJ/kg
L	Latent heat (heat of vaporization)	kJ/kg
l	Single loss	—
l	Inflow length	m
l_u	Ratio of unburned combustibles to supplied fuel mass flow	—
M	Molar mass	—
$\dot{m}$	Mass flow (rate)	kg/s
n	Air factor at boiler outlet	—
n	Lime ratio	—
P	Power	kW
p	Pressure	N/mm ²
$\dot{Q}$	Heat flow	kW
T	Thermodynamic temperature	K
t	Temperature Celsius	°C
u	Unburned combustibles content (by mass)	kg/kg
u_M	Uncertainty of measurement	—
V	Combustion air and flue gas volume (per unit mass of fuel)	m ³ /kg
$\dot{V}$	Volume flow (rate)	m ³ /h
v	Specific volume	m ³ /kg
w	Velocity	m/s
W	Moisture content of fuel related to dry, ash free based fuel	—
x	Flue gas/combustion air components content by mass	kg/kg
x_{Ad}	Combustion air content by mass	kg/kg
y	Content by volume	m ³ /m ³
y_{Ad}	Combustion air content by volume	m ³ /m ³

NOTE 1 1 N/mm² = 1 MN/m² = 1 MPa

NOTE 2 The units shown are those normally used. Conversion can be necessary for use in the dimensionless equations.

^a "specific heat", for short.

Table 4.1-2 — Greek letters

Symbol	Quantity	Unit
α	Heat transfer coefficient	W/(m ² /K)
∂	Partial differential	—
Δ	Difference	—
ε	Relative uncertainty of measurement	—
ε	Emissivity	—
η	Thermal efficiency	—
η_{SL}	Ash collection efficiency	—
η_s	Desulfurization efficiency	—
γ	Fuel content (by mass)	kg/kg
v	Volatile matter content of ash	kg/kg
ρ	Density	kg/m ³
σ	Standard deviation	—
μ	Combustion air/flue gas mass to fuel mass ratio	kg/kg
τ	test duration	h or s

Table 4.1-3 — Subscripts

Symbol	Description
A	Air
Ash	Ash
AS	Atomizing steam or air
B	Boiler
BD	Blowdown water
c	corrected
Cn	Convection
C	Carbon
Ca	Calcium (lime)
CO	Carbon monoxide
CO ₂	Carbon dioxide
d	Dry (basis)
daf	Dry, ash-free
DC	Dust collector
e	Final value
EC	External cooling
FA	Flue dust (fly ash)
F	Fuel, burned fuel
F _o	Fuel supplied
FW	Feedwater
G	Flue gas (combustion gas)
(G)	Gross value
g	Guaranteed
H	Hydrogen
H ₂ O	Water
K	Lime (when used as additive)
L	Loss
LA	Leakage (infiltrated) air / tramp air
M	Pulverizer
m	Average
meas	Measured
min	Minimum
N	Useful, effective
N	Nitrogen
(N)	Net value
n	Standard condition
o	Stoichiometric
O; O ₂	Oxygen
p	Constant pressure

Table 4.1-3 (continued)

Symbol	Description
r	Reference
R	Radiation
RC	Radiation and convection
RH	Reheat steam
S	Sulfur
SS	Spray water
SA	Steam air heater
SL	Slag
Sam	Sampling
Sen	Sensor
ST	Live steam
tot	Total
tr	True (value)
u	Unburned matter
U	Circulating pump or recirculating fan
VM	Volatile matter
W	Wall
Z	Heat input
0	At 0 °C
1	Upstream, inlet
2	Downstream, outlet
I, II	Reheater stages
^	Maximum

4.2 Coefficients

For the purpose of this part, the coefficients given in Table 4.2-1 shall apply.

Table 4.2-1 — Coefficients

Designation	Symbol	Value	Unit
Specific latent heat at 25 °C	L_r	2442,5	kJ/kg
Specific heat of steam between 25 °C and 150 °C	$\bar{c}_{pSt}$	1,884	kJ/(kg K)
Specific heat of water between 25 °C and 150 °C	$\bar{c}_{pW}$	4,21	kJ/(kg K)
Specific heat of air between 25 °C and 150 °C	$\bar{c}_{pA}$	1,011	kJ/(kg K)
Specific heat of ash and flue dust between 25 °C and 200 °C	$\bar{c}_{Ash}, \bar{c}_{FA}$	0,84	kJ/(kg K)
Specific heat of slag			
Dry-bottom furnace	$\bar{c}_{SL}$	1,0	kJ/(kg K)
Slag-tap furnace	$\bar{c}_{SL}$	1,26	kJ/(kg K)
Specific heat of additives between 25 °C and 200 °C	$\bar{c}_{Ca}$		
	$CaCO_3$	0,97	kJ/(kg K)
	$Ca(HO)_2$	1,32	kJ/(kg K)
	CaO	0,84	kJ/(kg K)
Specific heat of dry and ash-free coal between 25 °C and 150 °C	$\bar{c}_{Fdaf}$	1,03	$(1 + \gamma_{vm})$ kJ/(kg K)
CV of carbon monoxide	H_{CO_n}	12,633	MJ/m ³
CV of unburned matter:			
Hard coal	H_{uu}	33,0	MJ/kg
Brown coal	H_{uu}	27,2	MJ/kg
CV of total organic carbon (10 °C)	H_{uu}	33,0	MJ/kg

5 Guaranteed parameters

5.1 Basis for determining guaranteed parameters

The following factors shall be considered when establishing the guaranteed parameters:

- fuel properties (composition, net calorific value (NCV), grindability, ash fusibility) and fuel group, if relevant;
- feedwater and spray water characteristics (pressure, temperature);
- cold reheat steam pressure, temperature and mass flow;
- air temperature, relative humidity, air pressure, negative-pressure condition at boiler outlet.

