We measure it.

Field Guide
Heating measurement technology

Practical advice, tips and tricks.

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Testo AG, June 2014

Foreword

Dear Reader

This guide provides an overview of measurement parameters, measuring tasks and measurement techniques in the heating sector. It contains competent answers to frequently answered practical questions. It is based on the worldwide experiences of Testo instrument users.

It offers the keen beginner an overview of the relevant legislation in Germany, and also of limit values which must be complied with when measuring emissions. For the experienced flue gas measurement professional, it is a valuable reference guide to current regulations.

Tips and tricks from practical experience for practical application offer valuable advice when it comes to using portable flue gas analyzers. The guide will therefore save you from having to search through various sources, which is both tedious and time-consuming.

We are always open to any additional ideas and suggestions for improvement that you may have.

Wolfgang Schwörer, Head of Product Management

Contents

1. What is flue gas?

Due to the increasing number of combustion processes of all kinds, the environment is being polluted with ever-increasing concentrations of pollutants. The formation of smog, production of acid rain and the increasing incidence of allergies are direct consequences of this trend. The way to environmentally-friendly recovery of energy must therefore be through limiting pollutants. Flue gas pollutants can only be limited effectively if existing plants are operated as efficiently as possible or polluting combustion plants are shut down. Flue gas analysis is used to determine the concentrations of pollutants and optimally configure heating systems.

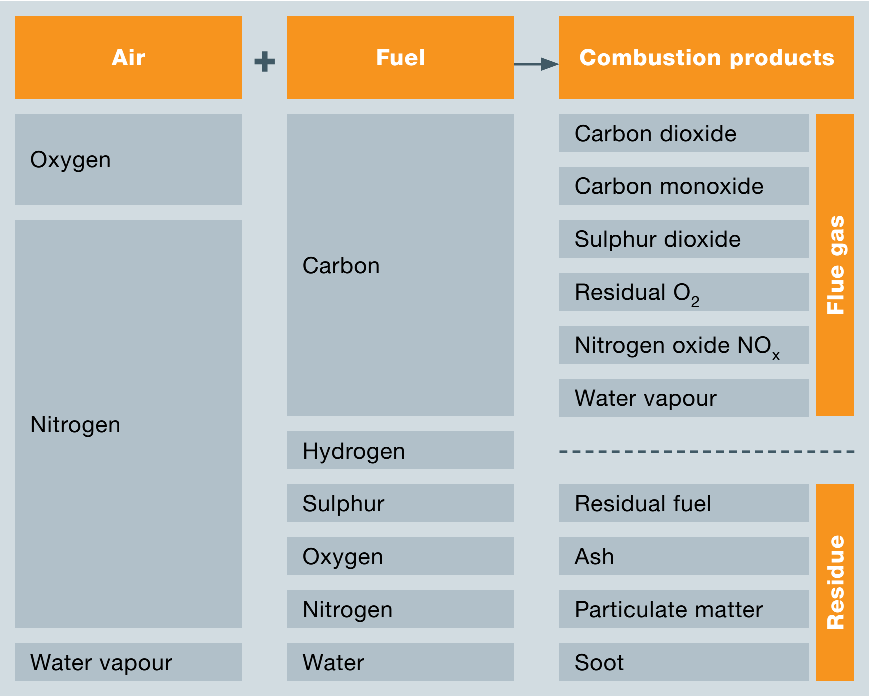

Fig. 1: Fuel/flue gas composition

Fuel essentially consists of carbon (C) and hydrogen (H_2). The combustion air is made up of oxygen (O_2), nitrogen (N_2) and a small proportion of residual gases and water vapour.
When this fuel is burned in air, oxygen (O_2) is consumed.
This process is called oxidation. The elements from the combustion air and fuel form new bonds.

1.1 Units of measurement

ppm (parts per million)
Pollutants in flue gas are detected from the concentration of the gas components. The following units are generally used:
Like the specification “percent (%)”, the unit ppm represents a proportion. Percent means “x number of parts per hundred parts”; ppm means “x number of parts per million parts”.
For example, if a gas bottle contains 250 ppm carbon monoxide (CO), and if one million particles are taken from that bottle, 250 of these will be carbon monoxide particles while the other 999,750 particles will be nitrogen dioxide (N_2) and oxygen particles (O_2). The unit ppm is not dependent on pressure or temperature and is used for lower concentrations. If larger concentrations are present, these are specified in percent (%).

Conversion is as follows:
10,000 ppm = 1%
1,000 ppm = 0.1%
100 ppm = 0.01%
10 ppm = 0,001%
1 ppm = 0.0001%

An oxygen concentration of 21% by volume would be equivalent to a concentration of 210,000 ppm O_2.

mg/Nm³ (milligrams per cubic metre)

In the case of the unit mg/Nm^3, the standard volume (standard cubic metres, Nm^3) is taken as a reference variable and the mass of the pollutant gas is specified in milligrams (mg). Since this unit is dependent on pressure and temperature, the volume in normal conditions is taken as reference:

Temperature: 0 °C
Pressure: 1013 mbar (hPa)

However, this information alone is not sufficient, because the volume ratios in the flue gas change according to the proportion of oxygen (dilution of flue gas with ambient air). The readings therefore need to be converted to a particular volume of oxygen, the reference oxygen content (O_2 reference). Only data with the same reference oxygen content can be directly compared. The measured oxygen content (O_2) in the flue gas is also required when converting ppm into mg/Nm^3. The conversions for carbon monoxide (CO) and nitrogen oxide (NO_x) are given below.
The factors contained in the formulae correspond to the standard density of the gases in mg/m^3.

mg/kWh (milligrams per kilowatt hour of energy used)

Calculations are made using fuel-specific data in order to determine the concentrations of noxious gases in the energy-related unit mg/kWh. There are therefore different conversion factors depending on the fuel. The factors for converting ppm and mg/m^3 to the energy-related unit mg/kWh are shown below. However, before converting to mg/kWh, the concentrations of measured emission values need to be converted to undiluted flue gas (0% reference oxygen content) (see Appendix 13.1).

$$\text{CO (mg/m}^3\text{)} = \left[\frac{21 - O_2 \text{ reference}}{(21 - O_2)}\right] \times \text{CO (ppm)} \times 1.25$$

$$NO_x \text{ (mg/m}^3\text{)} = \left[\frac{21 - O_2 \text{ reference}}{(21 - O_2)}\right] \times 2.05 \times (\text{NO (ppm)} + NO_2 \text{ (ppm)})$$

Conversion to mg/Nm^3

The conversion factors for solid fuels also depend on the form in which the fuel is available (in one piece, as chippings, powder, shred etc.). Hence the factors for these fuels should be looked up separately.

1.2 Flue gas components

The elements contained in flue gas are listed below in the order of their concentration in the gas.

Nitrogen (N_2)

Nitrogen (N_2) is the main element in the air that we breathe (79 % by volume). This colourless, odourless and tasteless gas plays no part in combustion. It is drawn into the boiler as ballast, heated and channelled to the flue.

Typical values in flue gas:
Oil/gas-fired systems: 78% – 80%

Light fuel oil						
CO	1 ppm	=	1.110 mg/kWh	1 mg/kWh	=	0.900 ppm
	1 mg/m^3	=	0.889 mg/kWh	1 mg/kWh	=	1.125 mg/m^3
NO_x	1 ppm	=	1.822 mg/kWh	1 mg/kWh	=	0.549 ppm
	1 mg/m^3	=	0.889 mg/kWh	1 mg/kWh	=	1.125 mg/m^3

Natural gas (G20)						
CO	1 ppm	=	1.074 mg/kWh	1 mg/kWh	=	0.931 ppm
	1 mg/m^3	=	0.859 mg/kWh	1 mg/kWh	=	1.164 mg/m^3
NO_x	1 ppm	=	1.759 mg/kWh	1 mg/kWh	=	0.569 ppm
	1 mg/m^3	=	0.859 mg/kWh	1 mg/kWh	=	1.164 mg/m^3

Fig. 2: Conversion factors for energy-related units

Carbon dioxide (CO_2)

Carbon dioxide is a colourless and odourless gas with a slightly acidic taste. Under the influence of sunlight and the green leaf pigment chlorophyll, plants convert carbon dioxide (CO_2) into oxygen (O_2). Human and animal respiration converts the oxygen (O_2) back into carbon dioxide (CO_2). This would create a balance, but it is disrupted by combustion gases. This disruption boosts the greenhouse effect. The maximum permissible concentration of CO_2 in the workplace is 5,000 ppm.
Typical values in flue gas:
Oil-fired systems: 12.5 – 14%
Gas-fired systems: 8 – 11%

Water vapour (moisture)

The hydrogen contained in the fuel combines with oxygen to form water (H_2O). Together with the water from the fuel and the combustion air, depending on the flue gas temperature (FT) this is discharged as flue gas moisture (at high FT) or as condensate (at low FT). The combustion of hydrogen produces water vapour. 1 kg H_2 requires 8 kg O_2 for complete combustion, resulting in 9 kg water as a product of combustion. In conventional combustion, the “combustion water“ is available as vapour and the quantity depends on the fuel. Natural gas (CH_4) has the highest H_2 content (approx. 22%) and coke the lowest (approx. 3%). The combustion gas water vapour (proportion up to approx. 15% by volume) contains energy (evaporation energy), which is used in condensing boiler technology.

Oxygen (O_2)

Remaining oxygen not used in combustion in the case of excess air is discharged as a gaseous flue gas component and is used to measure combustion efficiency. It is used to calculate the flue gas loss and the carbon dioxide content.
Typical values in flue gas:
Oil-fired systems: 2 – 5%
Gas-fired systems: 2 – 6%
(Note continuous-flow heater)

Carbon monoxide (CO)

Carbon monoxide is a colourless and odourless respiratory poison and the product of incomplete combustion. CO has the same density as air, in contrast to CO_2, which is heavier and therefore accumulates close to the ground. If the concentration exceeds a certain level, it stops the blood absorbing oxygen. CO acts as a blood poison by forming CO haemoglobin. CO is 300 times more attracted to the blood pigment haemoglobin than oxygen. If, for example, the air inhaled in a room contains 700 ppm CO, anyone inhaling this air would be dead within three hours. The maximum permissible concentration in the workplace is 30 ppm. When, due to a lack of oxygen, carbon burns to form only carbon monoxide, only ⅓ of the energy is converted to heat, ⅔ is lost!

Typical values in flue gas:
Oil-fired systems: 80 – 150 ppm
Gas-fired systems: 80 – 100 ppm

Nitrogen oxides (NO_x)

At high temperatures (combustion), the nitrogen (N_2) present in the fuel and in the ambient air combines with the atmospheric oxygen (O_2) to form nitrogen oxide (NO). After a certain time, this colourless gas oxidizes in combination with oxygen (O_2) to form nitrogen dioxide (NO_2). NO_2 is a water-soluble respiratory poison which causes severe lung damage if breathed in and contributes to ozone formation in combination with ultraviolet radiation (sunlight). The NO and NO_2 components together are called nitrogen oxides (NO_x). The MAC value is 5 ppm.

The formation of nitrogen oxides is dependent on the nitrogen bound in the fuel, the nitrogen dwell time in the flame zone (flame length) and the flame temperature. At flame temperatures over 1,300 °C, NO_x formation increases sharply. NO_x formation processes may be diminished by modern combustion technologies, a “cool flame”, flue gas recirculation and low excess air levels.

Typical values in flue gas:
Oil/gas-fired systems: 50 – 100 ppm

Prompt NO_x is formed during combustion by the free oxygen (excess air) in the flame reaction zone.

Fuel NO_x is formed at high combustion temperatures due to the nitrogen content bound in the fuel (fuel oil, coal) combining with the oxygen. This reaction traps the heat. No fuel-based NO_x is produced during the combustion of natural gas, as there are no nitrogen compounds in natural gas.

For thermal NO_x, the oxygen concentration during combustion, the combustion air dwell time in the flame zone (flame length) and the flame temperature (up to approx. 1,200 °C = low, from 1,400 °C = extensive and from 1,800 °C = maximum thermal NO_x formation) are the decisive criteria.

Sulphur dioxide (SO_2)

Sulphur dioxide (SO_2) is a colourless, toxic gas with a pungent smell. It is formed by the sulphur present in the fuel, and it irritates the respiratory tract and the eyes. The maximum permissible concentration in the workplace is 5 ppm. Sulphurous acid (H_2SO_3) is formed in combination with water (H_2O) or condensate.
Typical value in the flue gas of oil-fired systems: 180 ppm – 220 ppm

Sulphur - S

Sulphur is a solid, yellow/green, very chemically active substance. In conjunction with heat, sulphur combines with almost all elements. 1 kg S requires 1 kg O_2 for combustion. Ignition temperature: 260 °C.

Sulphur trioxide (SO_3)

During combustion, part of the SO_2 (approx. 3-7%) oxidizes further to form SO_3. This solid, white substance absorbs a lot of water, with the formation of sulphuric acid ($SO_3 + H_2O = H_2SO_4$), a component of acid rain.

Unburned hydrocarbons (C_XH_Y)

Unburned hydrocarbons (C_XH_Y) are formed when combustion is incomplete and contribute to the greenhouse effect. This group of substances includes methane (CH_4), butane (C_4H_{10}) and benzene (C_6H_6). The causes for their formation are similar to those involved in carbon monoxide formation: inadequate atomization and mixing in the case of fuel oil and lack of air in the case of natural gas or solid fuels. Detection using measuring technology is complex, therefore in practice an oil derivative test is carried out in the case of fuel oil, and CO measurement is carried out in the case of natural gas. When it comes to oil-fired systems, hydrocarbons become noticeable due to the typical, unpleasant “stink” of the combustion gases.
Typical value in the flue gas of oil-fired systems: less than 50 ppm

Soot

Soot consists almost exclusively of pure carbon (C) and is produced in the event of incomplete combustion in oil systems.
At normal temperatures, carbon reacts very sluggishly. 1 kg C requires 2.67 kg O_2 for complete combustion. Ignition temperature: 725 °C. Temperatures below this result in soot formation.
Typical value in the flue gas of oil-fired systems: smoke number 0 or 1

Particulate matter

Particulate matter is the name given to airborne particles which are so small that they can be inhaled, i.e. they cannot be separated from the air that we breathe into our nose and throat.
Since particulate matter can vary in size depending on its origin (ranging from a few nm to several µm), particulate matter is classified in different size categories. The aerodynamic diameter[1] is normally used for this. From this the measurement parameter commonly used these days, PM10 ("Particulate Matter < 10 µm"), is derived.
In Europe, there are limit values for PM10 of 50 µg/m^3 per day or an annual average of 40 µg/m^3. In the USA and Japan, limit values are also specified for the even finer fraction PM2.5.
Particles may vary in size, origin and composition.

Possible sources of particulate matter:

- Technical activities (transport, industry, agriculture), but also natural processes (e.g. Sahara dust).
- Generally speaking, mechanical processes usually generate particles of > 1 µm, whereas particles of < 1 µm, which pose a considerable risk to health, almost exclusively originate from combustion processes.
- Another source of particulate matter is atmospheric processes, where gaseous components are converted into droplets or salt particles due to condensation or due to chemical reactions – usually after exposure to sunlight.

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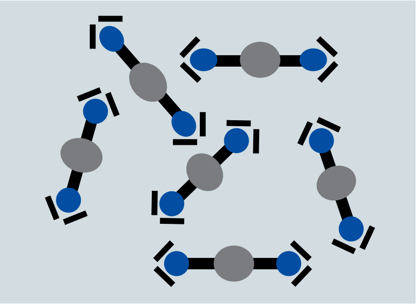
[1] The aerodynamic diameter of a particle is now defined as the geometric diameter of a spherical, rigid comparison particle

Difference between a gas and a particle

Gas molecules

- Clearly defined chemically and physically
- Identical to one another
- Specific characteristic

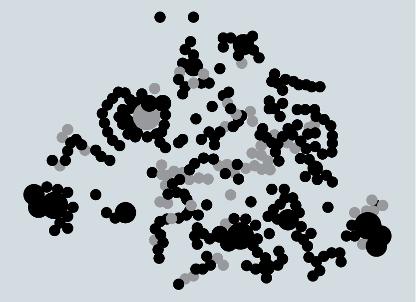
→ specific particles



Particles

- A really wide variety of geometrical characteristics
- A wide variety of material composition
- A wide variety of physical characteristics

→ non-specific particles



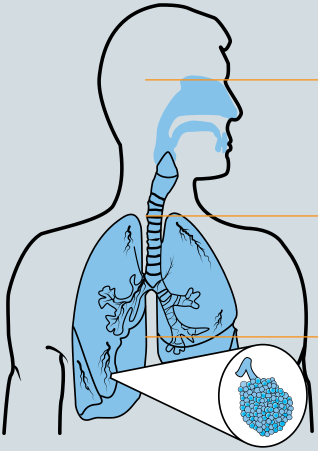
Particle measurement processes are therefore always statistical in nature and involve a certain amount of imprecision. The multitude of different particle characteristics therefore results in a similar quantity of measurement methods (each determining a different particle characteristic).
One common measurement method is determination of the particulate mass, where the particles are weighed. However, particularly small particles are only given limited consideration here.

Impact of particles on health

The link between particulate matter pollution and premature death is well-established (EU area approx. 250,000 – 300,000 people).
Dust particles almost exclusively get into the human body via the lungs.
The upper and lower respiratory tracts are an efficient filter for larger particles in particular (diameter: ~ 5 µm).
However, the smaller the particles, the deeper they penetrate into the lungs.
Particularly problematic due to:

- The absence of protective mechanisms of the pulmonary alveoli
- A tissue barrier to the adjacent blood vessels, which is only a few hundred nm thick – the particles can therefore get directly into the bloodstream and be transported to any organ.

  Typical value (for particulate mass) in the flue gas: 5 – 150 mg/m^3



Points of attack	Particle diameter
Nasopharynx	5 – 10 µm
Airways	3 – 5 µm
Bronchia	2 – 3 µm
Bronchioles	1 – 2 µm
Pulmonary alveoli	0.1 – 1 µm

Diseases caused by particles: various respiratory diseases, cardiovascular diseases which can result in death.

Particles from combustion processes are particularly harmful to health. In particular, diesel exhaust particulate is classified as carcinogenic by the WHO (WHO press release, 12 June 2012).

Aerosols

Aerosols are the dispersions (heterogeneous mixture of at least two substances) of liquid and/or solid particles (with sizes ranging from 2 nm – 100 µm) in a gaseous medium, for the most part air. This diversity also means that the particles can be composed of a really wide variety of substances and therefore also have different characteristics.

