Testo
White paper
testo 340 and testo 350

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Influencing factors and measurement parameters for burner and boiler systems and their importance for optimizing efficiency and emissions.

Heat generation in burner and boiler systems

Boiler systems provide the necessary thermal energy for power generation, the heating of buildings, cement and glass manufacture and many other industrial applications. With fuels such as coal, oil or gas, they are capable of generating large quantities of energy with good overall efficiency. Because large quantities of fuel are used for heat generation and large amounts of flue gases arise from the combustion, setting boiler systems involves achieving a high level of efficiency along with the lowest possible pollutant emissions – especially as the statutory emission limit levels for pollutants such as NO_X, CO and CO_2 are becoming stricter and stricter.

For this reason, the emission values are determined during the commissioning and maintenance of boilers and burners, as well as for official measurements. The cost-effectiveness of the system and the setting of the burner can be comprehensively assessed using these data.
It is important to know the basic principles of the combustion process and to understand the influence of the individual measurement and control parameters on performance and pollutant emissions in order to optimize the efficiency of the boiler system and to be able to adjust the emissions to the legal requirements.

Fig. 1: Boiler systems provide the thermal energy required for numerous processes in power generation, air conditioning in buildings and the chemical industry.

The combustion process in burner and boiler systems

Carbon or hydrocarbon compounds are burned with the oxygen in the air to generate heat in boiler systems. Combustion takes place in a sealed combustion chamber. The thermal energy that is created is transferred to a heat transfer medium by means of a heat exchanger and taken to its destination point. Solid fuels are burned either in a fixed bed, a fluidized bed or in an entrained dust cloud, liquid fuels are sprayed via a burner into the combustion chamber as a mist and gaseous fuels are already mixed with the combustion air in the burner.

The other system components ensure the supply and distribution of the fuel, the transfer and dissipation of the heat and the discharge of combustion gases and combustion residues, such as ash and slag.
Combustion gives rise to numerous substances which are discharged from the combustion chamber as flue gas. Water vapour and carbon dioxide (CO_2) constitute the largest proportion of the flue gas or exhaust gas. These arise as reaction products from fuel and combustion air. Depending on the air supply, the flue gas also contains nitrogen oxides (NO_x) or carbon monoxide (CO) and incompletely combusted fuel components. Impurities in the fuels may also mean the flue gas contains hydrogen sulphide, sulphur oxides, hydrofluoric acid (HF) and hydrochloric acid (HCl), and in addition soot, heavy metals and particulate matter are often to be found.