Parameters and thermodynamic properties relate to the envelope boundary (see 8.1) only.

5.2 Parameters subject to guarantee

An acceptance test of a steam generator shall be carried out to verify compliance with the guarantees.

The main parameters that shall be guaranteed are:

- the maximum continuous rating (MCR);
- the pressure and temperature of the generated live and reheat steam;
- the efficiency or losses, or the flue gas temperature.

The following parameters may also be subject to guarantee:

- the efficiency or losses for given fuels and/or partial loads;
- the steam condition for given fuels and at partial loads;
- the pressure drop across boiler high pressure (HP) system and reheater;
- the pressure loss in the combustion air and flue gas flows at agreed points;
- the air factor (ratio of actual to stoichiometric combustion air masses) at agreed points;
- the maximum throughput of reheater spray water;
- the unburned combustibles content of flue dust;
- the emission of flue gas.

Unless otherwise agreed, guarantees shall relate to steady-state conditions.

5.3 Additional measurements

The following parameters may also be taken into consideration when evaluating the steam generating unit:

- pressure and temperature of water and steam at different points;
- combustion air pressure, temperature and velocity (flow rate) at different points along the ducting system;
- flue gas composition, pressure, temperature and velocity (flow rate) at different points along the ducting system.

5.4 Supply of steam generator components by several manufacturers

If steam generator components are supplied by several manufacturers, additional measurements may be necessary in order to provide proof of conformance to the guarantees.

6 Basic test conditions

6.1 Methods of determining efficiency

The thermal efficiency of steam generators shall be determined using the direct or indirect method (see clause 3).

It is recommended that the major heat losses also should be determined when using the direct method.

Which method is to be given preference depends on the technical resources. Where solid fuels are used, for example, it is not possible or extremely difficult to accurately measure large mass flows. Here, the only viable choice is the indirect method, which should also be adopted when the fuel properties are subject to large fluctuations. If it is possible to take accurate measurements of fuel flow, the direct method may be the better choice, especially for small steam generators, owing to the uncertainty involved in the measurement of radiation and convection losses. The two methods have different levels of uncertainty. The method with the highest accuracy should always be employed.

The method shall be agreed with the purchaser, and stated in the contract.

6.2 General conditions

The parameters listed in 5.1 shall be determined before carrying out acceptance tests. If the operating conditions do not allow this, the tests may, subject to prior agreement, be performed under different conditions. However, deviations shall be kept to a minimum. It shall then be necessary to correct the efficiency to the guaranteed conditions. See clause 9 for details.

6.3 Preliminary test runs

Prior to the regular acceptance test, the supplier shall be given the opportunity to conduct preliminary test runs which serve to check the accuracy of test equipment and methods and to train test personnel.

If a preliminary test yields satisfactory results, it may be declared an acceptance test, subject to agreement of all parties involved.

6.4 Condition of steam generator

It shall be assumed that a steam generator is so designed that the guaranteed values can be attained with normal fouling. The supplier shall be given the opportunity to inspect the heating surface prior to the acceptance test. The time of the acceptance test shall be agreed between the operator and supplier. However the test should be carried out after optimization and the test run being carried out.

Where the steam generator has been supplied with cleaning equipment (e.g. sootblowers or a shot cleaning plant), such equipment shall be employed for cleaning before the acceptance test.

6.5 Steady-state conditions

6.5.1 Attaining steady-state conditions

As the guaranteed values refer to steady-state conditions only, it shall be ensured that the steam generator has reached equilibrium.

The time required to attain equilibrium shall vary widely with the boiler design. Normally, the steam generator shall have been in continuous operation for several days prior to the test.

Equilibrium shall have been reached before the test starts, which shall be established by all parties to the test.

For certain firing systems (e.g. slag-tap furnaces, fluidized-bed combustion systems) it may take an extremely long time to reach steady-state conditions.

6.5.2 Monitoring the steady-state condition

During the test, particular characteristic and significant measured values shall be continually monitored to verify that steady-state conditions have been maintained. Interim evaluation of results shall be recommended when determining efficiency by the direct method.

6.5.3 Adjustment of firing system

The test fuel shall be made available well in advance so that the supplier has sufficient time to adjust the fuel-burning equipment and to ensure that steady-state conditions with respect to the fuel are reached.

6.6 Performance of test

6.6.1 Test duration

For the direct method, the duration of testing depends on the type of boiler and firing system as well as on the level of measurement accuracy desired.

For the indirect method, the duration of testing is usually governed by the extent of traverse measurements ('traverses', for short) of flue gas losses or, in the case of fluidized-bed combustion systems, the time it takes to determine losses due to enthalpy and unburned combustibles.

The recommended duration of the test shall be in accordance with Table 6.6-1.

Table 6.6.1 — Recommended duration of tests

Direct tests	Duration
Solid fuel equipment giving steady burning rates	4 h
Solid fuel equipment giving possible cyclic variations in the mass of fuel present (e.g. underfeed, gravity feed stokers, hand de-ashed units) ^a	Not less than 8 h and at least one full cycle of firing or de-ashing operations, beginning and ending at the same points on the cycle
Solid fuel equipment burning bagasse and other solid fuels of variable calorific value	6 h
Liquid and gaseous fuels (including waste heat boilers)	2 h
Electric boilers	1 h
Indirect tests	
Solid fuel	4 h
Liquid and gaseous fuels (including waste heat boilers)	2 h
^a If the unit has to be taken off load for de-ashing, the period between de-ashing operations is the duration of the test.	

