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SUMMARY

A preventive explosion protection system can only be effective when it is a total system. The adjustment of the oxygen and carbon monoxide limit concentrations in relation to the process temperature is necessary. The evaluation of the measured values and an alignment with typical trial processes are guaranteed in robecco systems. This makes operating reactions possible, e.g. sealing of leakages or prevention of a further entry of oxygen into silos, mills and bag filters. A safe switching over of the fuel plant from "automatic mode" into "manual mode" during process conditions, like test run, maintenance, revision to avoid accidents must be guaranteed. robecco monitoring and control systems are able to take over self-sufficient system functions in case of failure situations of master systems: The monitoring of all system-relevant functions of the sensor system and the inerting plant with dosing station is necessary. An accurate inert gas dosing regarding effectiveness and environment must be considered. Maintaining of the existing inert gas stock and the future procurement of gas storage must be guaranteed. The functionality of the components has to be supervised, relevant errors or failures must be signalled to alarms. The automatic determination of the maintenance intervals, the maintenance dates and maintenance work of individual components in dependence of the actual working time and operating frequency guarantees operability and with this leads to a safe and productive process.

ZUSAMMENFASSUNG

Ein vorbeugender Explosionsschutz kann nur dann wirksam sein, wenn es sich um ein Gesamtsystem handelt. Die Einstellung der Sauerstoff- und Kohlenmonoxidgrenzkonzentrationen in Abhängigkeit von der Prozesstemperatur ist notwendig. Die Auswertung der Messwerte und ein Abgleich mit typischen Versuchsprozessen sind in Systemen von robecco gewährleistet. Dies ermöglicht betriebliche Maßnahmen, wie z.B. die Abdichtung von Leckagen oder die Verhinderung eines weiteren Sauerstoffeintrags in Silos, Mühlen und Schlauchfilter. Eine sichere Umschaltung der Brennstoffanlage vom „Automatikbetrieb" in den „Handbetrieb" unter Prozessbedingungen, wie Probelauf, Wartung oder Revision zur Vermeidung von Unfällen, muss gewährleistet sein. Überwachungs- und Steuerungssysteme von robecco sind in der Lage, bei Störungen von Leitsystemen autarke Anlagenfunktionen zu übernehmen: Die Überwachung aller systemrelevanten Funktionen der Sensorik und der Inertisierungsanlage mit Dosierstation ist notwendig. Eine genaue Inertgasdosierung in Bezug auf Wirksamkeit und Umgebung muss mit einbezogen werden. Die Aufrechterhaltung des bestehenden Inertgasbestands und die zukünftige Versorgung mit Gaslagern muss gewährleistet sein. Die Funktionalität der Komponenten muss überwacht werden, relevante Fehler oder Ausfälle müssen als Alarme gemeldet werden. Die automatische Ermittlung der Wartungsintervalle, der Wartungstermine und der Wartungsarbeiten einzelner Komponenten in Abhängigkeit von der tatsächlichen Arbeitszeit und Betriebsfrequenz garantiert die Funktionsfähigkeit und führt damit zu einem sicheren und produktiven Prozess.

PROCESSING

(English text supplied by the authors)

Preventive Explosion Protection in coal and secondary fuel combustible dust environments: monitoring and control

Vorbeugender Explosionsschutz in Umgebungen mit brennbaren Stäuben aus Kohle und Sekundärbrennstoffen: Überwachung und Steuerung

1 Introduction

To realize the safety of burn processes in the industry sector of cement production or power supply the selection of varied fuels becomes more and more important. The usual storage and containment of such materials are within silos. When deciding on the storage type, consideration must be taken regarding the explosion protection of such equipment, taking into account suitable monitoring and control.

Dust explosions are serious and represent danger. The presence of combustible dust air mixtures in different areas of the plant has the potential for an explosion to occur and need to be avoided.

Technical measuring and control equipment is necessary for the safe operation of coal grinding systems and fuel storage silos. Dust concentrations cannot be controlled; only the oxygen concentration can be varied.

Apart from constructive explosion protection equipment and pressure resistant construction methods in accordance with VDI guideline 3673, technical measuring and control equipment is necessary for the safe operation of a storage silo.