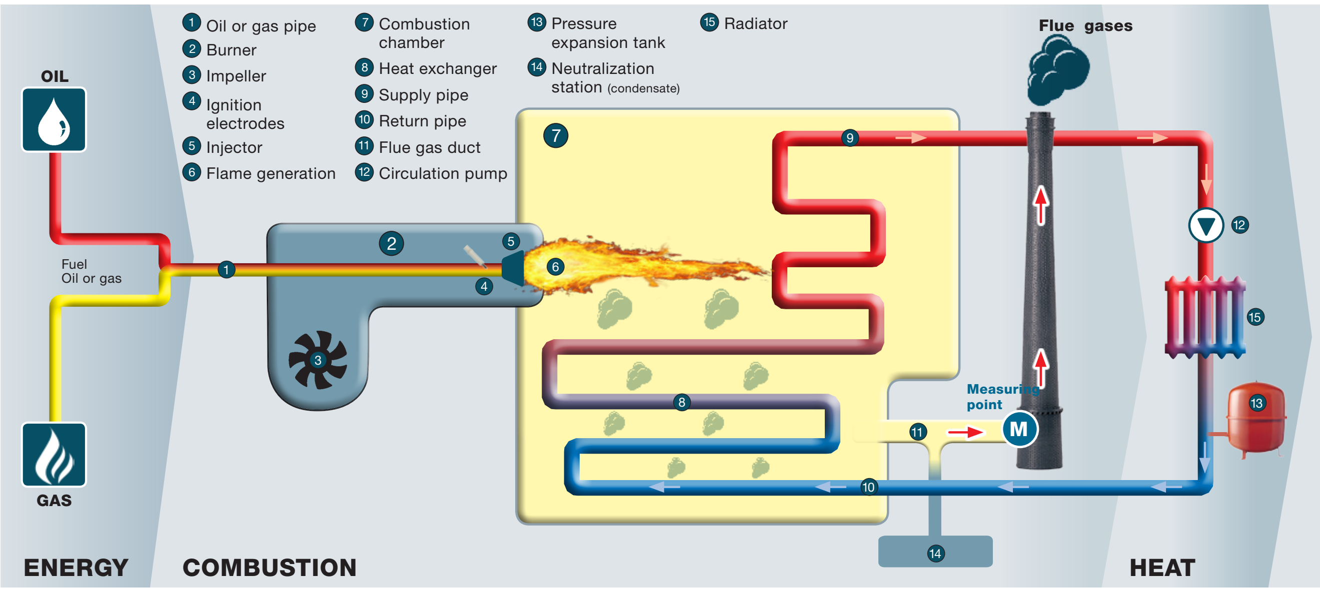

Fig. 2: The typical combustion process in a boiler system.

Chemical reactions during the combustion process
The combustion air itself is made up of several substances. It above all contains nitrogen (N_2) and oxygen (O_2), a variable proportion of water vapour and traces of carbon dioxide (CO_2), hydrogen (H_2) and noble gases. With the exception of the oxygen and small amounts of the nitrogen, these components are also to be found again in the flue gas.

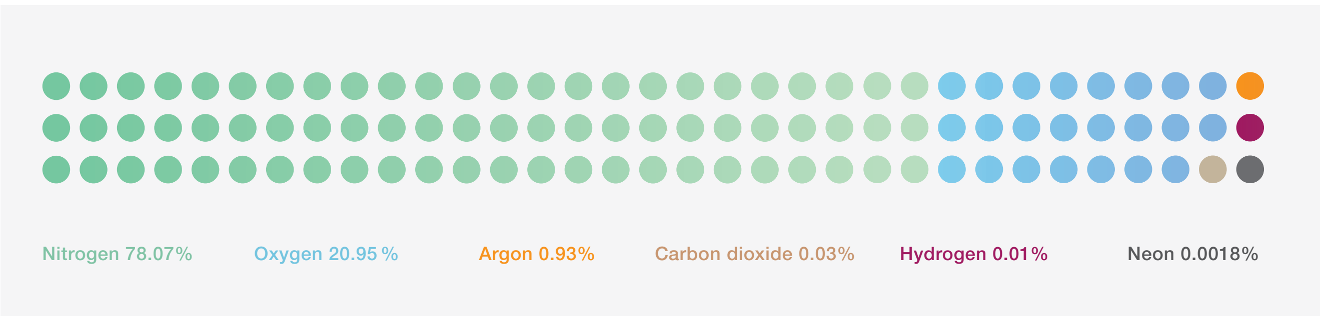

Fig. 3: The composition of pure, dry air on the earth's surface.

You can precisely calculate the amount of oxygen required to burn a specific energy carrier according to the algorithms of stoichiometry. For example:
two oxygen molecules are required for complete reaction with a methane molecule (CH_4); these give rise to two water molecules and a carbon dioxide molecule.

$$CH_4 + 2\,O_2 \longrightarrow CO_2 + 2\,H_2O$$

However, in practice this ideal, and at the same time minimum, amount of oxygen is not sufficient for complete combustion. Because fuels are always to some extent impure and fuel and oxygen can only be incompletely mixed, the combustion process in industrial plants has to be supplied with more oxygen and therefore more fuel than would seem to be required based on stoichiometry. This additional quantity of air is called the excess air.