6.6.2 Conditions at beginning and end of test

At the beginning and end of the test, values for the following shall be as close as practicable:

- water level and steam pressure;
- steam and feed water flows, and combustion conditions if possible;
- pressure drop across fluidized bed as a measure of the content of inert material;
- excess air.

For stoker firing, and particularly when using the direct method, the quantity of fuel on the grate shall be the same at the beginning and end of the test. For mechanical grates, the average grate speed and the depth of fuel bed, at least during the period of one pass of the fuel on the grate, shall be the same at the beginning and end of the test. The time for which measurements are taken shall be longer than the actual duration of the test. It is recommended that the above-mentioned values be monitored before commencement and after completion of the test in order to reliably establish that steady-state conditions have been attained.

6.6.3 Frequency of readings

All readings shall be taken as often as necessary to minimize the integration error (see also [1]).

This can be achieved by using automatic data recording equipment. When data are recorded manually, the following frequency of readings shall be observed:

flow measurements	3 min;
flue gas analyses	5 min;
pressure and temperature measurements	10 min;
sampling	15 min.

6.6.4 Permissible fluctuations

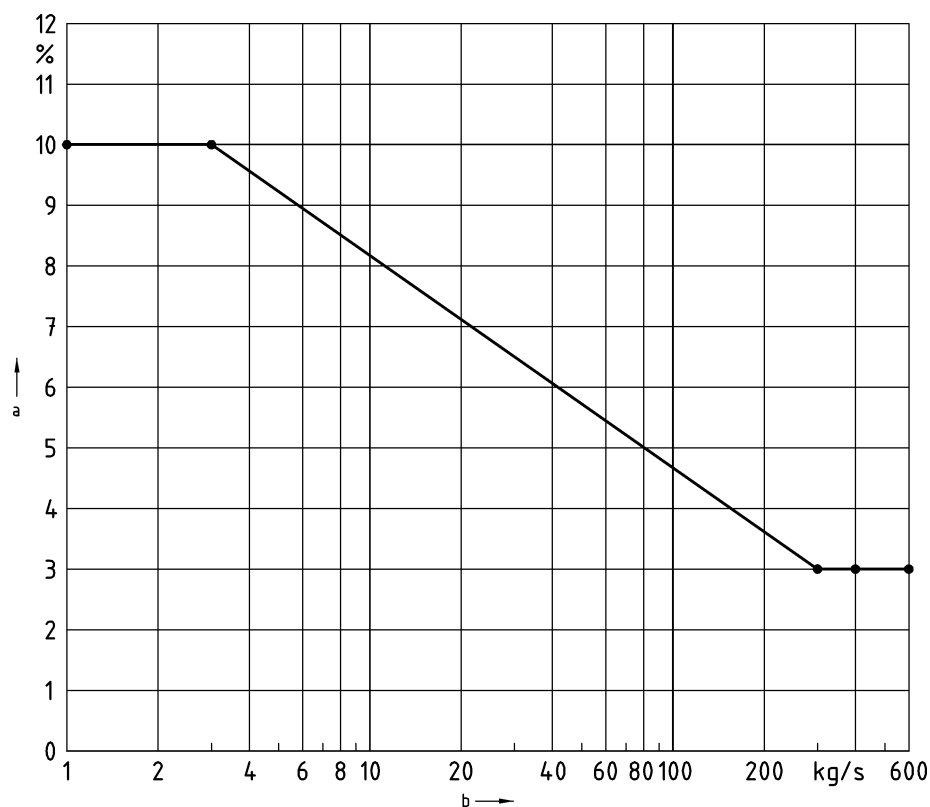
6.6.4.1 Steam boilers

Operationally induced fluctuations of steam mass flow (throughput) shall not exceed 3 % to 10 % of the average test results (they shall, however, be not greater than the maximum continuous rating); for details refer to Figure 6.6-1. See Figure 6.6-2 for the maximum permissible pressure fluctuations. Flue gas temperature shall be in steady state conditions. The fluctuations of the difference between

- the temperature of flue gas at the generator outlet and
- the temperature of cold fluid (water or air) at the last exchanger inlet

shall not exceed ± 3 %.

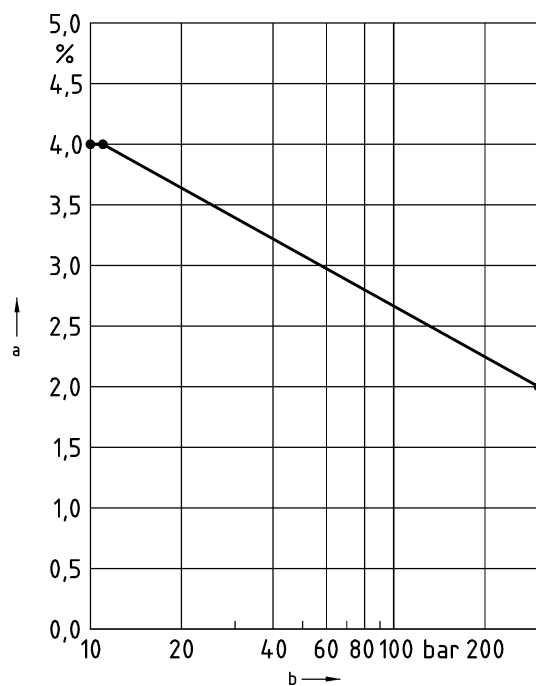
If the limit values specified in Figures 6.6-1 and 6.6-2 are exceeded, the test may be rejected.