The detection of smouldering fires will be realized in the main with CO and CH_4 analyser systems. Historically, oxygen-measuring instruments were not used in practicable silo plants, which supervise and guarantee the inerting procedure.

According to the guidelines (e.g. TRBS 2152, VDI 2263, CEN 15281) it is necessary in dangerous situations to maintain and supervise the limiting oxygen concentration (LOC) for different fuels.

Regarding the preventive explosion protection and process monitoring, the following electrical control problems have to be considered:

Task: Installation of an automatic central control system that guarantees the inert atmosphere. The function of operation, monitoring and control has to be realized automatically. The following important equipment has to be implemented:

- Gas Analyser Systems
- Temperature Sensors
- Inerting Systems
- Valves and Flaps

The control system has to connect safety systems and shall provide effective protection against hazardous system situations.

2 General issues

Monitoring and control is essential for establishing and maintaining an inert atmosphere. An early detection of explosive atmospheres and hazardous situations (e.g. CO, CH_4, measurement, temperature) is necessary to organize fast triggering of further activities.

Where the oxygen level is actually measured, the monitoring and control system is direct (EN 50104). Where there is no actual oxygen measurement, the system is not under control.

There will be a need to define the safe limits of variables which may be flow, pressure or oxygen concentration depending on the used method of inerting. The control system may have critical elements which need to be defined. The monitoring and control systems should have the appropriate hazardous area certification for the proposed application. It will be necessary to comply with any local national regulations, if there are any, which may be applicable.

Monitoring and Control systems are total systems in combination with an inerting system.

Sensors (gas analysers), a PLC and an actor (inerting system) are a combination of functionality, each depending on the other, which only work together in total (ATEX 2014/34/EU, article 1, passage 2).

Precondition of safe processes: To understand the risks of production, it is a requirement to evaluate the process. Knowledge of the actual process parameters is essential to recognize the risk. Dangerous and hazardous situations must be identified to trigger further activities.

As consequence of their knowledge and experience with the production and storage of hazardous products, robecco developed a suitable monitoring and control system.

3 Monitoring

3.1 General information about monitoring systems further called gas analyser systems (TRBS 2152-2, Chapter 2.5)

Gas analyser systems can be used to detect hazardous explosive atmospheres and are the basis for the initiation of protective measures. They are used for manual or automatic triggering of protective measures or emergency functions to stop or to continue a coal ginding system or a storage silo.

The following requirements are valid for the use of gas analyser systems:

- Sufficient knowledge and attention to the expected fuel and physical properties, the position of their sources, their maximum values and the conditions of propagation.
- A functionality of the analysers which is suitable with the conditions of use, in particular with regard to the response time, the response value and the cross-sensitivity.
- Avoidance of dangerous conditions in the event of failure of individual functions of the gas analyser system (availability).
- To record the expected gases sufficiently, quickly and reliably by means of a suitable choice of the number and location of the measuring points.
- Knowledge of the area, which will be explosive, until the protective measures are triggered by the device becoming effective. In this area (depending on items 1 to 4), protective measures are taken to: ignition source avoidance required.
- Sufficient secure prevention of the occurrence of hazardous explosive atmospheres outside the area in section 5, by means of the protective measures taken.
- No other dangers may arise due to fault triggering.

To resume: It is essential to have early detection of explosive atmospheres and hazardous situations (f.e. CO, CH_4 measurement, temperature). It is essential to maintain the equipment used and the inert atmospheres (O_2 measurement) (see chapter 1.4). The monitoring systems should have the appropriate hazardous area certification (ATEX).

The suitable selection of gas analyser systems and sensors for the use in the context of explosion protection measures according to TRBS 2152 part 2/TRGS 722 shall be made with regard to the measuring functionality and the functional safety. In each case the definitions of the manufacturer's instructions for the intended use must be taken into account.

The function of the gas analyser systems shall be checked after their installation and at appropriate intervals. In addition, they shall be maintained regularly. Gas analyser systems shall be installed and operated in such a way which allows a manual intervention in the automatic controlled process by the gas analyser system at any time. This procedure must not lead to the loss of explosion safety and must only be carried out by authorized personnel.