There is no typical value in the flue gas from solid fuel furnaces. An aerosol is a dynamic system and is subject to constant change due to condensation of vapours on particles present, evaporation of fluid constituents of the particles, coagulation of small particles to large ones or deposition of particles on surrounding objects.

2. Fuels

2.1 Solid fuels

Solid fuels include hard coal, lignite, peat, wood and straw. The main components of these fuels are carbon (C), hydrogen (H_2), oxygen (O_2) and small amounts of sulphur (S) and water (H_2O). Solid fuels are mainly differentiated by their net calorific value. Hard coal has the highest net calorific value, followed by lignite, peat and wood. A major problem when handling these fuels is the creation of large quantities of ash, particulate matter and soot. Appropriate mechanical devices must be provided at the combustion site to remove these “wastes” (e.g. shaking grate).

Wood

Wood is a natural, solid, long-flame fuel. Soft wood (spruce, fir and pine) is resinous and tends to form highly dangerous shining soot if the firing installation is wrongly operated. Hard wood such as beech and oak is suitable for firing installations with a high combustion chamber and for grateless firing installations (tiled stove). Wood burns with a long, bright flame, no further oxygen supply is required for the ember combustion.

Ignition temperature: approx. 290 °C, flue gas volume approx. 8 m^3/kg, net calorific value H12-15 MJ/kg depending on the moisture content, dew point of the combustion gases approx. 40 – 45 °C,
C 40%, H_2 6%, O_2 35 – 40%,
Ash 1 – 2%, H_2O 15 – 20%,
CO_{2max} 20.3%, excess air 10 – 200% (depending on burn-off phase).

Pellets and wood briquettes (Pressed items made of natural wood)

Mechanically formed, solid long-flame fuel made from untreated wood residues with no binding agents. Wood is hackled, ground and pressed into cylindrical shapes at high pressure. The H_2O content is very low (5 – 6%), thus the net calorific value is higher than in naturally grown wood. The net calorific value depends mainly on the actual water content of the pressed items. The requirements and inspection regulations for these fuels are defined in the legislation (e.g. ÖNORM M7135).

Wood briquettes

Like split logs, used for firing installations with or without grate firing.

Pellets

Used for domestic firing installations and boiler systems with automatic fuel feed and controlled air supply. Uniform, adjustable heating with low emissions is therefore possible.

Wood chips

Wood chips are normally produced using mobile or stationary disc, drum or snail chippers. They consist of 100% wood. However, residual forest wood, smallwood or other low-quality timber (e.g. from thinning), which can no longer be processed by the industry for high-quality products, is mostly used.

The water content probably has the greatest influence on the net calorific value. This can vary considerably depending on the species of tree and the storage. Wood chips fresh from the forest have a water content of 50-60%, and drying the material (e.g. water content of 20%) virtually doubles the net calorific value.

Lignite

Natural, solid, long-flame fuel derived from the remains of deciduous, coniferous and palm trees. Coalification takes place in the absence of air via geothermal energy and earth pressure. 90% surface mining. A distinction is made between lignite (woody structure) and anthracite (black, lustrous). Suitable for firing installations with a high combustion chamber, large grate, secondary air flow for afterburning. Highly sooting fuel with high ash content.

Ignition temperature: approx. 250 – 450 °C, flue gas volume approx. 7 m^3/kg, net calorific value H approx. 12 – 20 MJ/kg, C 40 – 60%,
H_2 3 – 5%, N 0.5%, O_2 15 – 20%,
S 1.5%, ash 5 – 20%,
H_2O 5 – 20%, CO_{2max} 19 – 20%, excess air 60 – 100%.

Hard coal

Natural, solid, long-flame fuel. Formation similar to lignite. Considerably older than lignite, therefore with a higher carbon content. Exclusively underground mining. Types ranked according to volatile fuel constituents: flame coal, gas coal, fat coal, forge coal, lean coal, anthracite. Suitable for tiled stoves with grate, magazine stoves, furnaces and boilers with lower combustion. Highly sooting during the heating-up phase, low smoke development during the ember combustion phase. Requires a sufficient supply of combustion air during the heating-up phase.

Ignition temperature: 320 – 600 °C, flue gas volume approx. 13 m^3/kg, dew point of the combustion gases approx. 30 – 35 °C, C 75 – 90%, H_2 4 – 6%, O_2 3 – 15%, N 1 – 1.5%, ash 3 – 12%, H_2O 2 – 4%, S 1% net calorific value H approx. 27 – 32 MJ/kg, CO_{2max} 17 – 20%, excess air 60 – 100%.

Briquettes

Artificial, solid, long or short-flame fuel. Coal dust and coal soot is pressed into moulds under high pressure or with the addition of binders.

Coke

Artificial, solid, short-flame fuel. Hard coal is heated to approx. 800 – 1000 °C in the absence of air. The volatile fuel components are discharged (= town gas), and coke, a hard porous fuel which is broken down into various particle sizes depending on the intended use and combustion system, remains. Suitable for endurance burning. Burns virtually smoke and soot-free, with a short bluish flame. Very low flue gas temperature, low dew point and long embers phase. Ignition temperature approx. 450 – 600 °C, flue gas volume approx. 12 m^3/kg, dew point of the combustion gases approx. 13 – 15 °C, C 85%, H_2 1 %, O_2 2 – 4%, N 1%, S 1%, ash 7 – 9%, H_2O 5%, net calorific value H approx. 29 MJ/kg, CO_{2max} 20.6%, excess air as lignite.

Anthracite

Natural, solid, short-flame fuel. Oldest and therefore highest-quality hard coal. Usually only marketed in briquette form (egg briquette). Highest C and lowest H_2 content.

Charcoal

Artificial, solid, short-flame fuel. Wood is heated in the absence of air (charcoal kiln). The volatile fuel constituents, such as wood gas, wood tar vapour and water, are discharged. For commercial use and as barbecue coal. Burns smoke-free with a short flame.

2.2 Liquid fuels

Liquid fuels derive from petroleum. This is processed at refineries to produce extra-light (EL), light (L), medium (M) and heavy (S) fuel oils. EL and S fuel oils are mainly used in heating boilers. EL fuel oil is widely used in small combustion plants and is identical to diesel fuel (dyed diesel fuel. When using S fuel oil, pre-heating is also required in order to maintain flowability. This is not necessary with EL fuel oil.

Fuel oils

Artificial, liquid, long-flame fuels. Fuel oil is obtained by the distillation (heating under the exclusion of air) of crude oil (petroleum) in refineries. Crude oil is produced in a similar way to hard coal, only the source materials are animal substances (plankton and microorganisms). Deposits in porous, closed rock layers. Extraction via inherent pressure or pumping up. Types of oil: Extra Light fuel oil (HEL) for vaporizing burners and atomizing burners, light fuel oil (HL), medium fuel oil (HM) and heavy fuel oil (HS) exclusively for atomizing burners with oil preheating. The requirements for the fuel oils are set out in the legislation (e.g. ÖNORM C 1108 and C 1109). Flue gas volume approx. 12 m^3/kg, dew point of the combustion gases approx. 45 – 50 °C, ignition temperature approx. 300 – 400 °C, flashpoint approx. 55 – 100 °C, excess air with vaporizing burner 30 – 40%, - with forced-air yellow flame burner 15 – 30%, - with forced-air blue flame burner 10 – 20%, HEL fuel oil H = 42.8 MJ/kg, S = 0.1%, C = 86%, H_2 = 13.7%, CO_{2max} 15.4%, HL fuel oil H = 41.8 MJ/kg S = 0.2%, C = 87.3%, H_2 = 12.1%, CO_{2max} 15.8%, HS fuel oil H = 40 MJ/kg, S = 1% C = 86.5%, H_2 = 10.7%, CO_{2max} 16.4%.

Properties of fuel oils

The density of fuel oils at 15 °C fluctuates, in the case of HEL between 0.83 - 0.86 kg/l, and in the case of HS between 0.90 - 0.98 kg/l. When comparing prices and net calorific values, check whether the price per litre or the price per kilo is specified, as differences of up to 20% are possible! The degree of oil viscosity drops when it is heated and increases when it is cooled, and is always based on a specific temperature. Residual oils (HL, HM and HS) must be preheated prior to atomization, so that the viscosity is as low as possible. The degree of coking is expressed by the Conradson value and indicates how much residue remains in the form of coke during the oil burning process (coking of the burner nozzles and baffle plates, and also of the inlet nozzle in the cup burner in the case of an oil furnace). The flashpoint is that temperature at which a flammable gas/air mixture forms, which ignites through spark ignition.

The flashpoint is divided into three hazard classes:
Class I flashpoint below 21 °C e.g. petrol
Class II flashpoint 21 °C-55 °C e.g. petroleum
Class III flashpoint 55 °C-100 °C HEL, HL, HM (HS flashpoint above 100 °C).

The ignition point is that temperature at which a gas/air mixture continues to burn independently. If the ignition point is not reached during combustion, this results in incomplete burnout (soot formation).

Pour point is that oil temperature at which the oil is still just capable of being poured. Setting point is that oil temperature at which paraffin separation occurs and the oil is no longer pourable.

2.3 Gaseous fuels

Gaseous fuels are a mixture of combustible and non-combustible gases. The combustible components of the gas are hydrocarbons (e.g. methane, butane), carbon monoxide (CO) and hydrogen (H_2). The principal gaseous fuel used for heating purposes these days is natural gas, the main component of which is methane (CH_4). A small proportion of households (10%) are still supplied with town gas, which mainly comprises hydrogen (H_2), carbon monoxide (CO) and methane (CH_4). The net calorific value of town gas is only half that of natural gas.

Natural gas (methane)

Gaseous, short or long-flame fuel depending on the flame length. Methane is naturally odourless. Its composition can vary greatly depending on the production area. Main components are CH_4 (methane) at 80 – 95% and N_2, sulphur compounds and water. Processing is required prior to use. An odorant (for odour detection) is fed to the natural gas. Unlike town gas, methane is non-toxic because it contains no CO. Natural gas is highly explosive! In most cases, natural gas fields, together with petroleum and coal deposits, originated from simple organisms which were deposited and transformed under high temperatures and pressures. Natural gas is pumped from the deposits via pipelines to the consumption locations, however it can also be liquefied at -162 °C (111 K) and transported pressureless via tankers. Storage facilities exist in empty gas reservoirs. Natural gas is burnt in surface burners (multiple burner nozzles), in forced-draught burners (one burner flame) and in matrix burners (premix burner). Ignition temperature approx. 630 °C, max. flame temperature approx. 1900 °C, flue gas volume approx. 10 m^3, water vapour volume approx. 2 m^3.

Composition: methane 93.1%, ethane 3.7%, N 2.2%, CO_2 0.9%, CO_{2max} 11.7%, air requirement approx. 9.5 m^3, density: 0.777 kg/m^3, net calorific value H 36.4 MJ/m^3 (10.1 kWh, gross calorific value 40.3 MJ/m^3 (11.2 kWh), net heating value HB 34.3 MJ/m^3 (9.5 kWh), excess air: burner without fan 200 – 300% (downstream of flow control), forced-draught burner 10 – 30%, premix burner 10 – 40%.

LPGs

These are by-products in the oil and fuel industry. The principal LPGs are propane and butane. They are stored under pressure in containers in liquid state. At standard pressure they are gaseous and heavier than air.

1 kg propane (C_3H_8) = 1.87 l results in approx. 0.5 m^3/N gas, 1 m^3. Propane has a net calorific value H of 93.8 MJ, air requirement approx. 23 m^3, dew point of the combustion gases approx. 45-50 °C, flue gas volume approx. 26 m^3, water vapour volume approx. 4 m^3, CO_{2max} 13.9%, excess air 20-40%, 1 kg butane (C_4H_{10}) = 1.67 l results in approx. 0.37 m^3/N gas, 1 m^3. Butane has a net calorific value of 123.6 MJ, air requirement approx. 31m^3, flue gas volume approx. 33 m^3, H_2OV approx. 5 m^3.

3. Firing installations

3.1 Principle of a firing installation

The firing installation is used in conjunction with a heat exchanger to generate heat. This means that the hot flue gases produced by a burner flame heat the water in a heating coil, and this is then led through pipes as a "heat transporter" (heat transfer medium) to the various consumers (e.g. radiators).

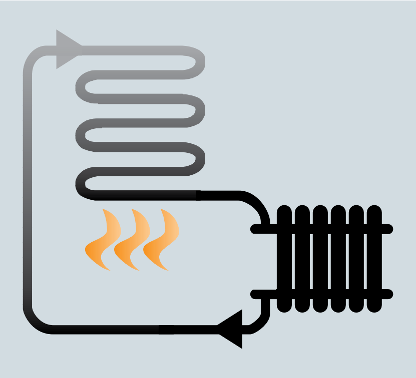


Fig. 3: Burner and boiler design

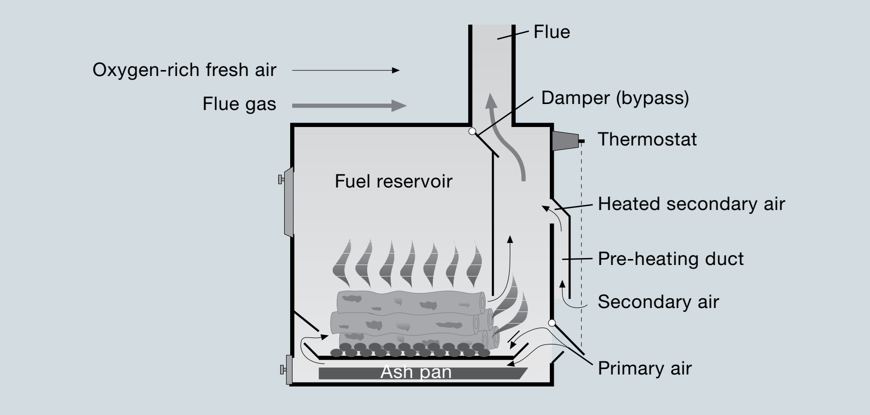


Fig. 4: Simple grate furnace

3.2 Current situation in the field of boiler construction

Boilers are constructed in the form of special burners and tailored precisely to the combustion of a particular fuel. Boilers are manufactured with very low combustion gas temperatures and partial condensation of the combustion gases in the heat generator or in a downstream heat exchanger (condensing boilers). The use of modulating-controlled devices is precisely tailored to the heat requirement, and the fuel input, and therefore the infinitely variable power output of the heater, varies. Lowering the boiler water temperature can reduce both the heat losses (hot flue gases) and also the radiation loss of the boiler.

Using boilers with gliding boiler water temperature can increase the annual use efficiency. Reducing the boiler water temperature, however, requires larger heaters (e.g. underfloor heating). In conventional boilers, the boiler water temperature (flow temperature) is approx. 70 – 90 °C and the flue gas temperature in the case of:

- Solid fuel boilers is above 160 – 300 °C approximately
- Oil boilers is above 160 – 260 °C approximately
- Gas boilers is above 100 – 260 °C approximately

When these boilers are in operation, combustion gas condensation does not occur in the boiler.

Low-temperature boilers are suitable, in terms of construction and material type, for operation at heat carrier temperatures of around 40 – 50 °C, without a risk of corrosion. The flue gas temperatures are lower, in accordance with the lower surface temperature of the heat exchangers, resulting in higher efficiency.

Ultra-low temperature boilers can be operated up to a boiler water temperature of around 20 – 40 °C with no risk of corrosion. An “ultra-low temperature boiler” can be “cold” started and heated up, and standby heat loss falls to a minimum. The flue gas temperature glides according to the boiler water and flow temperature. Flue gas temperatures of down to below 80 °C are possible, resulting in high efficiency with low radiation losses, however a moisture-resistant flue is necessary.

Condensing boilers

This type of boiler makes use of the condensation heat of the water vapour contained in the combustion gas by means of a second heat exchanger. The combustion gas must be cooled down as low as possible within the firing installation - below the dew point of the fuel. The lower the combustion gas temperature (depending on the boiler water temperature in the return), the higher the heat gain through condensation. The flue gas temperature can be lowered to 40 °C. Requirements are an exhaust fan, owing to the absence of negative flue pressure, and a moisture-resistant flue, owing to the dew point not being reached. Unlike the net calorific value, the gross calorific value denotes the amount of energy released during complete combustion, in relation to the amount of fuel involved. In the case of the net calorific value, the evaporation heat is deducted from the water vapour generated during combustion, which is why the net calorific value is always lower than the gross calorific value. Condensing boilers make use of this evaporation heat in addition to the combustion heat through appropriate re-cooling by means of a second heat exchanger. As a result, the flue gas temperatures in condensing instruments fall short of those in conventional boilers. The water vapour in the flue gases condenses, releasing additional heat (latent heat). The temperature below which the humidity in the flue gas turns into condensate is referred to as the condensation temperature or dew point. The condensation temperature varies from one fuel to another, and is around +58 °C

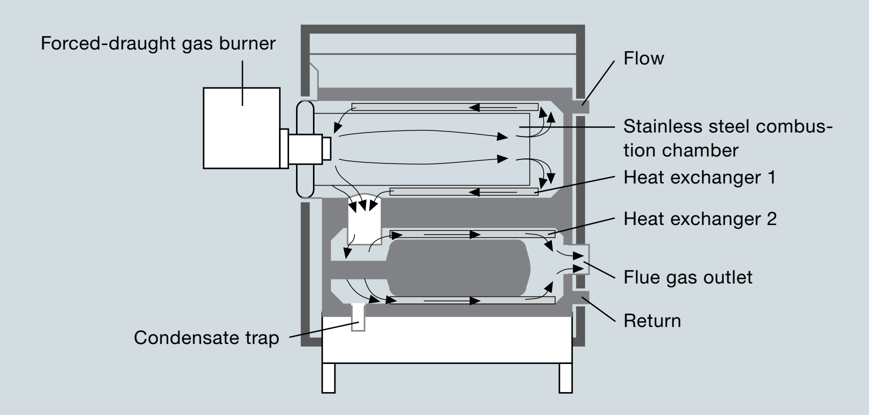


Fig. 5: Design of a gas condensing boiler

in the case of natural gas and around +48 °C in the case of fuel oil. If the flue gases are cooled, the condensation temperature for natural gas is reached sooner. This means that the condensation heat is released earlier. The energy gain is thus greater for gas than for oil. Because the burning of oil produces sulphur dioxide (SO_2), which in part turns into sulphurous acid in the condensate, gas is mainly used in condensing technology. In view of the condensate that occurs, the flue system must be moisture-sensitive and acid-resistant.