Key

- a Maximum mass flow deviations
- b Steam mass flow, $\dot{m}_{St}$

Figure 6.6-1 — Maximum permissible deviations in steam mass flow



Key

- a Maximum pressure deviation
- b Pressure, p

Figure 6.6-2 — Maximum permissible deviations in steam pressure

6.6.4.2 Hot water generators

During the acceptance test on a hot water generator, a situation can arise where the useful generator output is greater or less than the energy supplied to the heating system. This is accompanied by a gradual increase or decrease of the average hot water temperature and, consequently, also by a change in the average water temperature in the generator. Therefore, a transient fraction of the useful heat, which can be computed from the water content and the generator mass, shall be taken into account. As this calculation method involves errors, the hourly temperature change rate, $\Delta t_\tau/\tau$, should not exceed the following value:

$$\frac{\Delta t_\tau}{\tau} < \left| 0,03 \frac{\dot{V} (t_2 - t_1)}{115 V_B} \right| \quad \text{in } \frac{K}{h} \quad (6.6-1)$$

where

- $\dot{V}$ is the volume flow of water measured during the acceptance test, in m³/h;
- V_B is the content of water in hot water generator, in m³;
- t_1 is the average generator inlet temperature during the test ($t_1 = 0,5 (t_{1END} + t_{1BEGIN})$), in °C;
- t_2 is the average outlet temperature during the test ($t_2 = 0,5 (t_{2END} + t_{2BEGIN})$), in °C;
- τ is the test duration, in h;
- Δt_τ is the change in average hot water temperature during the test period
($\Delta t_\tau = t_{mEND} - t_{mBEGIN} = 0,5 ((t_{1END} + t_{2END}) - (t_{1BEGIN} + t_{2BEGIN}))$), in °C.

where subscript BEGIN denotes start of test and subscript END, end of test.

The acceptance test can be rejected where there is a greater increase in temperature.

6.7 Other information

Care shall be taken to avoid any leakages in lines and shutoff devices on the water/steam side, or any bypass flows which can cause errors in the mass flow measurement. Disused lines shall, therefore, be fitted with blind flanges, or where this is not practicable, provisions shall be made for continuous observation.

No blowdown should take place during the test. Where this cannot be avoided, the volumetric quantity of discharged boiler water shall be determined. Unless otherwise agreed, the quantity of heat absorbed in the boiler from the discharged water shall be added to the useful output of the steam boiler.

Whenever possible, sootblowers shall not be activated during the test.

7 Instrumentation and methods of measurement

7.1 General

Only such measuring instruments and/or transducers shall be used whose indicated and/or output values are verifiable and whose limits of error are known. Included are:

- a) instruments for which a verification certificate (calibration certificate issued by an authority) is submitted;
- b) verifiable instruments which have been calibrated before and after the test with the readings both rising and falling, preferably under conditions simulating those existing during the test, and compared with the instruments as per item a) above;

- c) standard instruments with known limits of error;
- d) other approved instruments with known limits of error, the use of which has been agreed upon by the parties to the test.

The measuring equipment shall not be subject to any appreciable permanent changes during the test.

Analog or digital readings can be taken, and the data recorded manually or automatically. The test report shall detail the instruments used and their limits of error.

If the data are recorded by automatic equipment, random checks shall be made to verify that the signals are correctly processed.

7.2 Pressure measurements

Pressure measurements shall be made using suitable pressure gauges or transducers. As far as possible, differential pressures shall be directly measured by means of suitable gauges and instruments (e.g. U-tube manometers, inclined-tube micromanometers or differential pressure transducers). Mercury, water or other liquids of suitable density shall be used as indicating fluid.

NOTE For measurement assembly details, it should be referred to [2].

The pressure measuring instruments shall be calibrated, with the reading both rising and falling, before and after the test. Further recommendations for pressure measurements for air or other gases are outlined in ISO 1217, ISO 5389 and EN 26801.

7.3 Temperature measurements

Measurements of temperature shall be taken using instruments in accordance with 7.1, items a) and b) (e.g. mercury-in-glass thermometers, thermocouples and resistance thermometers, the latter in conjunction with appropriate measuring circuits or transducers), (see also [3]).

When measurements taken in tubes of large diameter yield varying values at different points of the same cross section at the same time, a check shall be made as to whether such temperature differences are acceptable. Otherwise, the average temperature value shall be determined by a traverse. To that end, the cross section shall be divided into equal sub-areas, making sure that there is no cross flow or backflow in the measured section, (see also [4] and [5]). Normally, the arithmetic average of the measured values shall be taken as the average temperature. By special agreement, the velocity or differential pressure may be measured and the weighted average then employed. Since the influence of variations in density and specific heat is minimal, it may be neglected.

7.4 Mass and mass flow

7.4.1 Weighing

The weighing machines used shall be checked prior to testing for compliance with the relevant regulations on weights and measures.

The following calibration limits of error apply, (see also [6]):

- a) Decimal scales: 0,5 g for each kg of load, but not less than one-fifth of the error limit at maximum load. The in-service limit of error is double the calibration limit of error.
- b) Track scales: 3 to 4 g for each kg of load. The in-service limit of error is 1,5 times the calibration limit of error.
- c) Rope-traction weighers, weighing the full and empty container: 1 to 2 g for each kg of load, but not less than half the error limit at maximum load. The in-service limit of error is 1,5 times the calibration limit of error.

The use of bucket-elevator, belt, tipping and spring-scale weighers shall be permitted, provided they are checked before and after the test by weighing the transported quantities at approximately equal capacity.

