G 25074

ISSN 0935-7254

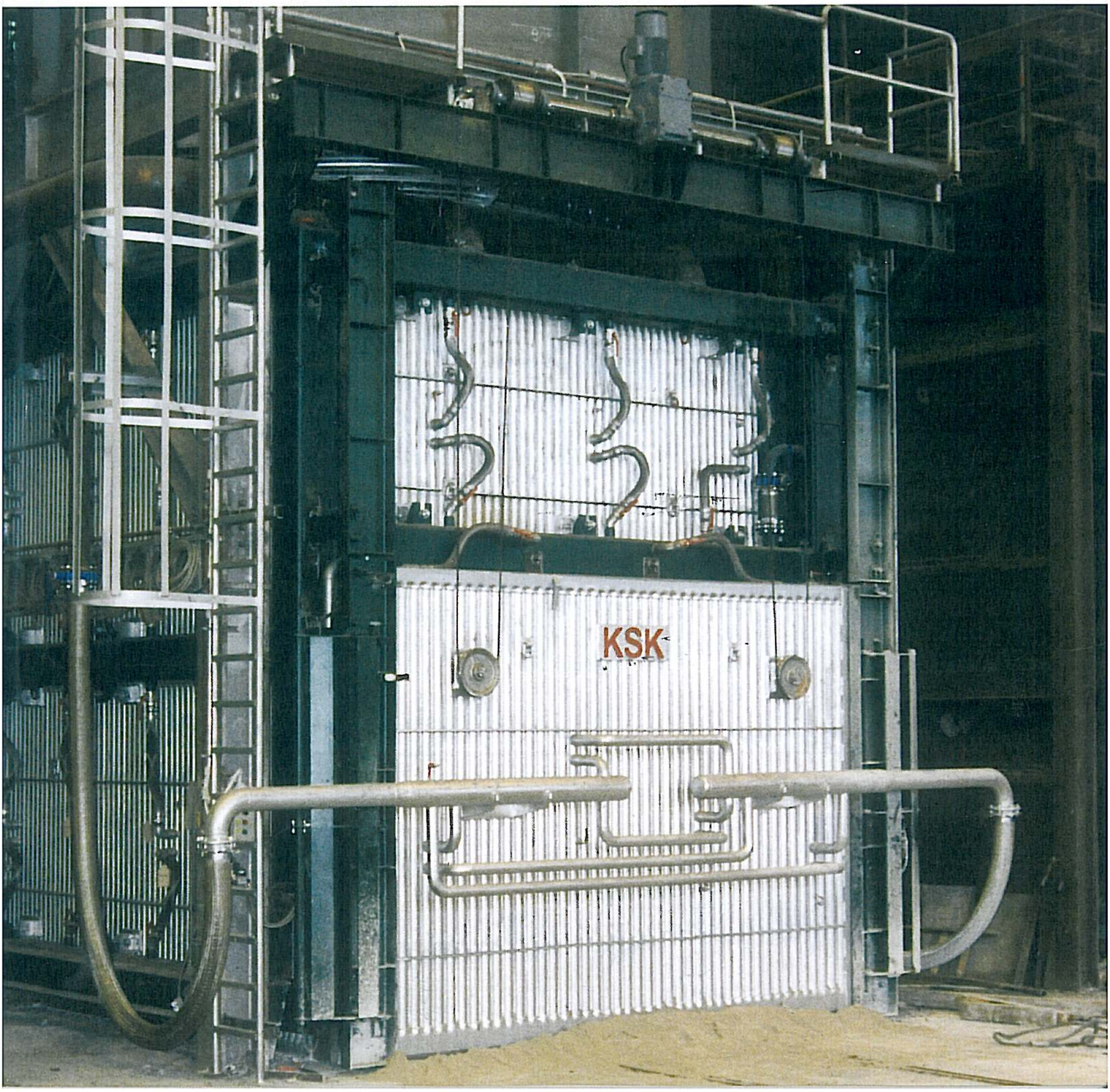
MPT

6

December
2002

Metallurgical Plant and Technology

INTERNATIONAL



Controlling the water temperature in the primary de-dusting systems of EAFs

Olaf Huscher
Jörg Teschner

Metallic surfaces nowadays are provided increasingly with coatings, such as paint films, thermoplastics or metallic platings. Melting down such treated steel scrap presents numerous melt shop operators with the problem of corrosion that shortens the life of their de-dusting systems. An effective possibility of protecting water-cooled boiler-tube-type de-dusting systems from the release of corrosive off-gas constituents is offered by Temperature Level Control (TLC) in a closed-circuit cooling system.
This concept can be applied not only to new constructions, but also in the modification of existing facilities.
The present article is intended to inform mainly about the metrological aspects of TLC, taking as an example the modernisation of the primary de-dusting system and conversion of the conventional cold water cooling system to a closed-circuit re-cooling system at Lech-Stahlwerke in Herbertshofen, Germany.

