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Practical Guide
Industrial Flue Gas Analysis

Emissions and process measurement guidelines

3rd, revised edition

Foreword

Dear Reader

Determining flue gas concentrations allows legally required emission limit values to be monitored, thus enabling protection of the environment. On the other hand, gas concentrations or gas matrices generated during the process often provide a very good indication of the existing process quality, which ultimately has a considerable influence on the product quality.

This Practical Guide contains the basic principles of common combustion processes, with a specific focus on their use in industrial applications. The available measurement methods, the characteristics associated with the measuring tasks, the expected gas

measurement parameters, concentrations and their significance with regard to the process are also described. This is a useful reference guide for using portable gas analyzers in industry, based on the experiences of global users of Testo measuring instruments.

Additional ideas and suggestions for improvement are always welcome.

Happy reading!

Prof. Burkart Knospe,
Chairman of the Board of Directors

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1. The combustion process

1. The combustion process

1.1 Energy and combustion

Energy

(from the Greek) means "acting force" and is defined as the ability of a substance, body or system to carry out work. Energy can be assigned to certain energy types depending on their form.

Energy can be classified into six categories:

- Mechanical energy (flowing water, driving car, helical spring)
- Thermal energy (boiling water, gas flame)
- Chemical energy (chemical reactions, combustion, explosion)
- Electrical energy (car battery, electric current)
- Electromagnetic energy (light, thermal radiation)
- Nuclear energy (nuclear fission)

The various forms of energy can be converted from one form into other, whereby, within an ideally closed system, the sum of all energies remains constant (conservation of energy). This actually applies in respect of the universe as a system. In practice, however, energy is lost to a greater or lesser extent when energy is converted, and this loss affects the efficiency of the conversion process. The natural energy carriers (coal, natural gas, petroleum, solar radiation, hydropower, etc.) are described as primary energies, while the forms generated through energy conversions (electricity, heat, etc.) are called secondary energies. These energy carriers differ not only in their appearance, but also in their energy content. For the purposes of comparison, the quantity of energy that could be released if a given quantity of the energy source were fully burned is generally specified. Table 1 gives a few examples to illustrate this.

The measuring unit for energy is the joule (J).

1. The combustion process

Energy source	Energy content [MJ]
1 kg lignite	9.0
1 kg wood	14.7
1 kg hard coal	29.3
1 m³ natural gas	31.7
1 kg crude oil	42.6
1 kg light fuel oil	42.7
1 kg gasoline	43.5
For comparison 1 kWh	3.6

Tab. 1: Energy content of various fuels

Conversion of energy units:
1 erg	10-7 J
1 cal	4.184 J
1 Btu	1055.06 J
Btu:	British thermal unit

Combustion

is the conversion of primary chemical energy contained in fuels such as coal, oil or wood into secondary thermal energy through the process of oxidation. Combustion is therefore the technical term for the reaction of oxygen with the combustible components of fuels, during which energy is released.

Combustions take place at high temperatures (up to 1000 °C and higher) and whilst emitting heat. The necessary oxygen is supplied as part of the combustion air. At the same time, a considerable volume of flue gas and, depending on the type of fuel, a certain quantity of residual materials (ash, slag) are formed.

Oxidation

Term for all chemical reactions during which a substance combines with oxygen. During oxidation, energy is released. Oxidation is of great significance when it comes to technology (combustion) and biology (respiration).

Greenhouse effect

In principle, the greenhouse effect is a natural phenomenon and a prerequisite for life on earth. Without this effect, the average global temperature near the Earth's surface would be -18 °C instead of +15 °C today; the earth would be uninhabitable! The cause of this natural effect is primarily the water vapour content of the atmosphere near the Earth's surface, which allows solar radiation to pass through, but prevents the long-wave thermal radiation that develops on the ground from escaping; this is reflected back to the Earth's surface. The heat management of greenhouses is also based on this principle. However, excessive burning of fossil fuels (carbon dioxide emissions) and the release of substances from chemicals and agriculture (CFCs, methane, etc.) considerably intensify this natural effect, which leads to a slow increase in the Earth's temperature and affects climatic conditions, etc.

More details on the topic of combustion can be found in Section 1.4.