The air ratio or the fuel-air ratio λ (pronounced lambda) is particularly important for the evaluation of combustion processes. It describes the ratio of the quantity of air actually needed to the quantity calculated stoichiometrically. The fuel-air ratio for a specific combustion process can be determined by means of the flue gas components of carbon monoxide (CO), carbon dioxide (CO_2) and oxygen (O_2) using the following formulas.

$$\lambda = 1 + \frac{O_2}{21 - O_2}$$

Calculation of the fuel-air ratio by means of the O_2 content in the flue gas.

Because it is normal to operate with excess air in modern combustion plants, clear calculation of the fuel-air ratio via the O_2 content is usually preferred nowadays.

The determination of λ by means of a CO_2 measurement has the advantage that the amounts of carbon dioxide in the flue gas can be established under all combustion conditions. However, the CO_2 content is not conclusive and does not suffice on its own to establish whether the combustion process is running with insufficient air or excess air.

For this, it is also necessary to measure whether the flue gas contains CO or O_2. The CO_2max value to be employed in the formula depends on the fuel being used.

$$\lambda = \frac{CO_2max}{CO_2}$$

Fuel	CO_2max
Fuel oil	15.4
Natural gas	11.9
LPG	13.9
Coke and wood	20.0
Briquettes	19.3
Lignite	19.2
Hard coal	18.5
Town gas	11.6
Test gas	13.0
Peat	15–30

Calculation of the fuel-air ratio by means of the CO_2 content in the flue gas. The CO_2max value depends on the material constant of the fuel.

The influence of the fuel-air ratio on the combustion process

Experienced service engineers know: optimum air supply is crucial for a wide adjustment range, stable combustion, optimum fuel utilization and the lowest possible emissions values. The following diagram shows why this is the case:

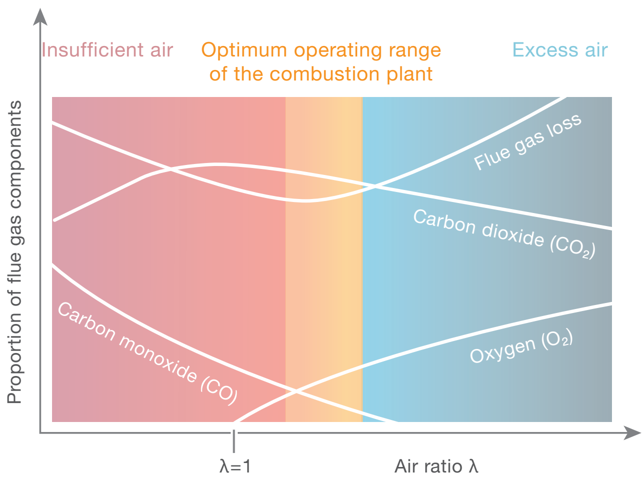

Fig. 4: The amounts of the flue gas components during the combustion process in a boiler system depending on the air ratio.

If the system is operated with insufficient air, there is not enough oxygen available to burn the fuel completely. This means that the flue gas contains carbon monoxide (CO), soot and fuel residues which get into the environment via the flue. In addition, the energy utilization is reduced, because not all the energy stored in the fuel is released by the combustion.

On the other hand, if the boiler runs with excess air, the fuel is completely burned. However, excess air also leads to increased formation of nitrogen oxides (NO_X) and efficiency is reduced as well, because the combustion temperature is lowered by dilution with cool outside air. As a rule of thumb, a 10 percent increase in the quantity of air results in a 1 percent rise in fuel consumption.

There is therefore an optimum fuel to air supply ratio for every combustion process. The combustion plant operates with a stable flame, optimum efficiency and lowest emissions in this range. The challenge for service engineers lies in determining the optimum air ratio and setting the system on that basis.

