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Fire and explosion protection of coal grinding systems. Where are we today?

One answer: We are not where we should be!

With 'everybody' in the cement industry focussing decarbonisation, but with coal grinding systems still being used in the foreseeable future, the topic dealt with here must not be shoved into the background. There is a serious need for change here too.

In the following text is explained what goes wrong with the coal grinding systems purchased by the industry and why and how it goes wrong.

In the text, the word coal stands for *coal*, *lignite* and *petcoke*. The following text doesn't refer to old configurations, e.g., configurations with cyclones in them, or systems with a vertical roller mill (VRM) and a separator/classifier that is not integrated in the VRM.

Today, the indirect firing coal grinding systems mostly are operated with process air from a source that will provide for air with a low O_2 percentage. Systems that work with clinker cooler air (21 % O_2) exist. For such systems, the need for correct fire and explosion protection is even more relevant than for systems with process air with reduced O_2.

The number of sources to which a cement producing organisation can turn (worldwide) when it intends to purchase a coal grinding system is not more than roughly 50.

It could be expected that it makes a difference, when a coal grinding system is purchased separately, e.g. for the replacement of an older installation, compared with its purchase as part of a larger job, e.g. setting up a complete clinker production line. When a system is purchased separately, more attention can be paid to design matters. In practice, positive effects as result of this difference are not observed.

In general, it can be said that the knowledge of fire and explosion protection technology, which is very special knowledge, is neither good on the purchasing side nor on the side of the system suppliers.

System suppliers in European countries and in the USA in which deep pit coal mining is taking place, or has taken place in the past, have a fundus in the form of literature and standards. In these countries industrial explosion protection developed starting from a basis of research in explosion protection for the mines, in which so called hybrid explosions would take place from time to time.

Hybrid explosions are explosions in which' combustibles are a mix of combustible gas and combustible dust. In the case of explosions in deep pit coalmines, the combustibles normally were methane and whirled-up coal dust.

It is in these countries that institutes and universities engaged and are still engaged in scientific approaches to industrial fire and explosion protection. Presently, research for the development of industrial fire and explosion protection is also taking place in other countries and a multinational community of organizations occupied with industrial explosion protection exists. This multinational community is not taking a special interest in the explosion protection of indirect firing coal grinding systems like those used in the cement industry.

The coal grinding systems of the cement industry today are so called *indirect firing coal grinding systems*, also known as *storage firing coal grinding systems*. The mills are either air-swept vertical roller mills (VRMs) or air-swept horizontal ball mills (HBMs).

Indirect firing (or storage firing) means that the ground coal is collected in silos from which it is discharged to be dosed into pneumatic conveying systems that feed a burner. In order to get the ground coal into the silos, a filter separates it from the process air.

When such technical configurations are processing coal, with dust airborne in certain concentrations, there are locations in the system in which temporarily or continuously an explosive atmosphere exists. That is, when the process air in the system has more than 12 % O_2.

It can be said that all today's well-developed industrial explosion protection had its beginnings in explosion protection for coalmines.

Having a fundus of information available unfortunately has not led to correct fire and explosion protection for the coal grinding systems supplied to the cement industry. But in the countries with a history in deep pit coal mining it has been understood that industrial explosion protection needs regulation.

example of successful explosion protection and unsuccessful fire protection

It can also be said, that, unfortunately, explosion and fire protection for coal grinding systems (and for many other fields of technology) never were developed coordinated. Standards for explosion protection in many ways completely ignore that good protection against explosions not necessarily will also protect against the fire that could follow after the explosion took place.

The result of all this is that the 50 or so suppliers of coal grinding systems to which the cement industry will talk all have different backgrounds and understanding of what good industrial fire and explosion protection is.

There are huge differences in industrial backgrounds and mentality. Some suppliers really want to get things right. Other suppliers are ignorant or careless, or both.

This also has to do with the fact that explosion and fire protection for coal grinding systems cannot be learned by reading the available literature and standards. Standards sometimes are hard to understand and apart from examples they may show, will not and cannot cover the complexity of industrial installations in which all kinds of scenarios can develop. At best, standards will point at certain hazards that need attention, but without giving all the answers on questions that then may come up.

It is a fact that the fire and explosion protection of coal grinding systems in the cement industry is not in order. This is true all over the world. For both large groups and smaller operations. And for plants with or without certified quality and safety management. The certifiers also are not knowledgeable enough.

