Optical temperature measurement in combustion plants

by Albert Book

Within the scope of legal provisions and licensing requirements, the requirements for NOx separation in the exhaust gas of combustion plants with a NOx value in the clean gas of <100 mg/Nm³ at an NH3 slip of <10 mg/ Nm³ are high. To meet these requirements, the temperature inside the boiler must be detected as controlled parameter for primary and secondary measures to reduce pollutants. The report explains the different measuring systems for optical temperature measurement in combustion plants.

Nitrogen oxides arise due to the nitrogen content in the waste and the high combustion temperature, which is necessary for the destruction of the organic pollutants. The aim of combustion engineering measures is to avoid largely the development of NOx already during the combustion process. In order to achieve with it low NOx emissions associated with the entire combustion, the particles must remain as long as possible in the primary reducing zone and be well mixed with the combustion air in the secondary zone. Furthermore, pressure is increasing on the operators of coal-fired power stations and thermal incineration plants for waste, substitutes or biomass to reduce their operating costs. At the same time efforts are made to increase the efficiency of the furnace and to minimize the wear and tear of the furnace wall and heat exchangers, in order to increase their lifetime.

In order to meet these requirements and optimize the combustion process, the correct recording and homogeneous distribution of the temperature in the combustion chamber plays a decisive role. According to the German Federal Immission Control Ordinance (BImSchV) and the German Technical Instructions on Air Quality Control (TA Luft), waste incineration plants are to be set up and operated in such a way that a minimum temperature of 850 °C is to be observed for the combustion gases produced during the incineration of waste or substances after the last supply of combustion air. This should keep the pollutant emissions below the permissible limit values. When incinerating hazardous waste with a halogen content of >1 %, the operator must ensure that a minimum temperature of 1100 °C is observed. The optimum temperature range in which a noticeable NOx reduction is achieved is between 850 and 1100 °C, depending on the exhaust gas composition.

Ultimately, it is the aim of the operators of combustion plants to burn the fuel more completely by means of a temperature-controlled process, to produce less ash. At the same time the requirements of pollutant emission has to fulfil and the consumption of reducing agent has to reduce as much as possible. In addition, the temperature distribution within the furnace has a considerable influence on wear and lifetime. If the temperature is too high, there is a high risk of slagging on the walls and heat exchangers within a very short time. In addition to the loss of efficiency due to the insulating effect, the lumps of slag can become detached and cause considerable mechanical damage if they fall down. If the temperature is too low, the speed for reducing nitrogen oxides decreases, so that the ammonia is not completely dissolved: An ammonia slip is formed, which leads to the formation of ammonia salts. This increases the wear of the plant due to corrosion.

Temperature measurement in combustion plants

Temperature measurement in combustion processes is quite complex. The selection of suitable measuring equipment, the positioning of the measuring points and the interpretation of the measurement results in the interaction of the operating conditions, the fuel, the supply of combustion air and reducing agent already poses a great challenge to the experts for the optimization of the combustion process.

Much is based on empirical knowledge and less on physically deducible evidence. The origin of the fuel and thus the type and composition has a considerable influence on combustion.

If, in addition, an inadequate and unreliable measuring technique is used to record the temperature at the relevant measuring points, mathematical models and adaptive control systems cannot really function either.

A stable and meaningful temperature measurement is the prerequisite for a solid control engineering basis.

Measurement with thermocouples

In many cases, thermocouples are used for temperature measurement, which measure the temperature in the area of a few centimeters close to the wall. However, this does not necessarily correspond to the central temperature of large furnaces with dimensions of up to 20 x 20 m and in particular when the walls are fitted with heat exchangers. Thus a statement about the temperature distribution within the furnace is impossible.

Another problem of thermocouples is a physically caused aging and thus drifting of the devices. Depending on the gas temperature and pollutant content, the displayed measured value can change slowly within weeks. This problem is minimized by equipping redundant measuring points and regularly exchanging the sensors, which results in permanent consumption costs.

In addition, the inertia of the thermocouples with a reaction time of several minutes prevents a rapid reaction to temporary temperature changes. Accordingly, the variation of the process control is high.

Measurement using pyrometers

Another possibility for temperature measurement in a furnace is the use of pyrometers. These determine the temperature from the infrared radiation emitted by a measuring object using Planck's radiation law. Since the response time of pyrometers is only a few milliseconds, it can also be used to react to rapid temperature changes. Modern devices based on continuous-wave light technology work without moving parts. They are therefore wear-free and have no time limit on their use.

Depending on the requirements and needs, pyrometers are used for the different measuring locations of a combustion plant from the measurement of the firebed, the flames, the hot flue gases or the walls (**Fig. 1**). It should be noted that different pyrometer types are required depending on the measuring task.