7.4.2 Volumetric measurements

Measurements of volume flow shall be carried out by volumetric meters which shall be calibrated prior to and, where possible, after the test. Only genuine volumetric meters (i.e. no vane-type meters) shall be permitted downstream of reciprocating pumps. A uniform specific volume or density shall be maintained throughout the test.

The volume may also be determined by means of tanks that have been filled from verified tanks or containers and checked by metering or calibrated with weighed increments of water.

In the use of volumetric tanks, density corrections shall be made for differences in water temperature during testing and calibration. Corrections shall also be made for the thermal expansion of the tank. (The volume of a steel tank, for example, increases by roughly 0,4 % when heated by 100 K).

7.4.3 Flow measurement

7.4.3.1 Flow measurement with orifices and nozzles

EN ISO 5167-1 shall apply in the case of flow measurements with orifices and nozzles. Where the application limits specified in EN ISO 5167-1 are exceeded in large-capacity steam boilers other specifications shall be applied (see also [7] and [8]).

For flow measurements with weld-in orifices, the following shall be observed.

Since dimensions cannot be checked and measurements taken prior to the acceptance test, this shall be carried out before the welding operations, and the results recorded. Inconsistencies of inflow are dealt with in EN ISO 5167-1. Where flow rate transducers are used, the working characteristics under test conditions shall be determined before the test or a calibration graph plotted.

7.4.3.2 Flow measurement with velocity probes

Flow measurements using velocity probes (pitot tubes or anemometers) shall be made in accordance with ISO 1217, ISO 5389 or EN 26801.

7.4.4 Measurement of flue dust flow

A suitable method shall be agreed for measuring the flue dust flow through a particular cross section (see also [4] and [9]).

7.4.5 Determination of density

For the determination of mass flow, the density shall be taken from the appropriate tables (see also [10]), employing the variables, i.e. pressure and temperature, and the composition.

For gases of unknown composition, the density shall be determined using a gas densimeter (e.g. in accordance with 'Bunsen-Schilling') as specified in EN ISO 3993.

7.5 Calorific values

7.5.1 Calorific values of fuel

The gross calorific value, $H_{(G)}$, and net calorific value, $H_{(N)}$, of solid and liquid fuels shall be determined on the basis of ISO 1928. Using ISO 6976, the GCV and NCV can be determined from an analysis of gases of known and fixed composition. For certain gaseous fuels (natural and refinery gases), the determination of the NCV from a gas analysis can involve errors (e.g. in cases where small fractions of heavy hydrocarbons are excluded from the gas analysis). In such cases, the GCV and NCV shall be continually determined manually by means of a calorimeter. Automatic calorimeters that are capable of being verified may also be used in order to determine the GCV.

7.5.2 Sampling of fuels

Solid fuel samples shall be taken and prepared in accordance with ISO 1988. The sampling of liquid and gaseous fuels shall be carried out, respectively, in accordance with EN ISO 3170 (see also [11]). The samples taken shall adequately represent the grade, composition and quality of the fuel fired during the test. This applies particularly to fuels of fluctuating composition. The composition of the samples shall be similar to that at the envelope boundary.

7.5.3 Net calorific value and sampling of refuse

The NCV of refuse required for calculating the loss due to unburned combustibles shall be determined in accordance with ISO 1928.

The parties to the test may agree upon a simplified method for determining the NCV from the carbon content or loss on ignition. If the method of determination of the NCV has not been agreed upon, the values specified in 4.2 shall be employed as the NCV of total organic carbon.

Refuse sampling shall be carried out as described in ISO 1988 as for solid fuel. When refuse is weighed in the wet condition, it shall be ensured that the moisture carried by the sample corresponds to the average moisture content of the refuse. If the refuse quantity measurements serve to determine the efficiency by the heat loss method, it is recommended that the recorded amounts be checked against an ash balance.

7.6 Chemical composition

7.6.1 Fuels

If required, the ultimate analysis of solid and liquid fuels shall be made in accordance with ISO 157, ISO 334, ISO 589, ISO 609 and ISO 625 (see also [12]), and of gaseous fuels by means of a gas analysis.

7.6.2 Flue dust and ash

When determining the efficiency by the heat loss method, the flue dust and slag shall be analysed for their combustibles content, the method of determination being the subject of agreement. This shall apply particularly to total organic carbon in the ash from fluidized-bed combustion systems, where, the test temperature level is a major factor. Relevant information is provided in ISO 609 and ISO 625.

7.6.3 Flue gas

The composition of flue gas shall be determined by means of analysing equipment which operates on chemical, physicochemical or purely physical principles, either intermittently or continuously. The instruments shall be designed so that the scatter of measured values, with a confidence level 95 %, conforms to the following:

carbon dioxide: $\pm 0,2$ percentage points;

oxygen: $\pm 0,15$ percentage points;

carbon monoxide content by volume: ± 1 % of the full-scale value of the measurement range, but not less than $\pm 0,01$ percentage points.

Where automatically operating gas analysers are used, the zero and sensitivity adjustments made prior to the test shall be checked (e.g. by the admission of test gases) after the test.

When making CO₂ measurements with chemical analysers, it shall be taken into account that the CO₂ and SO₂ contents shall be measured in relation to dry flue gas.

The ambient temperature local to the sensor shall be kept constant. For traverses, 7.3 shall apply accordingly.

7.7 Electric power

The power consumed by electric drives shall be determined using verified meters or by power input measurements employing the 3-wattmeter or 2-wattmeter method. For the determination of power output, the supplier shall make available the motor characteristics.

