



Practical Handbook

# Heating Measurement Technology

Full of useful information



°C

O<sub>2</sub>

CO

NO

NO<sub>2</sub>

NO<sub>x</sub>

λ/qA

Efficiency

3rd Edition

## Foreword

This manual provides an outline on parameters, measurement tasks and measurement engineering in the heating branch. It contains competent answers to frequently asked questions arising out of practical experience. They are based on the worldwide experience of Testo instrument users.

The handbook has been designed to give the serious new user an overall view of emission measurement. For the experienced flue gas analysis professional, the handbook is a valuable reference work. Tips and hints collected in practice for use in practice provide useful advice.

The manual saves you from laborious and time-consuming searching in different sources.

We welcome your ideas and suggestions. Simply write your ideas and suggestions on the last page of this handbook and send it to us by fax.

Your ideas will be incorporated in the next edition.

Management

Burkart Knospe

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## I. What is Flue Gas ?

The increase in all kinds of combustion is contaminating the environment with ever-greater concentrations of pollutants. Smog formation, acid rain and the growing numbers of allergies are direct consequences of this development. The solution to environmentally sound energy production must therefore involve reducing pollutant emissions. Pollutants in flue gas can only effectively be reduced if existing plants operate as efficiently as possible or noxious boilers are shut down. Flue gas analysis offers a means of determining pollutant concentrations and adjusting heating installations for maximum efficiency.

### Units of Measurement

The presence of pollutants in flue gas can be detected from the concentration of the gas components. The following units are generally used:

#### ppm (parts per million)

Like "per cent (%)", ppm describes a proportion. Per cent means "x number of parts in every hundred parts", while ppm means "x number of parts in a million parts". For example, if a gas cylinder contains 250 ppm carbon monoxide (CO), then if one million gas particles are taken from that cylinder, 250 of them will be carbon monoxide particles. The other 999,750 particles are nitrogen dioxide (N<sub>2</sub>) and oxygen particles (O<sub>2</sub>). The unit ppm is independent of pressure and temperature, and is used for low concentrations. If larger concentrations are present, these are expressed as percentages (%). The 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 %

Unit of measurement ppm

An oxygen concentration of 21% volume would be equivalent to a concentration of 210,000 ppm O<sub>2</sub>.

**mg/Nm<sup>3</sup> (milligrams per cubic metre)**

With the unit mg/Nm<sup>3</sup>, the standard volume (standard cubic metres, Nm<sup>3</sup>) is taken as a reference variable and the mass of the pollutant gas given in milligrams (mg). Because this unit varies with pressure and temperature, the volume in normal conditions is taken as reference. Normal conditions are as follows:

Temperature: 0 °C

Pressure: 1013 mbar (hPa)

However, this information alone is not sufficient, because the respective volumes in the flue gas change according to the proportion of oxygen (dilution of flue gas with ambient air). The measured values therefore have to be converted to a particular volume of oxygen, the reference oxygen content (reference O<sub>2</sub>). Only data with the same reference oxygen content can be directly compared. The measured oxygen content (O<sub>2</sub>) of the flue gas is also needed when converting ppm into mg/Nm<sup>3</sup>. The conversions for carbon monoxide (CO) nitrogen oxide (NO<sub>x</sub>) and sulphur dioxide (SO<sub>2</sub>) are given below.

Unit of measurement  
mg/Nm<sup>3</sup>

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

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

Conversions to mg/Nm<sup>3</sup>

The factors in the formulae correspond to the standard density of the gases in mg/m<sup>3</sup>.

Unit of Measurement  
mg/kWh

**mg/kWh (milligrams per kilowatt-hour of energy)**

Calculations are made with fuel-specific data in order to determine pollutant gas concentrations in the energy-related unit mg/kWh. There are thus different conversion factors for each fuel. The conversion factors for ppm and mg/m<sup>3</sup> into the energy-related unit mg/kWh are shown below. Before converting to mg/kWh, the measured emission value concentrations first have to be converted to undiluted flue gas (0 % reference oxygen content).

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.) For this reason the factors should be checked carefully.

Light Fuel Oil EL			
CO	1 ppm	= 1.110 mg/kWh	1 mg/kWh = 0.900 ppm
	1 mg/m <sup>3</sup>	= 0.889 mg/kWh	1 mg/kWh = 1.125 mg/m <sup>3</sup>
NO <sub>x</sub>	1 ppm	= 1.822 mg/kWh	1 mg/kWh = 0.549 ppm
	1 mg/m <sup>3</sup>	= 0.889 mg/kWh	1 mg/kWh = 1.125 mg/m <sup>3</sup>
Natural Gas H (G20)			
CO	1 ppm	= 1.074 mg/kWh	1 mg/kWh = 0.931 ppm
	1 mg/m <sup>3</sup>	= 0.859 mg/kWh	1 mg/kWh = 1.164 mg/m <sup>3</sup>
NO <sub>x</sub>	1 ppm	= 1.759 mg/kWh	1 mg/kWh = 0.569 ppm
	1 mg/m <sup>3</sup>	= 0.859 mg/kWh	1 mg/kWh = 1.164 mg/m <sup>3</sup>

Fig. 1: Conversion Factors for Energy-Related Units

## Components of Flue Gas

The components of flue gas are listed below in the order of concentration in the gas.

### Nitrogen (N<sub>2</sub>)

Nitrogen (N<sub>2</sub>) is the main component (79 vol.%) of the air we breathe. This colourless, odourless, tasteless gas plays no part in combustion. It is drawn into the boiler as ballast, heated and sent to the stack.

Nitrogen

*Typical values in flue gas:* Oil/gas burners: 78 % - 80 %

### Carbon dioxide (CO<sub>2</sub>)

Carbon dioxide is a colourless, odourless gas with a slightly sour taste. Under the influence of sunlight and the green leaf colour, chlorophyll, plants convert carbon dioxide (CO<sub>2</sub>) into oxygen (O<sub>2</sub>). Human and animal respiration converts the oxygen (O<sub>2</sub>) back into carbon dioxide (CO<sub>2</sub>). This creates an equilibrium which gaseous products of combustion distort. This distortion accelerates the greenhouse effect. The threshold limit value is 5000 ppm. At concentrations of over 15% volume (150000 ppm) in breath, loss of consciousness occurs immediately.

Carbon dioxide

*Typical values in flue gas:* Oil burners: 12.5 % - 14 %  
Gas burners: 8 % - 11 %

### Water vapour (Humidity)

The hydrogen contained in the fuel combines with oxygen to form water (H<sub>2</sub>O). This escapes with the water from the fuel and the combusted air, depending on the flue gas temperature (FT), in the form of flue gas moisture (at a high flue gas temperature FT) or as condensate (at a low flue gas temperature).

Hydrogen

### Oxygen (O<sub>2</sub>)

The remaining oxygen not used in combustion in the case of excess air appears as gaseous flue gas and is used to measure combustion efficiency. It is used to determine flue gas loss and carbon dioxide content.

Oxygen

*Typical values in flue gas:*

<i>Oil burners:</i>	<i>2% - 5%</i>
<i>Gas burners:</i>	<i>2% - 6%</i>

*(Note flow heater)*

### Carbon monoxide

#### **Carbon monoxide (CO)**

Carbon monoxide is a colourless, odourless breathing poison and is the product of incomplete combustion. In too high a concentration, it prevents the blood from absorbing oxygen. If for example the air for breathing in a room contained 700 ppm CO, a human being breathing in that air would be dead in 3 hours. The threshold limit value is 50 ppm.

*Typical values in flue gas:*

<i>Oil burners:</i>	<i>80 ppm - 150 ppm</i>
<i>Gas burners:</i>	<i>80 ppm - 100 ppm</i>

### Nitrogen oxide

#### **Nitrogen oxides (NO<sub>x</sub>)**

At high temperatures (combustion), the nitrogen (N<sub>2</sub>) present in the fuel and in the ambient air combines with the oxygen of the air (O<sub>2</sub>) to form nitrogen monoxide (NO). After some time, this colourless gas oxidises in combination with oxygen (O<sub>2</sub>) to form nitrogen dioxide (NO<sub>2</sub>). NO<sub>2</sub> 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<sub>2</sub> components together are called nitrogen oxides (NO<sub>x</sub>).

*Typical values in flue gas: Oil/gas burners: 50 ppm - 100 ppm*

### Sulphur dioxide

#### **Sulphur dioxide (SO<sub>2</sub>)**

Sulphur dioxide (SO<sub>2</sub>) is a colourless, toxic gas with a pungent smell. It is formed by the sulphur present in the fuel. The threshold limit value is 5 ppm. Sulphurous acid (H<sub>2</sub>SO<sub>3</sub>) is formed in combination with water (H<sub>2</sub>O) or condensate.

Typical value in flue gas of oil burners: 180 ppm - 220 ppm

### Note

**Refer to the Testo Technical Handbook, Flue Gas Analysis in Industry, (Part No. 0981 2773), for more information about measuring SO<sub>2</sub>.**

### **Unburned Hydrocarbons (HC)**

Unburned hydrocarbons (HC) are formed when combustion is incomplete and contribute to the greenhouse effect. This group includes methane ( $\text{CH}_4$ ), butane ( $\text{C}_4\text{H}_{10}$ ) and benzene ( $\text{C}_6\text{H}_6$ ).

*Typical value in flue gas of oil burners: < 50 ppm*

Unburned Hydrocarbons

### **Soot**

Soot is almost pure carbon (C) resulting from incomplete combustion.

*Typical value in flue gas oil burners: Smoke spot number 0 or 1*

Soot

### **Particulate Matter**

Particulate matter (dust) is the name given to the smallest solids distributed through the air. These may occur in any shape and density. Particulate matter is formed by the ash and mineral components of solid fuels.