Lech-Stahlwerke, one of Germany's leading steel recyclers, has been making diverse bar steel products exclusively from steel scrap since 1972. Its crude steel output, amounting to 1 million t/year, is produced in two electric arc furnaces (EAFs) that have an installed load of 40 and 65 MVA, and a heat size of 70 t. Additional energy is introduced through carbon injection and natural-gas burners. The furnace upper shell and roof linings are water-cooled.

Situation prior to the modernisation

With the aim of boosting the melt shop productivity, in 1999 modernisation work was commenced on one of the identically designed electric arc furnaces at Lech-Stahlwerke. The transformer capacity was increased from 40 MVA to 65 MVA. In addition, the energy input was augmented through the installation of gas burners and carbon injectors. As a result of these measures it was possible to reduce the tap-to-tap time by 20%.

Melting operations continued for the time being with the existing de-dusting system. With this system, the furnace off-gases were drawn off through the roof elbow into a water-cooled exhaust duct. The exhaust duct led into a water-cooled boiler-tube-type primary separator. Located between the exhaust duct and roof elbow was an annular gap, via which atmospheric air was drawn-in under controlled conditions into the cylindrical combustion chamber for the post-combustion of the CO in the off-gas. The width of the annular gap was adjustable, so that it was possible to regulate the amount of exhausted off-gas in relation to atmospheric air.

Primary cleaning of the furnace off-gases took place in the primary separator by reducing the gas velocity through the expansion of the gas volume. Flow turbulence was induced in the combustion chamber under controlled conditions by swirling the off-gases.

After the post-combustion of the CO and the primary de-dusting, the furnace off-gas was conducted via a hot-gas line comprising a cooled and a non-cooled line section, firstly to an air cooler and then to a bag filter plant.

The water-cooled components of the primary de-dusting equipment were supplied with "cold" cooling water from an open-circuit cooling system. The heat was dissipated from the cooling medium by means of cascade coolers.

Limits of the existing system

In the course of operating the EAFs with a higher melting rate, it became evident that the existing de-dusting system had to be adjusted to the changed conditions of an increased off-gas quantity and higher off-gas temperatures. The system's primary separator did not have an adequate volume to cope with the 30% growth in the off-gas quantity.

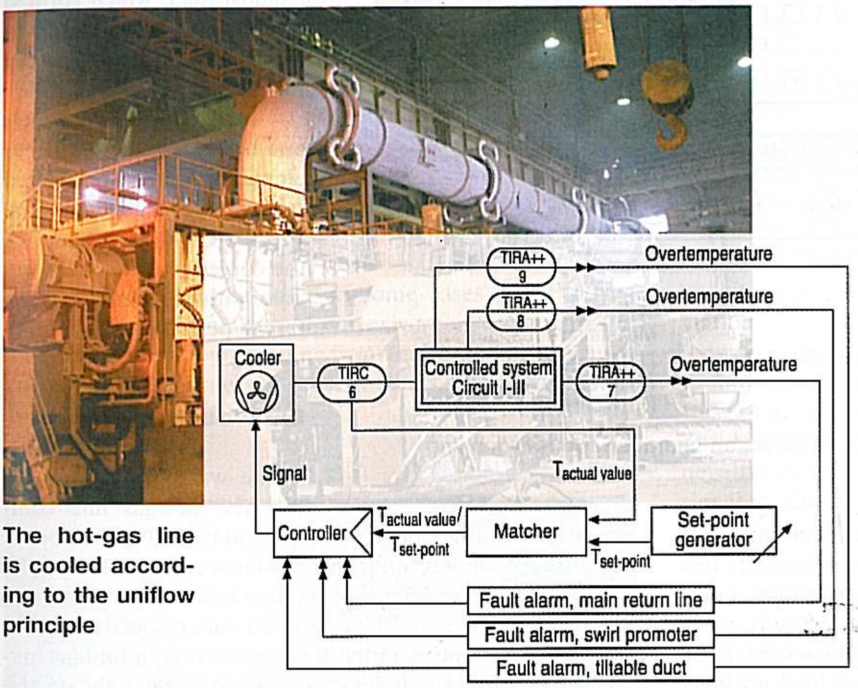
Coarse dust removal in the primary separator deteriorated as a consequence of the increased off-gas velocity and shifted into the cooled hot-gas line. The high dust content of the off-gas on leaving the combustion chamber led to greatly non-uniform thermal loading about the line's circumference. An insulating layer of dust formed on the piping interior bottom, while the upper regions were subjected to many times higher temperatures. Different stress ratios within the line were the outcome.