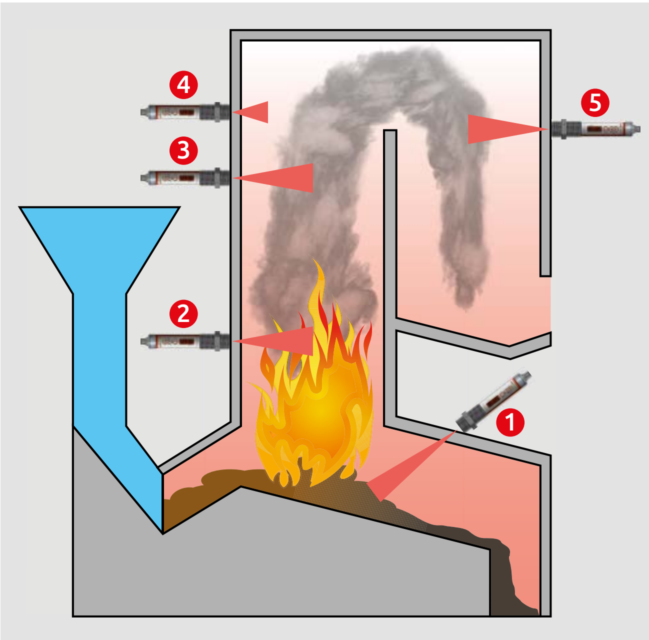

Fig. 1 *Principle representation of the different measuring locations in a combustion chamber*
1: Firebed, 2: Flame, 3: Exhaust gas inside the furnace,
4: Exhaust gas in the area close to the wall,
5: Exhaust gas after the last supply of combustion gas

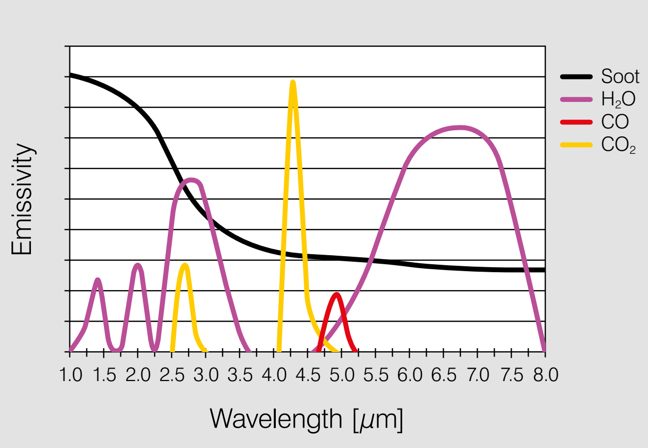

Fig. 2 *Radiation characteristics of combustion gas*

Measurement in the firebed

When measuring the firebed, use pyrometers which cannot be influenced by the hot flue gas in the field of view to the firebed. The devices measure in a very selective wavelength range of 3.9 µm. In this range, water vapour (H_2O) and carbon dioxide (CO_2) are transparent and do not influence the measured value (**Fig. 2**).

Measurement of flame temperatures

So-called flame pyrometers are used for non-contact measurement of the temperature of sooty flames. The measurement is based on the two-colour measuring method, i.e. the infrared radiation is detected simultaneously in the near infrared range at two wavelengths and, from this, the temperature is determined. A complex algorithm in the devices ensures that fluctuations in particle density and particle size are compensated for over the length of the measuring distance and do not interfere with the measured value.

Measurement of exhaust gas temperatures

The prerequisite for temperature measurement with pyrometers is an object that emits infrared radiation. Since the particle concentration in the exhaust gas is rather low and not constant, a conventional pyrometer would measure more or less through the gas a mixture of the temperature of the particles and the opposite wall. The measured value would thus depend on the density of the particles under different load conditions.

The pyrometer manufacturers therefore take advantage of the special radiation characteristics of the exhaust gas and have developed devices with a spectral sensitivity in the range of 4.4 to 4.8 µm. In this area, hot carbon-containing gas has a high optical density and thus good radiation properties (**Fig. 2**).

The emission capability of the exhaust gas depends on the wavelength and temperature. As the temperature rises, the absorption band widens towards the long-wave range (**Fig. 3**). When measuring hot exhaust gases, therefore, narrowband pyrometers with a spectral range of > 4.35 µm must be selected so that the infrared radiation of the hot CO_2 gas in the furnace chamber is detected without being disturbed by the colder CO_2 gas near the wall.