Particulate Matter

## II. Fuel Composition

Fuel essentially consists of carbon (C) and hydrogen (H<sub>2</sub>). When these substances are burned in air, oxygen (O<sub>2</sub>) is consumed. This process is called oxidation. The elements from the combustion air and fuel form new bonds.

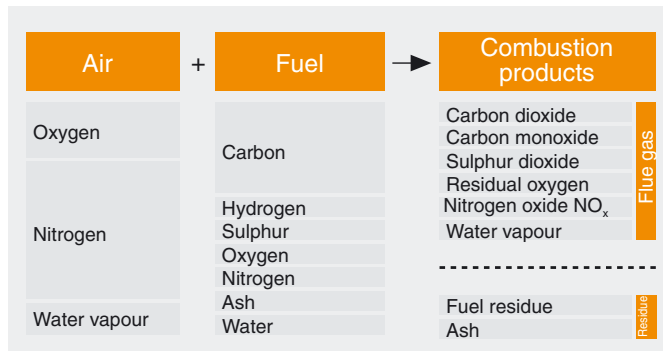


Fig. 2: Fuel Flue Gas Composition

Combustion air comprises oxygen (O<sub>2</sub>), nitrogen (N<sub>2</sub>) and a small proportion of residual gases and water vapour. The theoretical air requirement for complete combustion  $L_{min}$  is not sufficient in practice. In order to achieve optimum complete combustion, more air has to be supplied to the heat generator than theoretically necessary. The ratio between the actual quantity of air and the theoretical air requirement is called the air ratio  $\lambda$  (lambda). Maximum combustion efficiency is reached with slight excess air, when the proportions of unburned fuel and flue gas heat loss are at their smallest. The following combustion model makes this clear:

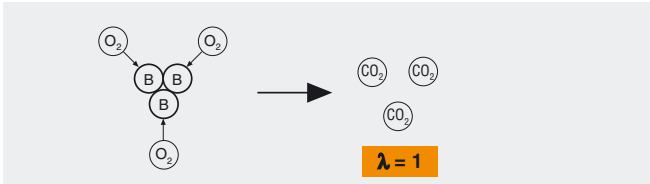


Fig. 3: Ideal combustion

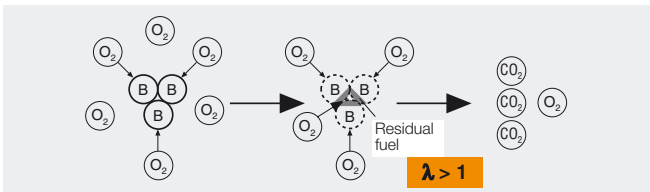


Fig. 4: Actual combustion

### Solid fuels

Solid fuels include hard coal, bituminous coal, peat, wood and straw. The main components of these fuels are carbon (C), hydrogen (H<sub>2</sub>), oxygen (O<sub>2</sub>) and small amounts of sulphur (S) and water (H<sub>2</sub>O). Solid fuels are mainly differentiated by their calorific value, with hard coal having the highest calorific value, followed by bituminous coal, peat and wood. A major problem when handling such fuels is the creation of large quantities of ash, particulate matter and soot. Appropriate mechanical means have to be provided at the combustion site to remove these “wastes” (e.g. shaking grate).

Solid fuels

### Liquid fuels

Liquid fuels derive from petroleum. This is processed at refineries to produce light, medium and heavy fuel oil. Light and heavy fuel oil are mainly used in heating boilers. Light fuel oil is widely used in small combustion plants and is identical with diesel fuel (diesel fuel). Heavy fuel oil has to be heated before use to make it fluid. This is not necessary with light fuel oil.

Liquid fuels

## Gaseous Fuels

### **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<sub>2</sub>).

The principal gaseous fuel used for heating purposes today is natural gas, the main component of which is methane (CH<sub>4</sub>). A small proportion of homes (10 %) is still supplied with town gas, which chiefly comprises hydrogen (H<sub>2</sub>), carbon monoxide (CO) and methane (CH<sub>4</sub>). The calorific value of town gas is only half that of natural gas, however.

### III. Burners

#### Principle of a Burner

The burner 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, which is then led through pipes as a "heat carrier" (heat transfer fluid) to the various consumers (e.g. radiators).

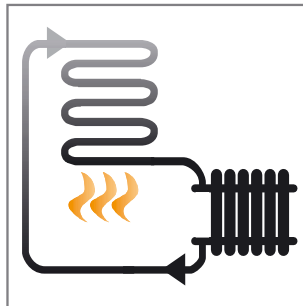


Fig. 5: Illustration of Burner and Boiler

#### Solid Fuel Boiler

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

#### Solid Fuel Boiler

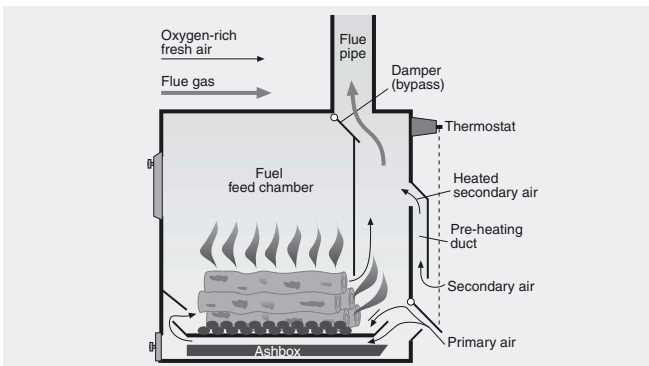


Fig. 6: Simple Grate Furnace

## Atmospheric Gas Burners

### Atmospheric Gas Burners

The principal advantage of gas furnaces is that combustion leaves no residues and the space saving on the fuel feed chamber. 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 flue gas escaping flows through a flow control and into the flue. The role of the flow control is to prevent too great a flue draught or a back draught in the flue system from affecting combustion in the burner.

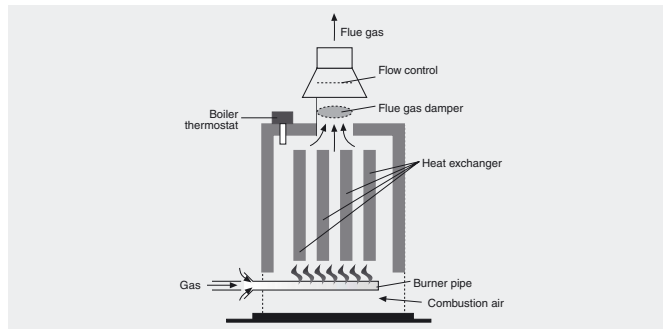


Fig. 7: Heating Boiler with Atmospheric Burner

### Heating Boilers with Forced Draught Oil or Gas Burners

Here, the combustion air is supplied to the burner flame by a blower. Since modern oil and gas boilers are virtually indistinguishable in terms of design, a gas heating boiler can for example be combined with a forced draught oil burner. The advantages of forced draught burners are independence from the flue draught, the smaller flue section, stable combustion and greater efficiency. They do have the disadvantage, however, of the greater expenditure of energy by the boiler.

## Forced Draught Gas Burners

## Condensing Boilers

Unlike net calorific value, the gross calorific value describes the amount of energy released from the fuel during complete combustion in relation to the amount of fuel involved. In the case of the net calorific value, the heat of evaporation is deducted from the water vapour generated during combustion. For this reason, the gross calorific value is principally higher than the net value.

Condensing boilers make use of the heat of evaporation added to combustion heat by means of a second heat exchanger. The flue gas temperatures in condensing instruments fall short of the usual values in conventional boilers. Condensing boilers work below the usual boiler flue gas temperatures. 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 dew point varies from one fuel to another, being around +58 °C in the case of natural gas and around +48 °C in that of fuel oil. If the flue gases are cooled, the dew point 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<sub>2</sub>), which partly turns into sulphurous acid in the condensate, gas is mainly used in condensing technology. In view of the condensate that occurs, the flue system has to be insensitive to humidity and acid-resistant.

## Condensing systems

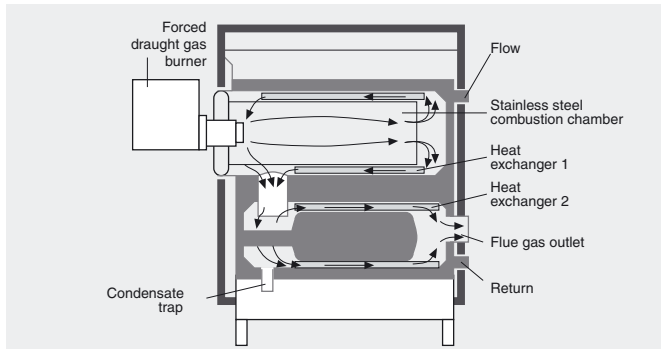


Fig. 8: Design of a Gas Condensing Boiler

Practical information

- Efficiencies of over 100 % are possible, because the energy used is measured in terms of the net calorific value.
- Take care with  $\text{NO}_x$  measurements: the proportion of  $\text{NO}$  to  $\text{NO}_2$  may be as much as 50:50. This means that the  $\text{NO}$  and  $\text{NO}_2$  concentrations should be measured separately in order to measure  $\text{NO}_x$ .

## IV. Parameters

### Directly Measured Parameters

#### Smoke spot number

The smoke spot number is determined using an instrument similar to a bicycle pump. A certain quantity of flue gas is drawn through a filter paper by a certain number of pump strokes. The degree of blackening of the resulting spot on the filter paper is compared with a scale of grey tones with different numbers. The smoke spot number derivative determined in this way (according to Bacharach) is between 0 and 9. The smoke spot number is not measured in gas burners.

Smoke spot number

#### Oil Derivatives (Oil residues)

When combustion is incomplete due to insufficient atomizing, the unburned hydrocarbons (HC) form a deposit on the filter paper used to measure soot. They can be detected by observation and demonstrated using a solvent (acetone).