	Insufficient air	Optimum operating range of the combustion plant	Excess air
Advantages	• No emission of nitrogen oxides		• Complete combustion of the fuel • No soot or fuel residues in the flue gas • Reliable operation
Disadvantages	• Incomplete combustion of the fuel and thus reduced energy utilization • Carbon monoxide, soot and fuel residues in the flue gas • Unreliable operation, going as far as extinction of the burner flame		• Lower efficiency due to heat losses • Increase in the emission of nitrogen oxides (NO_X)
Carbon monoxide (CO)	Carbon monoxide (CO) arises because there is not enough oxygen available for complete oxidation to CO_2.		Because there is sufficient oxygen available, the CO that arises is further oxidized completely to CO_2.
Carbon dioxide (CO_2)	With an increasing amount of oxygen, the CO content also decreases through oxidation to CO_2. The CO_2 concentration increases to the same extent. This process is completed slightly over $\lambda = 1$ and the CO_2 content reaches its maximum.		The CO_2 content decreases again with values above λ=1, however not only through a chemical reaction, but as a dilution effect due to the increasing amount of combustion air which itself brings in practically no CO_2.
Oxygen (O_2)	The oxygen (O_2) is completely used up by the combustion and is virtually or totally untraceable in the flue gas.		The oxygen content in the flue gas rises as the air supply increases. The combustion process is cooled down by the excess air and the system's energy efficiency falls.

Advantages and disadvantages with non-stoichiometric combustion.

Challenges when setting boiler systems

Starting up the boiler system

Boiler systems in industrial applications normally run in continuous operation and as a result the critical start-up phase rarely arises. The start-up procedure is difficult to regulate, because the ignition of the air-fuel mixture leads to a sudden increase in the gas volume and thus to an abrupt pressure increase in the combustion chamber. This pressure increase not only causes shifts in volume in the heating gas and exhaust air ducts, but also leads to a reduction of the blower pressure and thus of the quantity of air supplied. This means that the flue gas contains more carbon monoxide, soot and unburned fuels during start-up.
The start-up process becomes particularly critical when the start-up pressure exceeds the maximum blower pressure that can be achieved. When the fall in airflow rate increases, there is a reduction in fuel combustion and thus in the pressure in the combustion chamber as well. When the full air supply then resumes, the fuel combustion and pressure rise again in the boiler – the burner pulsates. In most cases, changes on the burner are required to achieve satisfactory start-up behaviour. These range from replacing the nozzle, through reduction of the burner output to changing the impeller.
However, if the start-up behaviour is properly adjusted, the excessive pollutant emissions usually quickly subside when the combustion plant changes from start-up to normal mode.

Optimizing the combustion process by means of the air ratio

The measurement and regulation tasks for the service engineer are directly derived from the considerations of the combustion process in general and of the fuel-air ratio in particular:

- An optimum air ratio and thus an optimum fuel-air supply ratio are crucial in terms of ensuring a large operating range, stable flame and the best efficiency along with the lowest emissions.
- In order to achieve an optimum air supply, the fan output, blower and air ducts must be coordinated with one another and their function regularly checked.

The details of how the fuel-air mixture can be best set vary according to the boiler manufacturer, type of fuel and control plan. Some burners control the quantity of air which is taken into the boiler, others the quantity of fuel and still more allow the setting of both parameters. In any case, it is important to know the exact oxygen content in the process to ensure reliable and cost-effective operation.

Efficient setting of burner and boiler systems

Flue gas analysis with the testo 340 and testo 350

Using their gas sensors, the testo 340 and testo 350 flue gas analyzers record all the components of the flue gas which are required for a comprehensive analysis of the combustion process and optimum setting of the system.