Dipl.-Ing. Oalf Huscher, President and CEO; *Dipl.-Ing. Jörg Teschner,* Project Engineer, **KSK Kuhlmann-System-Kühltechnik GmbH,** Haltern am See, Germany.

The increased off-gas temperatures at the air cooler outlet made conditions for the gas cleaning process in the bag filter plant more difficult. When the furnace was operating at maximum melting rate, the dissipation of the heat from the off-gas via the water-cooled primary de-dusting system components and air coolers was insufficient to reduce the gas temperature to the maximum inlet temperature permissible for the filter plant.

The temperature reduction necessary to protect the filter plant was realised by means of atmospheric air drawn in via an emergency damper. Opening the atmospheric-air damper, however, retroactively influenced the rate at which the furnace off-gases were directly exhausted. A visible sign of the exhaust rate being too low was when fumes billowed out of the furnace shell.

Added to this, there were increased signs of heavy corrosion and degradation inside the hot-gas line, caused by the furnace off-gas temperature falling below the dew point locally.



The hot-gas line is cooled according to the uniflow principle

The Temperature Level Control concept encompasses all the water-cooled components

Lech-Stahlwerke logged and assessed these increasing problems and, in co-operation with KSK, drew up improvement measures without delay.

Objective of the modernisation

At the beginning of the year 2000, the decision was taken to modernise the de-dusting system completely.

KSK Kuhlmann-System-Kühltechnik, Haltern, Germany, was commissioned to supply the water-cooled system components and actively took part in the implementation and start-up of the Temperature Level Control concept.

Certain preconditions relating to the primary de-dusting stage had to be met:

The removal of the dust and post-combustion of the CO should take place in the combustion chamber. Proven concepts, such as an adjustable atmospheric-air gap on the exhaust duct and controlled gas turbulence in the combustion chamber, should be adopted. To improve the dissipation of heat via the primary de-dusting system it was necessary to dimension the cooling surface of the combustion chamber, the hot-gas line diameter and the length of the line for a defined outlet temperature. A small number of diverse spare parts had to be kept in stock which should be easily accessible and simple to replace. To improve the possibility of cleaning, there should be good accessibility for heavy clearing equipment. Temperature Level Control of the cooling water should be implemented in order to avoid dew-point corrosion and thereby prolong the life of the cooled components. For measurement and monitoring purposes, suitable measurable variables, measuring points and measuring techniques should be selected for operation of the feedback control circuit.

The gas cooler, suction plant and closed-circuit cooling equipment were to be modernised with the following requirements in mind:

Enlargement of the gas cooler to ensure adequate reduction of the off-gas temperature before the gas enters the filters, without opening the emergency damper.

Enlargement of the suction plant, involving an increase of the exhaust rate to cope with the maximum amount of off-gas generated by the furnace and upgrading of the filter plant.

Conversion of the existing open-circuit cooling system to a closed-circuit re-cooling arrangement and installation of a feedback control circuit for temperature level control of the cooling water.

Stage-by-stage modernisation of the de-dusting system

Status 1999/2000. A water-cooled primary separator with connecting hot-gas line, comprising a cooled and a non-cooled line component, was installed.

Both system components were divided into sections, with the cooling water being supplied from an open-circuit cooling network.