- Condensing systems do not have to comply with any minimum efficiency requirements. Limit values are not given in the 1st BImSchV.
- Efficiencies of over 100% are possible, since the energy used is measured in relation to the lower net calorific value (Hu).
- Take care with NO_x measurements: the proportion of NO to NO_2 may be as much as 50:50. This means that the NO and NO_2 concentrations must be measured separately in order to measure NO_x.

3.3 Classification of firing installations according to fuel type

3.3.1 Solid fuel boilers

In the case of solid fuel heating systems, a distinction is made between wood-burning boilers and boilers in which coal, coke or briquettes are burned. In solid fuel systems, 80% of the combustion air is needed for the actual combustion process. 20% of the combustion air (secondary air) is fed to the flue gases produced during combustion. This ensures thorough burning. This secondary air should be preheated to prevent it from cooling the flue gas (incomplete combustion).

3.3.2 Gas-fired installations

These are firing installations for the combustion of gaseous fuels such as natural gas, LPG and biogas. A distinction is made between gas-fired installations featuring **atmospheric burners** with check valve and gas-fired installations featuring **forced-draught burners** with no check valve. **Premix burners** are fan-supported, atmospheric burners with no check valve, where the combustion air is precisely dosed and hence the CO_2 content is extremely high.

The main advantage of gas systems is the residue-free combustion and the space-saving fuel reserve. In the case of atmospheric gas burners in particular, the combustion air is drawn in by the buoyancy of the flue gases and mixes with gas as it enters the combustion chamber. The fuel/air mixture burned in the combustion chamber quietly releases its heat to the heat transfer surfaces and the escaping flue gas flows through a flow control and into the flue. The purpose of the flow control is to prevent too great a flue draught or back pressure in the flue system from affecting combustion in the firing installation.

Forced-draught burners

The combustion air is supplied to the gas pre-combustion by a blower. This enables precise dosing of the combustion air and thorough mixing with the gas. High efficiency due to low excess air levels (10 – 20%). Forced-draught burners feature a high degree of operational safety and wide-ranging insensitivity to atmospheric influences. The overpressure in the boiler is released by resistors. At the end of the boiler, the natural negative pressure of the flue is responsible for transporting the flue gases outdoors. Forced-draught gas burners are designed very similarly to oil burners, with many components taken from these. As is the case with forced-draught oil burners, downtime losses are prevented by means of automatic air flaps, which prevent air from flowing through the boiler when the burner is down. Draught fluctuations or excess negative pressure can be reduced through the installation and adjustment of draught limiters.

At the same time, this prevents any moisture penetrating the flue.

Atmospheric burners

These burners have evolved from injection burners and are predominantly installed as burner grates or surface burners. These burners work with automatic air intake. The burner grates consist of individual combustion tubes or fuel rods, each with an injector and a mixing tube. The primary air (approx. 60% share) is sucked into the injection pipe due to the negative pressure of the flowing gas. The gas/air mixture flows through the burner nozzles and when exiting is mixed once again with secondary air (approx. 40 %) and ignited. A streamlined, bluish flame forms. The combustion gas is forced through the heat exchanger via thermal buoyancy. Downstream of the heat exchanger, the natural negative pressure of the flue is responsible for removing the flue gases. The combustion air supply, and hence specific excess air, cannot be precisely adjusted and regulated, as is the case with forced-draught burners. Since disruptions to the transport of flue gas must not affect the combustion, atmospheric burners must be equipped with a check valve. Depending on the intensity of the negative pressure, more or less regulating “infiltrated air” gets into the flue gas stream through the open check valve, so that the most consistent combustion conditions possible (air supply) prevail in the combustion chamber. The infiltrated air or secondary air content can significantly influence a measurement result (CO_2 or O_2 measurement upstream or downstream of the check valve). In the event of a jam or reverse current,

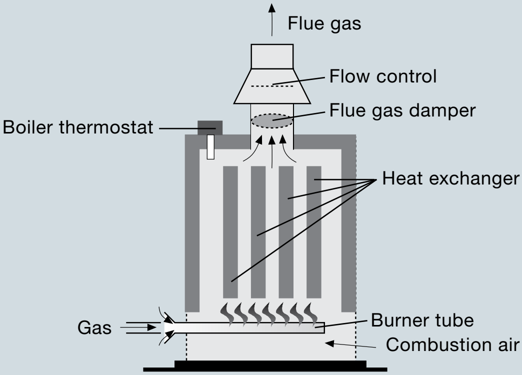


Fig. 6: Boiler with atmospheric burner

the flue gases are forced through the reverse current openings into the installation room. After a safety time of approx. 1-2 minutes, a flue gas monitor (safety device) switches the gas supply off via a magnetic valve. To reduce the NO_x percentage in the flue gas (potentially up to 30% reduction), atmospheric burners are furnished with cooling ducts or water-cooled combustion grates.

Premix burners

Due to the more stringent legal requirements (efficiency, NO_x and CO values), new combustion techniques have been developed. Premix burners feature high efficiency levels (up to 92%) and low pollutant loads. Premix burners rank among the atmospheric burners. The combustion air can be fed through an intake pipe from the installation room as an open flue, or from outside as a balanced flue. A fan sucks combustion air via the air inlets into the gas-tight sealed inner sheath or radiator. Above the fan, the air volume required for the gas volume (boiler output) is set via a differential pressure regulator. Very small excess air quantities can therefore be set. Advantage: lower flue gas loss, therefore higher efficiency. The gas/air mixture is forced through a ceramic surface burner or a matrix burner, ignited and burns with a short flame or a flame film. The flue gases get into the sealed flue gas system with overpressure (200 Pa) after cooling and subsequently outside via the flue system.

3.3.3 Oil burners

The task of oil burners in boilers is to atomize or vaporize the fuel oil as finely as possible. The different types of burner are:
Vaporizing burners for HEL
Atomizing burners for HEL, HL, HM and HS

Vaporizing burners

The main component of all vaporizing burners is a bowl or a pot (therefore also bowl or pot burners). In this container, the oil is vaporized by the application of heat. Combustion air flows through openings on the sides of the burner pot and brings about the required mixing for flame stabilization in the combustion chamber. The oil supply, and therefore the heating output, is modified via a control valve in the oil regulator. In the oil regulator there is a float gauge, which keeps the oil level constant so that there is a constant flow rate regardless of the admission pressure. If the flame should go out, the float gauge prevents oil leaking out above the safety mark. The oil runs out of the tank in the oil furnace (approx. 20 litres) or an external tank (up to 300 litres). The oil is ignited manually via paraffin wicks or spirit igniters, or during automatic operation via an electrical heating wire. Fully automated operation is possible via thermostat control. All vaporizing burners are extremely draught-sensitive. Draught pressure of at least 10-15 Pa is required. Draught fluctuations or too strong a draught can be regulated and configured using a draught limiter. Fan-supported vaporizing burners are largely independent of atmospheric influences. The fan speed can be regulated, therefore the air volume and the oil flow rate can be controlled collectively. Vaporization burners are extremely efficient! Heating output with no fan approximately 3 to 15 kW, with fan up to 50 kW, smoke number max. 2, efficiency 70 – 80 %, CO_2 content of the flue gases 8 – 10%.

The heating surfaces must be cleaned regularly. Oil furnaces become slightly sooted at insufficient or excessive vacuum pressure, or if the air holes are obstructed. Insufficient vacuum pressure can result in deflagrations.

Atomizing burners

With these burners, the oil is delivered via an electrically-driven oil pump at high pressure (7 – 20 bar) and then fed to an oil nozzle, where it is atomized into very fine droplets. A fan draws air out of the boiler room and conveys this through the burner tube to the oil nozzle, where it is intermixed with the atomized oil via suitable mixing devices (orifice plate, congestion filter, annular discs, swirl discs etc.). The air volume is set via valves or flaps on the suction or pressure side. Air chokes prevent cooling losses during burner downtime. The mixture is ignited via a high-voltage spark (ignition electrodes) and continues to burn independently as long as oil and air are conveyed.

The oil mist is additionally vaporized via the flame heat. Single-stage burners work in on/off mode, i.e. they always work at the full nominal output of the burner. For better regulation and efficiency, two-stage burners or two nozzles are used in the case of burners above 100 kW or thereabouts. The air flap is controlled via a hydraulic drive in two different positions. The start-up impact is significantly lower for two-stage burners. These days, two-stage burners are used even for small capacities to save energy. This means that the burner can be operated with reduced output for the majority of the year. For large capacities, adjustable (modulating) burners with spill-back nozzles are used. The air volume is controlled in accordance with the quantity of oil added. In the case of oil burners with lambda sensor control, subject to a continuous flue gas analysis via a zirconium measuring probe, the O_2 content of the flue gases is measured and kept within a range of 1 – 1.5%. This results in high efficiency and low pollutant emissions. Depending on the viscosity of the oil, preheating to around 70 – 120 °C is necessary to ensure the relevant “fluidity” for atomization. Heating reduces the viscosity of the oil. For better, low-emission combustion, burners with oil preheating are also used for HEL.

Rotary burners

With these burners, the fuel oil flows through a fast-rotating hollow shaft, an open cup downstream of the boiler side. The centrifugal force effect causes the oil to be evenly distributed on the inside of the cup, spun off from the edge of the cup at high speed and finely atomized. Other types of burner are the emulsion burner, the air pressure atomizer and the steam atomizer.

Regulating and safety devices for atomizing oil burners

Since the main advantage of oil heating is automatic operation, the automatic mechanism must be constructed particularly carefully, safely and trouble-free. Small systems work according to the on/off switching principle. Medium-sized systems can be adjusted in steps: off-part load-full load. Large systems are continuously adjustable.

Components of an oil-fired system

A fully-automated oil-fired system consists of the following components: The *ignition transformer* generates high-voltage sparks (around 10,000 volts) between two electrodes when the burner is switched on, and these ignite the oil/air mixture.

The task of the *flame detector* is to monitor and report the presence or absence of the flame.

The *boiler thermostat (temperature controller)* is installed in the boiler, responds to the water temperature and switches the burner on or off in the event of any deviation from the setpoint.

The *temperature monitor* switches the oil burner off if the maximum permissible temperature is exceeded.

The *automatic oil firing device (control unit)* coordinates all switching operations in the correct order.

How an automatic oil-firing device works

Start-up:

- Switch the motor on with fan and oil pumps
- The ignition transformer is energized
- After a few seconds of pre-ignition time, the magnetic valve is opened
- The oil mist is ignited
- The flame burns
- The flame detector is activated and the ignition transformer is switched off

Operation:

The oil burner remains in operation as long as heat is required

Fault circuitry:

If ignition does not materialize once the safety time has elapsed or the flame goes out during operation, the burner is switched off and locked (unlocking button).

3.3.4 Other types of burner

Boilers with forced-draught oil or gas burners

Here, the combustion air is fed to the burner flame via a blower. Since there is very little difference between modern oil and gas-fired boilers in terms of their design, a gas boiler can be combined with a forced-draught oil burner, for example. The advantages of these forced-draught burners are their independence from the flue draught, the smaller chimney flue cross-section, stable combustion and higher efficiency. However, the high energy expenditure of the burner is a downside.

Pressurized boilers

With this type of boiler for forced-draught oil and gas burners, an overpressure is generated to overcome the internal boiler resistances from the forced-draught burner. This is reduced again at the end of the boiler through the installation of turbulators, chicanes and cross-draughts. Cleaning apertures and burner connections must therefore be sealable overpressure-tight.

Dual-fuel burners

These gas/oil burners are constructed for the alternating combustion of oil and gas. These burners are used where a reliable heat supply is required (e.g. hospitals and power stations). The construction of these burners essentially corresponds to that of oil burners. In the centre of the burner head is the oil nozzle, with gas distribution all around via individual burner lances.

4. Legal background for measurements on heating systems (taking Germany as an example)

In the Federal Republic of Germany, the operation of small combustion plants is regulated by two pieces of legislation. Firstly by the **1st German Federal Immission Control Act (1st BImschV)**, which was created primarily to protect the environment, and secondly by the German Sweeping and Inspection Act (KÜO), which ensures the operational reliability of the system.
Up until 2013, the district master chimney sweep was the officer in charge of monitoring these regulations. Due to discrepancies with guidelines of the European Union, the new German Chimney Sweep Trade Act (SchfHwG) was adopted in 2008 by the Bundestag. This mandates that certain public service duties must only be carried out by an authorized district chimney sweep, for example the inspection of connected combustion equipment.
For the authorized district chimney sweep, this sets out the tasks that are to be carried out, in accordance with KÜO and 1st BImSchV, and the respective time frames. The owner of the system is obliged to have these tasks carried out by an authorized chimney sweep company of his choice.

The following measurements must be carried out as per the 1st BImSchV:

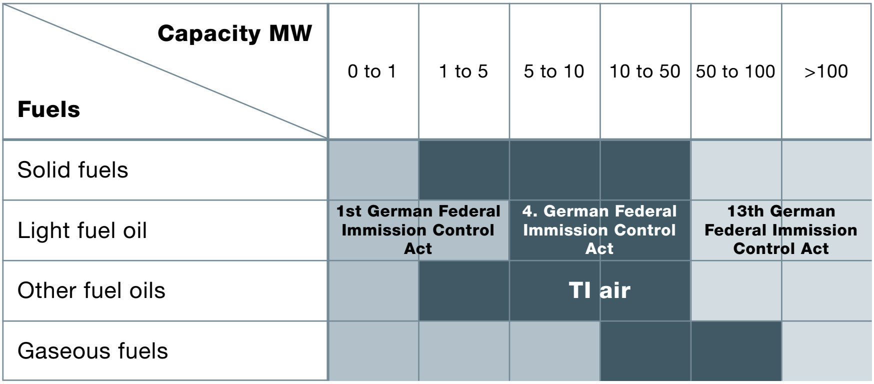
Fuels	Measurements to be carried out
Oil	- Flue gas loss - CO concentration - Buoyancy / flue draught - Smoke number (oil)
Gas	- Flue gas losses - CO concentration - Buoyancy / flue draught
Wood	- Dust content - CO concentration

4.1 Ordinance on small and medium-sized combustion plants (1st BImSchV)

The Federal Immission Control Law was adopted in 1974 to protect the environment. In view of the various threats to the environment, the statutory framework for environmental protection was anchored in 18 Federal Immission Control Ordinances. There are four sets of regulations on emission control regarding the recovery of heat by heating systems, and these prescribe how systems are to be operated in an environmentally compatible manner according to the capacity of the system and the fuel used.

The 1st Federal Immission Control Ordinance governs the condition and operation of small combustion plants. The 4th Federal Immission Control Ordinance applies to medium capacities in the low megawatt range and prescribes the operation of systems requiring approval.

Large systems above 50 MW are governed by the 13th Federal Immission Control Ordinance (BImSchV). The operation of systems that incinerate waste or similar flammable substances is prescribed by the 17th Federal Immission Control Ordinance (BImSchV). Since small combustion plants in congested urban areas significantly contribute to pollution, as part of air pollution control the technical equipping of heating systems is subject to more stringent requirements. It is particularly important to seek to minimize emissions of pollutants and preserve fuel reserves in plants requiring approval. For optimum tuning of small combus-



Capacity MW / Fuels	0 to 1	1 to 5	5 to 10	10 to 50	50 to 100	>100
Solid fuels	▒	█	█	█	░	░
Light fuel oil	**1st German Federal Immission Control Act**		**4. German Federal Immission Control Act**		**13th German Federal Immission Control Act**	
Other fuel oils	▒	█	**TI air**	█	░	░
Gaseous fuels	▒	▒	▒	█	█	░

Fig. 7: BImSchV allocation according to system capacity and fuel

tion plants, system-specific data must be recorded and the concentrations of pollutants determined. The instruments used for measurement must have passed the qualification test (TÜV test). For official measurements in Germany, the measuring instruments must be inspected every six months on a test bed.

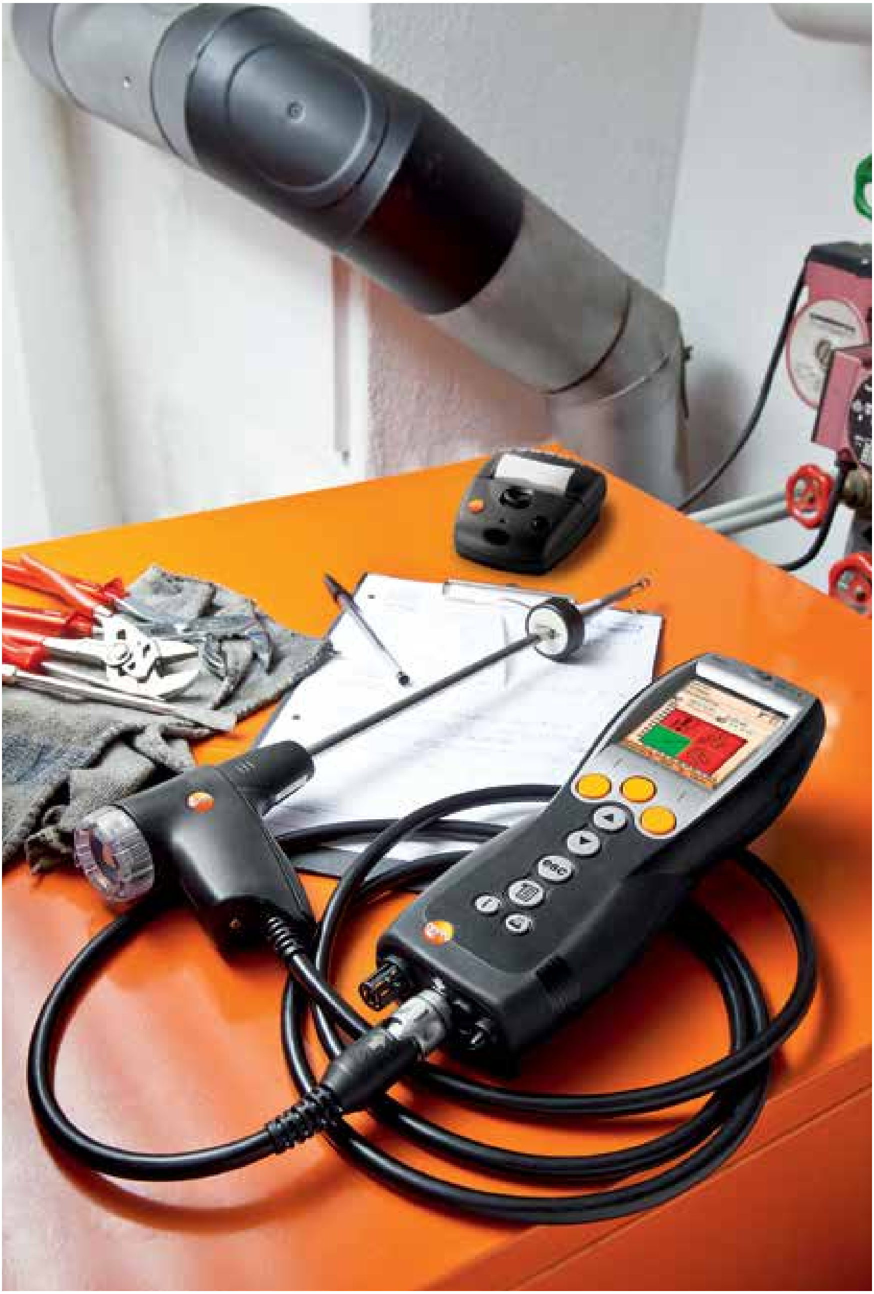
4.2 German Sweeping and Inspection Act (KÜO)

In January 2010, the KÜO was published in Germany as a nationwide ordinance and amended on 8 April 2013. The German 'Sweeping and Inspection Act' (KÜO) sets out the duties of flue gas inspectors/chimney sweeps regarding the maintenance of operational and fire safety, environmental protection, energy efficiency, and climate protection. It includes definitions of the type of systems checked, time periods and limit values, as well as procedures to be observed during cleaning or inspections.