Derivatives

#### Ambient Air Temperature (AT)

The ambient air temperature is measured at the burner inlet. In the case of burners not dependent on ambient air, the temperature is measured at an appropriate point in the supply pipe.



Ambient Air Temperature

Fig. 9: Temperature measurement in an air/flue gas stack

#### Flue Gas Temperature in the Hot Spot

The flue gas temperature is measured in the flue gas hot spot. This is where the temperature and carbon dioxide (CO<sub>2</sub>) concentration is highest and the oxygen (O<sub>2</sub>) level at its lowest.

Flue Gas Temperature

#### Buoyancy/Flue Draught

In natural draught boilers, the buoyancy or flue draught is the basic requirement for the flue gas flow through the flue. Because the

Draught

density of the hot waste gases is lower than that of the colder external air, a partial vacuum is created in the flue. This is known as the draught. This draught sucks in the ambient air and overcomes all resistances of the boiler and flue pipe. In pressurized boilers, the pressure ratios in the flue can be disregarded because in this case a forced draught burner creates the pressure needed to draw away the flue gases. A smaller flue diameter can be used in plants of this type.

### **Nitrogen Oxides (NO<sub>x</sub>)**

Measuring nitrogen oxides offers a means of checking the combustion measures taken to reduce nitrogen oxide output from burners. The term nitrogen oxides (NO<sub>x</sub>) refers to the total of nitrogen monoxide (NO) and nitrogen dioxide (NO<sub>2</sub>). In small furnaces (other than condensing burners), the proportion of NO to NO<sub>2</sub> is always the same (97 % NO, 3 % NO<sub>2</sub>). Nitrogen oxides (NO<sub>x</sub>) are therefore normally calculated from the nitrogen monoxide (NO) measurement. If precise NO<sub>x</sub> measurements are required, the nitrogen monoxide (NO) and nitrogen dioxide (NO<sub>2</sub>) have to be measured and added together.

## **Nitrogen Oxide**

### **Flow Pressure**

When checking gas heaters, the gas flow pressure in the supply pipe must be measured and checked against the value specified by the manufacturer. This is done using differential pressure measurement. Differential pressure measurement is used to set nozzle pressure on gas heaters whereby instrument power is adapted to the heat required.

## **Pressure**

## Calculated Parameters

Formulae which form the basis for calculating the following parameters are listed and explained briefly in the Appendix.

### Flue Gas Loss (qA) (German Calculation)

Flue gas loss is the difference between the heat level of the flue gas and the heat level of the ambient air, in relation to the net calorific value of the fuel. It is therefore a measure of the heat level of the flue gas conducted through the flue. The higher the heat gas loss, the worse the efficiency and therefore energy use resulting in higher emissions from the heating unit. For this reason, flue gas loss in burners is limited. After determining the oxygen content and the difference between the flue gas and ambient air temperature, the fuel-specific factors of flue gas heat loss can be calculated. Instead of the oxygen content, the carbon dioxide (CO<sub>2</sub>) concentration can be used to calculate. The flue gas temperature (AT) and oxygen content or carbon dioxide (CO<sub>2</sub>) content have to be measured simultaneously at a single point.

### Flue Gas Loss

An optimum setting of the heating system based on flue gas loss calculations pays for itself:

$$1 \% \text{ flue gas loss} = 1 \% \text{ additional fuel consumption or}$$

$$\text{Energy loss/Year} = \text{Flue gas loss} \times \text{Consumption of fuel/year}$$

The following example should clarify the point:

$$\text{Calculated flue gas loss} = 10 \%$$

$$\text{Consumption of fuel/year} = 3000 \text{ l light fuel oil}$$

Energy loss corresponds to approx. 300 l light fuel oil/year

## Carbon Dioxide

### Carbon Dioxide Concentration (CO<sub>2</sub>)

The carbon dioxide level in the flue gas provides an indication of the quality (efficiency) of the burner. If the proportion of CO<sub>2</sub> is as high as possible with slight excess air (complete combustion), the flue gas heat losses are at their lowest.

For each fuel there is a maximum possible flue gas CO<sub>2</sub> level (CO<sub>2 max</sub>) which is determined by the chemical composition of the fuel and which is not in fact reached in practice.

CO<sub>2 max</sub> values for different fuels:

- Light fuel oil      15.4 vol.% CO<sub>2</sub>
- Natural gas        11.8 vol.% CO<sub>2</sub>
- Coal                 18.5 vol.% CO<sub>2</sub>

The CO<sub>2 max</sub> values and flue gas oxygen level can be used to calculate the CO<sub>2</sub> values in flue gas.

### Air Ratio λ

The oxygen necessary for combustion is supplied to the boiler plant via the ambient air. To achieve complete combustion, more than the theoretically necessary quantity of air has to be available for combustion. The ratio of the excess combustion air to the theoretical air requirement is called the air ratio λ (Lambda).

## Lambda

The air ratio is determined from the concentration of CO, CO<sub>2</sub> and O<sub>2</sub>. These relations are shown in the combustion diagram, (compare Fig. 10). During combustion each CO<sub>2</sub> level is related to a specific CO level (with air shortage/λ<1) or O<sub>2</sub> level (with excess air/λ>1)

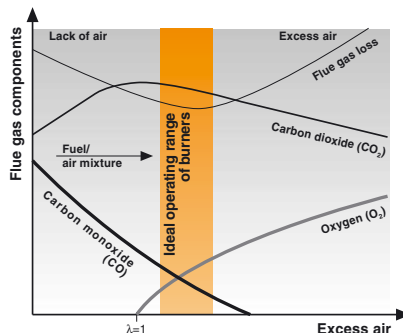


Fig. 10: Combustion diagram

Since the  $\text{CO}_2$  value shows a maximum it is not clear in itself so that a  $\text{CO}$  or  $\text{O}_2$  measurement is required. When operating with excess air (normal), determination of the  $\text{O}_2$  is preferred nowadays. There is a specific diagram for each fuel and a separate value for  $\text{CO}_{2 \text{ max}}$  (cf. Appendix).

### Net Efficiency

Net efficiency is the calculated efficiency in flue gas analysis when no water vapour and thus only the sensible heat is contained in the flue gas. For calculation therefore the net calorific value of the fuel is used.

### Gross Efficiency

Gross efficiency is the calculated efficiency in flue gas analysis when the latent heat of the water vapour is contained in the flue gas. Therefore in the calculation of the flue gas loss the gross calorific value of the fuel is used.

### Dew Point Temperature

The dew point of a gas is the temperature at which the water vapour contained in the gas changes to the liquid state. This change is called condensation, the liquid formed is condensate. Below the dew point temperature, moisture exists as liquid, above the dew point as gas. The formation and decomposition of fog or dew depending on temperature is an example. The dew point temperature is determined by the moisture level: the dew point of air with a 30 % moisture level is approx. 70 °C while dry air with a moisture level of only 5 % has a dew point of only 35 °C.

Efficiency

Dew Point Temperature

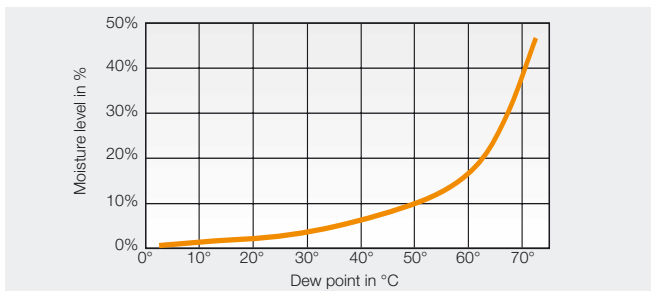


Fig. 11: Moisture level in air depending on dew point (air pressure: 1013 mbar)

## V. Basic Flue Gas Measurement

### Oil and Gas Burners

#### Step 1

#### Measuring the ambient air temperature (AT)

The flue gas probe is held at the intake point of the burner and the temperature of the ambient air is measured. This temperature value is saved or is measured constantly with a special temperature probe. The temperature is needed to calculate flue gas loss.



Fig. 12: Measuring the ambient air temperature

#### Step 2

#### Measuring flue gas loss (qA)

The flue gas probe is introduced into the flue gas duct through the measurement opening. Through constant temperature measurement, the hot spot of the flue gas i.e. the point with the highest temperature, is sought. Mechanical devices are used to position the flue gas probe. The flue gas temperature is measured at the tip of the flue gas probe. The flue gas is sucked in via the flue gas probe using a diaphragm pump and then enters the analyser. The oxygen concentration ( $O_2$ ) is measured at one point

and the carbon dioxide concentration ( $\text{CO}_2$ ) is calculated based on this. The flue gas loss ( $q_A$ ) in the analyser is calculated from these measured values ( $\text{AT}$ ,  $\text{FT}$ ,  $\text{O}_2$  or  $\text{CO}_2$ ). The calculated flue gas loss value is rounded off. Decimal values up to 0.50 are rounded down, higher decimal values are rounded off.



Fig. 13: Determining flue gas loss

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

- Condensate drops on the thermocouple (temperature sensor) while the flue gas probe is in a vertical position.

**Remedy:** Flue gas probe should be mounted horizontally so that the condensate can be extracted or can drip away.

**Flue gas loss which is too high can be caused by the following:**

- Incorrect ambient air temperature through calibration with hot flue gas probe. **Recommendation:** measure with separate ambient air probe.
- Incorrect fuel set.
- The hot spot temperature fluctuates in atmospheric gas burners. For this reason, a reference measurement is made difficult.

Practical information

Predefined tolerance points are added to the limit values because of the measurement uncertainties at different combustion settings. The limit value plus the maximum tolerance percentage points result in the assessment value. The rounded off measured result for the flue gas loss should be the same as or smaller than the assessment value. This definitive assessment value is calculated as shown in the diagram below.

