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Content

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.

1. Checking the gas connection pressure

Prior to commissioning, the gas connection pressure must be tested as flow pressure. It must be within the permissible pressure range according to the manufacturer's documentation (in the case of natural gas usually 18 to 25 mbar). If this is not the case, the gas boiler may not be commissioned 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 the gas shut-off valve closed. When the gas tap is opened, the burner is run to full capacity via the respective operating menu and the gas connection pressure measured as flow pressure. When the connection pressure is correct, the measurement connection is closed again and commissioning continues.

A flue gas analyzer, e.g. testo 300, is essential for carrying out settings

Reading the gas connection and nozzle pressure on the testo 510

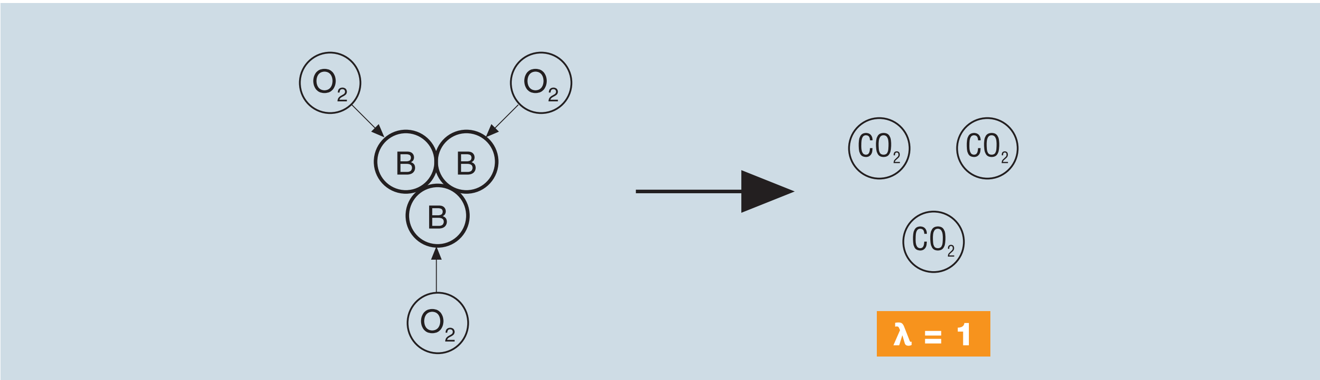
Possible consequences of incorrect gas pressure

Gas pressure too high	Gas pressure too low
• Flame goes out • Incomplete combustion • High CO concentration (danger of poisoning) • High gas consumption	• Flame goes out • High flue gas losses • High O_2 content • Low CO_2 content

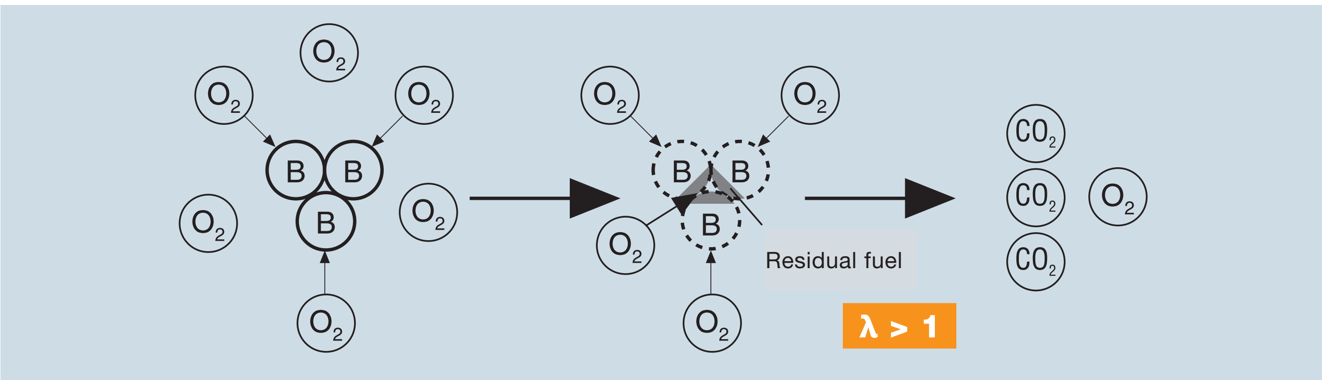
2. Setting the gas-air ratio

The aim of environmentally compatible system operation is complete combustion of the fuel and the best possible utilization of the system. The combustion air volume setting is a crucial parameter for optimum operation. In practice, a small amount of excess air has proven to be ideal for system operation. A little more air is supplied for 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:

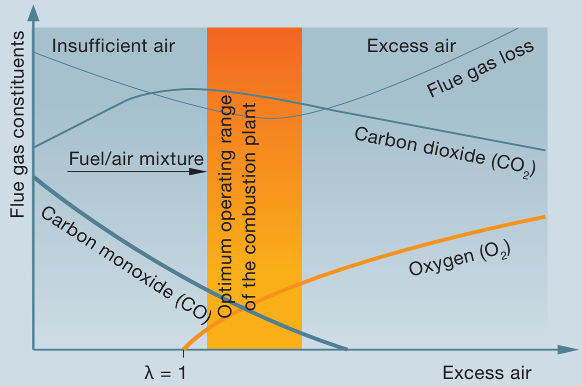


Ideal combustion



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 content (for insufficient air/λ<1) or O_2 content (for excess air/λ>1). The CO_2 value is not clear in itself, as it runs beyond 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}.