The following measurements must be carried out as per the KÜO:

Fuels	Measurements to be carried out
Oil/gas	- CO concentration - Measurements in the dual wall clearance

For details regarding carrying out the measurements, please see Section 5.



5. Measuring tasks on heating systems

In order to ensure that a system is working optimally, various functional checks, adjustment and measurement activities need to be carried out on gas-fired systems, oil and solid fuel systems, both during commissioning and at regular intervals.
These activities are explained in detail below and the statutory limit values, taking Germany as an example, are shown.
Please also refer to country-specific guidelines, standards and limit values!

5.1 Functional testing and settings for gas-fired systems

The work steps and tips described here illustrate the essential elements of the functional checking and configuration when commissioning atmospheric gas boilers and condensing boilers. Activities to be carried out on forced-draught gas burners are not included.

Fig. 8: A flue gas analyzer, e.g. testo 330, is essential for carrying out adjustments

1 Check the gas connection pressure

Prior to commissioning the instrument, the gas connection pressure (flow pressure) must be tested. This must be within the permissible pressure range according to the manufacturer's documentation (in the case of natural gas usually between 18 – 25 mbar). If this is not the case, the gas boiler may not be put into operation and the responsible gas supply company must be notified so that the problem can be remedied.

A pressure gauge is connected to the relevant measurement connection of the gas boiler fittings for measuring the gas connection pressure, with gas shut-off valve closed. When the gas tap is opened, the burner is driven to full capacity via the respective operating menu and the gas connection pressure measured as flow pressure.

Fig. 9: Reading the gas connection and nozzle pressure on the testo 510

Once the connection pressure is correct, the measurement connection is closed again and commissioning continues.

Consequences of the wrong gas pressure may be:	
Gas pressure too high	• Flame goes out • Incomplete combustion • High CO concentrations • Risk of poisoning • High gas consumption
Gas pressure too low	• Flame goes out • High flue gas losses • High O_2 content • Low CO_2 content

2 Set the gas/air ratio

The aim of environmentally compatible system operation is complete combustion of the fuel and the best possible utilization of the system. The key to optimum operation is the combustion air volume setting. In practice, a small amount of excess air has proven to be ideal for system operation. A bit more air is supplied for the combustion than would be theoretically necessary. The ratio of the excess combustion air to the theoretical air requirement is referred to as the fuel-air ratio λ (lambda).

The following combustion model illustrates this.

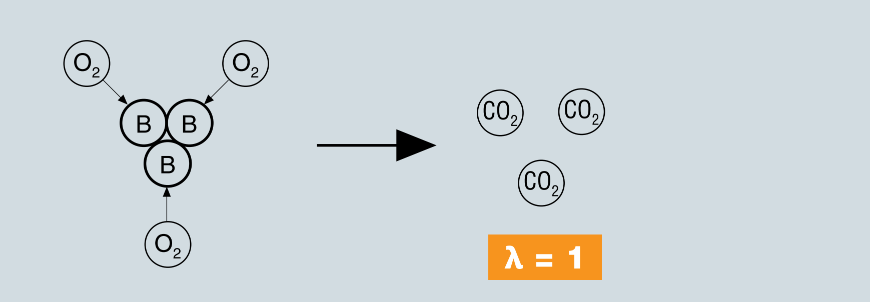


Fig. 10: Ideal combustion

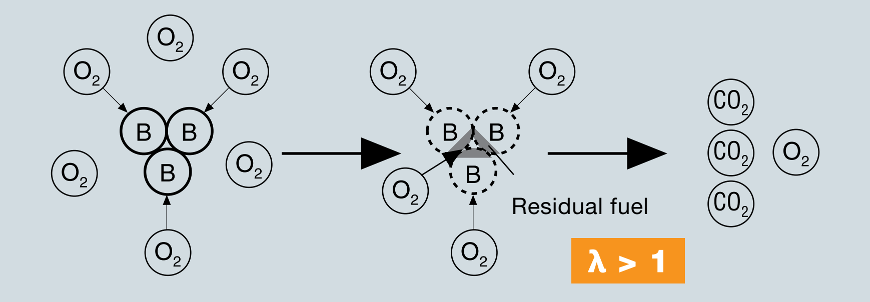
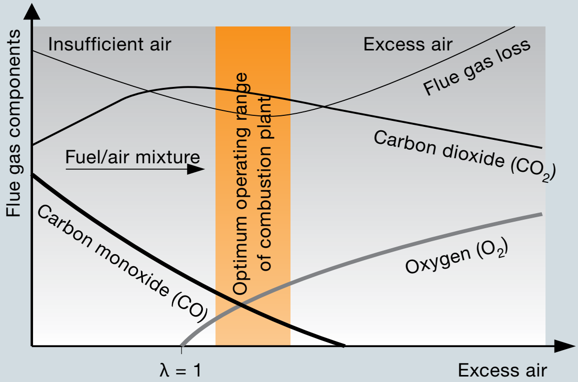


Fig. 11: Actual combustion

The fuel-air ratio is determined on the basis of the concentration of the flue gas components CO, CO_2 and O_2. The so-called combustion chart shows the correlations (see Fig. below). During combustion, any CO_2 content has a specific CO (for insufficient air/$\lambda<1$) or O_2 content (for excess air/$\lambda>1$).
The CO_2 value is not clear in itself as it shows a maximum, therefore a CO or O_2 measurement is required in addition. For operation with excess air (normal scenario), determining the O_2 is now generally preferred. Each fuel has a specific diagram and its own value for CO_{2max} (see Appendix).

Maximum combustion efficiency is only achieved if the flue gas heat loss is minimized with a slight excess of air.



The diagram shows that the flue gas loss increases if there is a specific lack of air and also if there is a specific quantity of excess air.
The relative increasing flue gas loss can be explained as follows:
1. Within the deficient air range, the available fuel is not completely burned and is converted into heat.
2. Within the excess air range, too much oxygen is heated and channelled directly through the flue into the open air, without being used to generate heat.

The individual work steps for setting the appropriate gas/air ratio for the required heat output are set out in detail in the manufacturer's documentation and described in general terms below:

In the case of non-condensing appliances, the gas/air ratio is set using the manometric method, i.e. the nozzle pressure is set for minimum and maximum output. The sealing screw is removed from, and a pressure gauge connected to the measurement connection for the nozzle pressure.

The gas boiler is then usually first powered up to maximum (full load) and then down to minimum appliance output (low load) via the operating menu. For both output levels, the nozzle pressure is modified at the relevant adjustment screws on the gas fitting and controlled via the pressure gauge. Information about the required nozzle pressure can be found in the manufacturer's documentation (depending on the Wobbe index of the gas used, which you can ask the gas supplier about):

In the case of condensing boilers, the gas/air ratio is usually configured by measuring the carbon dioxide content (CO_2) in the flue gas. Prepare the flue gas analyzer as described from step 3 onwards and place the flue gas probe in the flue gas duct. Subsequently, get the boiler up to maximum output via the operating menu and measure the CO_2 content in the flue gas. To set the gas/air ratio, the gas volume is now modified via the adjustment screw (gas throttle), until the CO_2 values in the flue gas correspond to the manufac-

Nozzle pressure (mbar)		**Heat output (kW)**			
		11	**13**	**15**	**17**
Wobbe index (kWh/m^3)	12.0 – 16.1	6.0	8.4	11.2	14.5
	10.0 – 13.1	4.8	6.9	8.7	11.3

Table 1: Examples of nozzle pressure values

Gas type	**CO_2 at maximum heat output**	**CO_2 at minimum heat output**
Natural gas E (H)	9.5%	8.7%
Natural gas LL (L)	9.2%	8.6%

Table 2: Examples of CO_2 settings

turer's specifications. In some cases manufacturers give setting values for minimum appliance output. Implement the setting in accordance with the procedure for the maximum output.

Once these basic settings have been implemented, carry out an inspection of the configured gas boiler. This consists of measuring the flue gas loss (qA) and the carbon monoxide content (CO) in the flue gas.

In Germany there are limit values for both these parameters, which are defined in the 1st German Federal Immission Control Act (1st BImSchV) and the German Sweeping and Inspection Act (KÜO).

In Austria, the limit values are set by the Clean Air Act and the Ordinance on Firing Installations (see Appendix).

3 Prepare the flue gas analyzer

The following steps are recommended to prepare the measuring instrument:

- Definition of the sensor protection: threshold values can be defined to protect the sensors from overloading in the event of high CO concentrations. If these threshold values are exceeded, the flue gas pump switches off and flue gas is no longer sucked into the measuring instrument. For some measuring instruments, such as the testo 330-2 LL, when the threshold value is exceeded the flue gas is diluted with fresh air and the measurement need not be interrupted.
- Tightness test: in order to prevent fresh air being drawn into the measuring instrument unnoticed and distorting the measurement results, a tightness test should be carried out prior to the flue gas measurement. The flue gas probe is sealed with a cap so that the flow rate at the measuring gas pump is driven to zero after a certain time. If this is not the case, this indicates an instrument leak and you need to check whether the plug on the condensate trap is properly sealed.

- Gas sensor and draught sensor zeroing: to zero the sensors, the flue gas probe must be located outside the flue gas valve, ideally in the fresh air. The measuring instrument sucks in the ambient air via the flue gas probe and blows it across the gas sensors. These are therefore “flushed” and the measured gas concentration set as the “zero point”. At the same time, the pressure sensor of the flue gas analyzer is zeroed to the air pressure around the firing installation.
  For some measuring instruments, such as the testo 330-2 LL, the probe may also be located in the flue gas duct during zeroing. Here, both the measurement gas path and also the pressure sensor are decoupled from the flue gas probe during zeroing and the gas concentration or the air pressure around the flue gas analyzer is used for zeroing.

4 Determine the flue gas loss

The flue gas loss is the difference between the heat content of the flue gas and the heat content of the combustion air, in relation to the net calorific value of the fuel. It is therefore a measure of the heat content of the flue gases diverted via the flue. The greater the flue gas loss is, the poorer the efficiency and therefore the energy exploitation and the higher the emissions from a heating plant. For this reason, the permissible flue gas loss from combustion plants is limited in some countries. Table 3 lists the limit values in Germany, as an example.
After determining the oxygen content and the difference between the flue gas and combustion air temperature, the fuel-specific factors of the flue gas loss can be calculated. The fuel-specific factors (A2, B) are stored in the flue gas analyzers. Appropriate fuel selection on the measuring instrument is necessary in order to ensure that the correct values for A2 and B are used.

Rated heat output in kilowatts	Limit values for flue gas losses in percent
≥ 4 ≤ 25	11
> 25 ≤ 50	10
> 50	9

Table 3: Limit values in Germany for flue gas losses in accordance with the 1st BImSchV

Instead of the oxygen content, the carbon dioxide (CO_2) concentration can also be used to calculate. The flue gas temperature (FT) and oxygen content or carbon dioxide (CO_2) content need to be measured simultaneously at a single point. The AT should also be measured simultaneously.

Finding the ideal setting for the heating plant by calculating the flue gas loss pays off:
1% flue gas loss = 1% additional fuel consumption or Energy loss/year = flue gas loss x consumption of fuel/year
The following example should clarify the point:
Calculated flue gas loss = 10%
Fuel consumption/year = 3000 l fuel oil
On this basis, the energy loss corresponds to approximately 300 l fuel oil/year.
You can find the calculation formulae for the flue gas loss in the Appendix under point 13.1.

i Condensing boilers are excluded from this measurement due to their high efficiency.

The parameters needed for the calculation are explained in detail below:

Measuring the combustion air temperature (AT)

Most flue gas analyzers are fitted with a temperature probe on the instrument as standard. Thus, the combustion air temperature in the immediate proximity of the intake point of the burner can be measured by attaching the measuring instrument to the burner housing. In the case of balanced flue systems, this probe is replaced by a separate temperature probe, which is inserted into the fresh air/combustion air feed (see Figure 12).

i A separate temperature probe for calculating the combustion air temperature must be used for all systems in accordance with BImSchV, since the combustion air temperature may change during the measurement.

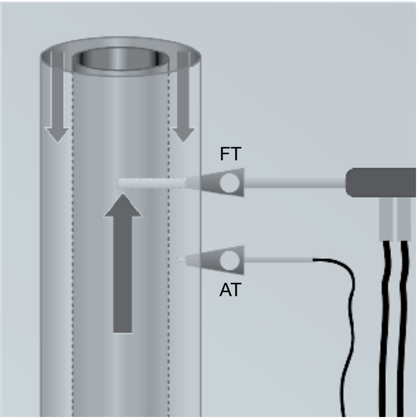


Fig. 12: Measurements on balanced flue systems

Measuring the flue gas temperature (FT)

The thermocouple in the flue gas probe measures the flue gas temperature. The flue gas probe is conducted through the measurement orifice into the flue gas duct (the distance between the measurement orifice and the boiler should be at least twice the diameter of the flue gas duct). Through constant temperature measurement, the point with the highest flue gas temperature (i.e. the centre of flow) is sought and the probe is placed there. The centre of flow is where the temperature and the carbon dioxide (CO_2) concentration are at their highest and the oxygen (O_2) content at its lowest.

Note: Condensate deposition on the temperature sensor can result in a sudden drop in the flue gas temperature.

Measuring the O_2 concentration

Oxygen that has not been combusted in the case of excess air is discharged as a gaseous flue gas component and is used to measure combustion efficiency.
The flue gas is sucked in via the flue gas probe using a pump and channelled into the measurement gas path of the flue gas analyzer. There it is channelled through the gas sensor (measuring cell) for O_2 and the gas concentration is determined.
The O_2 content is also used to calculate the CO_2 concentration in the flue gas, which is used for configuring gas-powered condensing boilers as described above.

Surprisingly high O_2 values may be caused by leakage of the measuring instrument, because fresh air is sucked in and the flue gas is diluted. To check this, the measuring instrument should be tested for tightness.

Measuring the carbon dioxide (CO_2) concentration

Instead of the oxygen content, as previously stated the carbon dioxide (CO_2) concentration can also be used to calculate the flue gas loss.
When the proportion of CO_2 is as high as possible with low excess air (complete combustion), the flue gas losses are at their lowest. For each fuel there is a maximum possible flue gas CO_2 content (CO_{2max}) which is determined by the chemical composition of the fuel. However, this value cannot be reached in practice, because a certain amount of excess air is always required for safe burner operation, and this reduces the percentage of CO_2 in the flue gas. This is why, when configuring the burner, the aim is not the maximum CO_2 content but a CO_2 content that is as high as possible.

CO_{2max} values for different fuels:

- Fuel oil	15.4% by volume CO_2
- Natural gas	11.8% by volume CO_2
- Coal	18.5% by volume CO_2

In the manufacturer's documentation you will find information on the CO_2 concentrations that can be attained and the modifications that need to be made in the air volume settings to achieve these values.

Most flue gas analyzers do not contain a CO_2 sensor, but the CO_2 concentration in the flue gas is calculated by means of the measured O_2 content. This is possible because both values are directly proportional to one another. Since the maximum CO_2 content of the relevant fuel is incorporated into this calculation, prior to each measurement the appropriate system fuel must be input into the flue gas analyzer.

Calculating the flue gas loss (qA)

The measuring instrument calculates the flue gas loss from these measured values. In Germany, once adjustment work on the gas boiler has been completed, the flue gas loss must be below the limit values given in Table 3.

An unusually high flue gas loss may be due to the following:

- Incorrect zeroing of the measuring instrument
- Wrong fuel set

A sudden drop in the flue gas temperature can be caused by the following:

- There is a condensate droplet on the thermocouple (temperature sensor)
- Remedy: Mount the flue gas probe horizontally or beneath the system so that the condensate can drip off.

5

Calculate the efficiency (η)

Conventional heating systems

The level of combustion efficiency (η) of a conventional heating system is calculated by deducting the flue gas loss (qA) from the total energy supplied (net calorific value HU = 100% of the energy supplied). To calculate the efficiency, therefore, the flue gas loss needs to be determined first (see details above).

Condensing systems

Since condensation heat is reclaimed in modern condensing systems, for correct calculation Testo introduced the additional value XK, which includes use of the condensation heat in relation to the net calorific value. When the flue gases cool down below their dew point temperature, whose theoretical value is stored specific to the fuel in the Testo analyzer (cf. Fig. 14), the coefficient XK indicates the reclaimed evaporation heat of the condensed water as a negative value, whereby the flue gas loss may decrease or become negative. The efficiency level

Fuel	Dew point temperature (in °C)
Natural gas H	57.53
Light fuel oil	50.37
LPG (70/30)	53.95
Town gas	61.09

Fig. 13: Fuel-specific dew point temperatures of flue gas. Calculated for standard pressure (1013 mbar) and stoichiometric combustion based on ZIV documents.

in relation to the net calorific value can take on values of more than 100% (cf. the following example).