1.2 Combustion plants

Combustion plants are facilities for generating heat by burning solid, liquid or gaseous fuels. They are needed for many different purposes, for example
- For heating purposes (heating plants and building heating systems)
- For generating electricity
- For generating steam or hot water (used in processing plants, for example)
- For manufacturing certain materials (for use in the cement, glass or ceramics industry, for example)
- For thermal surface treatment of metallic workpieces
- For burning waste and scrap materials (waste, used tyres etc.)

Please refer to the detailed application examples in Section 4.

The combustion takes place in a furnace; other parts of the plant supply and distribute the fuel, supply the combustion air, transfer the heat and carry away the combustion gases and combustion residues (ash and slag).

Solid fuels are burnt either in a fixed bed, a fluidized bed or in an entrained dust cloud. Via a burner, liquid fuels are fed to the combustion chamber together with the combustion air in the form of mist; gaseous fuels are already mixed with the combustion air in the burner.

Flue gas from combustion plants contains the reaction products of fuel and combustion air as well as residual substances, generating primarily dust, sulphur and nitrogen oxides and also carbon monoxide. During the combustion of coal, HCl and HF, and during the combustion of scrap material, their constituents (HCl and HF, but also various hydrocarbons, heavy metals, etc.) may also be present in the flue gas.

Within the context of environmental protection, the flue gas from combustion plants is subject to strict regulations with regard to the limit values of pollutants such as dust, sulphur and nitrogen oxides and also carbon monoxide which are permissible in the clean gas (when released into the atmosphere). To comply with these limit values, combustion plants are equipped with extensive facilities for cleaning flue gas, such as dust filters and various flue gas scrubbers. In Germany, the specific requirements are laid down in the 13th and 17th Federal Immission Control Ordinance (BImSchV) and in TI Air. Further information about this can be found in Section 2.3.

1.3 Fuels

Fuels are available in various forms and compositions:

- Solid fuels (coal, peat, wood, straw) primarily contain carbon (C), hydrogen (H_2), oxygen (O_2) and small quantities of sulphur (S), nitrogen (N_2) and water (H_2O).
- Liquid fuels derive from petroleum or the processing of it, whereby a distinction is made between extra-light (EL), light (L), medium (M) and heavy (S) fuel oils.
- Gaseous fuels are a mixture of combustible (CO, H_2 and hydrocarbons) and non-combustible gases. These days, natural gas is very often used, the main component of which is the hydrocarbon gas methane (CH_4).

Knowledge of the composition of the fuel is essential to managing combustion as efficiently, and therefore as economically, as possible. An increasing portion of non-flammable (inert) substances reduces the gross/net calorific value and increases the level of dirt that collects on the heating surfaces. An increasing water content pushes up the water vapour dew point and consumes fuel energy to evaporate the water in the flue gas. The sulphur contained in the fuel is combusted to SO_2 and SO_3, which can generate aggressive sulphurous acid or sulphuric acid when the gas cools down to below the dew point. Please also refer to Section 1.7

The composition of some solid fuels is shown in the following table.

Fuel	Content (mass content in %)			
	Carbon in dry matter	Sulphur	Ash	Water
Hard coal	80-90	1	5	3-10
Ortho-lignite	60-70	2	5	30-60
Meta-lignite	70-80			10-30
Wood (air-dry)	50	1	1	15
Peat	50-60	1	5	15-30

Tab. 2: Composition of fuels

Please refer to Section 1.6 for explanations relating to the calorific value of fuels.

1.4 Combustion air, air ratio

The combustion air provides the oxygen required for combustion. It consists of nitrogen (N_2), oxygen (O_2), a small proportion of noble gases and a variable proportion of water vapour (Tab. 3). In some cases, even pure oxygen or an oxygen/air mixture is used for combustion.

Essential combustion air constituents (except the oxygen used in the combustion process) can all be found in the flue gas.

Component	Volume content [%]
Nitrogen	78.07
Oxygen	20.95
Carbon dioxide	0.03
Hydrogen	0.01
Argon	0.93
Neon	0.0018

Tab. 3: Composition of pure and dry air on the Earth's surface

1.4.1 Ideal combustion, fuel-air ratio, material balance

The minimum oxygen requirement for complete (ideal) combustion of the combustible constituents depends on the fuel composition: For example, the combustion of 1 kg of carbon requires 2.67 kg of oxygen, but 1 kg of hydrogen requires 8 kg and 1 kg of sulphur only 1 kg of oxygen. This case of exact quantity ratios is considered an ideal combustion or combustion under stoichiometric conditions.