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. This is to be explained as follows:

1. Within the insufficient air range, the available fuel is not completely burned and 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.

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. To do this, the sealing screw is removed from the measurement connection for the nozzle pressure and a pressure gauge connected to it. 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 set 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, bring 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 manufacturer's specifications. In some cases, manufacturers also give setting values for minimum appliance output. Carry out the setting in accordance with the procedure for the maximum output. Once these basic settings have been carried out, the configured gas boiler must be inspected. This involves measuring the flue gas loss (qA) and the carbon monoxide content (CO) in the flue gas.

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

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%

Examples of CO_2 setting values

3. Preparing the flue gas analyzer

- 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 drawn into the analyzer. For some measuring instruments (testo 300* and testo 330i), the flue gas is diluted with fresh air when the threshold value is exceeded and the measurement need not be interrupted.
- Tightness test: in order to prevent fresh air being drawn into the analyzer without being noticed and distorting the measurement results, a tightness test should be carried out prior to the measurement. This involves the flue gas probe being sealed with a cap, so that the flow rate on the measuring gas pump goes to zero after a certain time. If this is not the case, it indicates an instrument leak and you should 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 duct, ideally in the fresh air. The measuring instrument draws 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 analyzers, such as the testo 300** or the testo 330i, the probe may also be located in the flue gas duct during zeroing. Here, both the measurement gas path and the pressure sensor are decoupled from the flue gas probe during zeroing and the gas concentration or the pressure around the flue gas analyzer is used for zeroing.

4. Determining 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 utilization and the higher the emissions of a heating system. For this reason, the permissible flue gas loss from combustion plants is limited in some countries. After determining the oxygen content and the difference between the flue gas and combustion air temperature, the flue gas loss can be calculated using the fuel-specific factors. 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. Instead of the oxygen content, the carbon dioxide (CO_2) concentration can also be used for the calculation. The flue gas temperature (FT) and oxygen content or carbon dioxide (CO_2) content need to be measured simultaneously during the measurement process at a single point. The AT should also be measured simultaneously.

Finding the ideal setting for the heating system by calculating the flue gas loss pays off:
- 1% flue gas loss = 1% increase in fuel consumption
- Energy loss/year = flue gas loss x fuel consumption/ year

For a calculated flue gas loss of 10% and an annual fuel oil consumption of 3,000 l, the energy loss corresponds to approx. 300 l fuel oil/year.

An unusually high flue gas loss may be caused by the following:
- Incorrect zeroing of the analyzer
- Wrong fuel setting

A sudden drop in the flue gas temperature may be caused by the following:
- There is condensate on the thermocouple (temperature sensor)
- Remedy: mount the flue gas probe horizontally or pointing downwards, so that the condensate can drip off.

*Applies only to the versions of the testo 300 with the „Dilution“ function
**Applies only to the versions of the testo 300 with the „Probe zeroing in flue gas“ function

Calculation formulae for flue gas loss

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

FT: flue gas temperature
AT: combustion air temperature
A2/B: fuel-specific factors (see table)
21: oxygen content 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 measurement on condensing systems. If the dew point temperature is reached, the XK value = 0.

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

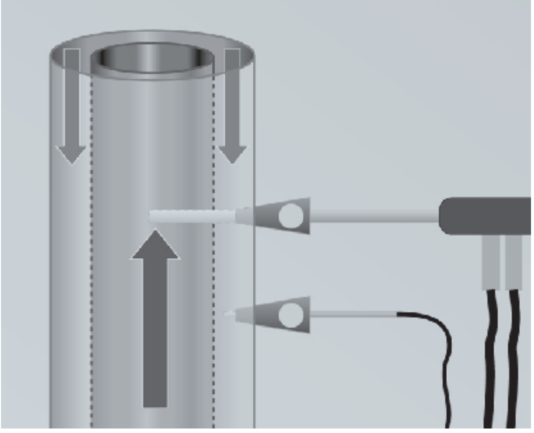
Siegert formula to calculate flue gas loss.
This is used when the fuel-specific factors A2 and B (cf. table) are zero.