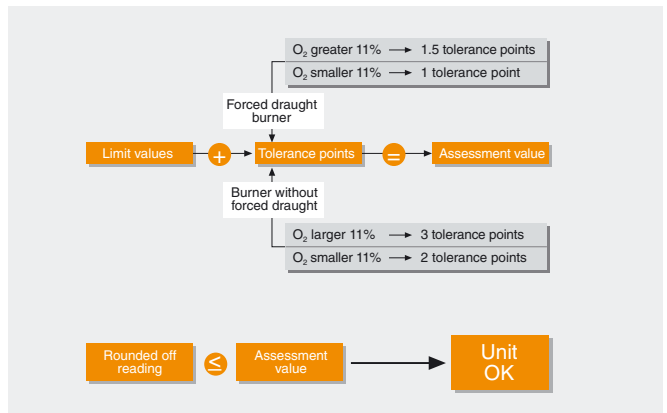


Fig. 14: Diagram on how to calculate the assessment value

### Determining the smoke spot number in oil burners

When measuring the smoke spot number, the smoke tester is placed in the flue gas duct with filter paper and flue gas is sucked in via even pumping. The filter sheet is then removed and is checked for the presence of oil derivatives. If the filter is discoloured due to oil derivatives, then the filter should not be used to determine the smoke spot number. Three separate measurements have to be carried out. The blackening on the filter is compared with the Bacharach scale and the smoke spot number is then determined. If the filter has become damp during a measurement due to the development of condensate, the measurement must be repeated. The final value for the smoke spot number is determined by calculating the arithmetic mean value from three separate measurements. The smoke spot number is not calculated in gas burners.

Step 3

Fig.: 15: Limit values of smoke spot number in liquid fuels

Nominal heat output in KW	Type of burner	Smoke spot number		
		Unit set up or fundamentally changed		
		to 30.9.1988	from 1.10.1988	from 1.11.1996
more than 4	Forced draught burner	2	1	1
up to 11	Condensation burner	3	3	3
more than 11	Forced draught burner	2	1	1
	Condensation burner	2	2	2

In systems which are unknown to you, soot should first be measured so that the analysers are not subjected to too much pressure unnecessarily.

### **Measurement of flue draught**

In order to determine the flue draught (buoyancy), necessary to conduct away flue gases in atmospheric burners, the flue probe is again inserted through the opening for the measurement in the flue gas duct. In this position the flue measurement or pressure measurement is started by first zeroing the pressure sensor. The flue gas probe is removed and the air pressure around the burner is measured. The analyser automatically indicates the differential pressure between the surrounding environment and the flue with a negative sign. The zero point can also be set outside the flue gas pipe in order to be able to recognise fluctuations in pressure. Flue gas is not drawn in for this type of measurement.

Typical value of flue draught:

Positive pressure boiler with  
forced draught burner + gross calorific value: 0.12 to 0.20 hPa  
(mbar) positive pressure

Oil vapourisation burner and  
atmospheric gas burner: 0.03 to 0.10 hPa (mbar) negative  
pressure

**Too low values during draught measurement could be caused by the following:**

- Value of pressure sensor is not zeroed correctly.
- The pressure path in the analyser is not pressure-tight.
- A draught in the atmospheric gas burners which is too strong can lead to increased CO values. This can be avoided by using a draught valve control system.

**Practical information**

## VI. CO Measurement on Gas Burners

Gas burners are checked to protect the safety of the system operators. It must be ensured that the flue gases are drawn off completely. This is particularly important in gas systems independent of ambient air and with flow control as the flue gases are conducted out only via the flue draught. If the flue gas paths became clogged, the flue gases would enter the boiler room via the flow control thus putting the operator at risk. To prevent this, the carbon monoxide (CO) concentration is measured in burners with an open combustion chamber and in forced draught gas burners and the flue gas paths are checked. This safety measure is not necessary in forced draught gas burners since the flue gases are forced into the flue.

### Safety checks on gas burners with an open combustion chamber and on forced draught gas burners.

The following checklist includes all the tasks needed for a complete inspection of the flue gas paths.

*Fig. 16: Checklist for inspection of flue gas paths in atmospheric gas systems:*

Task	OK	Objections
Check burner's readiness to operate		
Close all windows and doors in the vicinity of the burner		
Observe influence of ventilators available		
Check vents for a free cross-section		
Check flue gas hose for free cross-section		
Check combustion chamber for dirt and defects		
Check heated gas paths for free cross-section		
Start up gas burner		
Check that flue gas damper functions		
Assess combustion by observing the flame aspect		
Check the exiting gas in the burner for problem-free disposal of flue gases		
Check that the flow control functions		
Measure CO concentration in flue gas		
Supplement working documents		
Set up inspection log		

### **Measuring the carbon monoxide concentration (CO) in flue gas**

The CO level and the CO<sub>2</sub> or O<sub>2</sub> levels are measured in flue gas diluted with fresh air (after flow control) with a probe. For a clear statement that the system is working properly the CO should be calculated back to the undiluted flue gas. It is possible that the CO level will be inaccurate if air is added. The oxygen level of the flue gas is needed for this calculation. The O<sub>2</sub> concentration must be measured simultaneously with the CO concentration.

#### **A single CO measurement is not sufficient**

The undiluted CO concentration is calculated in the analyser and is expressed as CO<sub>undiluted</sub> (puCO). 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 level drops to the normal operating value.

**Important**

Limit values for the CO concentration referred to undiluted flue gas:

CO<sub>undiluted</sub> larger 500 ppm: System maintenance necessary

CO<sub>undiluted</sub> larger 1000 ppm: Objection

**Important**

**Only diluted CO concentrations can be used to assess a burner since the volume parts of the oxygen have already been calculated. The readings may be inaccurate if air is added (dilution).**

**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 poisoning. This measurement should be carried out before all other measurements.

CO concentration in the air		Inhalation time and effects
30 ppm	0.003 %	Threshold limit value (max.concentration which can be breathed in over a period of 8 hours)
200 ppm	0.02 %	Light headache within 2 to 3 hours
400 ppm	0.04 %	Headache in forehead area within 1 to 2 hours, spreads to whole head area
800 ppm	0.08 %	Dizziness, nausea and tremors in limbs within 45 minutes. Unconscious within 2 hours
1600 ppm	0.16 %	Headache, nausea and dizziness within 20 minutes. <b>Death</b> within 2 hours
3200 ppm	0.32 %	Headache, nausea and dizziness within 5 to 10 minutes, <b>death</b> within 30 minutes
6400 ppm	0.64 %	Headachen and dizziness within 1 to 2 minutes. <b>Death</b> within 10 to 15 minutes
12800 ppm	1.28 %	<b>Death</b> within 1 to 3 minutes

- Cigarette smoke influences the measurement (min. 50 ppm).
- Smoker's breath influences the measurement by approx. 5 ppm.
- Zeroing should ideally be carried out in fresh air.

## VII. Calculating Efficiency

### In Conventional Heating Systems

Net efficiency is the calculated efficiency in flue gas analysis when no water vapour and thus only the sensible heat is contained in the flue gas. For calculation therefore the net calorific value of the fuel is used.

$$\eta = 100\% - q_A$$

Gross efficiency is the calculated efficiency in flue gas analysis when the latent heat of the water vapour is contained in the flue gas. Therefore in the calculation of the flue gas loss the gross calorific value of the fuel is used.

$$q_A = \left[ (AT - VT) \left[ \frac{A_2}{(21 - O_2)} + B \right] \right]$$

The combustion and flue gas temperature as well as the oxygen concentration in the flue gas are measured simultaneously for this calculation and offset with fuel-specific factors (A<sub>2</sub>, B) and the oxygen level in the air (21) which are stored in the analyser. To ensure that the correct values for A<sub>2</sub> and B are used, the corresponding fuel selection in the analyser is required.

### Condensing furnaces

Since condensation heat is reclaimed in modern condensing furnaces, Testo introduced the additional value XK for correct calculation. The value 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 analyser, (cf. Fig. 24), the proportional coefficient XK indicates the reclaimed vaporisation heat of the condensed water whereby the flue gas loss may drop or become negative. The efficiency level related to the net calorific value can take on values of more than 100% (cf. following example).

**Proportional coefficient XK**

Example of light fuel oil

A2 = 0.68	--> qA = 19 % (proportional coefficient XK)
B = 0.007	
FT = 30 °C	--> qA = -5 % (with proportional coeff. XK)
AT = 22 °C	--> h = 100 % - (-5%)
O <sub>2</sub> = 3%	= 105 %
XK = 5.47 %	

Using another example, the diagram below clearly shows why efficiency in condensing boilers is greater than 100 %.

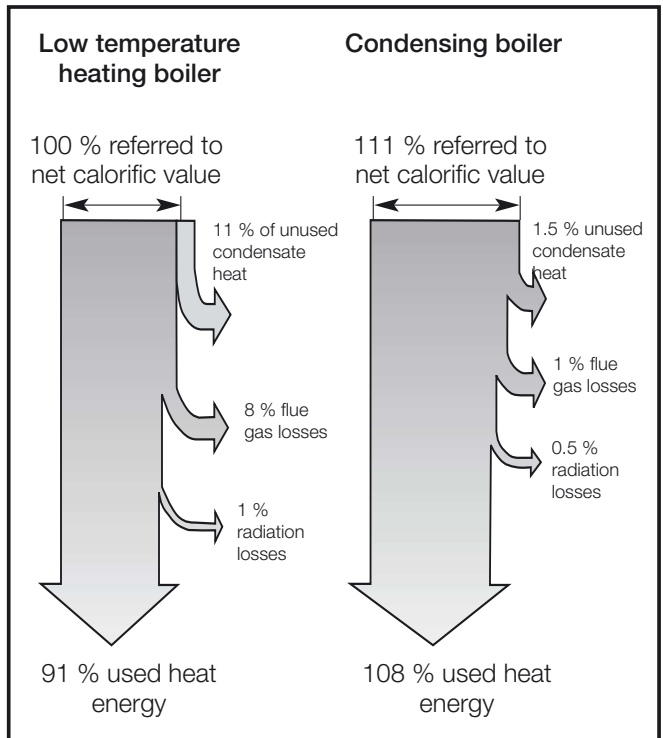


Fig. 17: Energy losses in low temperature and condensing boilers.