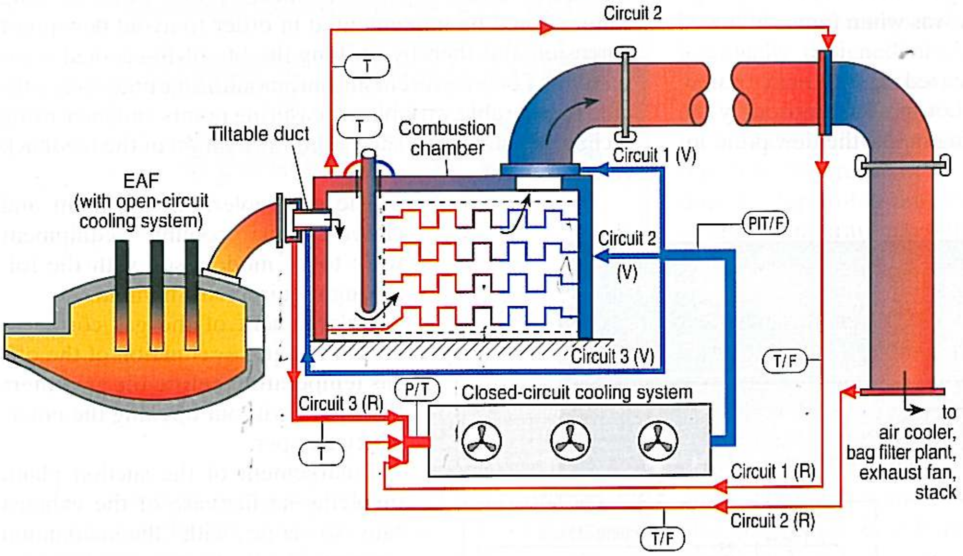
Status from June 2000 onwards. A new and larger-volume combustion chamber, comprising a water-cooled supporting structure and individual sectionalised panels, was installed.

The chamber was connected via an adapter to the existing hot-gas line (1400 mm dia.). A closed-circuit re-cooling system was installed to supply cooling water to the primary gas de-dusting system and preparations were made for the realisation of a feedback circuit to control the cooling water temperature.

The feedback control circuit was not used until the hot-gas line was replaced the following year and the components were operated with cold water until June 2001.

Status since June 2001. A new, enlarged-diameter hot-gas line comprising a cooled and a non-cooled length has been installed.

Compared with the original structure, the inside diameter of the line has been increased from 1400 mm to 1750 mm and the water-cooled length of the line extended. The flow through the multi-length line no longer takes place on a section-by-section basis, but according to the "uniflow" principle. The feedback control circuit for the cooling water temperature of the combustion chamber and hot-gas line has been functioning successfully since being put into operation. The de-dusting system has been completely modernised and, besides having a more powerful gas cooler, the system is equipped with enlarged suction and filter arrangements.



Circuit 1 Hot gas line (forward section)
Circuit 2 Combustion chamber, swirl promoter, hot-gas line (rear section)
Circuit 3 Tiltable duct

Measuring apparatus for:
(T) Temperature
(P) Pressure
(F) Flow rate

Three cooling circuits cool the tiltable duct, combustion chamber and hot-gas line

More effective combustion chamber

The new rectangular combustion chamber comprises a brick-lined bottom section and a water-cooled top section. An important component of the structure is a solid steel framework with replaceable panels of tubular design. The panels and also the steel supporting structure are water-cooled, with the supporting structure serving to distribute the cooling water and hold the panels in place.

The off-gas is drawn-off via an opening in the furnace roof into an oval elbow. Downstream of an adjustable annular gap designed for the controlled addition of atmospheric air, the off-gas flows through a horizontal exhaust duct into the combustion chamber. The post-combustion of CO components in the off-gas already begins to take place in the exhaust duct due to the high gas temperature and continues in the combustion chamber.

The volumetric capacity of the chamber has been greatly enlarged compared with its predecessor and measures around 140 m^3. As a result of the gas expansion, the gas velocity decreases and dust and slag components are separated out.

A replaceable swirl-promoting body protrudes from the furnace-side roof panel into the stream of gas. This generates friction losses through flow turbulence and thus brings about a further reduction of the gas velocity. This measure is prolonging the residence time of the off-gas in the chamber. The off-gas leaves the chamber through a round opening in the rear roof panel and flows via a swirl promoter into the hot-gas line.

For cleaning purposes, the combustion chamber can be accessed with heavy clearing equipment via an electrically operated vertical-lift door. A further feature of the structure is the furnace-side exhaust duct, which is tilted pneumatically into the combustion chamber when the furnace roof is swung aside.