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, coal	–	–	0.74	20.0
Briquettes	–	–	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

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 analyzer 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:



Measurement on balanced flue systems

Flue gas temperature (FT)

The thermocouple in the flue gas probe measures the flue gas temperature. The flue gas probe is inserted through the measurement aperture into the flue gas duct (the distance between the measurement aperture and the boiler should be at least twice the diameter of the flue gas duct). The point with the highest flue gas temperature (i.e. the centre of flow) is sought through constant temperature measurement 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.

O_2 concentration

Oxygen that has not been used in combustion in the event of excess air is discharged as a gaseous flue gas component and is a measure of combustion efficiency. The flue gas is drawn 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 as a basis for calculating the CO_2 concentration in the flue gas, which is used for setting gas-powered condensing boilers, as described above.

Carbon dioxide (CO_2) concentration

Instead of the oxygen content, as previously stated the carbon dioxide concentration can also be used to calculate the flue gas loss. If the proportion of CO_2 is as high as possible with low excess air (complete combustion), then 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 attained 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 setting 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 various fuels:

- Fuel oil 15.4 vol. % CO_2
- Natural gas 11.8 vol. % CO_2
- Coal 1.5 vol. % 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, the appropriate system fuel must be input into the flue gas analyzer prior to each measurement.

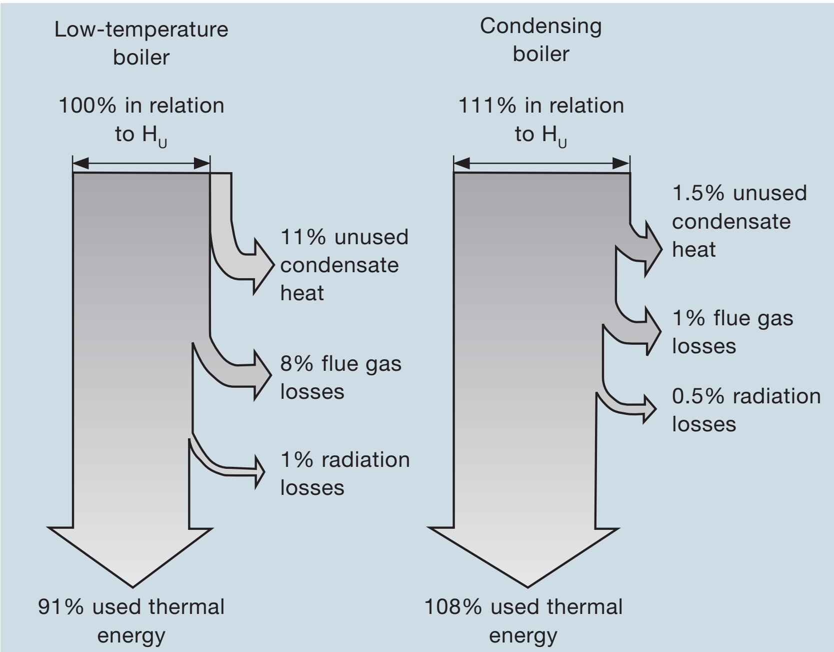
5. Calculating the efficiency (η)

For 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).

For condensing systems
Since condensation heat is reclaimed in modern condensing systems, for correct calculation Testo introduced the additional value XK, which includes utilization 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, 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. This means the efficiency in relation to the net calorific value can assume values of more than 100%.

For 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 graphic uses another example to illustrate once again why efficiency in condensing systems is greater than 100%:



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. Measuring 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 flue 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 drawn in, overpowering all the resistances of the boiler and flue gas pipe. In the case of pressurized boilers, the pressure conditions in the flue need not be taken into account, since 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 centre of flow of the flue gas duct. As described above, the pressure sensor of the analyzer must be zeroed prior to measurement.

Typical flue draught values:
Pressurized boiler with forced-draught burner + gross calorific value: 0.12 to 0.20 hPa (mbar) overpressure oil vaporization burner and atmospheric gas burner: 0.03 to 0.10 hPa (mbar) overpressure

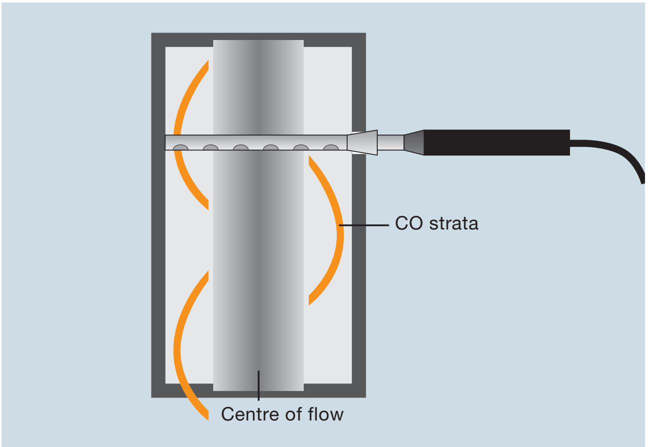
Draught measurement values that are too low may be due to the following:
- Draught path in the analyzer leaking
- Pressure sensor not correctly zeroed