The corresponding chemical equations are as follows:

Carbon: $C + O_2 \longrightarrow CO_2$
Hydrogen: $2H_2 + O_2 \longrightarrow 2H_2O$
Sulphur: $S + O_2 \longrightarrow SO_2$
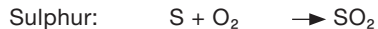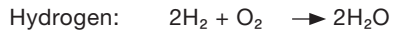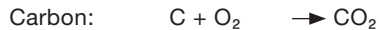
The ideal combustion can be based on the model shown in Figure 1:
The amount of oxygen supplied is just enough to fully burn the fuel present; there is no surplus oxygen or fuel.
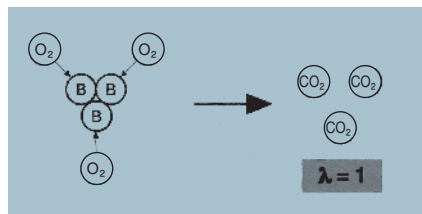
Figure 1: Model for an ideal combustion

In practice, however, this ideal (minimum) amount of oxygen is not sufficient for complete combustion due to the imperfect mixing of fuel and oxygen, so the system needs to be supplied with more oxygen, and therefore combustion air, than is required stoichiometrically. This additional air is referred to as "excess air" and the ratio of the actual air volume to the air volume required stoichiometrically is referred to as the air ratio (λ).
Fig. 2 shows this excess air combustion model; here, due to the excess air, λ is >1.

Maximum combustion efficiency is therefore established with marginal excess air or oxygen, i.e. at λ>1 (oxidizing atmosphere). The air ratio and knowing what it is are extremely important factors for ensuring optimum combustion and economic efficiency of the plant operation:
• Unnecessarily high excess air reduces the combustion temperature and increases the amount of unused energy dissipated via the larger volume of flue gas.
• With too little excess air, apart from poor fuel utilization this will also increase the harmful environmental impact due to unburned residues in the flue gas.
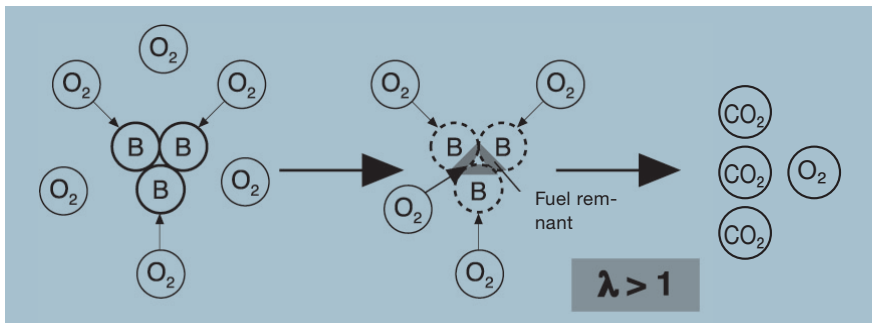
Figure 2: Model for combustion with excess air

Table 4 shows the typical air ratio ranges for various combustion plants. As a matter of principle, the following applies: the smaller the reaction surface for the fuel in relation to the unit of mass (coarse-grained fuel), the higher the amount of excess air that must be chosen to ensure complete combustion. The reverse is also true, which is why solid fuels are ground finely and liquid fuels are atomized. However, special processes, e.g. thermal surface treatment, are deliberately operated with insufficient air at $\lambda<1$, as this is necessary to ensure the required refinement process.

Oxidizing atmosphere

Here, more oxygen is available than is necessary for the oxidation of oxidizable substances in the fuel. Complete oxidation (combustion) is therefore possible.
Simply put: Oxidation = addition of oxygen (CO is oxidized to CO_2).

Reducing atmosphere

Here, there is too little oxygen to oxidize all oxidizable substances. The opposite of oxidation occurs, i.e. a reduction.
Simply put: Reduction = removal of oxygen (SO_2 is reduced to S).