The water-cooled panels and other installed chamber elements are fabricated from boiler tube material P235G1TH (1.0305). All of the cooled parts are replaceable, with the number of different parts kept to a minimum.

Larger hot-gas line

The water-cooled part of the new hot-gas line comprises four straight lengths of pipe and two 90° pipe elbows. The inside diameter of the line has been enlarged from 1400 to 1750 mm. Each length of the line has a ring-shaped distributor and collector at its start and end, respectively.

The hot-gas line is a tube-fin construction in tubular material P235G1TH (1.0305) and is welded gas-tight on the outside. A cooled swirl promoter at the off-gas inlet to the hot-gas line creates additional flow turbulence in the stream of gas. The turbulence brings about intimate mixing of the off-gases and thus increased dissipation of the heat in-line. The heat dissipation is additionally enhanced through the enlarged cooling surface and the lower gas velocity in the new line.

All of the primary de-dusting components are sealed in relation to one another and to the supporting structure side by means of ceramic fibre matting. The amount of drawn-in atmospheric air is minimised and more off-gas is exhausted from the furnace. The appreciably increased volume of the de-dusting system, encompassing combustion chamber, tiltable duct and hot-gas line, leads through the lower flow velocity of the off-gases to reduced pressure losses in the de-dusting system. The exhaust capacity of the system is greatly improved.

The water-cooled length of the new hot-gas line is divided into two separate cooling circuits, which are operated according to the uniflow principle.

Cooling facilitated by uniflow principle

The uniflow principle, compared with sectionalisation, offers many advantages for the implementation of Temperature Level Control (TLC) in hot-gas lines. The line is divided structurally into several, where possible, identical lengths that are connected to one another in series. Long lines additionally have to be divided into several separate cooling circuits in order to limit the pressure loss caused by the series connection.

All of the pipes about the circumference of the line are fed simultaneously from ring-like headers and are flowed-through in the same direction as that of the off-gas flow. Because of the homogeneous mixing temperature in the headers, the line heats up uniformly about its circumference and the temperature level of the cooling water rises steadily from component to component. The return temperature in the last component of each cooling circuit is monitored and used for TLC.

The measuring arrangements involved with sectionalisation are much greater, since every section would have to be monitored, as well as controlled as a function of the section exposed to maximum thermal loading.

Condensation cannot be ruled out in less thermally exposed sections or in 'shadow' regions (e.g. beneath dust) if the hot-gas line is sectionalised.

Dew-point corrosion

The share of coated scrap in some cases leads, during melting, to the formation of corrosive constituents in the off-gas. Water vapour deriving from the combustion oxygen and use of gas burners is present as an additional off-gas component.


When the EAF roof is swung aside during tapping, the exhaust duct is tilted into the combustion chamber

If the off-gas temperature falls below dew point, for example due to non-constantly high off-gas temperatures during electric arc furnace charging, the water vapour condenses on the colder tubular wall. Aggressive gas constituents such as chlorine, sulphur and phosphorus are dissolved in the condensation water. These acid solutions are heavily corrosive and degrade the boiler materials within a short space of time.

Temperature level feedback control circuit

The standard "cold water cooling" of de-dusting systems is conducive to dew-point corrosion. An effective possibility of precluding condensation of the damp off-gas constituents is to raise the temperature level of the cooling water above the dew point of the off-gas.

To do this, it is necessary to have a closed-circuit and temperature-controlled cooling water system in which the entire water volume is adjusted to a pre-given temperature level of around 70 °C on the inlet side of the controlled system. The maximum temperature on the return side is required to be around 95 °C and must not be exceeded.

The heat from the off-gas is used to heat up the cooling water, i.e. the system air coolers are enabled in stages only after the set-point inlet side temperature has been exceeded, or if malfunctions occur.

The controlled system encompasses all the water-cooled components and supply lines of the de-dusting system. Downstream of the closed-circuit re-cooling system, the main circuit divides into three individual circuits, which, after passing through the cooled components, re-unite ahead of the cooler. The mixing temperature of circuits I-III is measured as an actual value on the inlet side of the main circuit.

The striven-for temperature level is input as a set-point in the controller, which continually compares that level with the actual value that is fed back. Using the difference between the actual value and set-point as a basis, the controller generates an actuating signal, which enables the air coolers in stages according to the extent of the set-point deviation.

In order to start up the system – after down-periods, for example – the selected set-point must first of all be attained. It is not achieved after disruptions in the melting process or during charging. In both cases the set-point deviation is negative and the controller does not generate any actuating signal for the coolers until the circuit warms up again.