3.2 Methods of monitoring

There are different methods of determing whether a system is inert:

- Direct method: Actual oxygen concentration is continuously measured using an oxygen sensor.
- Inferential method: No direct measurement, the oxgen concentration is inferred from actual measurements taken at various times.

3.3 Continuous measurement

Detection of hazardous situations needs a continuous measurement at relevant process points to proceed with further actions. In this consequence, it is necessary to measure the oxygen concentration at a point or several points that are representative of the system which shall be inerted.

The gas sampling system used needs to be reliable to feed the oxygen analyser and to ensure that representative samples are taken. Where oxygen monitoring is carried out by means of an in-situ sensor (i.e. a sensor which is inserted directly into a process stream or vessel), then it is likely that the sensor will become contaminated and consequently have a shorter life than expected.

In order to enable reliable measurements, it will be necessary to ensure that the sample is conditioned to remove contamination or materials which will cross-sensitise the gas analyser. For this, a reliable gas conditioning system should be used to prevent sensor contaminations and malfunctions.

Provision will be required for maintaining and calibrating the sensor periodically. Where a process is continuous, it will be necessary to be able to undertake maintenance and calibration without interrupting the process. The advantages of continuous gas measurement are:

- Direct measurement of the safety critical parameter and ability to control directly.
- Minimises inert gas consumption as gas is only used as required.
- Can be used for a differential measurement.
- Detects leaks and process upsets.
- Entry of personnel into hazard areas is not necessary.

3.4 Sequential measurement

One gas analyser samples a number of items of process equipment in regular sequence, so that any deviation from the required level for each sample point is detected when the pre-set sequence takes the sample. It can be used to control the oxygen concentration directly. Inherent problems with time delays may make it unsuitable where rapid changes in the oxygen level may occur. In practice, the sequential measurement is suitable for use where a slow development of hazardous atmospheres is assumed. The advantages of a sequential gas measurement are:

- Direct measurement of the safety critical parameter and ability to control directly (only if the process allows time delays).
- Minimises inert gas consumption as gas is only used as required.
- Detects leaks and process upsets.
- Entry of personnel into hazard areas is not necessary.

3.5 Practical choice of monitoring equipment (EN 60070-29-2)

The choice of the gas sensor or gas analyser system used, depends on process situations and process parameters like the position of the measuring point, explosive zones (ATEX), gas temperature, dust content, pressure range, range of measurement, gas dew point and the operating gas composition should be done according to individual process situations and required safety aspects. Further support for the choice and application of different sensors can be done with EN 60079-29 (part 1 and 2).

A proven technology is the use of carbon monoxide (CO) analysis for early fire detection and oxygen (O_2) analysis to control the inert atmosphere. The early detection of smouldering fires allows the operators to mitigate fire propagation with the help of technical measures. Continuous carbon monoxide (CO) and oxygen (O_2) monitoring is essential to ensure prevention of fires and explosions.