Combustion plant	Range for λ
Combustion engines	0.8-1.2
Pressure jet gas-fired installation	1.1-1.3
Oil burner	1.2-1.5
Coal dust burner	1.1-1.3
Grate furnace for brown coal	1.3-1.7
Neon	0.001

Tab. 4: Typical ranges for air ratio λ

1.4.2 Determining the air ratio

The air ratio can be determined from the concentrations of the flue gas components CO, CO_2 and O_2, the correlations are shown in the so-called combustion chart, Fig. 3. When there is ideal mixing of fuel and air, any CO_2 content is related to a specific CO content (in the range $\lambda < 1$) or to a specific O_2 content (in the range $\lambda > 1$). The CO_2 value on its own is not definite due to the curve profile beyond a maximum, which means that an additional test is required to establish whether the gas also contains CO or O_2 in addition to the CO_2. When operating with excess air (i.e. normal scenario), a definitive measurement of O_2 is now generally preferred. The curve progressions are fuel-specific, i.e. each fuel has its own diagram and a specific value for $CO_{2\,max}$, see Table 7. In practice, the correlations of these numerous diagrams are often summarized in the form of an easily manageable nomogram ("fire triangle", not illustrated here). This can be applied to any type of fuel.

The following two formulae may be applied to the theoretical calculation of the air ratio from the CO_2 or O_2 readings:

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

with

$CO_{2\,max}$: Fuel-specific maximum CO_2 value (see Tab. 7). If required, this value can be determined by Testo as a service.

CO_2 and O_2: Measured (or calculated) values in the flue gas
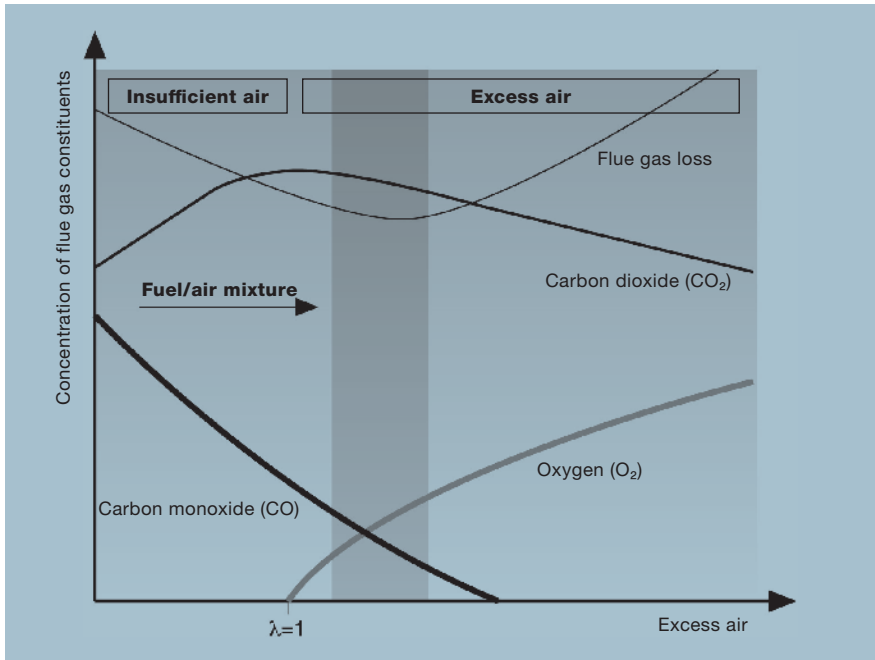
Figure 3: Combustion chart

Please refer to Section 2.1 (com-
bustion optimization) for a detailed
depiction of the correlations in the
combustion chart.

1.4.3 Combustion air requirement

The actual air requirement is calculated
- From the minimum oxygen required for ideal combustion (this depends on the fuel)
- The required excess oxygen and
- The relative oxygen content in the air. For dry air under atmospheric pressure, this is 20.95 %. In practice, however, the ambient air used as combustion air is never completely dry, which means that the humidity also has to be factored into the calculation of the air volume to ensure an exact process.

1.4.4 Gas volume, diluting effect, reference value

Combustion air and humidity (water vapour) increase the absolute gas volume.

Figure 4 illustrates this phenomenon for the combustion of 1 kg fuel. In stoichiometric conditions, i.e. without excess air, approx. 10 m^3 of flue gas is produced in dry conditions and 11.2 m^3 in humid conditions, while the same amount of fuel on combustion with 25% excess air results in a flue gas volume of 13.9 m^3 in humid conditions. This has the same effect as a dilution, which reduces the relative portions of the constituents of the flue gas! For example, the absolutely constant SO$_2$ content is reduced in relative terms from 0.2 (stoichiometric, dry) to 0.18 (stoichiometric, humid) or 0.14 (25% excess air, humid) and the oxygen from 4.4 to 4. Please refer to Table 5.