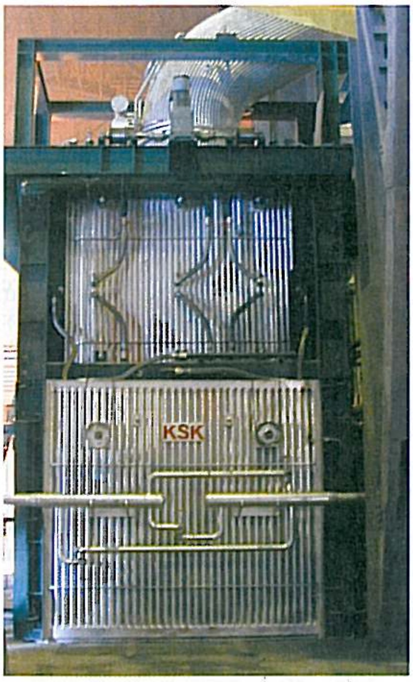
The behaviour of the controlled system is also influenced by disturbance variables, to which the controller must respond with an actuating signal. The controller does not receive any information from the actual-value feedback or temperature monitoring arrangement in the main return line whether all the system components warm up uniformly, or whether there are areas exposed to high thermal loading in the main return line where water temperatures exceed the mixing temperature.

The cooling water temperatures of the components exposed to maximum thermal loading have to be monitored separately and notified to the controller as disturbance variables by means of limit value signals.

The controller responds to a limit value signal with a defined actuating signal, e.g. maximum cooling rate for the lower limit value and furnace de-activation for the upper limit value. When a limit value signal is received, the actuating signal has overriding importance until the actual value falls below the lower limit value.

Although the cooling system is pressurised, the temperature for the upper limit value is set at less than 100 °C for safety reasons.

The temperature difference between the upper and lower limit value is governed by the time lag for each controlled system. Within the context of Temperature Level Control, that is the time that passes after the receipt of an



Heavy clearing equipment can be moved through a large vertical-lift door into the combustion chamber for cleaning purposes

actuating signal at the cooler, until the colder water has an effect on the component.

Which components need to be considered as disturbance variables in the feedback control circuit depends on the operating behaviour of each system. In practice, it is often sufficient to monitor the highly exposed components at the off-gas inlet to the combustion chamber.

Measurement technique

The most important parameters relating to the operation of de-dusting system cooling circuits are pressure, temperature and flow rate. Pressure sensors are essential particularly for the operation of the pump equipment and provide information about the pressure conditions in the cooling circuit.

Temperature measurement is necessary to provide actual data about the cooling circuit for temperature control purposes. Frequently used in this respect are PT-100 resistance thermometers which have a temperature-linear output signal and a measuring transducer accommodated in the terminal housing.

The flow rate is the most important parameter for trouble-free operation of water-cooled equipment components at electric arc furnaces or in downstream systems. Measurement of the flow rate makes it possible not only to monitor, but also control, a pre-given flow rate. In the event of a leakage or pump failure, an operational malfunction can be prevented in good time.

Numerous devices operating according to various principles are available for the measurement of volume flows. Methods widely used for measured value registration include the magnetically inductive measurement principle, probe measurement, and flow rate determination by means of ultrasound.

Magnetically inductive measurement. With magnetically inductive flow rate measurement, the liquid flows through a magnetic field generated perpendicularly to the flow direction. An electric voltage is induced in the liquid because of the latter's movement (law of induction). The voltage is proportional to the mean flow velocity, and thus also to the volume flow. A precondition for the practicability of magnetically inductive measurement is minimum electrical conductivity of the flowing medium. The measurement apparatus comprises a sensor, which picks up the induced signal via two electrodes and a transducer, which transforms this measuring signal into a current signal.

Measurement is largely independent of the flow profile and other measured medium characteristics, such as pressure, temperature and viscosity, as well as of the state of the piping inner surface. The sensor is flange-mounted between the piping.

Depending on the apparatus design, the transducer is attached to the sensor or installed in the control room. The measurement tolerance of the magnetically inductive apparatus is around ±2% of the measured value, according to type and manufacturer.