Despite efforts here and there to improve situations, for a multitude of reasons not much progress is being made. One reason has already been mentioned: Ignorance.

The realization of each coal grinding system begins with discussions between buyers and sellers.

Seller reps think that the people in their company are doing things right and buyer reps want to trust the sellers and leave the responsibility for getting their design right with the sellers.

On both sides, the participants in the discussions are not experts in fire and explosion protection of coal grinding systems. They can't be! They have to be good at making cement and building cement manufacturing facilities. Coal grinding systems are not the main thing.

Now this is the result: Sellers go home and look for a design their company made for a similar case. That then is the design that will be offered.

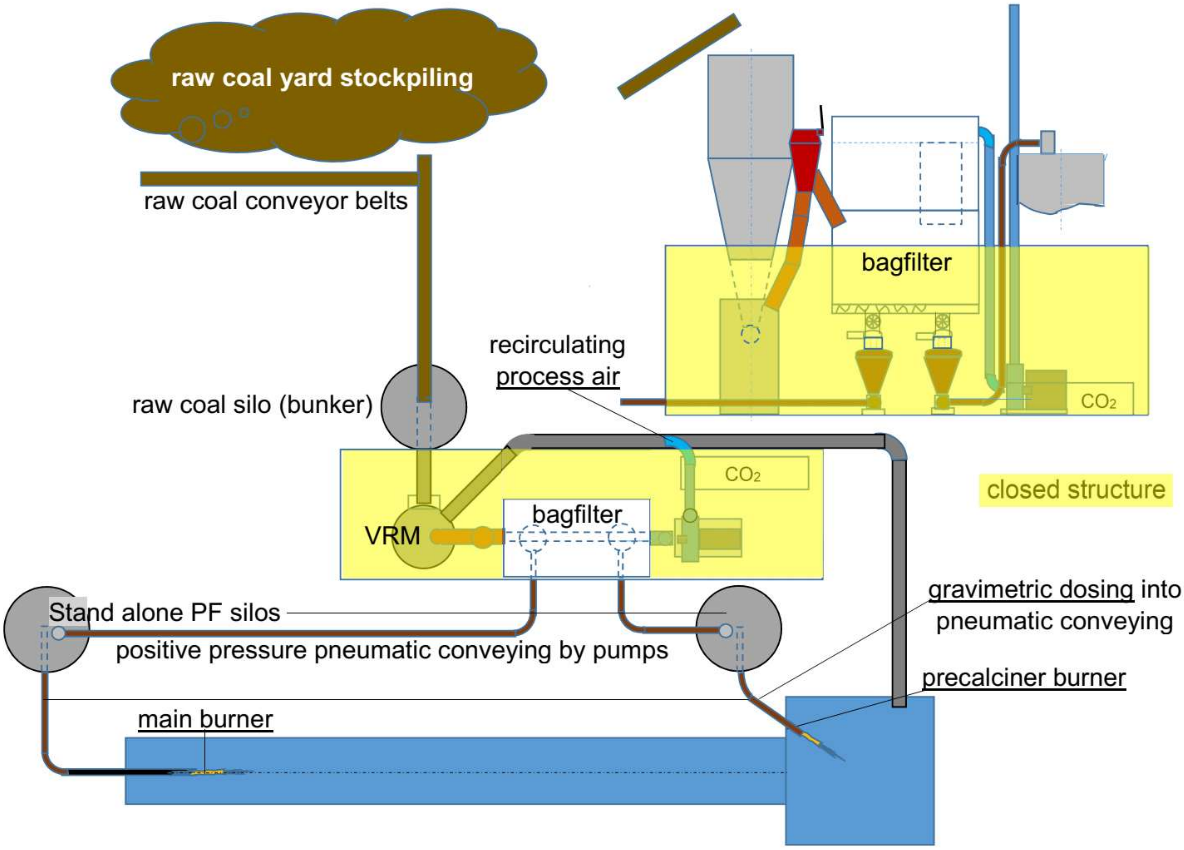
Approaching the matter in this way is economical. Cheap for sellers!

Since the approach is repeated over and over again, today's coal mill system designs are decades old. Not mill or dust collector designs. This core equipment is under continuous development. The general designs of the system are not developed. Changing the drawings is expensive.

For the realisation of new systems often engineering in form of drawings is provided. The buyer bears the cost of construction material (steel and concrete) and execution. Consequently, vendors' interest in saving space, steel and concrete will be lost against the costs of having to change system designs.