	Nitrogen	CO_2	SO_2	Water	Oxygen
Stoich./dry	82.6	16	0.20	0	0
Stoich./humid	74.7	14.4	0.18	10.7	0
25 % EA/dry	82.8	12.7	0.16	0	4.4
25 % EA/humid	75.6	11.6	0.14	8.7	4

Tab. 5: Relative composition of flue gas in % in different conditions
(EA = excess air)
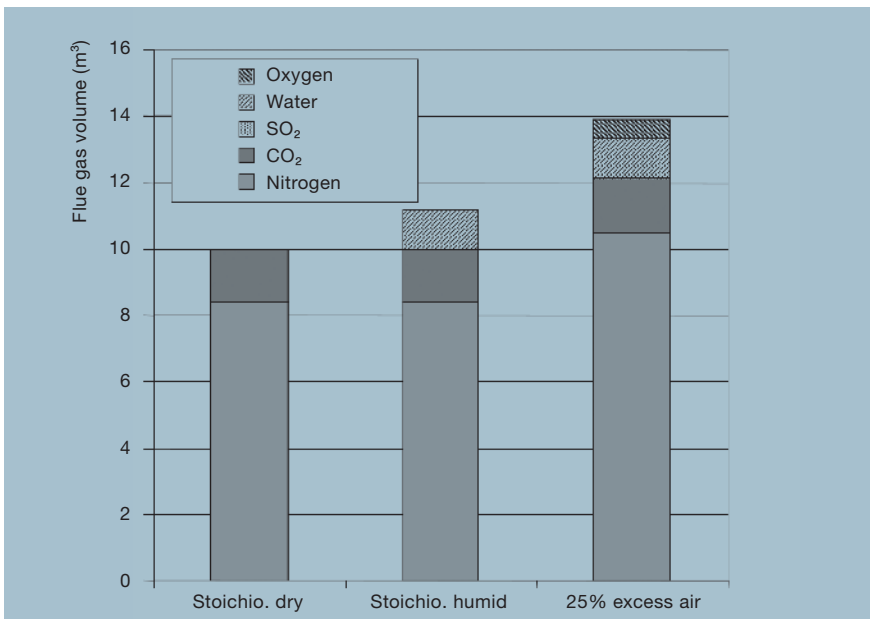
Figure 4: Diluting effect of humidity content and excess air

Reference values

From the depicted correlations, it is clear that concentration observations can usually only be made in conjunction with reference values. It is only then that the readings have any meaning and can be compared with other measurement results, and in particular with statutory requirements! In practice, the following are used:

• Reference to a specific dilution due to excess air; a measure of this is the oxygen content, the reference is expressed by e.g."Reference value 8% oxygen".

  This reference to the oxygen value is generally applied in the specifications of the TI Air; however, it is also used outside of the TI Air: for a plant, the reference point is defined close to the oxygen content when the plant is started up.

• Reference to a specific dilution due to the humidity content of the gas; a measure of this is the temperature of the gas, the reference is expressed, for example, by "based on dry flue gas" or "at dew point 4 °C".

• Reference to the normal state of a gas. This pertains to the dependence of a gas volume on the actual values of pressure and temperature, please refer to Section 3.1.1

1.5 Flue gas (exhaust gas) and its composition

The flue gas generated in combustion processes is also referred to as exhaust gas. Its composition depends on the fuel and the combustion conditions, e.g. the air ratio. Many of the constituents of flue gas are classified as air pollutants, and must therefore be removed from the flue gas before it is released into the atmosphere via cleaning processes, which are extremely time-consuming and costly in some cases, in conformity with statutory regulations (please refer to Section 2.3). Flue gas in its original composition after combustion is also referred to as crude gas, and once it has passed through the cleaning stages it is called clean gas.

The most important flue gas components are explained below.

Nitrogen (N_2)
At 79 vol.%, nitrogen is the main component of the air. This colourless, odourless and tasteless gas is supplied via the combustion air, but does not play a direct role in the actual combustion process; it is carried as a ballast and a waste heat carrier and is returned to the atmosphere. However, parts of the nitrogen, in combination with the nitrogen contained in the fuel, contribute to the formation of the hazardous nitrogen oxides (see below).