8 Heat balance and thermal efficiency

8.1 Heat balance and envelope boundary

8.1.1 General

The main prerequisite for calculating the efficiency is the identification of the envelope boundary covered by the heat balance of the steam generator.

The boundary of the envelope relevant to the heat account shall coincide with the boundary of the steam generator 'as supplied' and it shall be possible for the heat input, output and losses essential for determining the efficiency to be established with certainty. Where it is not possible to take satisfactory measurements at the boundary 'as supplied', the boundary can be redefined by agreement between the manufacturer and purchaser. In certain cases, this may require the correction of measured values to the conditions at the boundary 'as supplied'.

8.1.2 Normal envelope

The normal envelope shall encompass the entire steam-water system with circulating pumps, the firing system complete with the pulverizer (for coal-fired systems), the recirculating flue gas fan, the flue dust return system and the steam air heater. This envelope shall not include oil or gas heating installations, the dust collector, and FD and ID fans and normally forms the basis for acceptance testing in most cases. If a return of flue dust across the boundary of this particular envelope occurs, it would then become necessary, in accordance with the definition of 'input' and 'output', to consider the enthalpy of flue dust upstream of the dust collector as heat loss and that of the returned ash as input. This approach, although being formally correct, should be somewhat impractical. As the temperature of the returned ash deviates only slightly from that of the flue gas temperature, it is recommended that the recirculated flue dust always be assumed to be separated upstream of the dust collector (i.e. still inside the envelope boundary), and that recirculation always takes place inside the boundary. If this assumption cannot be made, the dust collector shall be integrated into the unit (see 8.1.3.4).

Figure 8.1-1 shows a diagram of a steam generator, complete with the envelope boundary and all associated mass flows, input and losses, as determined based on the quantities measured during the test.

8.1.3 Other envelopes

8.1.3.1 General

For practical reasons, it may be necessary to define a boundary which is different from that described in 8.1.2 for establishing the heat balance. If this alternative approach is adopted, it shall be established in each case which heat input and losses, in addition to those dealt with in 8.3, shall be taken into account.

Some possible alternative envelope boundaries are presented below.

8.1.3.2 Envelope without steam air heater

The steam air heater shall be located outside the envelope, which corresponds to the envelope specified in the ASME test code (see Figure 8.1-2).

NOTE ANSI Power test code 4.1 [13].

Where the steam air heater is heated with auxiliary steam, the output is only indirectly allowed for in the heat balance since the output of the steam air heater is added to the enthalpy of combustion air. If, by contrast, the air heater is supplied with steam from an internal source, the output of the steam air heater shall be added to the useful heat (see 8.3.1).

8.1.3.3 Envelope with FD fan

By including the FD fan within the boundary, the measurement of hot air flows is no longer necessary, although the input shall then include the FD fan shaft power (cf. chain line in Figure 8.1-1). This envelope is useful when measurements cannot be taken at any point between the FD fan and air heater, or when hot air recirculation is employed.

8.1.3.4 Envelope with dust collector or with dust collector and ID fan

This envelope shall be used if the flue gas duct upstream of dust collector or up to the ID fan fails to provide a suitable plane for the flue gas measurement. In such cases, the electric power of an electrostatic precipitator (P_{DC}) and the heat losses of the dust collector (Q_{DC}) or the ID fan shaft power (P_G) shall be added as extra input. In the absence of any empirical values, an agreement shall be reached prior to the test as to the power of the dust collector. For this envelope, the measured flue gas temperature shall be corrected to the boundary on which the guarantees have been based.