Strong electromagnetic fields in proximity of the sensor have an influence on the induction principle and a negative effect on the technique's measuring accuracy. The apparatus, depending on type and manufacturer, requires straight in- and outlet lengths roughly 5 times the nominal pipe size. The magnetically inductive principle is suitable for measuring flow velocities up to ~~10 m/s~~; as well as for all nominal pipe sizes.

Probe measurement. The differential-pressure measurement principle is based on the laws of fluid mechanics. The probe is inserted into the piping and fastened in place with the aid of a mounting socket.

The sum of the static and dynamic pressure of the flowing medium is measured on the upstream surface of the probe. The static pressure is measured on the downstream side. The difference between the two pressures is a measure of the flow velocity and of the volume flow.

Probe measurement can be used for determining the flow rate of liquids and gases in round or polygonal piping. The flow-rate probes are suitable for all nominal pipe sizes, as well as for flow velocities up to 10 m/s for liquid and 200 m/s for gaseous media.

Depending on the type of apparatus, probe measurement can also be applied at very high liquid, vapour and gas temperatures. Electromagnetic fields have no influence on the technique's measuring accuracy. The measurement tolerance of the probes is normally around 2% of the measured value.

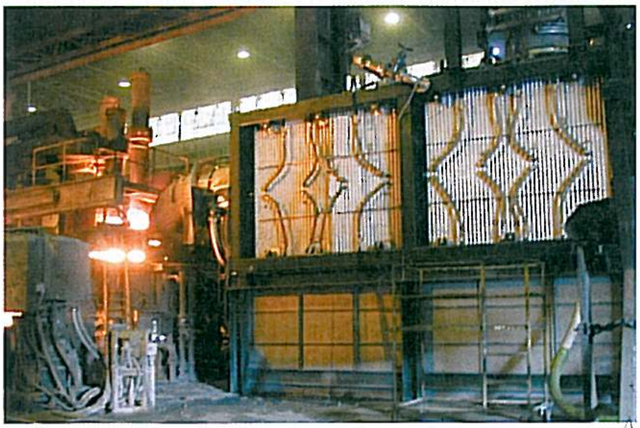
The pressure loss during probe measurement is much lower compared with orifice measurement because of the hydrodynamic design of the apparatus. The method is unsuitable for use in polyphase substance mixtures and heavily contaminated media. When the measuring probes are installed, it is necessary to include straight in- and outlet lengths roughly 7 times the nominal pipe size.

Ultrasound. When determining the flow rate by ultrasound, two acoustic pulses pass through the measured medium in different directions and their transit time is measured.

An acoustic wave that propagates in the flow direction of the medium requires a shorter transit time than one moving counter to the flow direction.

The flow rate is calculated on the basis of the pulse transit time difference.

The stationary type of measuring apparatus comprises two ultrasonic probes, which are attached to the opposite sides of an installed measuring pipe. Both probes are able to transmit and receive ultrasonic waves.



The upper section of the combustion chamber comprises water-cooled, replaceable panels of tubular design

The measurement takes place without any contact, without any constriction of the pipe cross-section and without any additional pressure loss. Measured-medium parameters, such as electrical conductivity, pressure and temperature, have no influence on the measurement result.

The measurement tolerance of the ultrasonic flow meters is around ±1% of the measuring-range end value. When using such ultrasonic measuring apparatus, it is necessary, depending on the type of pipe internals and manufacturer's specifications, to include straight in- and outlet lengths roughly 5 to 15 times the nominal pipe size.

The ultrasonic measurement principle is suitable for determining the flow rate of liquids with any flow velocity and temperatures up to around 150 °C. It can be used for all nominal pipe sizes.

An alternative to the stationary ultrasonic measuring apparatus is the portable flow meter.

Portable apparatus comprises two ultrasonic transducers and a device for their attachment to the piping.

The measurement principle and the installation conditions are largely consistent with those of the stationary apparatus. The method can also be used on coated piping.

The advantage of the portable ultrasonic method is the simple installation at any measuring point and the very accurate measurement data. With a measurement tolerance of around ±3%, the portable apparatus achieves a similarly high accuracy to that of the stationary ultrasonic flow meter.

Conclusion

Controlling the water temperature in the off-gas system of electric arc furnaces is an effective possibility of protecting water-cooled de-dusting systems from the release of corrosive off-gas constituents. Measurement-based monitoring of the primary exhaust system, including temperature control, can be practised not only in new constructions but also at existing facilities, thereby prolonging the life of the de-dusting systems. ■