A2 = 0.68
B = 0.007
FT = 45 °C
AT = 30 °C
O_2 = 3%
XK = 5.47%

qA (without coefficient XK) = 1%
qA (with coefficient XK) = -5%

η = 100%-(-5%)

The following diagram uses another example to illustrate once again why efficiency in condensing boilers is greater than 100%.

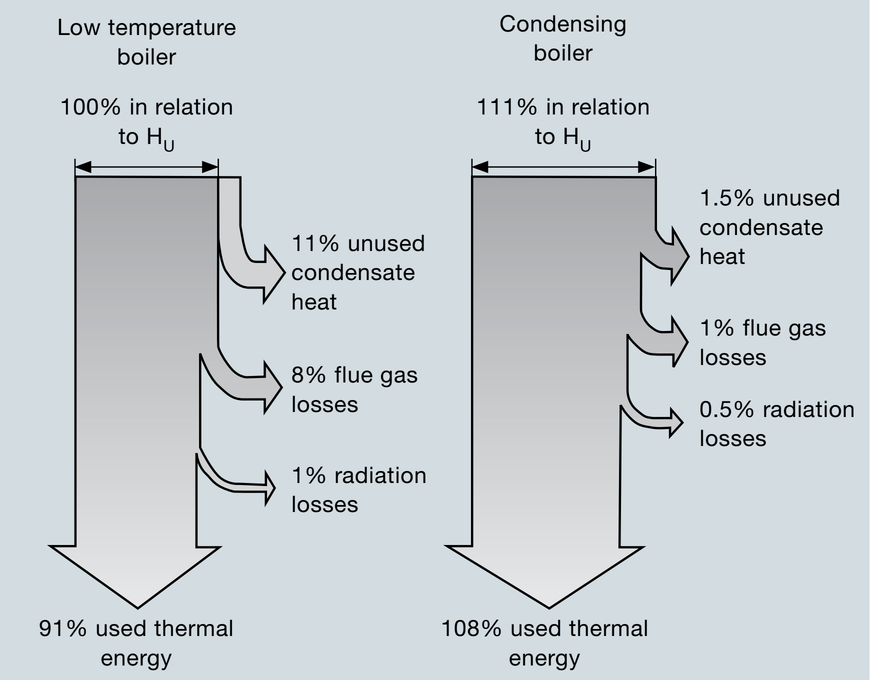


Fig. 14: Energy losses in low temperature and condensing boilers

Once the fuel has been fully implemented, heat and water vapour develop.

- If the heat is fully recorded, 100% of the net calorific value HU is obtained.
- If the energy contained in the water vapour (condensation heat) is added, the gross calorific value HS is obtained.
- The total gross calorific value HS is always higher than the net calorific value HU.
- The net calorific value HU is always taken as the basis when calculating the efficiency.
- However, condensing boilers use condensation energy in addition to the net calorific value. This means that, in terms of the calculation, the efficiency can be greater than 100%.

6 Measure the flue draught

For natural draught boilers, the buoyancy or flue draught is the basic requirement for diverting the flue gases through the flue. Because the density of the hot waste gases is lower than that of the colder external air, a vacuum, also known as a flue draught, is created in the flue. As a result of this vacuum, the combustion air is sucked in, overpowering all the resistances of the boiler and flue gas duct. In the case of pressurized boilers, the pressures in the flue are not important, as a forced-draught burner generates the necessary overpressure to divert the flue gases. A smaller flue diameter can be used in systems of this kind.

When measuring the flue draught, the difference between the pressure inside the flue gas duct and the pressure of the equipment room is determined. As when determining the flue gas loss, this is carried out in the core current of the flue gas duct.

As described above, the pressure sensor of the measuring instrument must be zeroed prior to measurement.

Typical flue draught values:

Pressurized boiler with forced-draught burner + gross calorific value: 0.12 – 0.20 hPa (mbar)

Draught readings can be too low for any of the following reasons:
- The draught path in the measuring instrument is leaking.
- Pressure sensor not correctly zeroed.

Values that are too high may be due to the following:
- Flue draught too strong.
- Pressure sensor not correctly zeroed.

overpressure oil vaporization burner and atmospheric gas burner:
0.03 – 0.10 hPa (mbar) vacuum

7 Measure the CO concentration

Checking the CO value offers an indication of the combustion quality and enforces the safety of the system operator. If the flue gas paths became blocked, the flue gases would enter the boiler room via the flow control in the case of atmospheric gas burner systems for example, thereby posing a risk to the operator. To prevent this, once adjustment work on the boiler has been completed, the carbon monoxide (CO) concentration must be measured and the flue gas paths checked. This safety measure is not required for gas burners with a blower, as the flue gases are forced into the flue in these burners.

The measurement should not be carried out until the gas burner has been operating for at least 2 minutes, as it is only when the system has been started that the increased CO content drops to the normal operating value. This also applies to gas boilers with combustion control, since these carry out calibration during burner start-up, during which very high CO emissions may occur briefly.

Fig. 15: As well as flue gas readings, the testo 320 flue gas analyzer can also be used to measure absolute and differential pressures quickly and precisely.

As when determining the flue gas loss, the measurement is carried out in the core current of the flue gas duct. However, since the flue gas is diluted with fresh air, the CO content must be calculated back to the undiluted flue gas (otherwise the CO content could be manipulated as a result of the addition of air). For this, the measuring instrument calculates the undiluted CO concentration with the oxygen content measured simultaneously in the flue gas duct and displays this as $CO_{undiluted}$.

The calculation formula for the undiluted carbon monoxide concentration can be found in Appendix 13.1.

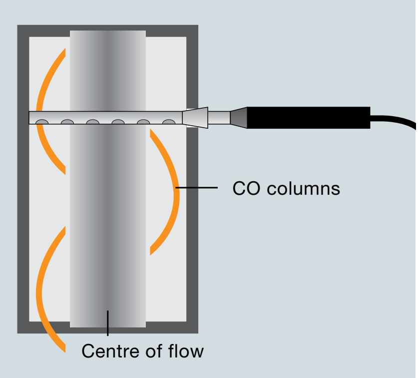


Fig. 16: CO measurement with the multi-hole probe

For atmospheric gas systems, the CO concentrations in the flue gas pipe are not the same all over (stratification). Therefore the sampling must be carried out at a concentration of > 500 ppm using a multi-hole probe. The multi-hole probe features a series of holes, which record the CO concentration over the entire diameter of the flue gas pipe.

In Germany, limit values for the CO content for gas-fired installations are established in the KÜO and refer to undiluted flue gas (see Table 4).

Reading	Procedure
$CO_{undiluted}$ > 500 ppm*	System maintenance required
$CO_{undiluted}$ > 1000 ppm*	System shut-down

Table 4: CO readings and consequence

The causes of back pressure may be:
- Constriction of the flue gas pipe due to dirt or deformation.
- Insufficient combustion air supply.
- Material fatigue of seals, pipe connections that have slid apart from each other, corrosion

8 Flue gas path inspection

Checking the flow control

For atmospheric gas boilers with flow control, flawless extraction of the flue gases is a prerequisite for the combustion plant to function safely. A back pressure indicator can be used for this, and this is held next to the flow control where it detects the precipitation of moisture contained in the flue gas.

Tightness test in flue gas paths

In balanced flue heating systems, the flue gas paths are checked for leaks by measuring the O_2 intake air level in the dual wall clearance. The O_2 concentration in the intake air in the dual wall clearance is usually 21%. If values below 20.5% are measured, this indicates that there is a leak in the inner flue gas duct and the system needs to be checked.

Fig. 17: Using a back pressure indicator

The sickle-shaped multi-hole probe from Testo facilitates reliable and fast measurement of the O_2 content in the dual wall clearance. The conventional method of testing for tightness in a flue gas pipe by checking pressure is only used in flues nowadays. Air is introduced to the flue gas pipe using a pressure tester until there is a pressure of 200 Pa. The volume of air escaping through a leak is determined by maintaining the pressure.
The flue gas pipe is considered sufficiently leak-proof if it has a leak rate of 50 l/(hm2).

9 Maintenance of the measuring instrument

Following the measurement, the flue gas probe should be removed from the flue gas duct when the measuring gas pump is running. As a result, the clean ambient air is blown across the gas sensors, flushing them.

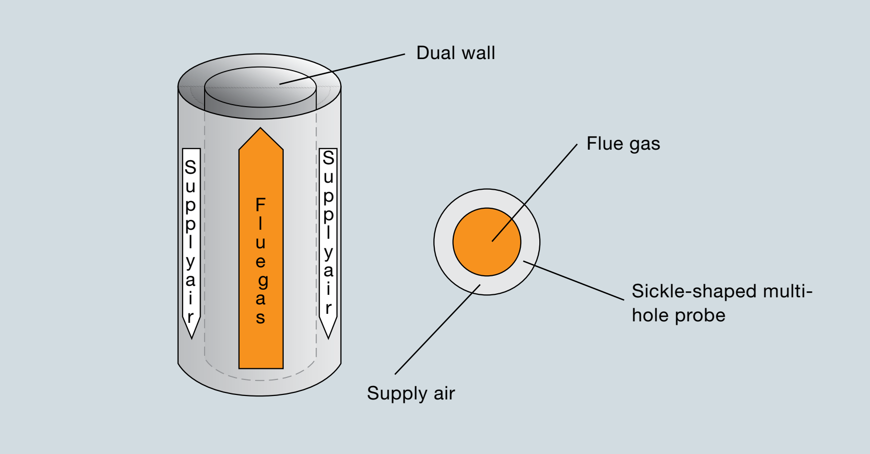


Fig. 18: O_2 dual wall clearance measurement with sickle-shaped multi-hole probe

Additional inspection of combustion plants:

Checking nitrogen oxides (NO_x)

Check the combustion measures needed to reduce nitrogen oxide emissions from combustion plants by measuring nitrogen oxides. Nitrogen oxides (NO_x) are the sum of nitrogen monoxide (NO) and nitrogen dioxide (NO_2). The ratio of NO and NO_2 in small combustion plants (except condensing systems) is always the same (97% NO, 3% NO_2). Therefore the nitrogen oxides NO_x are normally calculated after measuring the nitrogen monoxide NO.

If exact NO_x measurements are required, the nitrogen monoxide (NO) and nitrogen dioxide content (NO_2) needs to be measured and added up. This applies when it comes to condensing boilers or when using mixed fuels, since the ratio in these cases is not 97% to 3%.

Because of the good water solubility of nitrogen dioxide (NO_2), dry flue gas needs to be measured in order to accurately determine the NO_2 concentration, as otherwise the NO_2 dissolved in the condensate will not be factored in. This is why gas preparation is always carried out for nitrogen dioxide measurements, to dry the flue gas before the actual measurement.

- When measuring in the vicinity of an electrostatic filter, the flue gas probe should be earthed because of the static charge.
- If high particulate matter and soot loads are expected, clean, dry filters should be used. A preliminary filter may be used.

- Cigarette smoke influences the measurement (min. 50 ppm).
- Smoker’s breath influences the measurement by approx. 5 ppm.
- Carry out zeroing in fresh air.

Checking CO/CO$_2$ in the environment Ambient CO measurement

For safety reasons, an ambient CO measurement should be carried out in addition to flue gas measurement when servicing gas heaters in living areas, since backflowing flue gases can lead to high CO concentrations and result in the risk of poisoning for the operator. A CO concentration of 0.16% by volume (1,600 ppm) and above in inhaled air will result in death for humans.

This measurement should be carried out before all other measurements.

CO concentration in the air		Inhalation time and effects
30 ppm	0.003%	MAC value (max. concentration in the workplace over a period of 8 hours in Germany)
200 ppm	0.02%	Slight headache within 2 to 3 hours
400 ppm	0.04%	Headache in the forehead area within 1 to 2 hours, spreads to whole head area
800 ppm	0.08%	Dizziness, nausea and limb twitching within 45 minutes, loss of consciousness within 2 hours
1,600 ppm	0.16%	Headache, nausea and dizziness within 20 minutes, **Death** within 2 hours
3,200 ppm	0.32%	Headache, nausea and dizziness within 5 to 10 minutes, **Death** within 30 minutes
6,400 ppm	0.64%	Headaches and dizziness within 1 to 2 minutes, **death** within 10 to 15 minutes
12,800 ppm	1.28%	**Death** within 1 to 3 minutes

Ambient CO_2 measurement

Ambient measurements often only specify the CO content of the ambient air. However, CO_2 is also harmful to humans above certain concentrations, such as those caused by blocked flue gas exhausts.

In order to safely rule out potential hazards, both values need to be considered. The CO_2 content is a reliable early indicator of poisoning and therefore perfectly complements the CO measurement. Parallel measurement of both values offers an early overall indication of hazardous concentrations.

Effect of the CO_2 concentration on humans

387 ppm	0.0387%	Normal CO_2 concentration outdoors
5,000 ppm	0.5%	Maximum permissible concentration in the workplace
15,000 ppm	1.5%	Minute respiratory volume increases by at least 40 percent
40,000 ppm	4%	CO_2 concentration when exhaling
50,000 ppm	5%	Dizziness, headache
80,000 – 100,000 ppm	8 to 10%	Shortness of breath, feeling faint or even loss of consciousness Death within 30 to 60 minutes
200,000 ppm	20%	Rapid loss of consciousness Death within 5 to 10 minutes

5.2 Functional testing and settings for oil-fired systems

The work steps and tips described here illustrate the essential elements of the settings and measurements involved when commissioning non-condensing appliances. These are low temperature boilers with forced-draught oil burners. Condensing appliances are not included here.

1 Measuring the smoke number

To measure the smoke number, the soot pump is inserted into the flue gas duct with a filter paper in place, and the flue gas is drawn in by ten even strokes. The filter sleeve is then removed and examined for the presence of oil derivatives (drops of oil). If the filter is discoloured due to oil derivatives or the filter has become damp due to condensate build-up, then the measurement must be repeated.
To officially determine the smoke number in Germany, three separate measurements must be carried out. The blackening on the filter paper is compared with the Bacharach scale. The final value is determined by calculating the mean value from the individual measurements. Table 5 provides information on the permissible limit values in Germany. The aim should be to achieve a smoke number of 0.
In the case of high smoke numbers, the basic settings of the oil burner

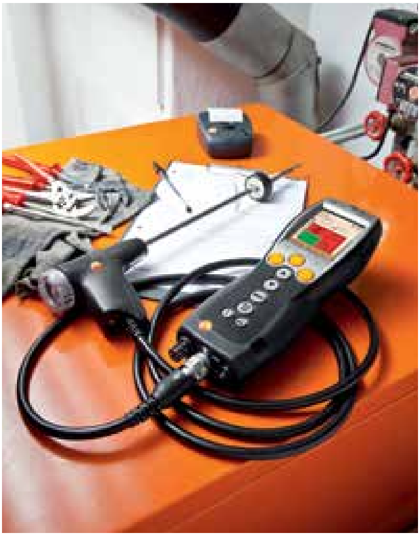


Fig. 19: All key readings and calculation values can be calculated simply and precisely using a flue gas analyzer.

Smoke number System set up or fundamentally modified...	
to 30/09/1988	from 01/10/1988
2	1

Table 5: Limit values of smoke number in oil boilers with forced-draught burner and more than 11 kW

On unknown systems, a smoke measurement should first be undertaken, so that there is no unnecessary pollution of the analyzers by any combustion residues that may be present (soot and oil derivatives).

The cause of oil residues is usually a dirty oil nozzle. The cause could also be the ignition electrodes, which protrude into the oil mist. In both cases, the drops of oil are not atomized finely enough and therefore not burned. Less common – but not to be overlooked – are the cases of incomplete combustion (due to not enough oxygen) or “flame subcooling”. The latter occurs when the boiler and burner are not compatible with each other, when the burner output is much smaller than the boiler output.

should be checked and amended first of all, before further optimizing the settings using a flue gas analyzer. Step 2 explains this procedure:

2 Settings for oil burners

When commissioning and servicing oil burners, the key parameters must be set and checked. The individual work steps for this are listed in detail in the manufacturer's documentation and are described in general terms below for so-called yellow flame burners.

Selecting the right nozzle

In the nozzle selection table, use the required burner output to select the right nozzle and the oil pressure to be set.

Basic air volume settings

The manufacturer's documentation contains information on the basic settings for the required air volume of the burner. Depending on the furnace's required thermal capacity, the corresponding values for configuring the air flap and the orifice plate are specified on a scale.

Basic oil pump settings (pump pressure)

The pump pressure has already been defined via the required burner output and nozzle selection in the nozzle selection table.
A pressure gauge is screwed onto the oil pump to read off the pump pressure and the pump pressure is adjusted accordingly via the pump's pressure adjusting screw. Using a vacuum gauge, which is also attached to the oil pump, check that the vacuum in the suction pipe does not exceed 0.4 bar.

In the case of a **yellow flame burner,** the fuel oil is atomized via a nozzle and oil gasification takes place within the flame. During combustion a yellow flame can be seen.

In the case of a **blue flame burner,** the hot flue gas is used to heat up the atomized oil prior to the actual combustion and thus oil gasification takes place in front of the flame. This produces a bluish flame.

Combustion optimization and control

These basic air volume and oil pressure settings should already have ensured appropriate combustion values, which can be further optimized via a flue gas measurement.

Combustion optimization is generally carried out by changing the air volume at the air flap (rough adjustment) or the orifice plate (fine adjustment). Too little combustion air prevents complete combustion and therefore full exploitation of the fuel and leads to a build-up of soot. Too much combustion air results in excess air being heated up in the combustion chamber and dissipated through the flue unused.

Depending on the burner manufacturer there are guidelines for CO_2 or CO values, excess air or flue gas loss/efficiency, for optimizing the combustion. These values are determined using a flue gas analyzer.

The following work steps are not explained in detail because they are no different from the steps for checking and configuring gas-fired systems and can be found in Section 5.1 (steps 3 to 7).

Step 3: Prepare the flue gas analyzer
Step 4: Determine the flue gas loss
Step 5: Calculate the efficiency (η)
Step 6: Measure the flue draught
Step 7: Measure the CO concentration

5.3 Periodic monitoring of solid fuel systems according to the 1st BImSchV

The revised version of the 1st BImSchV prescribes the periodic inspection of small and medium-sized solid fuel combustion plants. In this Section, we aim to show you the procedure for a periodic inspection in accordance with the 1st BImSchV. The procedure is adapted for using the testo 380 particulate matter analyzer in order to save as much time as possible.

1. General information

Even if, at first glance, it's not obvious from its small, light case: the testo 380 particulate matter analyzer is a high-precision measuring instrument, which can measure CO, O_2 and particulate matter simultaneously.