- Once the fuel has been put to use, heat and water vapour develop.
- If the heat is measured fully, 100% of the net calorific value is obtained.
- If the energy contained in the water vapour (condensation heat) is added the gross calorific value is obtained.
- The gross calorific value is always higher than the net calorific value.
- The net calorific value is always taken as the basis when calculating efficiency.
- However, condensing boilers also use condensation energy in addition to the net calorific value which means that efficiency can be greater than 100%.

#### Note

**Condensing boilers still function with losses which is clear if efficiency is related to the net calorific value instead of the gross calorific value.**

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

Fig.18: Fuel-specific dew point temperatures of flue gas. Calculated for standard pressure (1013 mbar) and stoichiometry combustion.

## VIII. NO<sub>2</sub> Measurement on Gas Burners

Nitrogen oxides NO<sub>x</sub> represent the total of nitrogen monoxide (NO) and nitrogen (NO<sub>2</sub>). Normally, the ratio of the NO concentration to



the NO<sub>2</sub> concentration is constant (97 % NO, 3 % NO<sub>2</sub>). For this reason, an NO measurement is sufficient to determine the NO<sub>x</sub> concentration. However, if mixed fuels or condensing boilers are used, this ratio alters. The two components (NO and NO<sub>2</sub>) therefore have to be measured separately and added to produce NO<sub>x</sub>.

Fig. 19: testo 300 XXL with integrated gas preparation to measure NO<sub>2</sub>

### Important

Because nitrogen dioxide (NO<sub>2</sub>) is water-soluble, dry flue gas must be used to determine the NO<sub>2</sub> concentration accurately, as otherwise the NO<sub>2</sub> dissolved in the condensate will not be taken into account. This is why gas preparation is always carried out before nitrogen dioxide measurements to dry the flue gas before the actual measurement.

### Practical information

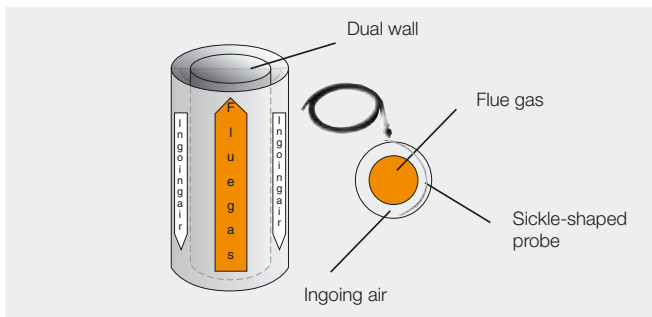
- If measuring in the vicinity of an electrostatic filter, the flue gas probe should be earthed because of the static charge.
- If a high particulate matter and soot level is expected, clean, dry filters should be used. A preliminary filter may be used.

## IX. Function tests on heating units

### Leak test in flue gas paths

The flue gas paths in heating units, independent of ambient air, are checked for leaks by measuring the  $O_2$  level in the dual wall. This test must be carried out in modern systems. The  $O_2$  concentration in the intake air in the dual wall is usually 21%. If values below 20.5% are measured, this is an indication that there is a leak in the inner flue gas duct; the system has to be checked.

Fig. 20:  $O_2$  dual wall clearance measurement with sickle-shaped probe



The sickel-shaped probe from Testo (e.g. for testo 300, Part no. 0632.1244) enables fast and efficient measurement of  $O_2$  in the dual wall.

The conventional method of testing for leaks in a flue gas pipe by checking pressure is only used nowadays in flues. Air is introduced to the flue gas pipe using a pressure tester until there is a pressure of 200 Pa (previously: 1000 Pa). The amount of air escaping through a leak is determined by maintaining the pressure. The flue gas pipe is considered leak-proof if it has a leak rate of  $50 \text{ l} / (\text{h}\cdot\text{m}^2)$ .



## Flow control by electronic spillage detector

The faultless extraction of flue gases from the flow control unit is required to ensure that a burner functions efficiently. There are several options available to determine whether the flue gases are drawn off correctly. Flue gas emission is determined by condensation on the dew plate or on the flue gas tester, by an increase in temperature measured by a thermocouple or by the visualisation of flow using a small flue pipe.

The following errors could cause a back flow to the flow control unit:

- Leaking flue gas pipe caused by missing or deformed seals, material fatigue in the seals, pipe connections which have slipped out, pitting, corrosion or cracks.
- Confinement of heating gas draughts by particles or deformation.
- Air supply unavailable due to well sealed environment.
- Blocked or dirt ingressed ventilation openings.
- Restrictions or blockages in the area of the flue gas line.

### Possible faults



Fig. 21: Detection of escaping flue gases in the flow control unit using the testo 317-1 spillage detector

## Problem diagnosis using a fibrescope

The revolutionary flexible shaft adjusts into almost any position. The comfort grip handle allows one hand operation with all the TestoView controls at your finger tips, thus saving you time and money.



Fig. 22: Maintenance and inspection of heating unit without need for dismantling when testo 318 is used

## X. Burner Tuning

### Small burners

The aim of environmentally sound plant operation is complete combustion (stoichiometric combustion) of the fuel and best possible utilisation of the plant. One determining parameter for optimum operation is the combustion air setting. In practice, slight excess air has been found to be ideal for plant operation. More air is supplied to combustion than is theoretically necessary. The following rule applies to practical applications:

*Maximum combustion efficiency is only achieved when the flue gas heat loss is at its lowest with low excess air.*

Fig. 23 shows the concentrations of flue gas components as a function of the quantity of air set.

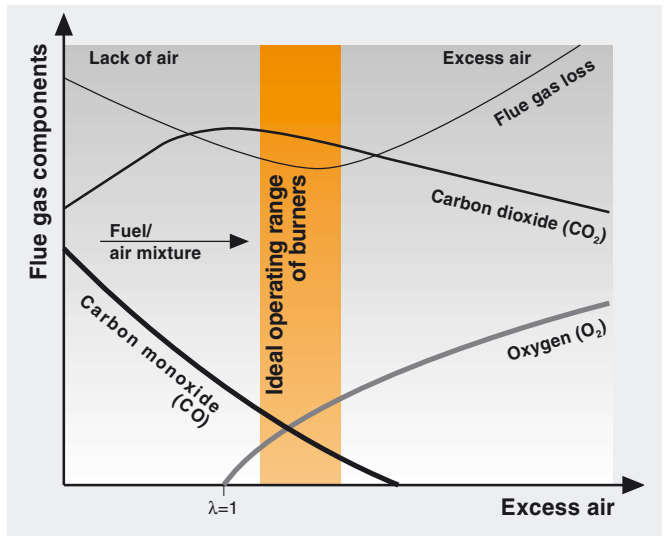


Fig. 23: Combustion Diagram

In simplified form, the following rules of thumb apply:

For maximum efficiency:	CO <sub>2</sub> should be as high as possible
	CO should be within safe limits (very low)

### Low temperature and condensing boilers

How are the boilers tuned?

- Adapt burner to the rated heat capacity of boiler.
  - Adjust flue gases to limit values such as flue gas loss.
  - Adjust new systems such that the soot derivative is below 1.
  - Adjust CO<sub>2</sub> concentration in new systems to approx. 11-13 %.
  - Adjust flue gas temperature as specified by the manufacturer.
  - Optimize CO concentrations.
- **If the differential temperature corresponds to the manufacturer's specifications then the system is, in the most cases, correctly regulated**
  - **A large amount of condensate develops if the flue gas temperatures are low which can result in incorrect readings or damage to the analyser. Remedy: use of a gas drier instead of a condensate trap (See Fig. 24).**

Practical information



Fig. 24: The gas drier guarantees accurate readings and protects the testo 300 analyser from damage caused by condensate.

### Gas heating systems

The aim of the adjustment is the most environmentally sound and best possible use of the fuel. When operating gas burners the gas flow volume must be adjusted and monitored. This is done by measuring the gas flow pressure. This is specified by the manufacturer and must be adjusted following installation. A further option is the nozzle pressure which influences combustion.

#### How is a gas heating system adjusted?

- Adjustment of flue gas to limit values,
- Adjustment of correct gas flow pressure with differential pressure measurement (e.g. testo 300). The correct pressure value can be found in the manufacturer's data sheets. With this adjustment the correct gas pressure is achieved in the nozzle.
- The instrument capacity can be adapted to the required heat via the nozzle pressure. Incorrect gas pressure could result in the following:

Gas pressure too high	<ul style="list-style-type: none"><li>• Flame goes out</li><li>• Incomplete combustion</li><li>• High CO concentrations</li><li>• Risk of poisoning</li><li>• High gas consumption</li></ul>
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Gas pressure too low	<ul style="list-style-type: none"><li>• Flame goes out</li><li>• High flue gas losses</li><li>• High O<sub>2</sub> level</li><li>• Low CO<sub>2</sub> level</li></ul>
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- **Do not carry out pressure measurement on a main pipe (observe measurement ranges).**
- **Ensure that there are no leaks between the sample point and analyser (risk of explosion).**

Practical information

## XI. Leakage Test on Gas and Water Pipes in accordance with DVGW

- Before starting work on pipes used to conduct gas, the shut-off device should be closed and protected from opening by unauthorised persons (e.g. by removing the key or handwheel). Wherever gas escapes or can be discharged, it must be ensured that the gas can be safely disposed of via ventilation or by conducting it outside via a hose. The shut-off device should only be opened if all the openings of the blocked pipes through which the gas could flow are tightly closed. The above does not apply to external maintenance work on the pipes.
- Leaks in gas pipes must be detected using gas detection instruments or foam in accordance with DIN 30657; gas tests using flames are not allowed. Temporary sealing measures are only allowed if a dangerous situation has to be dealt with immediately.
- Pipes with operating pressures up to 100 mbar are subjected to a pre-test and main test. Tests are to be carried out before the cable is plastered over or covered over and your connections are coated over or encased. The tests can also be carried out section by section.
- All tests should be documented.