The integrated pressure sensors also enable additional measuring values to be recorded, such as the airflow rate, flue draught or differential pressure between boiler and room. The two models differ in terms of design, equipment and intended use:

testo 340 is a handheld instrument for efficient service when commissioning and maintaining boiler systems. With 4 gas sensors – one O_2 sensor and three other, freely selectable sensors for CO, CO_{low}, NO, NO_{low}, NO_2 and SO_2 – all the relevant components of the flue gas can be reliably analyzed and the combustion process can be set to ensure the best possible fuel-air supply ratio is achieved. Hose extensions of up to 7.8 m enable convenient setting of all parameters, even when the measuring point is further away from the burner and air supply.

testo 350 comprises a Control Unit and an analyzer unit and is the first choice for high-precision and lengthy flue gas measurements with comprehensive gas preparation. Thanks to a gas cooler, condensate trap and dilution, the testo 350 flue gas analysis system meets the requirements for official emissions tests in many countries. A total of 6 gas sensors can be used and offer additional measurement options for hydrogen sulphide (H_2S), hydrocarbons (C_XH_Y) and carbon dioxide (CO_2) using non-dispersive infrared sensor technology (NDIR). The Control Unit and analyzer unit are linked via Bluetooth. The large range enables service engineers to track all the analysis values irrespective of the measuring location. They can therefore immediately see what effects their air supply or burner settings have on the combustion plant's emissions.

The testo 340 flue gas analyzer for efficient service measurements

The testo 350 flue gas analyzer for high-precision emissions measurements

Real NO_X measurements – essential for correct burner setting

Nitrogen oxide emissions are essential for correct burner setting and they are also strictly regulated by legislators. The testo 350 flue gas analysis system can be equipped with sensors for NO, NO_{low} and NO_2 and in addition the integrated Peltier element for drying, the automatic condensate pump and the teflon-lined gas sampling hose ensure optimum gas preparation and a high level of measuring accuracy. This means the testo 350 meets the requirements stipulated for many legally prescribed measurements.

NDIR CO_2 measurements – perfect for concrete, glass production, greenhouse gases and lots more

When manufacturing concrete, lime, steel or glass, the CO_2 content not only provides information about the combustion process of the boiler system, but also about the production process and the product quality associated with this.

The testo 350's CO_2 sensor determines the carbon dioxide content using non-dispersive infrared sensor technology (NDIR) and therefore fulfils the strict requirements which measuring instruments have to meet for the manufacture of these materials.

The high level of measuring accuracy means the testo 350, configured with an O_2 and a CO_2 measuring cell, can be used as an NDIR reference measuring instrument.

Heated or unheated measurement gas lines and probes?

There are measurement gas lines and probes available in an unheated and a heated version for both flue gas analyzers: The unheated measurement gas lines and probes are particularly suitable when short-term measurements need to be carried out at many different measuring points, thanks to their compact design, low weight and operation without an external power supply. The low dead volume also enables the flue gas analyzers to respond very quickly to changes in terms of the parameters.

The heated versions are always the resource of choice when particularly high levels of accuracy are required or when long-term measurements with a measurement period of between one day and several months need to be carried out. Because the measurement gas line and probe are taken up to a temperature above the flue gas dew point, there is considerably less accumulation of dust particles and condensate in the gas paths. This means that high levels of measuring accuracy are achieved for NO_2 and SO_2, even with long-term measurements.

Summary

When it comes to combustion processes in boiler systems, the right ratio of fuel and air is crucial for cost-effective and standard-compliant operation.
In order to achieve the greatest possible efficiency of the system and to comply with the legal emissions values for nitrogen oxide (NO_X), carbon monoxide (CO) and carbon dioxide (CO_2), the service engineer has to set the optimum air ratio using the setting options on the air supply, burner and flue.
The testo 340 and testo 350 flue gas analyzers record all the relevant flue gas components and thus provide engineers with immediate feedback on all their settings. This enables demanding measurement and regulation tasks to be carried out quickly and reliably.

More information at www.testo.com

You can get more information about the testo 340 and testo 350 flue gas analyzers and answers to all your questions concerning emissions measurement on industrial burners from our experts and at www.testo.com