The testo 380 primarily consists of three main components:

The particulate matter sensor

The particulate matter sensor facilitates online measurement, enabling the user to make a considerably better assessment of when and why high particulate matter emissions occur. Readings can also be displayed immediately.

The particulate matter probe with the rotation diluter

CO, O_2 and particulate matter values are measured using just one probe. The probe can, of course, also carry out the draught measurement and the flue gas temperature measurement.

The testo 330

The flue gas analyzer, which enables the parallel measurement of CO and O_2. The best thing about it is that you can take the testo 330 out of the testo 380 at any time and use it independently for measurements on oil and gas burners. The advantage of this is that you only need a few electrochemical sensors, which wear out over time. Fortunately, however, these sensors have a 4-year warranty as is customary.

Like all other electronic instruments, however, the testo 380 should not be exposed to cold and humidity or condensation. Therefore the measuring instrument should not be left overnight in the car.

2. Preparation

The particulate matter analyzer requires a certain stabilization period (generally < 10 min). During the stabilization period, the system heats up to the operating temperature. In the event that the measuring instrument was chilled overnight in the car, this stabilization duration would obviously be longer.
As soon as the measuring instrument has been set up and connected, the tightness test should be carried out and the fuel selected. Only then is the instrument heated up to the correct temperatures. Once the fuel is configured, it is perfectly OK to carry out other tasks where you are not standing right next to the instrument (such as checking the fuel humidity).

3. Tightness test

When you are carrying out an official compliance measurement or an approval test, you are automatically asked whether the measuring instrument passed the tightness test. If you click on “No”, you are taken to the tightness test. During the tightness test, two gas paths must be closed.

Crude gas path

In order to seal the crude gas path, the cover cap must be fitted on the probe. This closes the path between probe and CO and O_2 sensors.

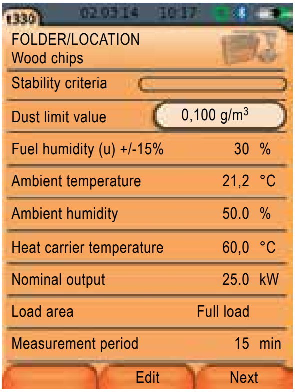
Measurement gas path

In order to seal the measurement gas path, the small cover cap must be plugged onto the condensate trap. This tests the leak-tightness between the box, the rotation diluter and the particulate matter sensor. Since the spot is difficult to get to, you can also block the air inlet with your finger. Please note that you should not remove your finger before completing the testing of both gas paths (confirmed by clicking on “OK”). If you remove your finger too early, you will subject the pressure sensor to a violent impact, and if this happens repeatedly it can result in damage to the pressure sensor.

4. Fuel selection

As soon as you have selected the fuel, the testo 380 begins to adjust itself to the required operating temperatures. The stabilization period now begins, which brings the particulate matter sensor into a defined state and zeroes it. During the stabilization period, you can input coefficients.

The following points must be observed:



FOLDER/LOCATION
Wood chips
Stability criteria
Dust limit value 0,100 g/m³
Fuel humidity (u) +/-15% 30 %
Ambient temperature 21,2 °C
Ambient humidity 50.0 %
Heat carrier temperature 60,0 °C
Nominal output 25.0 kW
Load area Full load
Measurement period 15 min

Dust limit value

Depending on the dust limit value entered, the measurement uncertainty associated with the limit value is deducted from the measurement result. The measurement uncertainties can be looked up in the Federal Gazette or printed out via instrument information.

Fuel humidity

The fuel humidity has an impact on the development of particulate matter. Therefore the value should be entered as accurately as possible. To ensure that you do not obtain any incorrect measurement results, however, it is sufficient to specify the fuel humidity with a measurement uncertainty of ±15% (u). This means that an entry of 20% (u) covers the range from 5% (u) to 35% (u). In order to measure the fuel humidity, we recommend the testo 606-2.

Ambient temperature

In order to have a guide value for the ambient temperature, we have integrated a temperature probe into the testo 380. However, with prolonged run time this is influenced by the temperature of the measurement box. Therefore it is recommended to check the ambient temperature with an external measuring instrument (e.g. testo 606-2) in parallel.

Ambient humidity

Ideally, the ambient humidity should be measured at the same place as the ambient temperature. Hence we recommend also using the testo 606-2 here. Therefore ambient temperature and ambient humidity can be measured with just a few button clicks.

Heat carrier temperature

This value is used for documentation. It is also displayed when printing out the log, enabling the documentation of all relevant values on one sheet.

Nominal output

This value is also only used for documentation. It is also displayed when printing out the log.

Load range

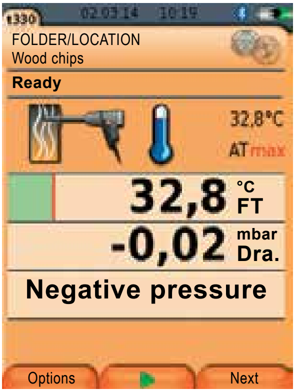
Depending on the system, the combustion process must be set to half load after 5 minutes. If the “half load” menu item is selected, testo 330 emits a signal after 5 minutes.

Measurement period

As the measurement period was set to 15 min during the compliance measurement, you cannot change anything within this menu item. This is possible only within the “Adjustment help” menu item. However, this menu does not follow the sequence of the 1st BImSchV and is therefore not suitable for official measurements.
Once you have entered the coefficients and pressed on “Continue” or once the stabilization duration has finished, then you move on to the draught measurement and search for the centre of flow. However, you can get back to the coefficient input any time via “ESC”.

5. Preparing for measurement

Once you start the draught measurement, first of all zeroing is carried out and then the instrument starts to measure the draught and the flue gas temperature.



02.03.14 10:19

FOLDER/LOCATION
Wood chips

Ready

32,8°C
ATmax

32,8 °C FT

-0,02 mbar Dra.

Negative pressure

To make it easier to locate the centre of flow, a red bar appears on the display, which remains permanently at the highest value. The green area displays the current value.
As soon as the centre of flow is located, the measurement can be stopped. Press “Continue” to be ready for measurement.
The testo 380 can stay in this mode until all the other tasks or the correct burner status have been attained. The measurement will not be started until the start button is pressed.

6. Particulate matter measurement

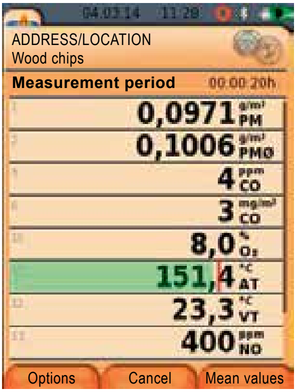
As soon as the measurement is started, the rotation diluter starts to rotate. During this phase, the particulate matter sensor is loaded with particulate matter for the first time. The measuring instrument uses the loading that occurs during this phase to decide whether it is being exposed to a high or low concentration and adjusts the speed of the rotation diluter accordingly. After this second stabilization phase, which last approximately 3 minutes, the measuring instrument goes into measuring mode. The values now displayed are used to assess the system. If, contrary to expectations, the values are not yet to be used for the measurement, you can use “Options”, “Repeat” to allow the readings that have already appeared to lapse and the measuring time starts again from the beginning (e.g. if the burner is not yet in the correct operating mode).

Here's a brief overview of the readings:

g/m^3 PM = current dust value (converted to reference oxygen)

g/m^3 PM Ø = dust mean value since the start of measurement (converted to reference oxygen)

ppm CO = measured CO value in parts per million


04.03.14 11:28

ADDRESS/LOCATION
Wood chips

Measurement period 00:00:20h

0,0971 g/m^3 PM
0,1006 g/m^3 PMØ
4 ppm CO
3 mg/m^3 CO
8,0 % O_2
151,4 °C AT
23,3 °C VT
400 ppm NO

mg/m^3 CO = CO concentration (converted to reference oxygen)

% O$_2$ = oxygen in percent (if this value increases by more than 20% then no more values converted to reference oxygen are displayed, since these values then become unusable)

°C FT = flue gas temperature in °C

°C AT = combustion air temperature in °C (only permitted with the external temperature probe (0600 9787), since in the case of the mini-temperature probe the heat of the particulate matter box may have an influence on the result). The combustion air indication is for information purposes only. In Germany the qA value for solid fuel systems is currently (2014) unregulated.

ppm NO = measured NO value in parts per million (only appears if a NO sensor is used)

% AF = flue gas humidity in percent. The flue gas humidity is calculated from the parameters entered in the coefficient input. The more accurate the values entered, the more accurate the result.

7. Options

In this section we give you a brief overview of the additional functions offered by the testo 380, but which are not needed for the measurement.

The Options menu offers 5 options:

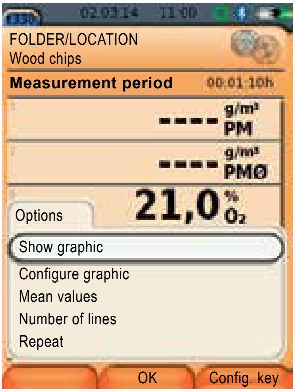
Show graphic: Here, the various parameters and their progression over the measurement period thus far are displayed graphically.

Configure graphic: In this menu, you can select the parameters (up to 4) which are to be shown as part of the graphical progression.

Mean values: This menu item takes you back to the reading display, however the display no longer shows the current values but the mean values since the start of measurement.

Number of lines: Used to select the number of lines displayed and also the font size.

Repeat: If combustion is not completely stable at the outset or if the “Start” button was pressed too soon, the “Repeat” option can be used to discard the current readings and start the measurement from the beginning.



02.03.14 11:00

FOLDER/LOCATION
Wood chips

Measurement period 00:01:10h

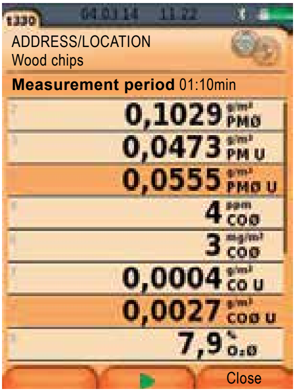
---- g/m³ PM

---- g/m³ PMØ

21,0 % O_2

8. Interpreting the end results

As soon as the measurement has finished, the summary of results follows:



04.03.14 11:22

ADDRESS/LOCATION
Wood chips

Measurement period 01:10min

0,1029 g/m³ PMØ
0,0473 g/m³ PM U
0,0555 g/m³ PMØ U
4 ppm COØ
3 mg/m³ COØ
0,0004 g/m³ CO U
0,0027 g/m³ COØ U
7,9 % O₂Ø

g/m^3 PM Ø = average PM value in g/m^3 over the entire measurement period

g/m^3 PM U = absolute measurement uncertainty that is deducted

g/m^3 PM Ø U = the PM value applicable (to official measurements) after deducting the associated measurement uncertainty

ppm CO Ø = average CO value in ppm

mg/m^3 CO Ø = average CO value in g/m^3

g/m^3 CO U = absolute measurement uncertainty that is deducted

g/m^3 CO Ø U = the CO value applicable after deducting the associated measurement uncertainty

% O$_2$ Ø = oxygen in percent (if this value increases by more than 20% then no more values converted to reference oxygen are displayed, since these values then become unusable)

°C FT = flue gas temperature in °C

°C AT = combustion air temperature in °C (only permitted with the external temperature probe (0600 9787), since in the case of the mini-temperature probe the heat of the particulate matter box may have an influence on the result). The combustion air indication is for information purposes only. In Germany the qA value for solid fuel systems is currently (2014) unregulated.

ppm NO = measured NO value in parts per million (only appears if a NO sensor is used)

% AF = flue gas humidity in percent. The flue gas humidity is calculated from the parameters entered in the coefficient input. The more accurate this value, the more accurate the result

6. Tightness tests on gas and water pipes

6.1 Gas pipe test

In Germany the gas pipe test is specified by the technical regulation for gas installations (DVGW worksheet G 600 TRGI). In general terms, this defines the planning, setting up, modification and operation of gas installations at an operating pressure of up to 1 bar in buildings and on sites.

It prescribes a load and tightness test for new or substantially modified pipes.

A serviceability test must also be carried out every 12 years for pipe systems operating at pressures of up to 100 mbar .

You can use the testo 324 to carry out these tests easily and reliably, using just one instrument.

6.1.1 Load test

The load test should be carried out prior to the tightness test, and is performed on newly laid pipes without fittings. The pipe openings must be tightly sealed for the duration of the test with plugs, caps, blinds or dummy flanges made of metal material. Connections to gas-conducting pipes are not permitted. The load test can also be carried out on pipes with fittings if the nominal pressure rating of the fittings corresponds at least to the test pressure.

The load test should be carried out using air or inert (low reaction) gas (e.g. nitrogen, carbon dioxide), but not with oxygen, and at a test pressure of 1 bar.

The test pressure should not drop during the test, which lasts 10 minutes.

The measurement must be carried out using a measuring instrument with a minimum resolution of 0.1 bar.

6.1.2 Tightness test

The tightness test should be carried out after the load test for pipes including the fittings, but without gas appliances and associated control and safety equipment. The gas meter can be included in the main test.

The tightness test should be carried out with air or inert (low reaction) gas (e.g. nitrogen, carbon dioxide), but not with oxygen, and at a test pressure of 150 mbar.

Following temperature compensation, the test pressure should not drop during the subsequent test, which takes at least 10 minutes.

The temperature compensation and the test duration depend on the pipe volume.

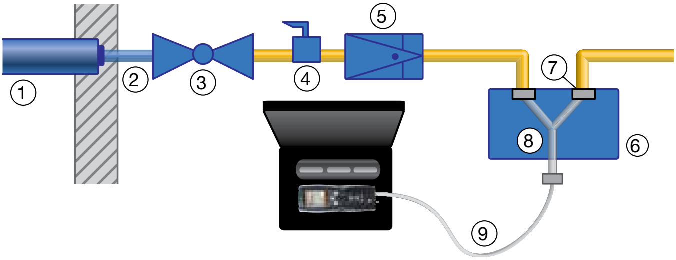
The measuring instrument must be so accurate that even a pressure drop of 0.1 mbar can be registered.

Tightness test

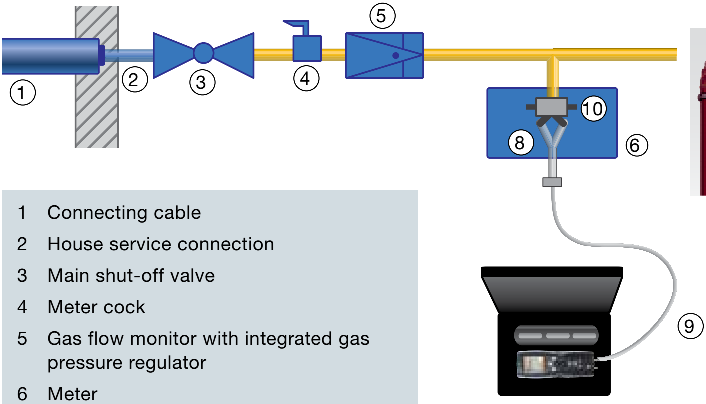
Pipe volume	Adjustment time	Min. test duration
< 100 l	10 min.	10 min.
> = 100 l < 200 l	30 min.	20 min.
> = 200 l	60 min.	30 min.

Sample connection drawings for load and tightness test:

With twin-pipe meter



With single-pipe meter



1 Connecting cable

2 House service connection

3 Main shut-off valve

4 Meter cock

5 Gas flow monitor with integrated gas pressure regulator

6 Meter

7 Conical stopper (150 mbar test)
½“ 0554 3151 / ¾“ 0554 3155

Stage stopper (1 bar test)
¾“ + 1¼“ 0554 0533
½“ + 1“ 0554 3164
3/8“ + ¾“ 0554 3163

8 Y distributor *0554 0532*
Use the Y distributor to simultaneously measure the supply and distribution pipe. Alternatively, these can be measured one after the other – for this, the testo 324 is connected directly to the relevant stopper.

9 testo 324 connection hose

10 Single-pipe counter cap *0554 315*

The gas boiler must be disconnected from the system being tested during the load test. The pressure build-up to 1 bar is achieved via the hand pump of the testo 324. A compressor can also be used. For the tightness test, the pressure build-up to 150 mbar is achieved automatically via the internal pump of the testo 324. The load test is carried out on the pipe without fittings. The tightness test is carried out with fittings, but without gas appliances and associated control and safety equipment.
Please also refer to country-specific guidelines and standards!

In Germany, the DVGW G 5952 specifies the minimum requirements for electrical instruments for measuring and determining the gas leakage rate, e.g. measuring range, accuracy, resolution, adjustment time, measuring time, etc.

G 5952 differentiates between the following device classes:
Pressure drop measuring instruments (Class D)
The leakage rate is determined using the measured pressure drop in relation to the pipe volume. The pipe volume must be determined by the instrument.
Leakage rate measuring instruments (Class L)
The gas leakage rate (l/h) is measured directly, e.g. testo 324.
Volumetric instruments (Class V)
The leakage rate is determined using the measured pressure difference while simultaneously supplying a defined volume to maintain constant pressure.
Measuring instruments involving other measurement methods (Class S)
Measurement methods not covered by Classes D, L and V.

6.1.3 Serviceability test

Low-pressure pipes (operating pressures up to 100 mbar), whether in operation or not, are tested to check their serviceability if leaks are suspected, in response to customer request or when recommissioned. Systems that are in operation must be examined to check their serviceability at least once every 12 years. For the serviceability test or leakage measurement, the gas pipe is always tested under operating conditions/operating pressure (no increased test pressure).

During this test a leakage tester, e.g. testo 324, certified to DVGW G 5952, detects whether gas is leaking from the pipe and how much.

The duration of the temperature compensation and the test time is determined by the pipe volume.

Leakage measurement

Pipe volume	Adjustment time	Min. test duration
< 100 l	10 min	5 min
< 200 l	30 min	10 min
< 300 l	60 min	15 min
< 400 l	120 min	20 min
< 500 l	240 min	25 min

Serviceability is divided into the following criteria:

a) Unlimited serviceability if the gas leakage rate at operating pressure is less than 1 litre per hour.

b) Reduced serviceability if the gas leakage rate at operating pressure is between 1 and 5 litres per hour.

c) No serviceability
if the gas leakage rate at operating pressure is more than 5 litres per hour.