Carbon dioxide (CO_2)
Carbon dioxide is a colourless and odourless gas with a slightly sour taste, which is generated in all combustion processes and by breathing. Due to its property of filtering radiated heat, it is a major contributor to the greenhouse effect. Natural air only contains 0.03 %; the permissible MAC (maximum allowable concentration) is 0.5 %; concentrations of more than 15 % in the air inhaled by humans cause unconsciousness.

Water vapour (humidity)
The hydrogen contained in the fuel combines with oxygen to form water (H_2O). Together with the water from the fuel and the combustion air, depending on the flue gas temperature (FT) this is discharged as flue gas humidity (at high FT) or as condensate (at low FT).

Oxygen (O$_2$)

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. It is used for the determination of combustion parameters and as a reference value.

Carbon monoxide (CO)

Carbon monoxide is a colourless and odourless toxic gas. It is mainly generated during the incomplete combustion of fossil fuels (furnaces) and automotive fuels (motor vehicles) and other materials containing carbon. CO is generally innocuous to humans, since it soon bonds with the oxygen in the air to form CO_2. However, within enclosed spaces CO is very dangerous, because a concentration of only 700 ppm in the air inhaled by humans will cause death within a few hours. The MAC value is 50 ppm.

Nitrogen oxides (NO and NO$_2$, total formula NOX)

In combustion processes, the nitrogen from the fuel and, at high temperatures, also from the combustion air, is combined to a certain extent with the combustion air/oxygen, initially forming nitrogen monoxide NO (fuel NO and thermal NO), which in the presence of oxygen is oxidized in a further step to form the hazardous nitrogen dioxide (NO_2) in the flue gas duct and later in the atmosphere. Both oxides are toxic; NO_2 in particular is a dangerous respiratory poison and, in combination with sunlight, contributes to the formation of ozone. Sophisticated technologies such as the SCR process are used to clean flue gases containing NO_X. Special combustion measures, e.g. staged air supply, are used to reduce nitrogen oxides during combustion.

Sulphur dioxide (SO$_2$)

Sulphur dioxide is a colourless, toxic gas with a pungent smell. It is produced as a result of the oxidation of the sulphur contained in the fuel. The MAC value is 5 ppm. In combination with water or condensate, sulphurous acid (H_2SO_3) and sulphuric acid (H_2SO_4) are produced, both of which are linked to numerous types of environmental damage to vegetation and building fabrics. Flue gas desulphurization plants (FGD) are used to reduce sulphur oxides.

Hydrogen sulphide (H_2S)

Hydrogen sulphide is a toxic and extremely malodorous gas, even in very low concentrations (approx. 2.5 µg/m^3). It is a naturally occurring constituent of natural gas and petroleum and is therefore present in refineries and natural gas processing plants, but also in tanneries, agricultural businesses and, last but not least, following incomplete combustion in vehicle catalytic converters. Combustion to SO_2, certain absorption processes or, in the case of larger quantities, conversion to elemental sulphur in a Claus plant are some of the processes used to eliminate H_2S from flue gases.

Hydrocarbons (HC or C_XH_Y)

Hydrocarbons are an extensive group of chemical compounds composed exclusively of carbon and hydrogen. HCs are the most important substances in organic chemistry; they occur naturally in petroleum, natural gas or carbon. HCs can be emitted both when HC products are manufactured (e.g. in refineries) but also when they are used and disposed of (solvents, plastics, paints, fuels, waste etc.). Incomplete combustions are a particular source of HC emissions. This also includes forest and bush fires as well as cigarettes, for example. HCs contribute to the greenhouse effect.

Examples of HCs include methane (CH_4), butane (C_4H_{10}) and benzene (C_6H_6), but also the carcinogenic substance benzo[a]pyrene. The whole potential of a flue gas for volatile organic compounds is often referred to as the total C or Ctotal. This total is usually determined in the flue gas.

Hydrogen cyanide (HCN)

Hydrogen cyanide (also known as hydrocyanic acid) is a very toxic liquid with a boiling point of 25.6 °C; it exists in flue gases, if present, in gaseous form. HCN may exist in waste incineration plants.

Ammonia (NH$_3$)

Ammonia plays a role in flue gases in conjunction with the SCR process for flue gas denitrification. In the denitrification reactors, it is added to the flue gas in precisely metered quantities and causes the conversion of the nitrogen oxides into nitrogen and water. The unused residue (NH$_3$ slip) is greatly reduced via downstream cleaning stages, and in the clean gas is usually at or below 2 mg/m^3.