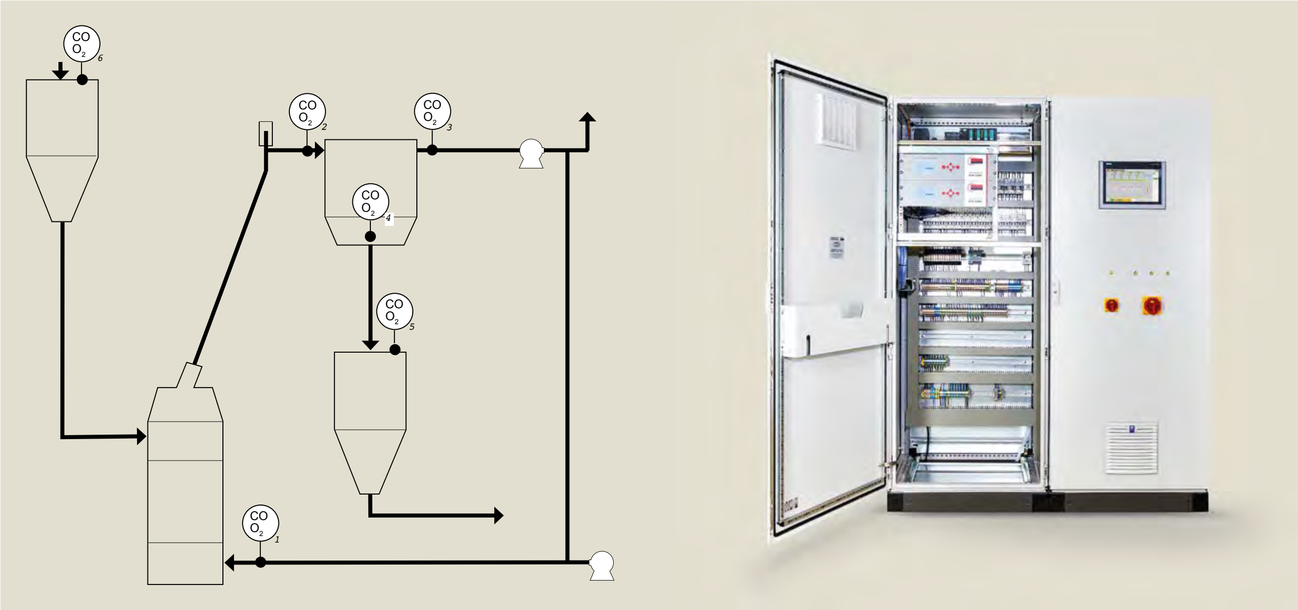

Figure 1: robecco measuring points and monitoring hardware in a coal mill system

3.6 Location of measuring points
The principal objective is that sensors and sampling points should be placed in such a way that gas accumulations are detected before they create a significant hazard (❱ Fig. 1).

3.7 Description of measuring points
Mesuring points should have a description and analysis to support the design and functionality of a gas analysing system or sensors (❱ Table 1).

3.8 Maintenance and calibration of monitoring systems, training
According to EN 60079-29-2 gas analyser systems or gas measuring devices need to be calibrated and to be maintained with a view to their measuring range and functionality (❱ Fig. 2). This maintenance shall be done according to the manufacturers manual. Training of personnel in the use, maintenance and calibration of monitoring equipment is essential and should be updated regularly.

Table 1: Typical robecco measuring point description

	Unit	Sampling point 1	Sampling point 2	Sampling point 3	Sampling point 4	Sampling point 5
Sample type	-	Continuous	Continuous	Continuous	Continuous	Continuous
Measuring point description	-	Before mill	Before filter	After filter	Product silo	Raw coal silo
Tag number	–	1	2	3	4	5
ATEX zone internal	–	21	21	22	20	20
ATEX zone external	–	22	22	22	22	22
Flange connection	–	DN 65/PN 6	DN 65/PN 6	DN 65/PN 6	DN 65/PN 6	DN 65/PN 6
Gas temperature Operating Maximum	°C °C	~310 350	~70 to 90 115	~70 to 90 115°C	0 to 100	0 to 100
Dust content	g/m³ (stp)	~20	~360	~10	max. 1 000	max. 1 000
Pressure range	mbar	0 to -5 (min. -100)	0 to -70 (min. 100)	0 to -85 (min. -100)	0 to +20	0 to +20
Measuring value		CO/O_2	CO/O_2	CO/O_2	CO/O_2	CO/O_2
Measuring range CO O_2	ppm vol. %	0 to 5 000 0 to 25	0 to 5 000 0 to 25	0 to 5 000 0 to 25	0 to 5 000 0 to 25	0 to 5 000 0 to 25
Gas dew point	°C	~ 58	~ 58	~ 58	19	19
Operating gas composition		Kiln gas	Kiln gas	Kiln gas	Ambient air	Ambient air
Sample line length	m	15	20	38	35	35

Figure 2: Full automatic prevention explosion protection system including monitoring and control, CO_2 storage tank and distribution

4 Control

When designing or increasing the automation of a plant or process, it is an absolute prerequisite to define safe operating conditions. It is highly recommended to estimate safety levels (❱ Fig. 3).

4.1 Specification of limits, definitions (VDI 2263-2)

- Limiting oxygen concentration (LOC) determined by EN 14034-4 or prEN 14756. The LOC varies with pressure and temperature.
- Maximum allowable oxygen concentration (MAOC) in the process.
- Trip point (TP), at which the process controller initiates a shut-down trip.
- Set point (SP), at which the process controller maintains the gas concentration (O2 and flammable gas indicators).