Depending on the degree of serviceability, the following measures must be taken:

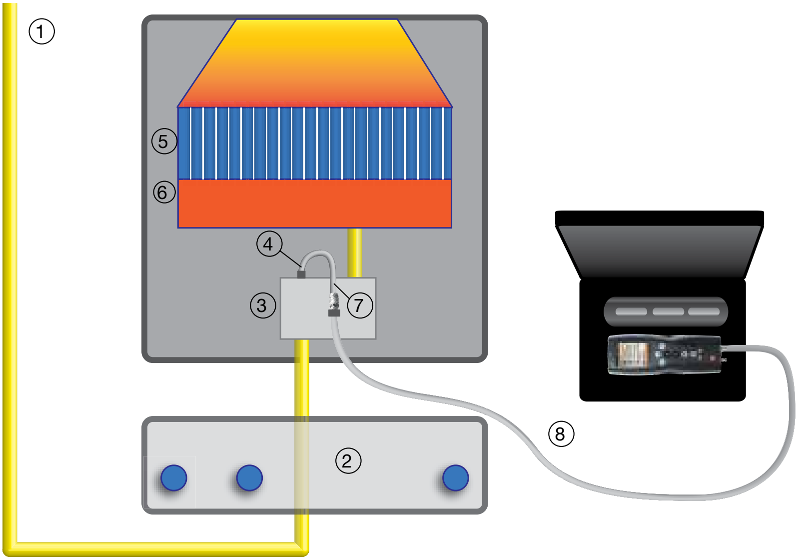
a) If there is unlimited serviceability, the pipes can continue to be operated.

b) If there is reduced serviceability, the pipes must be sealed or replaced. Leak-tightness must be restored within 4 weeks of determining reduced serviceability.

c) If there is no serviceability, the pipes must be taken out of service immediately. The specifications for newly-routed pipes are valid for repaired pipeline parts and their recommissioning

i After any repair work, a tightness test must be carried out.

Sample connection drawings for the serviceability test:



1 Supply line
2 Operating unit
3 Control unit with instrument gland connection
4 Test nipple / instrument gland
5 Heat exchanger
6 Burner
7 Gas boiler connection testo 324

8 testo 324 connection hose

The gas bladder is filled with native gas. This prevents the formation of a hazardous air/gas mixture. **Please also refer to country-specific guidelines and standards!**

6.1.4 Combined load and tightness test on gas pipes

In Germany, this test is prescribed in accordance with the TRGI for pipes with an operating pressure of > 100 mbar up to and including 1 bar.
The entire pipe is measured with fittings, but without pressure regulators, gas meters, gas appliances and associated control and safety equipment.
The test is carried out at a test pressure of 3 bar over a measuring period of at least 2 hours following a temperature compensation of 3 hours.
For a pipe volume of over 2000 litres, the test time per 100 litres is prolonged by 15 minutes.
In accordance with TRGI 2008 G 600, no drop in pressure is permitted.

6.1.5 Searching for gas leaks

There is a risk of poisoning or explosion if natural gas escapes from a pipe or heating system. Since natural gas is normally odourless, odour is added. If you smell gas, the room must be well-ventilated immediately. The gas pipe can then be checked for leaks using a gas leak detector or probe. For safety reasons, 20% of the lower explosion limit should not be exceeded.

Fig. 20: Leak detection on gas pipes using the testo 316-2

6.2. Testing drinking water installations

The European standard DIN EN 806-4 sets out requirements with respect to the installation and commissioning of drinking water systems inside buildings. A pressure test prior to commissioning is prescribed. This may be carried out using water or, if national provisions allow it, using air or inert gas.

6.2.1 Pressure test using water

In the event of a pressure test using water, in keeping with the pipe material there are various pressure tests (methods A, B and C), which are predefined by EN 806-4:

Type of material	Method
Linear-elastic materials (i.e. metals)	A
Elastic materials (PVC-U, PVC-C etc.) and multi-layer composite materials	A
Viscoelastic materials (i.e. PP, PE, PE-X, PA, PB etc.) with DN/OD ≤ 63	A
Viscoelastic materials with DN/OD > 63 (i.e. PP, PE, PE-X, PA, PB etc.)	B or C
Combined system with DN/OD ≤ 63 (metals and plastics)	A
Combined system with DN/OD > 63 (metals and plastics)	B or C

Method		Test pressure	Test time
A		1.1 times the highest operating pressure	10 min
B	Part 1	1.1 times the highest operating pressure	30 min
	Part 2	Lowered to 0.5 times the test pressure	30 min
C	Part 1	1.1 times the highest operating pressure	30 min
	Part 2	Based on Part 1, may be reduced by 0.6 bar maximum	30 min
	Part 3	Based on Part 2, may be reduced by 0.2 bar maximum	2 hrs

In Germany, pipes that include crimp connections must also be subject to a prior tightness test in accordance with the ZVSHK information sheet.
Test pressure = supply pressure / max. 6 bar or in accordance with the manufacturer's specifications
Test duration = 15 min

6.2.2 Pressure test using air or inert gas

As well as DIN EN 806-4, national provisions also need to be complied with when testing drinking water installations. Thus, in Germany the ZVSHK information sheet applies in addition to EN 806-4. The ZVSHK information sheet allows testing with air in Germany. This is recommended in the following cases:

- A long period of downtime between tightness test and commissioning, particularly if average ambient temperatures of > 25 °C are anticipated, in order to rule out any potential bacterial growth
- If, between tightness test and commissioning, the pipeline cannot remain completely full, e.g. due to a period of frost
- The corrosion resistance of a material in a partially-filled pipe is compromised.

The test should be carried out using water only if a regular exchange of water is guaranteed between tightness test and commissioning. In addition, when testing with water you need to ensure:

- That the house or construction site water connection is flushed and therefore approved for connection and operation
- The pipe system is filled using components that are in perfect hygienic condition
- From tightness test to commissioning, the system remains full and partial filling can be prevented.

The test medium inert gas is only recommended in buildings with more stringent hygiene-related requirements.
Carrying out a pressure test using air or inert gas requires a tightness test and a load test.
Due to the fact that air or gas is more highly compressed than water under pressure, when testing with air or inert gas the test pressures are limited to a maximum 3 bar for reasons of safety.

6.2.2.1 Tightness tests

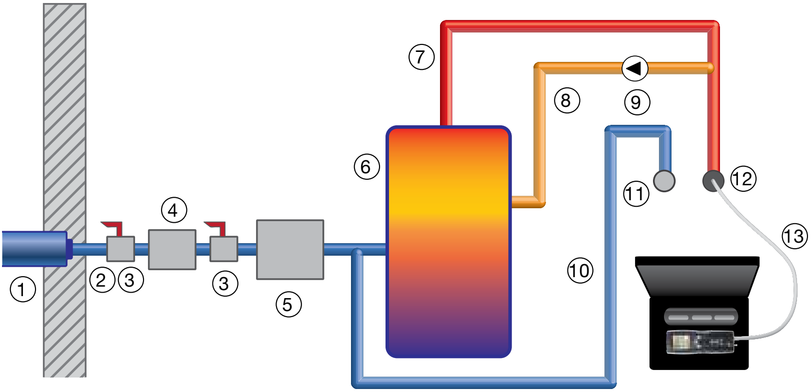
The tightness test is carried out prior to the load test and includes the components, provided that these are designed for the test pressure, otherwise they need to be removed.

Test pressure: 150 mbar

Test time: 120 min (up to a pipe volume of 100 l)

For each additional 100 l, the test time is extended by 20 min

Sample connection drawings for the tightness test using air

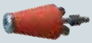


1 Supply line
2 House service connection
3 Shut-off valves
4 Domestic water meter
5 Filter
6 Boiler
7 Hot water pipe
8 Circulation
9 Pump
10 Cold water pipe
11 Fitting connection
12 High-pressure stage stopper

½“ + 1“	*0554 3164*
3/8“ + ¾“	*0554 3163*

Conical stopper

½“	*0554 3151*
¾“	*0554 3155*



13 testo 324 connection hose

Pressure builds up automatically via the internal pump of the testo 324. If the pipe is very large, you have the option of connecting a compressor to the pipe or also using the hand pump of the testo 324.

Note: maximum pressure 1 bar – when exceeded, the pressure relief valve responds.

6.2.2.2 Load tests

As previously mentioned, the load test is carried out after passing the tightness test.

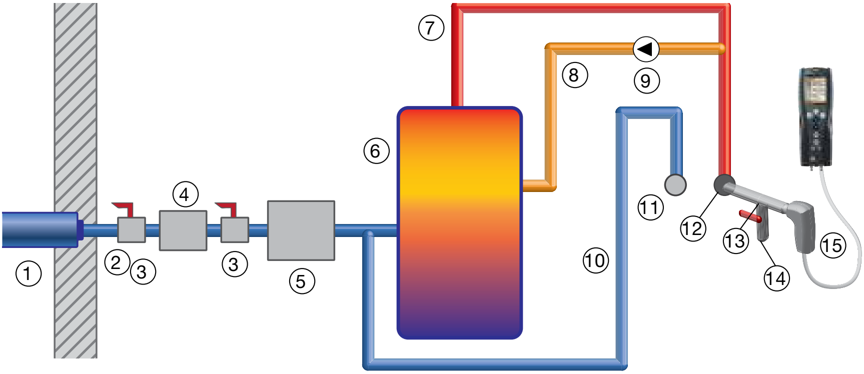
The test pressure depends on the nominal width of the pipe:

Test pressure: < DN 50 = 3 bar

DN 50-DN 100 = 1 bar

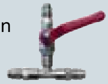
Test time: 10 min

Sample connection drawings for the load test using air



1 Supply line
2 House service connection
3 Shut-off valves
4 Domestic water meter
5 Filter
6 Boiler
7 Hot water pipe
8 Circulation
9 Pump
10 Cold water pipe
11 Fitting connection
12 High-pressure stage stopper
½" + 1" *0554 3164*
3/8" + ¾" *0554 3163*

13 High-pressure connection
0554 3139



14 Connection option for compressor
15 High-pressure probe with hose
0638 1748


22.2
177.3
4.4
9
12.17
0.0110
esc
testo

7. Measuring instruments for flue gas analysis

The requirements for portable flue gas analyzers pose a challenge for any measuring instrument manufacturer. The harsh measuring environment and the implementation of measurements without a mains power supply call for a high level of technical expertise and customer-oriented design. Instruments need to be light, manageable and easy to use. Other key points are the need to have readings available quickly and low energy consumption and maintenance requirements, so that the prescribed qualification test for flue gas analyzers can be accomplished.

7.1 The sensors

The requirements stipulated for measuring instruments directly affect the choice of sensors to determine gas concentrations. Electrochemical gas sensors have proved their worth in practice. The rapid availability of the readings and the small space requirements are the main advantages of this type of sensor. Efforts are constantly being undertaken in the field of research and development, for example to optimize the gas paths and the correct allowance for cross-sensitivities, and ideally to facilitate the design of gas sensors that are easy for users to replace.

7.2 How a chemical two/three-electrode sensor works

Two or three-electrode sensors are used to determine concentrations of toxic gases. The operation of a three-electrode sensor is explained with reference to the carbon monoxide (CO) sensor. A typical two-electrode sensor is the oxygen sensor (O_2).

7.2.1 How a chemical two-electrode sensor works

Figure 21 shows how an oxygen sensor works.

Overview of how an oxygen sensor works:

- O_2 molecules pass through the gas-permeable membrane to the cathode.
- Chemical reaction: OH- ions are created (ions = charged particles)
- The ions migrate through the electrolytic liquid to the anode.
- This ion movement generates a current flow in the external circuit in proportion to the O_2 concentration.
- This means the higher the concentration, the higher the current flow.
- The voltage drop in the resistance is measured and electronically processed.
- The integral resistance with negative temperature coefficient compensates for the temperature influences, ensuring the behaviour of the sensor is temperature-stable.
- The lifetime of an oxygen sensor is approx. 3 years – up to 6 years in the case of Testo long-life gas sensors.

Reaction equations

Cathode: $O_2 + 2H_2O + 4e^- \Rightarrow 4OH^-$

Anode: $2Pb + 4OH^- \Rightarrow 2PbO + 2H_2O + 4e^-$

Balance: $2Pb + O_2 \Rightarrow 2PbO$

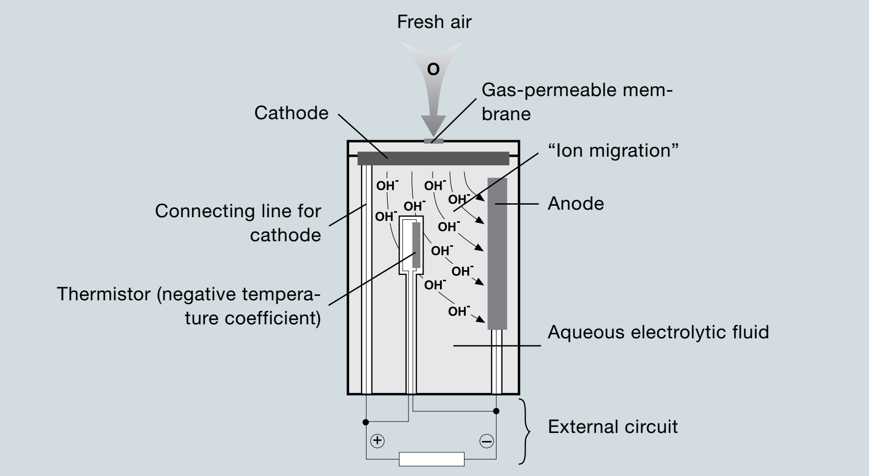


Fig. 21: Diagram of an oxygen sensor

7.2.2 How a chemical three-electrode sensor for toxic gases works

Overview of how a three-electrode sensor works (using a CO sensor as an example):

- The CO molecules migrate through the membrane to the working electrode.
- Chemical reaction: formation of H+ ions.
- The ions migrate to the counter-electrode.
- Second chemical reaction using O_2 in the fresh air: current flow in the external circuit.
- The reference electrode stabilizes the sensor signal.
- The lifetime of a carbon monoxide sensor is approx. 2 years – up to 5 years in the case of Testo long-life gas sensors.

Reaction equations:
Anode: CO + H2O => CO_2 + 2H+ + 2e–
Cathode: ½ O_2 + 2H+ + 2e– => H_2O

Frequent fluctuations in temperature and low temperatures can shorten the lifespan of the measuring cell.
Storage in a dry environment is recommended.

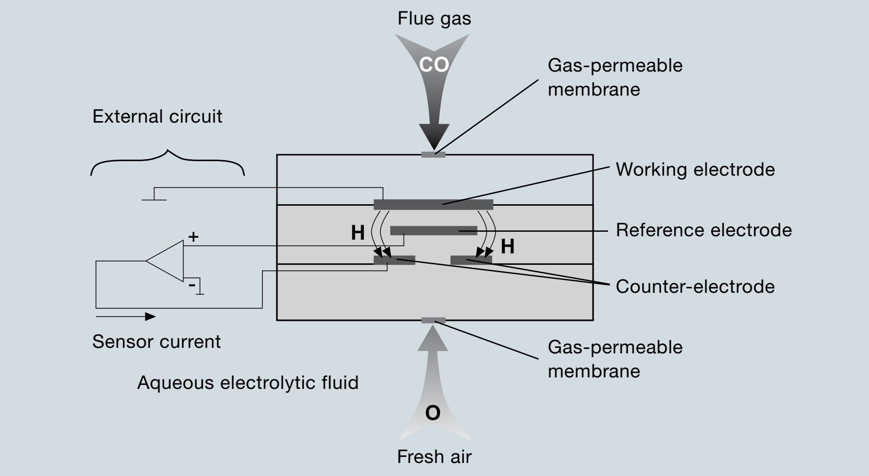


Fig. 22: Diagram of a carbon monoxide sensor

7.3 How a semi-conductor sensor for combustible gases works

The semi-conductor sensor is used for measuring combustible gases such as C_XH_Y, H_2 and CO. It is used in gas leak detection. The structure of a semi-conductor sensor is shown in Fig. 23. Overview of how a semi-conductor sensor works (for example used in a gas leak detector probe):

- The sensor element is heated to a working temperature of 300 °C.
- A high-impedance resistance develops when heated, by means of a stannic oxide coating.
- If there are combustible gases (CXHY, H2, CO) in the ambient air of the sensor element, i.e. inside the sensor, they will be deposited on the stannic oxide coating.
- Their electrical resistance will then decrease.
- A visual or audible alarm is triggered.

Contact with silicones, solvents, oils and grease can result in deposits on the surface of the sensor and should be avoided.

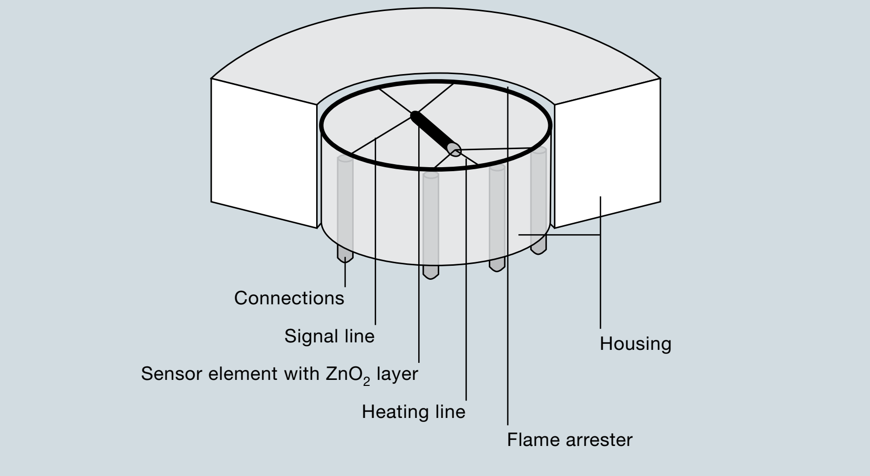


Fig. 23: Structure of a semi-conductor sensor

7.4 Particulate matter sensor

The particulate matter sensor involves a combination of impactor and quartz oscillator principles.

The quartz oscillator is the “scales”, while the impactor ensures that the particles suspended in the measurement gas flow get onto the “scales”.

The impactor consists of a fine nozzle, through which the measurement gas flows at high speed.

Opposite the nozzle outlet is a deflector plate, the quartz oscillator. This deflector plate forces the out-flowing gas to make a sharp change in direction. Due to the inertia of the particles, however, these cannot completely follow the change in direction and collide with the deflector plate, to which they then stick. This process is called impaction.

In the case of the testo 380, weighing is carried out during the collection phase. The deflector plate is set in fundamental vibration by special electronics.