### Pre-test

The pre-test is a load check for 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 with gas pipes are not allowed. The pre-test can be carried out on pipes with fittings if the rated pressure stage of the fittings corresponds at least to the test pressure.

The pre-test should be carried out with air or inert (low reaction) gas (e.g. nitrogen, carbon dioxide), but not with oxygen, and with a test pressure of 1 bar. The test pressure should not drop during the

test which lasts 10 minutes.

### Main test

The main test is a leak test for pipes including fittings but without gas instruments and respective control and safety devices. The gas counter can be included in the main test. The main test should be carried out with air or inert (low reaction) gas (e.g. nitrogen, carbon dioxide), but not with oxygen, with a test pressure of 110 mbar. Following temperature compensation, the test pressure should not drop during the test lasting minimum 10 minutes. The measuring instrument must be totally accurate such that a drop in pressure of 0.1 mbar is registered.

### Measuring leak quantities

Low pressure pipes which are in use or disused are tested for serviceability if leaks are suspected, on the customer's address or if reconnected. The pipe first undergoes a load check whereby it is subjected to a test pressure of 3 bar for a period of 3 to 5 minutes. The object of the load check is to detect corrosion damage. The pipe is pumped with air up to the respective test pressure and the drop in pressure in one minute is measured.

- a) Unlimited serviceability if the quantity of gas leaking is less than 1 litre per hour at operating pressure.
- b) Reduced serviceability if the quantity of gas leaking is between 1 and 5 litres an hour at operating pressure.
- c) No serviceability if the quantity of gas leaking is more than 5 litres an hour at operating pressure.

In order to establish the amount of gas leaking, the amount in the pipe is determined based on the measured or estimated length of the pipe. The amount of gas leaked can be shown in graphs based on the drop in pressure per minute, as measured by a differential pressure meter, and the amount of gas in the pipe using the DVGW Work Sheet G 624 or the special DVGW approved Testo slide rule.

Determine the amount of gas leaked using a slide rule

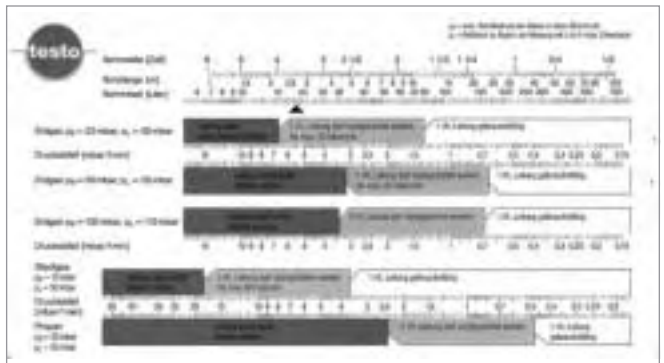


Fig. 25: Determine serviceability using the Testo slide rule

The use of a slide rule makes it unnecessary to enter data in the analyser. The graphical and computed value for the amount leaked is determined using the following formula:

$$V_B = V (p_1/p_2 - 1) \times p_B/p_L \times f \times 60$$

$V_B$  Amount of gas leaked during operation in l/min

$V$  Amount in pipe in l

$p_1$  Absolute test pressure at the beginning of the measurement in mbar  
(barometer reading + initial test pressure)

$p_2$  Absolute test pressure at the end of measurement in mbar (barometer reading + final test pressure)

$p_B$  Maximum operation of gas in mbar

$p_L$  Test pressure at the beginning of the measurement with air in mbar (positive pressure)

f Factor taking into account type of gas

As an alternative, instruments to measure the quantities leaked are available (not yet from Testo), for which there are currently no instrument test guidelines. This makes the graphical/computed measurement of the leaked amount the only traceable method available.

The following measures can be taken in accordance with the degree of serviceability:

- a) If there is unlimited serviceability, the pipes can be operated.
- b) If serviceability is reduced, the pipes have to be sealed or renewed. An additional option exists for pipes with an operating pressure of up to 100 mbar in accordance with the DVGW Worksheet G 624. According to Section 7.1.3 pressure tightness must be restored within 4 weeks of reduced serviceability having been determined.
- c) If serviceability is non-existing, the pipes have to be taken out of operation. The same specifications apply to repaired pipe sections when resuming work as for newly laid pipes.

These measures are indicated on the Testo slide rule.

**A pressure drop test should be carried out following all repair work (main test, cf. page 45)**

**Important**

### **Pressure test on water pipes**

This test is made up of the pre- and main test and is carried out on newly installed pipes and pipes which have not yet been plastered over or encased. It is used if the test with water cannot be carried out due to the risk of frost or corrosion. For safety reasons, the main test is carried out using 110 mbar prior to the pre-test with max. 3 bar (in rated pipe widths to DN 50) or max. 1 bar (in rated pipe widths to DN 50). This test does not replace the load test with water pressure as required by DIN 1988-2 TRWI 11.1.

## Detecting gas leaks

There is a risk of poisoning or explosions if natural gas escapes from a pipe or heating unit. Because natural gas is normally non-odorous, odour is added. If there is a smell of gas, the room must be ventilated immediately. The gas pipe can then be checked for leaks using a gas leak protection probe. For safety reasons, 20 % of the lower explosion limit should not be exceeded.



Fig. 26: Detecting leaks in gas pipes using testo 316

## XII. Measuring Instruments

The requirements made on portable flue gas analysers pose a challenge to any measuring instrument manufacturer. The severe conditions of the measuring environment and the need to make measurements without a mains power supply call for a high level of technical know-how and customer-oriented design. Instruments have to be compact, light, easily portable and easy to use. Other important points are the need to have measured values available quickly and low energy consumption and maintenance requirements.

### Sensors

The requirements made of 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 measured values, small space requirement, maintenance by the user and low manufacturing costs are the main advantages of this type of sensor. A great deal of research and development work is necessary, however, to create a suitable environment for gas measuring cells. This includes optimising the gas paths, making appropriate allowance for cross-sensitivities and designing gas measuring cells that are easy for the user to replace.

### Operation of a chemical two electrode sensor

Three-electrode sensors are used to determine concentrations of toxic gases. The operation of these instruments is explained with reference to the carbon monoxide (CO) sensor.

A typical two-electrode sensor is the oxygen sensor ( $O_2$ ). Fig. 27 shows how an oxygen sensor operates.

## Oxygen sensor

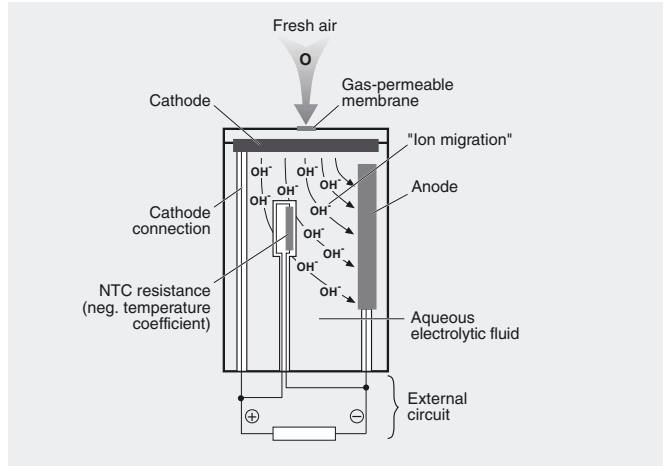
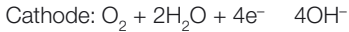


Fig. 27: Diagram of an Oxygen Sensor

Operation of an oxygen sensor in keywords:

- $O_2$  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 produces a current conduction in the outer electric circuit in proportion to the  $O_2$  concentration.
- This means the higher the concentration, the higher the current conduction.
- The voltage drop in the resistance is measured and is electronically processed.
- The integral resistance with negative temperature coefficient serves to compensate for the temperature influences, thus ensuring the behaviour of the sensor is temperature-stable.
- The lifetime of an oxygen sensor is approx. 3 years.

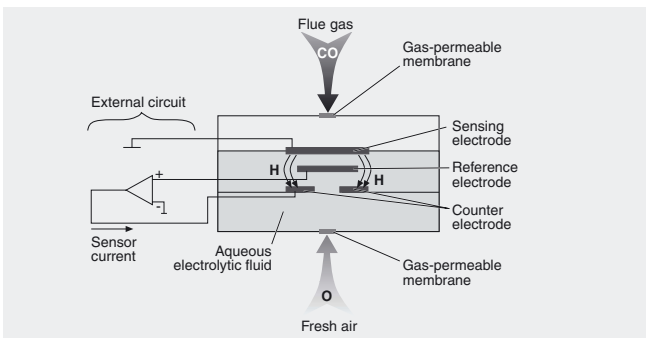
## Reaction equations



Excessive gas concentrations shorten the lifetime of the measuring cells.

Practical information

## Operation of a chemical three electrode sensor for toxic gases



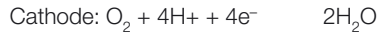
Carbon monoxide sensor

Fig. 28: Diagram of a Carbon Monoxide Sensor

Operation of a three electrode sensor in keywords (using a CO sensor as an example):

- The CO molecules migrate through the gas-permeable membrane to the sensing electrode.
- Chemical reaction: formation of  $\text{H}^+$  ions.
- The ions migrate to the counter electrode.
- Second chemical reaction with the help of  $\text{O}_2$  in the fresh air: current conduction in the external circuit.
- The reference electrode stabilises the sensor signal.
- Lifetime is approx. 2 years.