A new design would have to ensure that:

- movement of air and coal through the system follows the shortest possible paths
- the space occupied by the system is small and does not need many stairs and gangways, and it can be easily kept clean
- only the equipment that really needs to be installed inside a structure is installed in its structure - Silos are equipment that should not be installed inside a structure.
- access for maintenance is good
- uncompromised preventive and constructional fire and explosion protection are in place



simplified drawing of a coal grinding system with small footprint and short paths for process air and coal, little enclosed structure and with the raw coal silo, the upper part of the main bag filter and the PF silos outside of the structure

Fire and explosion protection must distinguish between preventive and constructional explosion protection.

preventive fire and explosion protection

Preventive protection can be realised by:

- yard management that ensures that no coal undergoing intensified oxidation reaches the raw coal silo(s)
- reliable separation of metals, Fe and non-Fe, out of the raw coal flow to the silo(s)

- limiting O_2 in the process air to maximal 12 % process wise
- process control that ensures that no set HIGH/HIGH limits for temperature, CO and O_2 are exceeded
- emergency measures and procedures (like gaseous CO_2 inundation = emergency inerting), with their use known by the operators and trained

A good example of a topic about which confusion exists is **emergency inerting**. The solutions sold by the relevant suppliers are sold under all kind of names, often under the name fire protection system or similar. Many solutions offered are outright wrong.

constructional fire and explosion protection

Constructional protection for air-swept indirect firing coal grinding systems usually is realised by:

- explosion pressure shock resistance (EPSR) withstanding unmitigated explosion pressure (i.e. Pfister calibration hopper and DRW rotor feeder)
- explosion venting (pressure mitigation) by means of self-reclosing explosion vents with the necessary degree of EPSR of the protected equipment in place
- explosion de-coupling with the necessary degree of EPSR in place
- explosion isolation with the necessary degree of EPSR in place

Explosion venting releases the pressure in a vessel in which explosive combustion causes heath and with that increases the pressure at a high rate per unit of time.

Explosion venting never reduces the explosion pressure to zero.

For indirect firing coal grinding systems (and for many other systems) it is important that self-reclosing explosion vents are used.

If, after the explosion venting has taken place, the explosion venting orifices remain open, a subsequent fire is supported by the O_2 of the ambient air and the use of CO_2 or N_2 will be ineffective, since the gas will dissipate into the atmosphere.

Constructional fire and explosion protection does not prevent fires and explosions. For prevention, preventive protection in form of safe operation methods and emergency technology has to be in place.

Constructional explosion protection is the ‘last ditch’ defence and limits hazards and damage to a pre-determined low extent or to zero when preventive protection fails.

Explosion de-coupling ensures that explosion effects as the result of a deflagration in one component of a system only reach connected components with sufficiently mitigated violence.

Explosion isolation ensures that explosion effects in one component of a system are not felt in other components.

In case of VRM systems the interconnected vessels normally are: VRM – DC – PF silo(s) and possibly (a) burner feeder system(s) or (a) pump(s).

In case of HBM systems the interconnected vessels normally are: HBM – separator – DC – PF silo(s) and possibly (a) burner feeder system(s) or (a) pump(s).

According to the rules for constructional explosion protection, interconnected vessels have to be explosion isolated or explosion de-coupled, depending on location, shape and possible exposure to violence.

In order to not blow up the volume of this article too far, it ends here with a short summary, followed by an additional part, which comprises descriptions of what goes wrong over and over again, both in the supply of technology and in its operation.

Design considerations for both preventive explosion protection and constructional explosion protection always have to include worst case scenarios.

summary

The situation of indirect firing coal grinding systems of the cement industry having so many design faults in them can only be improved by buying parties insisting on correct designs. This requires clear language in their communication with suppliers.

Listing a number of standards to comply with is not the clear language needed. Clear language requires the knowledge of what can go wrong and has to lead to avoiding what can go wrong. Although all this is no rocket science, the necessary very special knowledge is not and cannot be present, in the industry. Neither on the side of the suppliers nor on the purchaser side. It is too special.

The knowledge has to be brought-in by a knowledgeable side and the purchasing side has to ensure that the supplying side follows the shown way out of the troublesome past.