Adequate safety distances should be provided for the experimentally determined limits, in order to avoid glowing or smoldering fires, when deposits of combustible dusts are present, some significantly lower oxygen concentrations must be maintained to avoid dust explosions. The relevant oxygen concentrations must be determined separately. Note: To extinguish a glowing or smoldering fire it is necessary to reduce the oxygen content to below 2 to 3 vol. % (TRBS 2152-2).

The limiting oxygen concentration is determined by a test, such as EN 14034-4 or prEN 14756, and is determined under specified temperature and pressure conditions. As the process may operate at different temperatures and pressures from those used in the determination of Limiting Oxygen Concentration, it will be necessary to either apply a suitable margin or determine the LOC under the process conditions. This will give the maximum allowable oxygen concentration or MAOC. This oxygen level must never be exceeded, as above this value, the atmosphere would be flammable.

In order to allow adequate variation in oxygen content due to process upsets etc., it is necessary to have a suitable safety margin between the MAOC and the trip point. Any alarms or

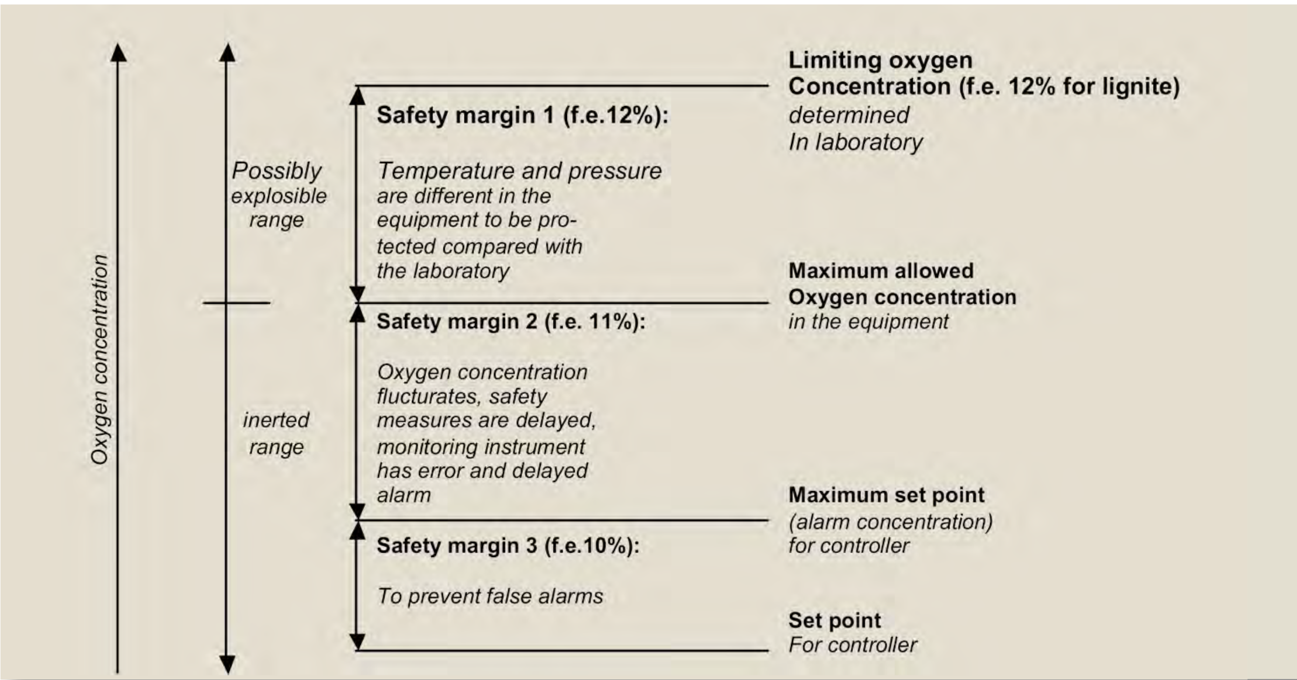

Figure 3: Safety margin table

trips will operate at the trip point, so that the process can be shut down or made safe. There should be sufficient margin between the trip point and the MAOC to ensure that the process can be shut down or made safe in the time between tripping and the oxygen concentration reaching the MAOC.