**Reaction equations:**



**Practical information**

**Excessive gas concentrations and cold, moisture and dirt particles shorten the lifetime of the measurement cells.**

**Operation of a semi-conductor sensor to measure combustible gases**

The semi-conductor sensor is used for measuring combustible gases such as HC, H<sub>2</sub> and CO. It is used in the detection of gas leaks. The semi-conductor sensor structure is shown in Fig. 29.

**Semi-conductor sensor**

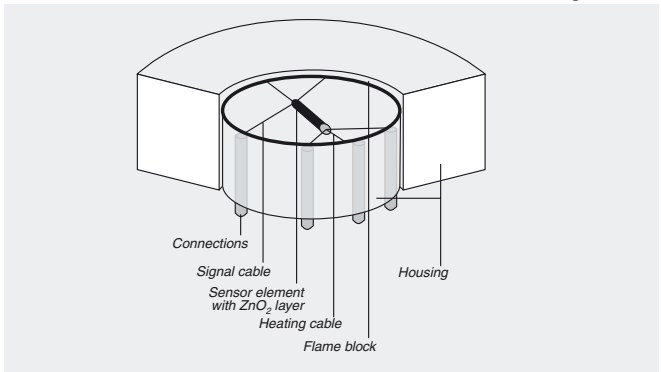


Fig. 29: Structure of a semi-conductor sensor

The operation of a semi-conductor sensor in keywords (taking its use in a gas leak detection probe as an example):

- The sensor element is heated to a working temperature of 300 °C.
- A high-impedance resistance develops via a stannic oxide when heated.
- If there are combustible gases (HC, H<sub>2</sub>, CO) in the ambient air of the sensor element, i.e. inside the sensor, they will be deposited on the stannic oxide layer.

- Their electrical resistance will then decrease.
- A visual or audible alarm is triggered.

**Excessive gas concentrations and cold, moisture and dirt particles shorten the lifetime of the measurement cells.**

Practical information

## Electronics

The trend in development and manufacture is towards ever smaller and more complex measuring instruments. Computer-aided design (CAD) and automated production make it possible to fit complex electronic circuits into the smallest possible space. The boards are designed on the multilayer principle and the electronic components mounted using the latest technology (surface mounted design, SMD). A test computer (incircuit tester) tests the assembled boards, identifying any faults at an early stage. Faulty boards can be inexpensively corrected and returned to the production circuit. Once the boards and measuring cell have been assembled inside the carefully designed case, the instruments are operationally tested on a computer-assisted test bench and calibrated using test gas. DIN ISO 9000 certification guarantees consistent quality, and this is complemented by competent after-sales service. The end result is measuring instruments which meet the requirement of flue gas analysis.

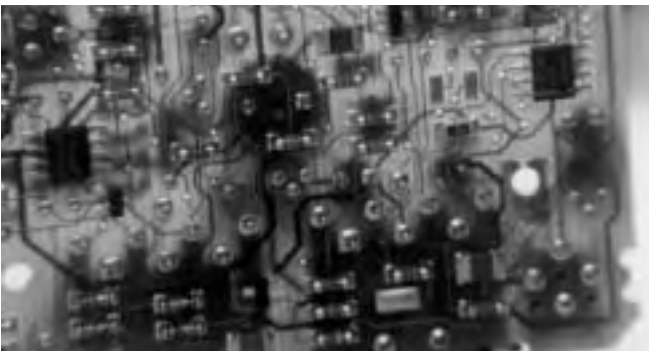


Fig. 30: SMD Board using Multilayer Technology

## Design

The layout of the gas path is a major consideration when designing portable flue gas analysers. Because leaks will distort the measurement result, connections along the gas path must be absolutely tight. Places where condensate can precipitate have to be avoided to prevent damage to the measuring cells. Modern flue gas analysers use location-independent condensate traps which collect the condensate, protecting the measuring instrument. The following Figure shows the arrangement of the gas path in simplified form.

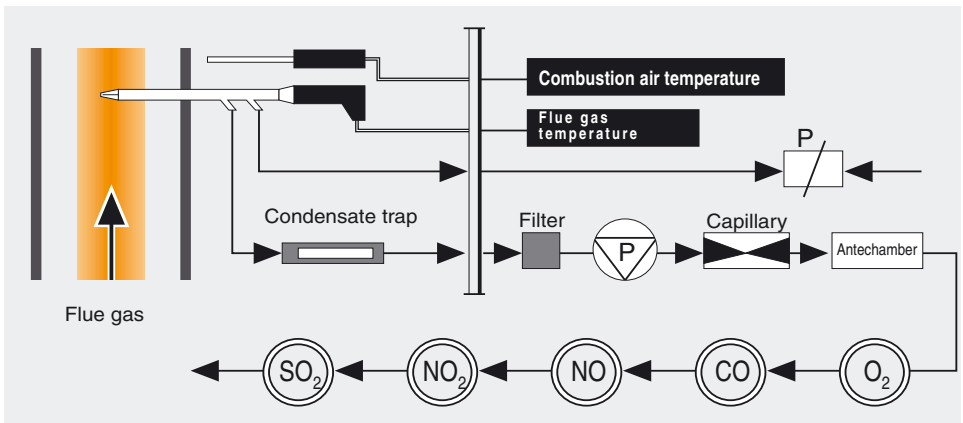


Fig. 31: Simplified Illustration of the Gas Path in a Flue Gas Analyser

The flue gas is drawn through the sampling probe by the pump P and sent to the condensate trap. The thermocouple built into the probe tip measures the flue gas temperature.

The condensate trap and integral filter “dry” the flue gas and retain dust and soot particles. The gas sample passes through the pump P and is forced through a capillary (narrowing the gas path) into an antechamber which damps the hammer effect produced by the diaphragm pump. On leaving the antechamber, the gas to be measured flows into the measuring cells, which - depending on the design - measure the O<sub>2</sub>, CO, NO, NO<sub>2</sub>, and SO<sub>2</sub> concentrations.

To measure the flue draught, no flue gas is drawn in. The waste gas travels directly from the probe via a dedicated gas path to the analyser pressure sensor, where the draught is measured.

The combustion air temperature is measured by a temperature sensor directly connected to the measuring instrument.

## XIII. Appendix

### Calculation Formulae (German)

Flue gas heat loss

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

FT: Flue gas temperature

AT: Ambient air temperature

A2/B: Fuel-specific factors (see Table)

21: Oxygen level in air

O<sub>2</sub>: Measured O<sub>2</sub> value (rounded to the nearest whole number)

XK: Proportional coefficient which expresses qA as a minus value when the dew point is not reached. Necessary for measurements on condensing burners. If the dew point temperature is not undershot XK = 0.

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

Siebert formula to calculate flue gas loss. It is used when the fuel-specific factors A2 and B (cf. Table) are zero.

Table of fuel-specific factors

Fuel	A2	B	f	CO <sub>2max</sub>
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	0	0.74	20.0
Briquette	0	0	0.75	19.3
Bituminous coal	0	0	0.90	19.2
Anthracite	0	0	0.60	18.5
Coke-oven gas	0.6	0.011	-	-
Town gas	0.63	0.011	-	11.6
Test gas	0	0	-	13.0

Fuel-specific factors

### Air Quantity L:

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

L: Actual air quantity  
 λ: Air ratio  
 L<sub>min</sub>: Theoretical air requirement

Air Quantity

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### Carbon dioxide concentration (CO<sub>2</sub>):

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

CO<sub>2max</sub>: Fuel-specific maximum CO<sub>2</sub> value

CO<sub>2</sub> concentration

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### Air Ratio λ:

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

CO<sub>2max</sub>: Fuel-specific maximum CO<sub>2</sub> value  
 CO<sub>2</sub>: Calculated CO<sub>2</sub> value in flue gas  
 O<sub>2</sub>: Measured O<sub>2</sub> value (rounded to the nearest whole no.)  
 21: Oxygen level in air

Lambda

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### Undiluted carbon monoxide concentration (CO<sub>undiluted</sub>):

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

CO: Measured CO value  
 λ: Excess air

CO<sub>undiluted</sub> concentration

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### Efficiency of system η:

$$\eta = 100 - qA$$

qA: Flue gas loss

Efficiency

## Calculation Formulae (British)

The following equations are used to calculate the listed values:

CO<sub>2</sub> value:

$$\text{CO}_2 = \text{CO}_{2\text{max}} \times \frac{\text{O}_{2\text{set}} \times \text{O}_2}{\text{O}_{2\text{set}}}$$

CO<sub>2max</sub>: Fuel-specific  
max. CO<sub>2</sub> value  
CO<sub>2set</sub>: Oxygen content in the air  
O<sub>2</sub>: Measured oxygen content

Flue gas loss:

$$\text{EffG} = 100 - \left[ \left[ \frac{K_{\text{gr}} \times (\text{FT} - \text{AT})}{\text{CO}_2} \right] + \left[ \frac{X \times (2488 + 2.1 \times \text{FT} - 4.2 \times \text{AT})}{Q_{\text{gr}} \times 1000} \right] + \left[ \frac{K1 \times \text{CO}}{\text{CO}_2 + \text{CO}} \right] \right]$$

$$\text{EffN} = 100 - \left[ \left[ \frac{K_{\text{net}} \times (\text{FT} - \text{AT})}{\text{CO}_2} \right] + \left[ \frac{X \times (210 + 2.1 \times \text{FT} - 4.2 \times \text{AT})}{Q_{\text{gr}} \times 1000} \right] + \left[ \frac{K1 \times Q_{\text{gr}} \times \text{CO}}{Q_{\text{net}} \times \text{CO}_2 + \text{CO}} \right] \right]$$

FT: Flue gas temperature

AT: Ambient temperature

K<sub>gr</sub>, K<sub>net</sub>, K<sub>1</sub>, Hydrogen content of fuel H, Moisture content of fuel MH<sub>2</sub>O, Q<sub>gr</sub>, Q<sub>net</sub>, ref are all fuel-specific factors.

$$\lambda = \left[ \frac{\text{O}_{2\text{set}}}{\text{O}_{2\text{set}} - \text{O}_2} - 1 \right] \times 100$$

$$\text{uCO} = \text{CO (ppm)} \times \frac{\text{O}_{2\text{set}}}{\text{O}_{2\text{set}} - \text{O}_2}$$

$$\text{rat} = \frac{\text{CO (ppm)}}{\text{CO}_2 (\%) \times 100}$$



## Presenting Testo Instruments

### **Measurement technology for Environment, HVAC, Industry**

The Testo AG in Lenzkirch/Black Forest, a medium-sized firm, was founded in 1957. More than 1000 employees develop, manufacture and sell environmental measuring technology worldwide: portable electronic measuring instruments and sensors for temperature, humidity, velocity, flue gas, water analysis, light, sound, pressure and rpm.