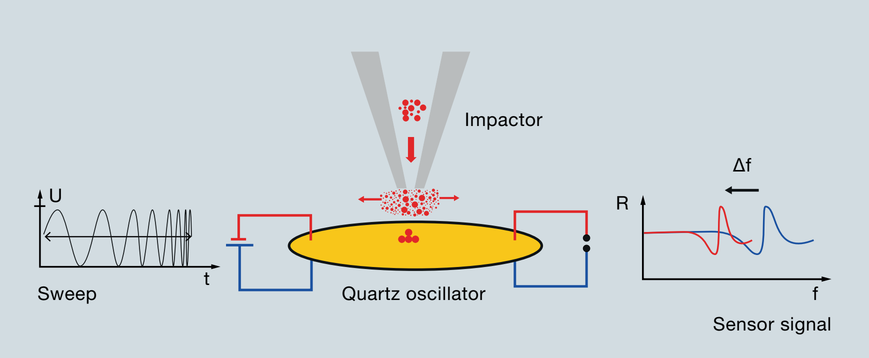
Once the small plate is now covered with particles, its mass increases and the frequency of the sensor signal is displaced.

From this frequency displacement (Δf), the deposited particulate mass can be inferred.

This method involves a gravimetric “online measurement method”. This means you obtain the readings in real time and can observe them during the measurement. You can also directly analyze and evaluate the measurement result at the end.

7.5 Electronics

The trend in development and manufacture is towards ever smaller measuring instruments. Only with computer-aided design (CAD) and automated production is it possible to manufacture electronic circuits in the smallest



of spaces. The boards are designed in line with the multilayer principle and the electronic components mounted using the latest placement technology (surface mounted design, SMD).
A test computer (in-circuit tester) tests the assembled boards, identifying any faults at an early stage. Faulty boards can be cost-effectively reworked and returned to the production circuit.
Once the boards and gas measuring cells have been assembled inside the structurally optimized housing, the instruments are tested on a computer-assisted test bench to make sure that they are working correctly and calibrated using test gas. DIN ISO 9001 certification guarantees consistent quality, and this is complemented by a competent after-sales service. This is the only way to manufacture measuring instruments which meet the requirement of flue gas analysis.

7.6 Design

The layout of the gas paths is a major consideration when designing portable flue gas analyzers. Since leaks will distort the measurement result, connections along the gas path must be absolutely leak-tight. Places where condensate precipitates must be avoided to prevent damage to the measuring cells. Flue gas analyzers are therefore equipped with a condensate trap, which collects the accumulated condensate, protecting the measuring instrument.
The flue gas is drawn through the flue gas probe by the pump. The thermocouple built into the flue gas probe tip measures the flue gas temperature. The condensate trap and built-in filter “dry” the flue gas and retain dust and soot particles. The gas sample passes the pump and is forced through a capillary (narrowing of the gas path) into an antechamber which absorbs the pressure surge produced by the diaphragm pump. On leaving the antechamber, the gas to be measured flows to the gas sensors, which - depending on the design - measure the O_2, CO, NO, NO_2, and SO_2 concentrations. To measure the flue draught, no flue gas is drawn in. The flue gas travels directly from the flue gas probe via a dedicated gas path to the analyzer pressure sensor, where the flue draught is measured. The combustion air temperature is measured by a temperature probe, which is directly connected to the measuring instrument.

8. Appendix

8.1 Calculation formulae

Flue gas loss: $qA = \left[(FT - AT) \left[\frac{A2}{(21 - O_2)} + B \right] \right] - XK$

FT: Flue gas temperature
AT: Combustion air temperature
A2/B: Fuel-specific factors (see table)
21: Oxygen level in the air
O_2: Measured O_2 value (rounded to the nearest whole number)
XK: Coefficient which expresses the flue gas loss qA as a minus value when the dew point is not reached. Required for measurements on condensing systems. If the dew point temperature is not reached, XK = 0.

$$qA = f \times \frac{(FT - AT)}{CO_2}$$

Siegert formula to calculate flue gas loss. This is used when the fuel-specific factors A2 and B (cf. table) are zero.

Table of fuel-specific factors

Fuel	**A2**	**B**	**f**	**CO_{2max}**
Fuel oil	0.68	0.007	–	15.4
Natural gas	0.65	0.009	–	11.9
LPG	0.63	0.008	–	13.9
Coke, wood	–	–	0.74	20.0
Briquette	–	–	0.75	19.3
Lignite	–	–	0.90	19.2
Hard coal	–	–	0.60	18.5
Coke oven gas	0.6	0.011	–	–
Town gas	0.63	0.011	–	11.6
Test gas	–	–	–	13.0

Air volume L:

$$L = \lambda \times L_{min}$$

L: Actual air volume
λ: Air ratio
L_{min}: Theoretical air requirement

Carbon dioxide concentration (CO_2):

$$CO_2 = \frac{CO_{2max} \times (21 - O_2)}{21}$$

CO_{2max}: Fuel-specific maximum CO_2 value

Air ratio λ:

$$\lambda = \frac{CO_{2max}}{CO_2} = 1 + \frac{O_2}{21 - O_2}$$

CO_{2max}: Fuel-specific maximum CO_2 value
CO_2: Calculated CO_2 value in the flue gas
O_2: Measured O_2 value (rounded to nearest whole number)
21: Oxygen level in the air

Undiluted carbon monoxide concentration ($CO_{undiluted}$):

$$CO_{undiluted} = CO_{diluted} \times \lambda$$

CO: Measured CO value
λ: Excess air rate

Efficiency of system η:

$$\eta = 100 - qA$$

qA: Flue gas loss

Limit values of the Ordinance on Firing Installations

Fuel thermal output	Solid fuels			Liquid fuels			Gaseous fuels	
	CO	NO	Dust/ Wood	CO	NO	SO_2	CO	NO
50 – 350 kW	800 mg/m^3	250 mg/m^3	150 mg/m^3					
350 kW – 2 MW	250 mg/m^3	250 mg/m^3	150 mg/m^3					
> 2 MW – 5 MW	250 mg/m^3	250 mg/m^3	50 mg/m^3					
> 5 MW – 10 MW	100 mg/m^3	250 mg/m^3	50 mg/m^3					
> 10 MW		200 mg/m^3	50 mg/m^3					
		13% O_2 reference						
					Fuel oil EL			
≤ 1 MW				100 mg/m^3				
> 1 MW				80 mg/m^3				
50 kW – 50 MW					150 mg/m^3			
> 50 MW					100 mg/m^3			
> 50 MW – 300 MW					100 mg/m^3	350 mg/m^3		
> 300 MW					100 mg/m^3	200 mg/m^3		
50 kW – 2 MW					Smoke number 1			
					3% O_2 reference			
								Natural gas
≤ 3 MW							80 mg/m^3	120 mg/m^3
> 3 MW							80 mg/m^3	100 mg/m^3
								LPG
≤ 3 MW							80 mg/m^3	160 mg/m^3
> 3 MW							80 mg/m^3	130 mg/m^3
								3% O_2-reference

Flue gas losses
In accordance with the fuel type used, combustion plants used only for room heating or water heating must not exceed the following flue gas losses with rated load:

1. Automatically loaded combustion plants for solid fuels	19%
2. Combustion plants for liquid or gaseous fuels	10%

Limit values of the Clean Air Acts of the Federal States of Austria

	Solid fuels		
	CO	**NO**	**qA**
Art. 15a B-VG < 50 kW	3500 mg/m^3 manual 1500 mg/m^3 automatic		20% manual 19% automatic
Art. 15a B-VG > 50 kW	FAV	FAV	FAV
Vienna1)	2000 mg/m^3	900 mg/m^3	23% 15 – 26 kW2)
	2000 mg/m^3	600 mg/m^3	20% 15 – 26 kW
	2000 mg/m^3	600 mg/m^3	19% 26 – 50 kW
	2000 mg/m^3	600 mg/m^3	18% 50 – 120 kW
Lower Austria3)			18% 11 – 50 kW
			18% 50 – 120 kW
			18% > 120 kW
B5)	4000 ppm < 50 kW		21% 15 – 50 kW
	2000 ppm 50 – 150 kW		19% > 50 kW
Styria6)			19% 8 – 26 kW
	2000 mg/m^3		17% 26 – 50 kW
	800 mg/m^3	300 mg/m^3	15% 50 – 200 kW
Upper Austria	1500 mg/m^3 ≤ 50 kW		19%
	800 mg/m^3 > 50 – 400 kW	300 mg/m^3	19%
Salzburg	1500 mg/m^3		19% < 50 kW
	800 mg/m^3	500 mg/m^3	19% > 50 kW
Carinthia	4000 mg/m^3 9)		21% 26 – 50 kW
			20% 51 – 120 kW
			19% > 120 kW
Tyrol	800 mg/m^3 < 400 kW		19%
	250 mg/m^3 > 400 kW		19%
Vorarlberg10)	1000 mg/m^3		20%

1) New systems from 01/06/2004, old systems up to 31/12/2011, see Clean Air Act
2) Individual furnaces
3) Systems prior to 23/07/1998, see Clean Air Act
5) Systems prior to 01/07/2000, see Clean Air Act
6) Systems up to 1996 and manually loaded, see Clean Air Act
9) From 01/03/1994
10) Automatically loaded

Limit values of the Clean Air Acts of the Federal States of Austria

	Liquid fuels		
	CO	**NO**	**qA**
Art. 15a B-VG < 50 kW	100 mg/m^3 Smoke No. 1		10%
Art. 15a B-VG > 50 kW	FAV	FAV	FAV
Vienna[1]	100 mg/m^3	400 mg/m^3 HEL	17% 15 – 26 kW[2]
	100 mg/m^3	150 mg/m^3 HEL	15% 15 – 26 kW
	100 mg/m^3	150 mg/m^3 HEL	14% 26 – 50 kW
	100 mg/m^3	150 mg/m^3 HEL	12% 50 – 120 kW
Lower Austria[3]	150 ppm undiluted[4]		12% 11 – 50 kW
	150 ppm undiluted[4]		11% 50 – 120 kW
	150 ppm undiluted[4]		10% > 120 kW
B[5]	500 ppm		100-(84+2logPn)
	500 ppm		10% > 50 kW
Styria[6]	100 mg/m^3	150 mg/m^3 HEL	16% 25 – 50 kW
	100 mg/m^3	150 mg/m^3 HEL	14% 50 – 120 kW
	100 mg/m^3	150 mg/m^3 HEL	12% > 120 kW
Upper Austria	100 mg/m^3 < 50 kW HEL		10%
	100 mg/m^3 50 kW – 1 MW	150 mg/m^3 50 kW – 1 MW	10%
Salzburg	100 mg/m^3 < 50 kW		10%
	100 mg/m^3 HEL	150 mg/m^3 HEL	10%
Carinthia			16% 26 – 50 kW
			14% 51 – 120 kW
			12% > 120 kW
Tyrol	300 ppm		ÖNORM 7510-1, -2 old
Vorarlberg[10]	100 mg/m^3		10%

[1] New systems from 01/06/2004, old systems up to 31/12/2011, see Clean Air Act

[2] Individual furnaces

[3] Systems prior to 23/07/1998, see Clean Air Act

[4] Undiluted = CO_x excess air λ

[5] Systems prior to 01/07/2000, see Clean Air Act

[6] Systems up to 1996 and manually loaded, see Clean Air Act

[10] Automatically loaded

Limit values of the Clean Air Acts of the Federal States of Austria

	Gaseous fuels		
	CO	**NO**	**qA**
Art. 15a B-VG < 50 kW	100 mg/m^3		10%
Art. 15a B-VG > 50 kW	FAV	FAV	FAV
Vienna1)	80 mg/m^3	300 mg/m^3	15% 15 – 26 kW2)
	80 mg/m^3	120 mg/m^3	13% 15 – 26 kW
	80 mg/m^3	120 mg/m^3	12% 26 – 50 kW
	80 mg/m^3	120 mg/m^3	11% 50 – 120 kW
Lower Austria3)	150 ppm undiluted4)		12% 11 – 50 kW
	150 ppm undiluted4)		11% 50 – 120 kW
	150 ppm undiluted4)		10% > 120 kW
B5)	500 ppm		100-(84+2logPn)
	500 ppm		10% > 50 kW
Styria6)	80 mg/m^3	120 mg/m^3 8)	16/14%7) 25 – 50 kW
	80 mg/m^3	120 mg/m^3 8)	14/13%7) 50 – 120 kW
	80 mg/m^3	120 mg/m^3 8)	12% > 120 kW
Upper Austria			
Salzburg	100 mg/m^3 < 50 kW		10%
	80 mg/m^3	120 mg/m^3 160 mg/m^3 FG	10%
Carinthia			16/14%7) 26 – 50 kW
			14/13%7) 51 – 120 kW
			12% > 120 kW
Tyrol	300 ppm		ÖNORM 7510-1, -2 old
Vorarlberg10)	100 mg/m^3		10%

1) New systems from 01/06/2004, old systems up to 31/12/2011, see Clean Air Act
2) Individual furnaces
3) Systems prior to 23/07/1998, see Clean Air Act
4) Undiluted = CO_x excess air λ
5) Systems prior to 01/07/2000, see Clean Air Act
6) Systems up to 1996 and manually loaded, see Clean Air Act
7) Atmospheric burners
8) Natural gas, LPG 160 mg/m^3
10) Automatically loaded

8.2 Introduction to Testo instruments

Measuring technology for the environment, HVAC and industry
"We measure it." This motto is both a slogan and also the key to success for Testo AG, which is based in Lenzkirch in the Black Forest. At the high-tech company from the vicinity of Freiburg, it is all about innovative measuring technology. Whether it's the new thermal imager models, the monitoring system testo Saveris or the ground-breaking fine particle measuring instrument testo 380 – the measuring technology experts excel through their high level of innovation and broad spectrum of products. Testo measuring instruments help the customer to save time and raw materials, they protect the environment and human health, and improve the quality of products and services. The high-tech instruments are used, for example, in the storage and transport of sensitive goods in the pharmaceutical and food sectors, in the production and quality assurance in industry or in the monitoring of climate data in energy production and by contractors.

In addition to the highly qualified and motivated staff, part of the recipe for success is the above-average investment in the future of the company. Testo AG spends approximately 10% of the annual turnover on Research & Development, consolidating its position as the world market leader in the field of portable and stationary measuring technology.

Testo on location
In the Federal Republic of Germany, six service centres look after the customers and prospective buyers. 30 subsidiaries in Argentina, Australia, Belgium, Brazil, China, France, Great Britain, Hong Kong, Italy, Japan, Korea, Netherlands, Austria, Poland, Switzerland, Spain, Czech Republic, Turkey, Hungary and the USA among others, as well as more than 80 commercial agencies, sell precision measuring instruments from Lenzkirch to all five continents and provide a service.

Tried-and-tested quality measuring instruments

More than 100,000 Testo flue gas analyzers are used by our customers all over the world. Users in industry, the trades and at the authorities rightly place their trust in Testo flue gas analyzers, reflecting Testo's own complete confidence in the quality of its products as confirmed by considerably extended warranty periods.

Qualified all-round service

Even after the warranty expires, Testo does not abandon its customers.
Its worldwide service ensures that help for users is quickly at hand. In Germany there is a 24-hour service (with urgency fee) and 24-hour spare parts service. Naturally, on request the customer gets an instrument on loan during the repair period for a small flat fee.

ISO 9001 certificate

Testo first obtained the ISO 9001 quality certificate in October 1992, and this was reconfirmed in October 1997. This consistently applied, future-oriented quality assurance system ensures the customer will always receive products of unvarying quality. The strict assessment and certification was carried out by an accredited, neutral authority: Germanischer Lloyd. This society regularly monitors application of the ISO 9001 standard at Testo.
Testo instruments for heating measurement technology are presented on the following two pages.

Flue gas analyzer testo 330 LL

- Colour display, self-explanatory graphics and symbols
- Extended measuring menus for comprehensive analyses
- Logger function
- °C, hPa, O_2, CO_2 determination, ambient CO/CO_2 measurement, gas leak measurement, ΔT, P, Eta, qA, gas pipe test
- Long sensor service life of up to 6 years, 4-year warranty
- USB interface
- BImSchV menu, manual CO switch-off, qA mean value

Highly efficient flue gas analyzer testo 320

- High-resolution colour display
- Fast, easy menu guidance
- Storage space for 500 readings
- Flue gas, draught, differential pressure, ambient CO, differential temperature and gas leak detection measurements
- O_2 and CO sensor and flue gas probe with temperature probe
- TÜV-tested according to EN 50379, Parts 1-3

Particulate matter measurement system testo 380

- In combination with testo 330-2 LL, the innovative complete solution for solid fuel, oil and gas systems
- Unrestricted TÜV-tested for limit value stages 1/2 and according to VDI 4206 Sheet 2
- Parallel measurement of particulate matter, O_2 and CO
- Graphical display of all readings in real time
- Particularly economical in terms of operation and maintenance
- Effortless handling and easy transport
- High-tech in a portable case: measurement of all relevant values with just one probe

Portable flue gas measurement system testo 350

- Max. 6 gas sensors (precalibrated, can be replaced by the user)
- Colour display (application-specific menu guidance) and helpful instrument settings
- Removable control unit
- Measuring range extensions with selectable dilution factors
- Integrated Peltier gas preparation

Pressure and leakage tester testo 324

- All measurements for gas and water pipes in one instrument
- High-resolution colour display
- Easy-to-follow menu guidance
- Extremely easy to operate thanks to the single-hose connection
- Case with gas bladder
- Integrated pressure build-up to 300 mbar
- High-precision sensors
- DVGW-compliant measurement results
- 2-year warranty

Pressure gauge for gas fitters and plumbers testo 312-3

- Load and tightness tests on gas pipes
- Pressure testing of water pipes
- Switchable measuring ranges, optimum resolution
- Alarm indicator when undershooting freely adjustable limit values
- Clear display with time

Carbon monoxide monitor testo 317-3

- Warning about hazardous CO concentrations in the ambient air
- No zero phase, instrument ready for use immediately
- Adjustable alarm threshold
- CO zeroing at measuring location
- Visual and audible alarm

Electronic gas leak detector testo 316-2

- Flexible probe for difficult-to-access areas
- Visual and audible alarm thanks to bar display of increasing and hazardous gas concentrations
- Trailing pointer indicates maximum leakages
- Integrated pump
- Earphone connection for safe leakage detection in loud surroundings
- Long service life with battery operation

Notes

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Notes

We measure it.

Subject to change, including technical changes, without notice.

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