8.1.3.5 Envelope with mill vapour separation

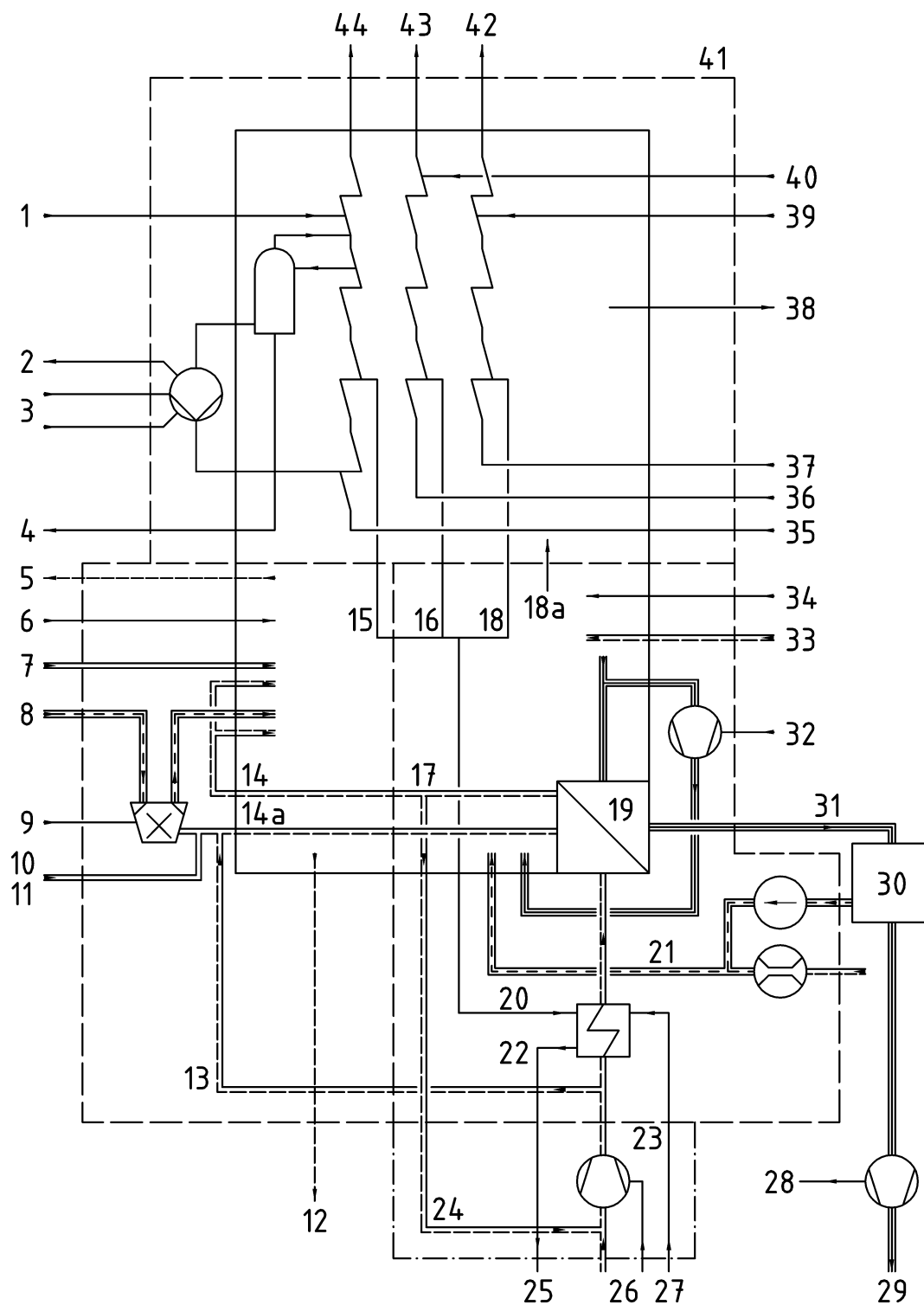
For brown coal with a relatively high moisture content it may be necessary to employ mill vapour separation, i.e. only part of the vapours produced in the combined drying and pulverizing process is fed to the steam generator. For this reason, vapour separation shall be included. The same applies when the flue gas is recirculated to the boiler outlet, in which case the withdrawal point shall also be within the boundary (see Figure 8.1-3). If this is not possible, any necessary corrections shall be agreed upon before defining the boundaries. In mill vapour separation, the flue gas flow to the stack is considered a 'further loss' (see 8.3.3.5). Therefore, the composition, inherent mass flow and dust burden of the flue gas shall also be measured.

8.1.3.6 Envelope for integral flue gas desulfurization and DENOX plants

If components of the flue gas desulfurization plant or the DENOX plant are located within flue gas or air ducts between the air heater and the steam generator, the normal heat balance including the air heater cannot be established. The envelope boundary for such a steam generator shall be defined as running along the hot air and flue gas ducts. In this case, a calculation or guarantee of the efficiency cannot be made; rather, guarantees shall be restricted to flue gas temperature at the steam generator outlet at an agreed capacity level.

8.1.3.7 Special envelopes

Envelope boundaries other than those described above may be practical for certain steam generator types. Here, the envelope boundary shall be identified together with the guarantee conditions in the supply contract and an agreement reached in respect of measurements or calculations of input and losses not covered by this standard.

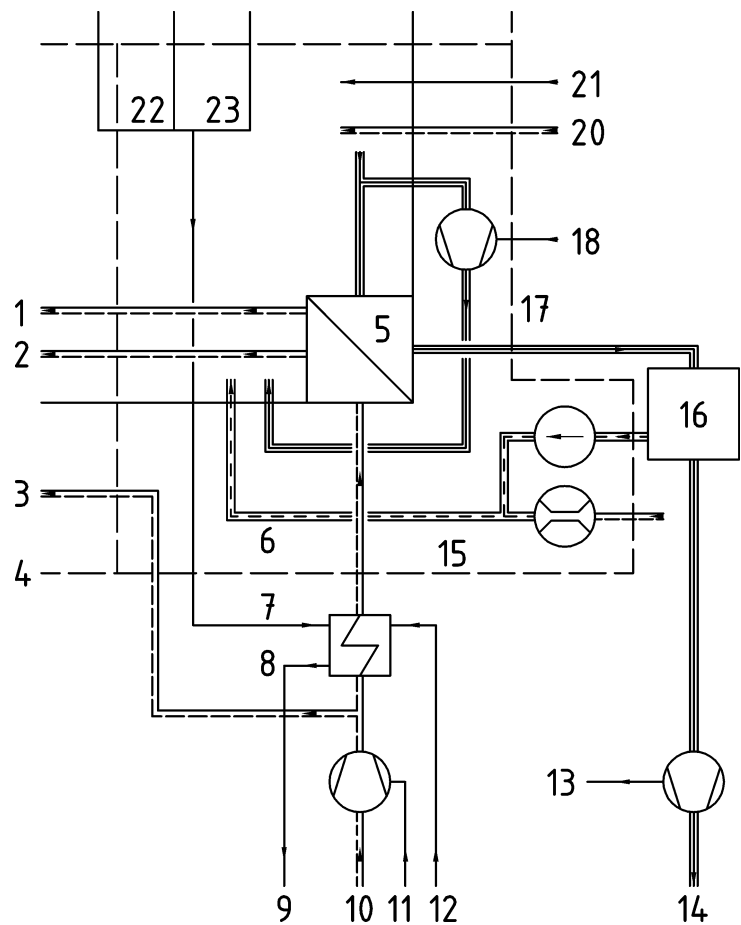


Key
see Table 8.1-1

Figure 8.1-1 — Steam generator diagram with input, losses and mass flows (normal envelope)