### **Innovation**

Innovation includes all activities involved in understanding our customers' current and future needs. Testo's extraordinary highly innovative research and development departments convert these needs to products which are then made available to our customers worldwide at the right time, at the right price and with the right features. 70% of our turnover comes from products which are not older than 3 years showing clearly Testo's innovation power.

### **Testo on location**

A network of sales office and customer centres in Germany serve new and existing customers. Subsidiaries in Argentina, Australia, Belgium, Brazil, China, France, Great Britain, Hong Kong, Italy, Japan, Korea, Holland, Austria, Poland, Portugal, Switzerland, Spain, Czech Republic, Turkey, Hungary and the USA as well as more than 40 agencies sell precision measuring instruments from Lenzkirch to all five continents and provide reliable Testo service.

### **A High Level of Quality**

More than 100,000 Testo flue gas analysers are in use by our customers worldwide. The users in industry, the trades and authorities rightly place their trust in Testo's flue gas analysers, reflecting Testo's own complete confidence in the quality of its own products as confirmed by considerable extended warranty periods.

### **Considerably Extended Warranty Periods**

Testo offers a two-year warranty on its flue gas analysers. From the customer's point of view, this is equivalent to a price reduction, bearing in mind that the costs of a measuring instrument break down into:

- 1) Purchase cost: the purchase price is unchanged.
- 2) Costs during use, e.g. there are no costs for repair or spare parts in the first two years because any such expenses are met by Testo (with the exception of maintenance work and working parts).

### **Qualified Round-the-Clock Service**

And even after the warranty expires, Testo does not abandon its customers: the worldwide service ensures help is soon at hand. Testo also provides a service for instruments which are 15 years old.

### **ISO 9001 Certificate**

Testo first gained the ISO 9001 quality certificate in October 1992 which 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 a neutral authority: Germanischer Lloyd. This society regularly monitors enforcement of the ISO 9001 standard at Testo.

Testo instruments for heating measurement technology are presented on the following two pages. If you would like more information, please use the Request for Information form on the last page.

# Testo Measuring Instruments for Heating Measurement Technology

## Measurements on gas pipes



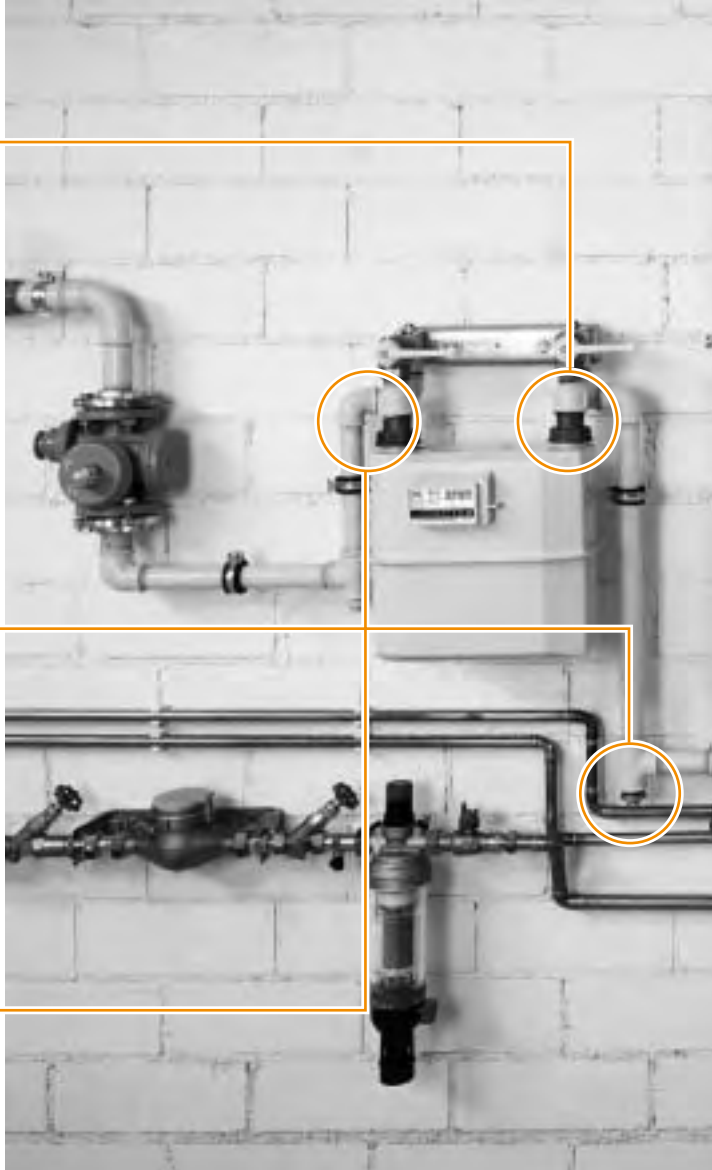
Pre-test with testo 312-3

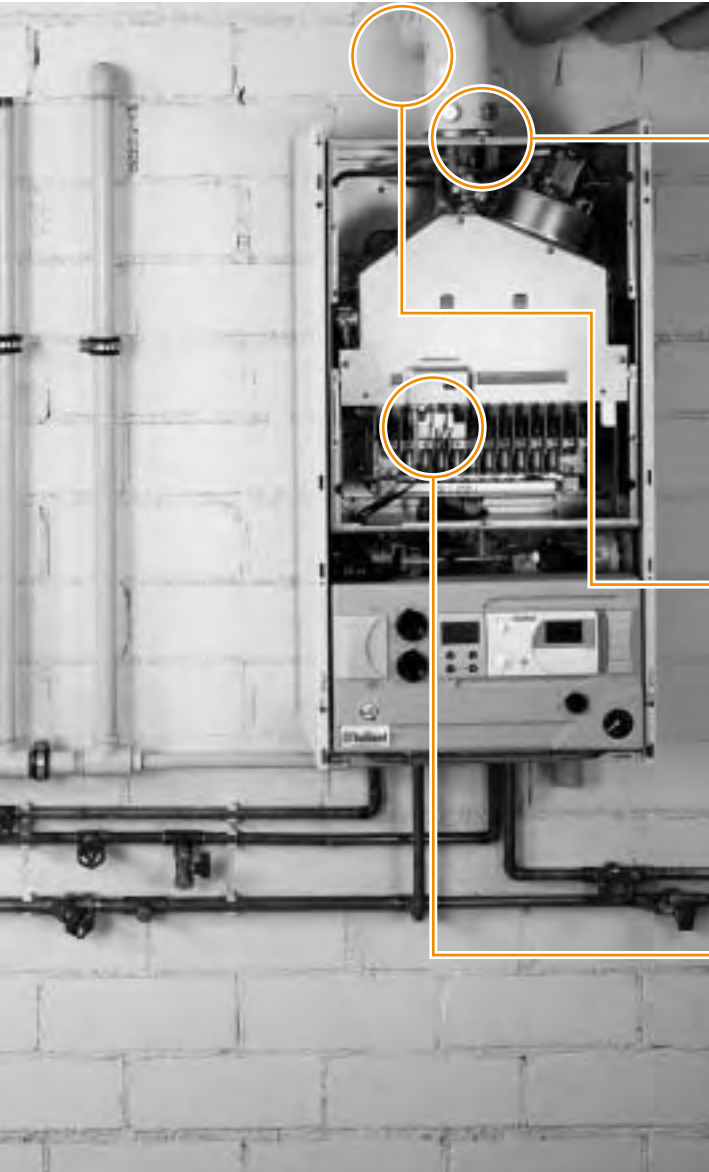


Main test with testo 312-2/3



Gas leak detection w. testo 316





Measurements on heating units



Flue gas test with testo 305, 325 or 300



Flue gas spillage test using testo 317



Gas pressure test with testo 312-1/2

## Master Copy

Copy this page as often as required and send the filled out page to us by mail or fax.

### Suggestions for improvement / Request for product information

<p>Sender:</p> <p>Name _____</p> <p>Department _____</p> <p>Address _____</p> <p>_____</p> <p>Tel. _____</p> <p>Fax _____</p> <p>Date, Signature _____</p>
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- I would like additional information on the following products:
- testo 305  testo 325  testo 300 M/XL  testo 300 XXL  Compact gas drier
- testo 312  testo 316  testo 317

In order to keep this flue gas handbook up-to-date and continue adapting it to the requirements in the field we would be grateful for your suggestions for improvement.

- I would like to make the following suggestion for improvement:

Chapter	Page	Topic	Suggestion