Halogen halides (HCl, HF)

During the combustion of coal and/or waste materials, the hydrogen halides HCl and HF may form, and these form aggressive acids in combination with humid atmospheres. These substances are largely washed out of the flue gas by the flue gas cleaning plants (scrubbers).

Solids (dust, soot)

Solid pollutants in the flue gas come from the incombustible components of solid and liquid fuels. These include, for example, the oxides of silicon, aluminium, calcium etc. in the case of coal and the sulphates of various substances in the case of heavy fuel oil. The harmful effect of dust on humans is mainly due to the accumulation of toxic and carcinogenic substances in the dust particles.

1.6 Gross calorific value, net calorific value, efficiency, flue gas loss

Gross calorific value, net calorific value

The gross calorific value (formerly referred to as the upper net calorific value) is a characteristic value for fuel and refers to the energy released during full combustion in relation to the quantity of fuel used. The net calorific value (formerly referred to as the lower net calorific value), on the other hand, is the released energy minus the evaporation heat of the water vapour generated during combustion at 25 °C, again in relation to the quantity of fuel used.

Basically, the net calorific value is less than the gross calorific value.

Condensing boiler

Condensing boilers are boilers which, in addition to the combustion heat, also make use of the condensation heat of the flue gas by means of heat exchangers. In terms of the net calorific value, these boilers can achieve combustion efficiencies of 107%. However, the condensate that is generated and contaminated with

pollutants must be disposed of in an environmentally friendly manner.

Efficiency of a combustion

The efficiency is a variable determined from performance values while the plant is in stationary operation. The efficiency (this is always less than 100%) is the ratio of the energy supplied to the combustion chamber overall to the energy required or used to carry out the process (heating, melting, sintering, etc.). Efficiency is made up of several components:

• The combustion efficiency describes the proportion of the total input power (energy per time unit) that is available in the combustion chamber after combustion. This makes it an important factor for the quality of the combustion.

• The furnace efficiency, which largely depends on its design, describes the quality of the furnace and the operation via the relationship between the supplied energy and the energy available in the furnace.

• The total efficiency is obtained by multiplying the combustion and furnace efficiencies.

1. The combustion process

Energy balance of a combustion plant

In stationary operating mode, the sum of all the energies supplied to the plant must be equal to the sum of the energies delivered by the plant; please refer to Table 6.

Supplied energies	Discharged energies
Net calorific value and tangible fuel energy	Tangible heat and chemically bound energy of flue gases (flue gas loss)
Tangible heat of combustion air	Tangible heat and net calorific value of fuel residues in ash and slag
Thermal equivalent of the mechanical energy converted in the plant	Surface losses as a result of heat conduction
Heat brought in through the product	Heat dissipated with the product
	Convection losses as a result of furnace leaks

Tab. 6: Contributions to maintaining the energy balance

The main contribution to the loss is the flue gas loss. It depends on the difference between the flue gas temperature and combustion air temperature, the O_2 or CO_2 concentration in the flue gas and on fuel-specific factors (Table 7). In condensing boilers, this flue gas loss is reduced in two ways – via utilization of the condensation heat and via the resultant lower flue gas temperature.

The flue gas loss can be calculated using the following formulae:

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

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 concentration
KK: Variable which shows the variable qA as a minus value if the dew point is undershot. Required for measurement on condensing systems.

For solid fuels, factors A2 and B equal zero. In that case, using the factor f, the formula is simplified to create the so-called Siegert formula.

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

The fuel-specific factors used in the formulae are set out below.

Fuel	A2	B	f	$CO_{2\,max}$
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
Briquettes	0	0	0.75	19.3
Lignite	0	0	0.90	19.2
Hard coal	0	0	0.60	18.5
Coke oven gas	0.60	0.011	-	-
Town gas	0.63	0.011	-	11.6
Test gas	0	0	-	13.0
Peat	50-60	1	5	15-30

Tab. 7: Fuel-specific factors

Note

If required, the fuel-specific factor $CO_{2\,max}$ can be determined by Testo as a service.

1.7 Dew point, condensate

Dew point

The dew point or dew point temperature of a gas is the temperature at which the water vapour contained in the gas changes from the gaseous to the liquid state of aggregation, see Fig. 5. This transition is known as condensation, the liquid it produces is called condensate. Below the dew point, the water vapour is in liquid state and above the dew point it is in gaseous state; an example of this is the formation and evaporation of mist or dew as the temperature changes. The humidity content determines the dew point temperature. The dew point of air with a humidity content of 30% is approx. 70 °C, while the dew point of dryer air with only 5% humidity content is approx. 35 °C.