Table 8.1-1 — Numbers in Figure 8.1-1

No	Description	No	Description
1	Spray water ($\dot{m}_{SS}, h_{SS}$)	22	Steam air heater
2	Pump cooling ($\dot{Q}_U$)	23	External steam
3	Circulating pump (P_U)	24	Hot air recirculation
4	Blowdown ($\dot{m}_{BD}, h_{BD}$)	25	Condensate (h_{SA2})
5	External cooling ($\dot{Q}_{EC}$)	26	FD fan (P_{FD})
6	Atomizing steam ($\dot{m}_{AS}, h_{AS}$)	27	Steam ($\dot{m}_{AS}, h_{AS}$)
7	Oil, gas ($\dot{m}_H, H_{(N)H}, h_H$)	28	ID fan (P_G)
8	Coal ($\dot{m}_{Fo}, H_{(N)F}, h_F$)	29	Loss due to flue dust ($\dot{Q}_{FA}$)
9	Pulverizer and fan power (P_M)	30	Dust collector ($\dot{Q}_{DC}, P_{DC}$)
10	Pulverizer	31	Loss due to carbon monoxide ($\dot{m}_F, h_G$)
11	Auxiliary pulverizer firing system (oil, gas) ($\dot{Q}_M$)	32	Recirculating gas fan (P_{UG})
12	Loss due to slag ($\dot{Q}_{SL}$)	33	Leakage air ($\dot{m}_{LA}, h_{LA}$)
13	Pulverizer tempering air	34	Other electric power (P)
14	Secondary air	35	Feed water ($\dot{m}_{FW}, h_{FW}$)
14a	Pulverizer hot air	36	RH steam inlet I ($\dot{m}_{RHI1}, h_{RHI1}$)
15	either	37	RH steam inlet II ($\dot{m}_{RHII1}, h_{RHII1}$)
16	or	38	Loss due to radiation and convection ($\dot{Q}_{RC}$)
17	Internal steam	39	Spray water RH steam II ($\dot{m}_{SRII1}, h_{SRII1}$)
18	or	40	Spray water RH steam I ($\dot{m}_{SRI1}, h_{SRI1}$)
18a	$\dot{Q}_N$	41	Normal envelope boundary
19	Air heater	42	RH steam outlet II ($\dot{m}_{RHII2}, h_{RHII2}$)
20	Flue dust return	43	RH steam outlet I ($\dot{m}_{RHI2}, h_{RHI2}$)
21	Injection air for ($\dot{m}_{ALa}$)	44	Main steam ($\dot{m}_{ST}, h_{ST}$)

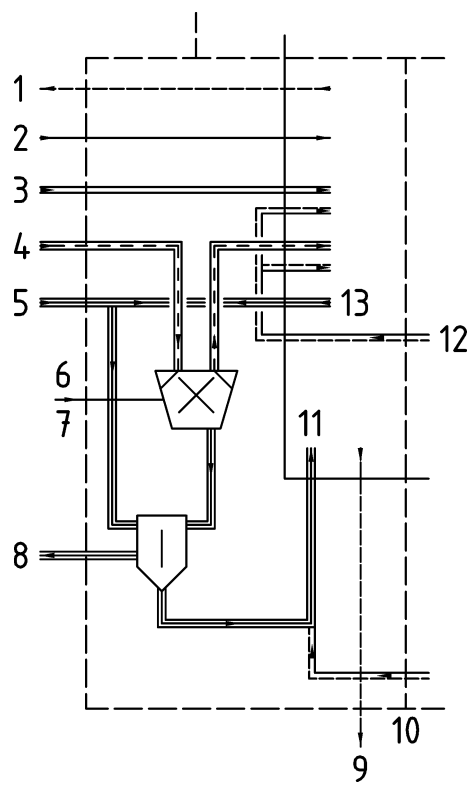


Key
see Table 8.1-2

Figure 8.1-2 — Envelope without steam air heater

Table 8.1-2: Numbers of Figure 8.1-2

No	Description	No	Description
1	Secondary air	12	External steam
2	Pulverizer hot air	13	ID fan (P_G)
3	Pulverizer tempering air	14	Loss due to flue dust
4	Envelope boundary	15	Injection air for $\dot{m}_{LA}$
5	Air heater	16	Dust collector ($\dot{Q}_{DC}, P_{DC}$)
6	Flue dust return	17	Loss due to carbonmonoxide ($\dot{m}_G, h_G$)
7	Internal steam	18	Recirculating gas fan (P_{UG})
8	Steam air heater	20	Leakage air ($\dot{m}_{LA}, h_{LA}$)
9	Condensate (h_{SA2})	21	Other electric power (P)
10	FD fan (P_{FD})	22	or
11	Steam ($\dot{m}_{SA}, h_{SA1}$)	23	or



Key
see Table 8.1-3

Figure 8.1-3 — Envelope with vapour separation

Table 8.1-3 — Numbers in Figure 8.1-3

No	Description
1	External cooling ($\dot{Q}_{EC}$)
2	Atomizing steam ($\dot{m}_{AS}, h_{AS}$)
3	Oil, gas ($\dot{m}_H, H_{(N)H}, h_H$)
4	Coal ($\dot{m}_{Fo}, H_{(N)F}, h_F$)
5	Flue gas
6	Pulverizer and fan power (P_M)
7	Pulverizers
8	Vapours
9	Loss due to slag ($\dot{Q}_{SL}$)
10	Envelope boundary
11	Vapour burner
12	Secondary air
13	Hot gas