

Measured Values

Directly measured values

Oxygen (O₂)

Measured to calculate CO₂ and efficiency. The value is used in many of the calculations carried out later using the measured values.

Ambient temperature (TA)

The ambient temperature needs to be measured at the air inlet of the burner / boiler. If the air is sucked from somewhere else, the temperature needs to be measured at a point representative for the inlet air temperature, otherwise there will be errors in the calculation of efficiency.

Flue gas temperature (TG)

The measurement should be taken in the core (hottest region) of the gas stream. That is where the carbon monoxide concentration is at its peak and the oxygen content is lowest. In industrial equipment the measurement should be carried out as soon after the last heat-exchanger as is practically possible. In many practical applications this is very much easier said than done, but the measurement is important for accuracy.

Carbon monoxide (CO)

In atmospheric gas installations the CO concentration may need to be detected with a so-called multi-hole probe, because the CO concentration in a chimney varies, and that probe makes it possible to sample across the whole diameter. The further along the flue the measurement is carried out, the better the gas is mixed and when a forced draught system is used, the turbulence is usually enough to mix the gas components homogenously. Such practices appear to be dying out, and most measurements are now carried out simply in the core of the gas stream. Today's equipment produces much lower levels of carbon monoxide, so a low range sensor may be needed for some applications.

Nitrogen oxides (NO_x)

By measuring the amount of nitrogen oxides (NO, NO₂) the appropriate steps can be taken to minimise the NO_x emissions. This is particularly a factor in some areas, where the NO_x

emissions are very carefully controlled and excessive emissions are taken very seriously.

Sulphur dioxide (SO₂)

The SO₂ content of flue gases is dependent on the sulphur content of the fuel and is not related to combustion efficiency. This can only really be altered by a change in the fuel or the use of filter systems. Modern fuels have very low levels of sulphur, but this is not the case with old style coal burners or some of the heavy oils in use for power generation.

Hydrocarbons (C_xH_y)

If incomplete combustion takes place, the (unburned) hydrocarbons in the form of soot can be spotted using a filter paper and, in the case of oil derivatives, detected by means of a special solvent. There are usually some gaseous hydrocarbons present, which can be measured with an appropriate sensor. The most accurate method of measuring hydrocarbon gas is an infrared sensor. This does, however, have the disadvantage of being only sensitive to one specific type of hydrocarbon, such as alkanes. There are also catalytic sensors available which react to all hydrocarbons. These have the drawback that they basically operate by combustion and hence require a certain level of excess oxygen to operate. The result will also be increased if any other combustible components of other types are present. In general, they are not especially accurate and the thin filament inside is very prone to damage. These catalytic (Pellistor) sensors are no longer acceptable for most flue gas applications due to the poor accuracy and the fragility of the element. Such a sensor is really designed for safety applications where there is no movement of the sensor and hence no danger of breakage. The poor accuracy of the Pellistor sensor is also less of a factor since a healthy safety margin is left in all cases. Although they react primarily to hydrocarbons and carbon monoxide, the Pellistor sensors will include any other material that can burn in oxygen, such as H₂S. This type of cross-sensitivity is unpredictable and hence cannot be compensated. The reaction of the Pellistor sensor to sulphur dioxide, SO₂, is extreme. The sensor will be poisoned very quickly with no way of regenerating it. Pellistor sensors have now disappeared from quality instruments almost entirely for these reasons. The only thing that still speaks for the Pellistor sensor is the low price, but this stands in no relationship to the other disadvantages.

Carbon dioxide (CO₂)

For many years, carbon dioxide has been calculated from the oxygen concentration and the maximum CO₂ value for the fuel. Increasingly people are interested in directly measuring this component, partly in a drive for higher accuracy in the face of special regulations about

this particular gas and partly due to the use of "indefinable" mixtures of gases that may be available as a waste product from another process. Here it is clearly not possible to calculate the CO₂ concentration with any acceptable degree of accuracy. Attempts have been made to develop an electrochemical sensor for this purpose, but the accuracy was poor, so the only real alternative is to use an infrared sensor. These may be slightly more expensive, but they do not have the disadvantages of limited operational life and regular calibration. They are a legal requirement in some countries nowadays. This information is available from your local government representatives.

Soot (smoke)

According to TÜV Standards a particular gas quantity (1.63 l) has to be sucked through a filter paper within a period of 60 seconds in order to provide accurate and comparable readings. It is generally also necessary to heat the area around the filter paper to prevent condensation altering the result. This is called Bacharach testing.

Calculated values

Carbon dioxide (CO₂)

Is an indicator for the quality of the combustion process. If there is a high CO₂ content together with low excess air, then the stack loss is at its minimum. CO₂ levels will naturally depend on the ratio of hydrogen to carbon in the fuel.

Excess air factor (λ)

This is the ratio of the actual quantity of air present to the quantity of air that would be needed for complete combustion to take place under ideal conditions.

In real combustion processes it is necessary to have a slight excess of air present ($\lambda > 1$) in order to burn the fuel completely. This is due to imperfect atomisation of the fuel and less than ideal mixing with the combustion air.

Excess air reduces efficiency and should therefore be kept to a minimum.

Stack loss (SL)

To be calculated after measuring the oxygen content and the difference between the flue gas and ambient temperatures.

Instead of the oxygen content, the CO₂ value can be used for the calculation as well.

Efficiency (ETA, η)

This is the percentage of the energy produced by the fuel that is available for use, not wasted.

It is calculated from the stack loss by subtracting from 100%. A further calculation is possible which takes account of the losses from incomplete combustion caused by the formation of CO.

Modern developments in the field of heat exchangers, especially the introduction of condensing burners has led to the strange condition of some heating units showing efficiencies above 100%. This is explained later.

Dewpoint

This is calculated from a number of factors, such as oxygen content, fuel type and SO₂ concentration, if known. This is the temperature at which the water in the flue gas will commence condensation. The formation of water within the stack is generally undesirable, since this will combine with corrosive gas components to form acid and attack the structure of the flue. This damage occurs more quickly than many people realise.

Flow velocity

The flow velocity can be measured in a number of ways. The two most common methods are pitot tubes and impellers. The impellers are not usually capable of withstanding the high temperatures met in flue gas applications, so the pitot tube is seen most often. The differential pressure connections measure the difference between static and dynamic pressure, producing a value that can be used for the velocity calculation. Theoretically, there may be a velocity profile across the width of the stack, particularly in the case of low flow rates, but higher flow rates and turbulent flow are to be expected in most cases. Turbulent flow gives a very flat and nearly constant velocity profile, reducing the errors to an insignificant level. The cross-sectional area of the stack can then be used to calculate the mass flow-rate for all components.