Note:

If measurement is carried out using an instrument without gas conditioning, the dew point temperature of the gas is approximately equal to the ambient temperature, .e.g. 25 °C. If these measurements are then compared with values measured with a gas conditioning unit, i.e. dew point temperature of 5 °C, for example, the resultant difference in the readings due to the different humidity content is approximately 3 %!
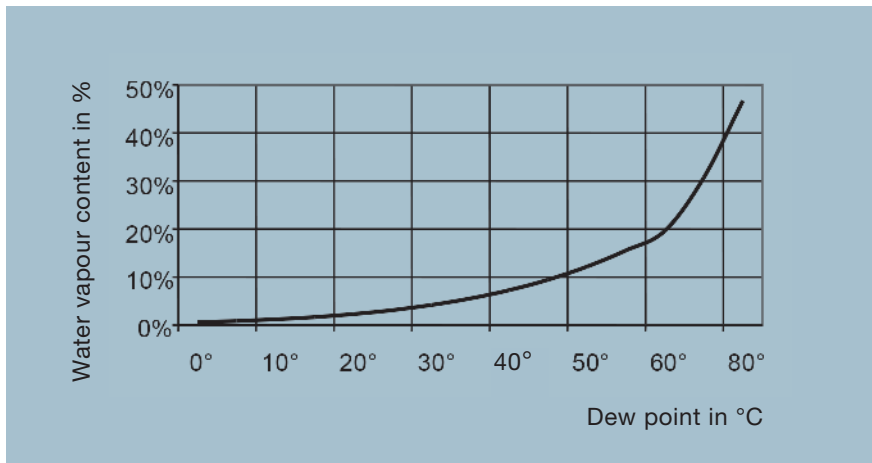

Figure 5: Water vapour content as a function of the dew point (air pressure 1013 mbar)

Heated lines, measuring gas coolers

Flue gases with 8% humidity, for example, have a dew point of about 40°C, which means that condensate forms below this temperature. This has two important consequences for the plant as a whole as well as for the measuring equipment:

- If the flue gas contains sulphur dioxides, for instance, then at temperatures below 40 °C (e.g. in unheated pipes) these combine with the condensing water vapour to form sulphurous acid (H_2SO_3) and sulphuric acid (H_2SO_4), both of which are extremely corrosive and can cause considerable damage to the system components that come into contact with them. For this reason, the temperature of the flue gas in the plant is kept above the dew point (i.e. above 40 °C in the case of the above example) until the flue gas reaches the scrubber.

  The same applies to those components of measuring instruments through which the flue gas flows and above all to the components of the sampling device, such as probes and hoses. For this reason, heated probes and measurement gas lines are used and their temperature is kept above the dew point of the gas. Failure to observe this measure will result in damage to the measuring instruments and incorrect measurements!

- Testo's newly developed and patented method of particularly high gas flow velocity combined with a specially coated surface of the measurement gas lines offers a further alternative for preventing the formation of condensation. As a result, it is no longer necessary to heat the lines, which is extremely important for mobile devices in view of the resulting reduction in power consumption. Water vapour is absent from the cooled flue gas to a greater or lesser extent depending on the temperature to which the gas is cooled, with the result that the other components of the gas, such as CO, which have not changed quantitatively form a higher relative portion of the flue gas; the corresponding readings are then higher than in the moist flue gas! For comparable readings, the respective measurement gas must therefore have the same temperatures and therefore the same humidity content.

As a consequence, measuring gas coolers (they could also be called measuring gas dryers) are used in the gas analysis upstream of the analyzer; these bring the gas to a defined temperature and therefore a defined level of drying and keep it there.

Note
- Cooling gas means drying gas.
- In dry gas, the readings for gas components are comparatively higher than those in humid gas.

Testo instruments use what is known as a Peltier cooler for measurement gas cooling, its function is based on the fact that the interface between two different types of metals heats up or cools down depending on the direction of current flow. This cooler can cool the measurement gas in the testo 350 to +3 °C and keep it constant.

Permeation coolers, which are also common on the market, have the disadvantage of not being able to maintain a defined dew point; moreover, they are susceptible to clogging by dust particles, which leads to increased spare parts costs.

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