The magnitude of the required safety margin should be determined by a risk assessment similar to that required for safety critical equipment. In order to prevent false trips, consideration should also be given to the response time of the sampling, monitoring and control system.

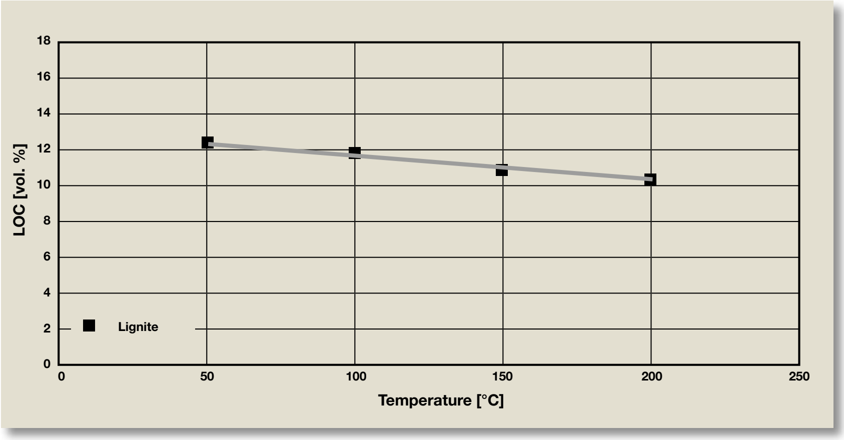

Figure 4: Dependence of process temperature and LOC

Where the oxygen concentration is continuously monitored, a safety margin of at least 2 to 3 vol. % below the MAOC should be maintained, unless the MAOC is less than 5 vol. %, in which case the oxygen concentration should be maintained at no more than 60 vol. % of the MAOC.

Where the oxygen concentration is not continuously monitored, the oxygen concentration should be maintained at less than 60 vol. % of the MAOC, unless the MAOC is less than 5 vol. %, in which case the oxygen concentration should be maintained at less than 40 vol. % of the MAOC.

4.2 Control characteristics

Each process requires control characteristics to ensure an successful inerting process. Some examples of characteristics and specifications for control are as follows:

- Losses of inert gases are not allowed and shall be replaced.
- Documentation of sudden and abnormal events.
- Organized fast triggering of further activities in case of emergency.
- Functionality control of safety relevant equipment.
- Adjustment of Limiting Oxygen Concentration (LOC) depending on the process temperature and volatiles.
- Adjustment of the carbon monoxide concentration (or other explosive gases/indicators) depending on the process temperature.
- Evaluation and an adjustment with typical processes. With help of this a sealing of leakages and preventing of an entry of oxygen is possible.
- Safe switching over of the control system from automatic control to manual control in process conditions like a test run, maintenance.
- Operation or revision mode to prevent accidents.
- Self-sufficient system functions without upper PLC control.
- Avoidance of human failures by fault operation, misinterpretation of measuring results or uncontrolled PLC stand.
- Logging (Data memory functions).
- Remote service and diagnostic function (Fast Service).
- Integrated Maintenance Documentation.

4.3 Typical dependence of process temperature and LOC (e.g. lignite) (DEKRA research report on LOC)

Recommendation on the temperature dependence of the limiting oxygen concentration: ❱ Fig. 4 shows that an increase of the ambient oxygen temperature will expect a tendency to decrease the oxygen concentration.

Table 2: Dependence of volatiles and LOC (Bhatty, Miller and Kosmatka 2004)

Coal type	Volatiles [%]	Limiting oxygen concentration (LOC) at 20 °C [vol. %]
Lignite	32 to 35	Approx. 8 to 12
Bituminous coal	14 to 31	Approx. 12 to 16
Anthracite coal	12 to 14	Approx. 16 to 17

Knowledge of the reduced oxygen concentration at elevated ambient temperatures is necessary for safe inerting. For organic dusts, investigated by Wiemann and Glarner, a decrease in the limiting oxygen concentration of 2 vol. % per 100 K temperature increase can be assumed for the practical application. If a measured value already exists at an elevated ambient temperature, it is possible to calculate the oxygen limit concentration of organic dusts at other ambient temperatures. This estimate can be used for temperatures up to 300 °C, taking into account a safety margin of approx. 10 vol. %.