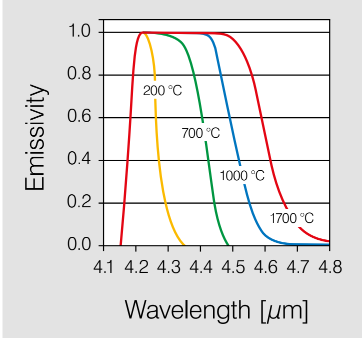

Fig. 3 *Emissivity of CO_2-containing gas as a function of wavelength and temperature*

In the area close to the wall, the temperatures are significantly lower than in the middle of the combustion chamber (**Fig. 4**). Depending on whether the temperature in the vicinity of the wall is to be measured as an alternative to thermocouples or the temperature inside the which is more decisive for the process, pyrometers with a small or large measuring depth should be used. Since gas is not a surface reflector, but a volume emitter, a pyrometer determines an average value over the measuring depth. The measuring depth depends on the CO_2 concentration of the hot gas.

Mounting and selection of pyrometers

A homogeneous temperature distribution in the furnace chamber is crucial for an optimum combustion and minimum wear. A two-dimensional temperature profile is determined from

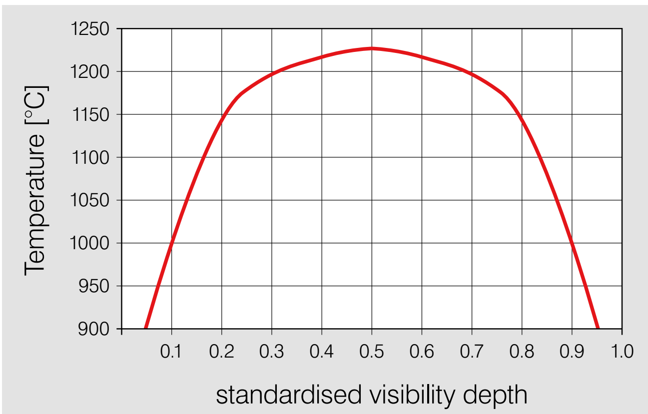

Fig. 4 *Temperature profile inside the combustion chamber*

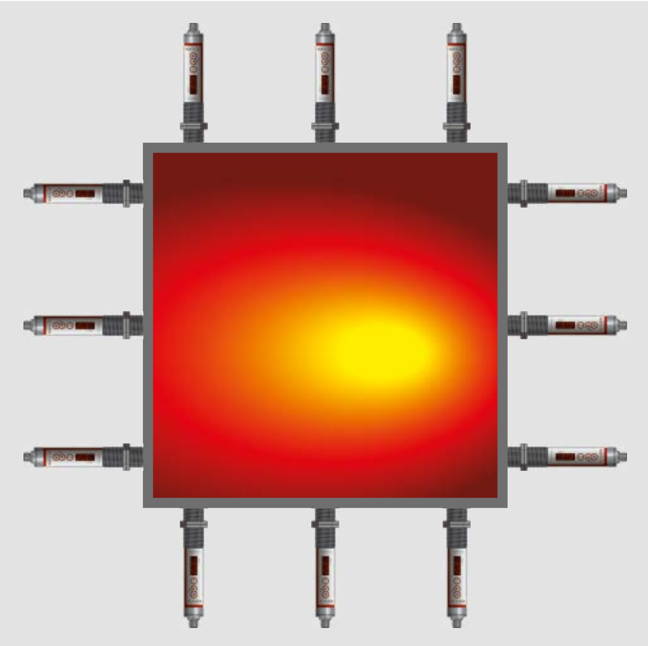

Fig. 5 *2-dimensional thermal image to display the skewness of the temperature distribution*

a matrix of devices. In this way, thermal imbalances can be detected and appropriate primary combustion engineering measures initiated (**Fig. 5**).

Figure 1 shows the typical measuring locations depending on the measuring task. When selecting the pyrometers, care must be taken to ensure that the instruments have a sufficiently narrow optical field of view to be able to measure through the kiln openings, some of which are only 1 inch in size. Recently, pyrometers with integrated video cameras have also been used, which, in addition to the measured value, simultaneously transmit the video image for visual control on a monitor in the control room. For fast control measurements, the market now offers portable devices for the respective measuring task and measuring location (**Fig. 6**).

Fig. 6 *Compact pyrometer with narrow optical field of view and modern digital IO-Link interface*

To record a two-dimensional temperature profile, up to 3 pyrometers are installed on one level per wall. Pyrometers with modern digital interfaces such as IO-Link are ideal for networking and interference-free data transmission.

Conclusion

Pyrometers are ideally suited to solve the various measuring tasks for temperature measurement in coal-fired power plants and incinerator plants when correctly selected and installed. As they are not subject to wear or ageing, they work reliably over a long period of time. Even rapid temperature fluctuations can be detected due to the short response time and immediately incorporated into the control process.

Due to the complexity of temperature measurement, however, it is advisable to call on the support of experts in the selection the measurement system, measurement value analysis and integration into the control process.

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