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

7. Measuring the CO concentration

Checking the CO value allows conclusions about combustion quality to be drawn and is conducive to the safety of the system operator. If the flue gas channels became blocked, the flue gases would for example enter the boiler room via the flow control in the case of atmospheric gas burner systems, 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 channels 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 then that the increased CO content during system start-up 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 for a short time. As when determining the flue gas loss, the measurement is carried out in the centre of flow of the flue gas duct. However, since the flue gas is diluted with fresh air, the CO content must be calculated back to undiluted flue gas (otherwise the CO content could be manipulated by the addition of air). For this, the analyzer calculates the undiluted CO concentration with the oxygen content measured simultaneously in the flue gas duct and displays this as CO undiluted.

For atmospheric gas systems, the CO concentration in the flue gas pipe is not the same all over (stratification). The sampling must therefore be carried out at a concentration of > 500 ppm using a multi-hole probe (e.g. dual wall clearance probe from Testo with order number 0632 1260). The multi-hole probe features a series of holes, which record the CO concentration over the entire diameter of the flue gas pipe.



CO measurement with the multi-hole probe

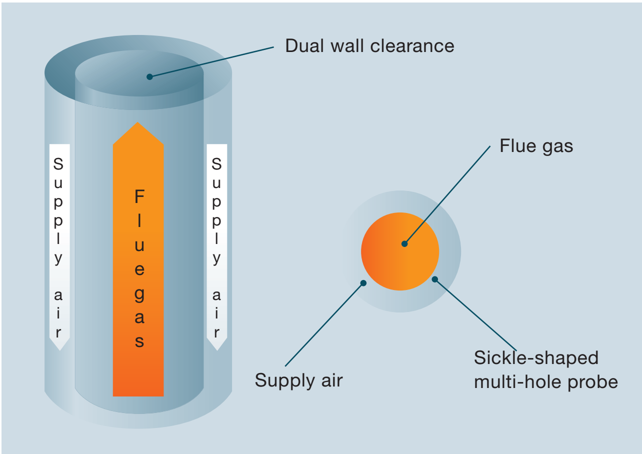
8. Flue gas channel inspection

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. It is held next to the flow control where it detects the precipitation of moisture contained in the flue gas.

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

Use of the testo 317-1 gas spillage detector

Tightness test of flue gas channels:
In balanced flue heating systems, the flue gas channels are checked for leaks by measuring the O_2 level of the supply air in the dual wall clearance. The O_2 concentration in the supply air in the dual wall clearance is usually 21%. If values below 20.5% are measured, this must be interpreted as a leak in the inner flue gas duct and the system needs to be checked.
The sickle-shaped multi-hole probe from Testo (order number 0632 1260) 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.
A gas spillage detector such as the testo 317-1 (order number: 0632 3170) enables fast and reliable detection of leaks on flue gas channels.



O_2 dual wall clearance measurement with sickle-shaped multi-hole probe

9. Maintenance of the analyzer

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

Additional inspection of combustion plants

Checking nitrogen oxides (NO_x)
You can check the technical 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 NOx are normally calculated after measuring nitrogen monoxide NO. If exact NO_x measurements are required, the nitrogen monoxide (NO) and nitrogen dioxide contents (NO_2) need 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%.

Due to 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 must be earthed because of the static charge.
- If high particulate matter and soot loads are expected, cleaned, dry filters must be used. A preliminary filter may be used.

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 gas can lead to high CO concentrations and therefore result in the risk of poisoning for the operator. A CO concentration of 0.16 vol. % (1,600 ppm) and above in inhaled air will result in death for humans.
This measurement should always 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 eight working hours in Germany)
200 ppm 400 ppm	0.02% 0.04%	Slight headache within 2 to 3 hours 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%	Headache and dizziness within 1 to 2 minutes, **death** within 10 to 15 minutes
12,800 ppm	1.28%	**Death** within 1 to 3 minutes

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

This involves the smoke tester being inserted into the flue gas duct with a filter paper in place and the flue gas being 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. The aim should be to achieve a smoke number of 0.

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). In the case of high smoke numbers, the basic setting of the oil burner 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 that needs 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 setting 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.

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 utilization 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, specifications are given for CO_2 or CO values, excess air or flue gas loss/efficiency to enable optimization of combustion. These values are determined using a flue gas analyzer.

With the yellow flame burner
the fuel oil is atomized via a nozzle and oil gasification takes place within the flame. During combustion a yellowish flame can be seen.

With the 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 upstream from the flame. This produces a bluish flame.

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You will find all analyzers for heating systems here:
www.testo.com

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