Also with gases and vapors, the limiting oxygen concentration depends on the type of inert gas. When carbon dioxide is used as the inert gas, higher limiting oxygen concentration values are measured than when using nitrogen. The limiting oxygen concentration decreases with increasing temperature and increasing pressure (TRBS 2152-2).

4.4 Typical dependence of volatiles and LOC

The consideration of volatiles for the design of a control system is important. ❱ Table 2 shows the dependence of volatiles of different coals on the limiting oxygen concentration.

5 Maintaining of inerting systems, monitoring and control systems for preventive explosion protection

If the inert condition has been established, the oxygen content needs to be monitored continuously. Losses of inert gas because of leakages or other process reasons (e.g. an open vent because of overpressure during the inerting process) are mostly the reason why oxygen limits will not be reached. During the whole process, this means that a suitable monitoring and control method will be required to ensure that the maximum allowable oxygen concentration is not exceeded. This is usually a direct measurement of the oxygen content.

PROCESSING

A loss of inert gas is not allowed and shall be replaced. An adequate control shall support the functionality and availbility of the monitoring and inerting system. Some characteristics:

- Availability of the inert gas flow.
- Availability of the inert gas operation pressure.
- Sufficient storage of the inert gas for procurement, stock and a full inerting trip.
- Availability of the inert gas distribution unit in an emergency case.
- Exact inert gas dosing regarding effectiveness and environment.
- Monitoring of relevant system functions of the inerting storage and the dosing unit.
- Monitoring of relevant system functions of the monitoring system: Sampling, gas preparation, gas flow and analyser (IR measuring unit, oxygen measuring unit).
- Automatic determination of maintenance of components.
- Integrated maintenance documentation.

Maintain the operability and reliability of an inerting system and monitoring devices in total:

- Detailed design of a control system.
- Integration of the monitoring system.
- Integration of the inert gas system.
- Integration of regular maintenance and calibration of monitoring systems.
- Integration of failure management.
- Personnel protection.
- Auto modifications if the process parameters change (e.g. fuel change).
- Data memory.

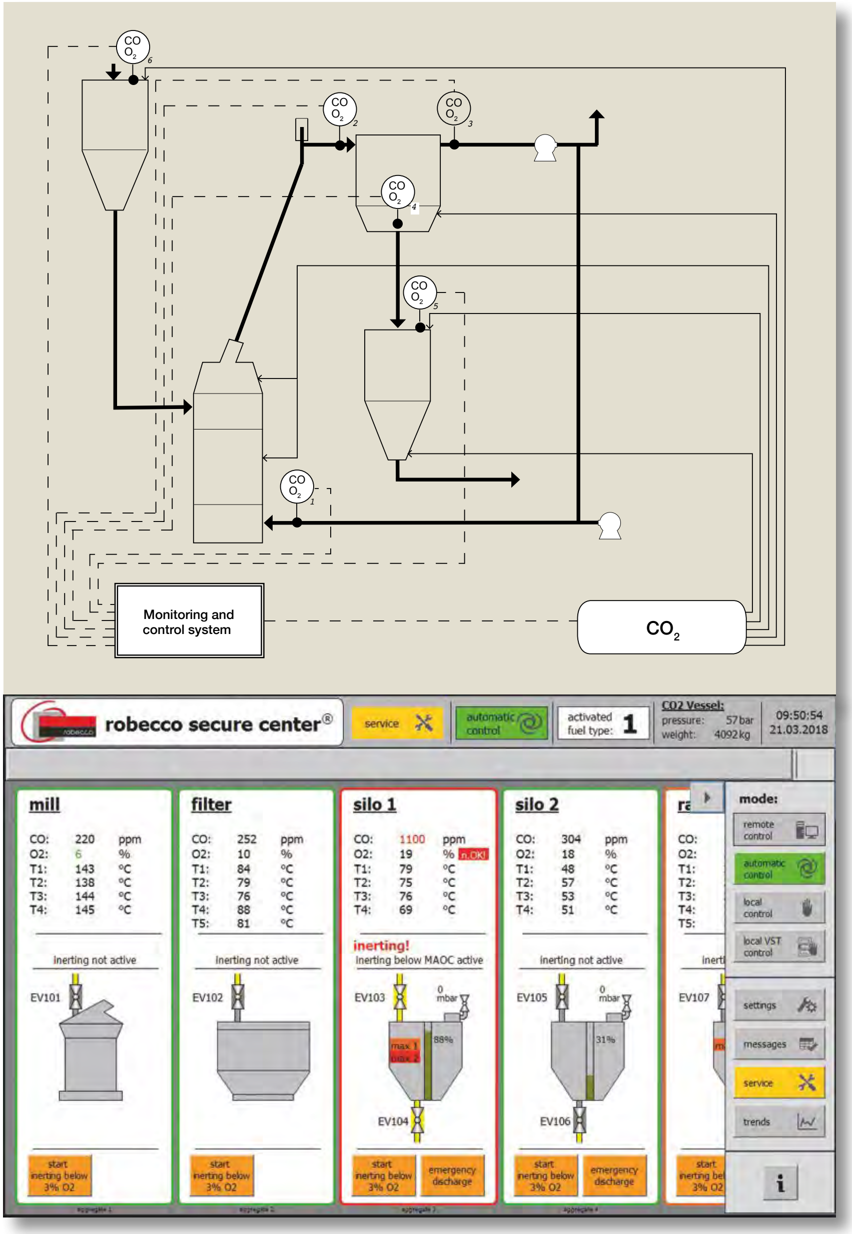

Figure 5: Control concept in a coal mill system, robecco secure center

The implementation of the above recommendations must take into account a fully automated central control system which guarantees the inert atmosphere in chemical and physical processes in the event of an alarm and emergency situation (› Fig. 5). The control system shall connect safety systems and provide effective protection against hazardous system situations. For a coal mill system as an example: Gas analyser systems, temperature sensors, valves and flaps, inerting systems.

6 Integrity, safety and reliability

6.1 General (IEC 60070-29-2)

If gas analyser systems or channels of a system or inerting systems fail or are removed from service, so that areas of the plant cannot be monitored and controlled sufficiently, additional measures may be required to preserve safety. Planning for such eventualities should happen before installation. It is similarly essential that safety is maintained when the gas warning system, or a part of it, becomes inoperative during routine calibration or there is an inerting system fail out during maintenance or refilling with inert gas.

Reliability of inerting systems vary according to the chosen method of inerting. After the risk assessment has been carried out on the equipment to be inerted, a decision will need to be taken about the type of inerting method needed to achieve the acceptable level of reliability required in the plant. This means that the inerting method will be defined according to the hazards of the process, and this will result in the choice between direct measurement of oxygen or inferential methods.

In each case, additional measures to preserve safety have to be included:

- Signaling of gas analyser system faults.
- Signaling of inerting system faults.
- Signaling of control system faults.
- Use of portable or transportable gas detection apparatus for temporary monitoring.
- Use of portable or temporary inert gas supply and distribution.
- Increased ventilation.
- Elimination of ignition sources.
- Interruption of supply of flammable gases or liquids.

- Switching-off of plants or parts of them.
- Training of personnel to organize fault functions.
- Duplication of the most essential sensors (redundancy).

6.2 Redundancy

In general, a system should be installed so that failure of individual elements of the system, or their temporary removal for maintenance, does not compromise the safety of the personnel. Duplication or triplication of remote sensors and control systems is recommended in all areas where continuous monitoring is absolutely essential. Devices that operate 'fail safe' should be used wherever possible. The availability of the inert gas supply and distribution, also temporary, shall be guaranteed in each case.

6.3 Safety critical equipment

The demands for safety critical equipment involves the following:

- Definition of the basis of safety for the inerted equipment. This may involve the use of inerting to modify the probability of the occurrence of flammable atmospheres.
- If possible, identification of safety critical equipment shall be distinguished from process control equipment.
- The safety critical equipment should comply with the requirements of the European Directive 2014/34/EU and should be covered by a conformity assessment and certificate.
- A risk assessment shall be carried out according to the safety standards and the safety critical equipment shall be evaluated. ◂