Without changing the basics of the grinding process, coal grinding systems have to look different from how they usually looked. The old patterns with the many faults in them have to be left behind.

situations in which the typical faults in the design and operation of coal grinding systems are found, with many of the faults being ubiquitous Some situations are described 'as should be' and others 'as (often) is'.

Abbreviations used are:

- DC for main bag filter
- EPSR explosion pressure shock resistance or resistant
- HBM for horizontal ball mill
- PF for pulverized fuel
- VM for volatile matter
- VRM for vertical roller mill or vertical ball mill

- **raw coal storage**

  In cases in which no intensified oxidation of the raw coal takes place 'ever', the management of the yard has not much to worry. But, in plants where the raw coal may start to have intensified oxidation going from time to time, the yard management and its personnel have to be charged with the task and the responsibility to ensure that no coal with any degree of ongoing intensified oxidation reaches the raw coal conveyor belts. The raw coal storage team has to be equipped with the right technology in order to do what they need to do.

  Critical situations have to trigger a systematic, trained approach in which every member of the team knows his role and the critical situations and the team's reactions on them have to be analysed and recorded for training purposes.

- **raw coal conveyor belts**

  Metal detection and separation has to be in place. Both Fe and non-Fe metals have to be ejected from the conveying stream automatically.

  Often Fe detection and separation are in place, but not non-Fe detection and separation.

  Pre-crushers and their connected equipment (think filter) mostly don't have the explosion pressure shock resistance they should have, so that an explosion in them can cause disintegration and possibly disintegrated parts, which then could turn into missiles.

  Most pre-crusher configurations don't have thought-out fire and explosion protection included in their design.

  Downstream of a crusher another Fe detection and separation have to be in place.

  Belt transition points are often equipped with a de-dusting filter. But this filter will drop the fine dust it has caught on top of the belt load, so that it often will get lost into the environment over a few meters downstream of the transition point.

  Such filters are enclosures in which coal dust can start to smoulder and a dust explosion can take place, so that it would be good not to need them.

  Most suppliers of such filters understand that there can be an explosive atmosphere in such filters. But they then mostly don't think it out to the end and all they will do is put an explosion vent on the filter. Apart from the fact that the explosion vent(s) in many cases is(are) not corresponding with the explosion pressure shock resistance of the filter, as they should, explosion venting is only one of the 3 elements of the constructional explosion protection that have to be in place.

  Just as important it is to make sure that an explosion in the filter is taken care of by explosion venting, it is important to ensure that the explosion effects (flames and pressure) don't affect the filter's suction side with fan and the situation below the filter's discharge orifice, which normally has a rotary valve. The rotary valves installed normally are not qualifying as explosion isolation system and serve only as airlock.

  Last but not least, the risk of a fire in such a filter is greater than the risk of a dust explosion, so that it is necessary to install a smoke detector that is connected with the control room. It is important that the filter's discharge on the conveying belt stops automatically, when the smoke detector signals trouble.

- **raw coal silos (bunkers)**

  In many situations, raw coal silos have no fire and explosion protection at all. This can be justified, or not.

  When coal with a high percentage (e.g. 35 %) of volatile matter (VM) is used, the ever-present potential of auto-starting intensified oxidation of such coal may become reality in a raw coal silo without given and noticed warning indications of this in the stockpiling in the yard.

  With ever-changing market conditions, it often makes sense to be prepared for the use of coal with a high VM percentage.

  If there are indications that in a given location, under given climate conditions and with certain types of coal, intensified oxidation must be expected to happen, it will be necessary to include the raw coal storage in the raw coal silo(s) in the monitoring and emergency inerting concept of the coal grinding plant.

  This means that CO and O_2 monitoring have to be installed and that the capacity of the emergency inerting system is chosen large enough to also cover the volume of raw coal silo(s).
  It makes sense to combine the CO monitoring with O_2 monitoring. The 2 gas analysers can both be in line with one single air pre-treating system and the availability of O_2 indication gives real time information on the progress of the emergency inerting process.
  Emergency inerting aims at a quick reduction of O_2 in the atmosphere of the relevant enclosure.

- **raw coal mill in-feed**

  Both VRMs and HBMs are enclosures in which a coal dust explosion can take place. This means that anything with an open connection with the grinding chamber will be affected by explosion pressure and flame effects.

  In cases in which an HBM is used there are, apart from the process air in-feed, 2 in-feeds for coal. Unlike VRM systems, where the separator normally is integrated in the VRM's body, the separator in an HBM system is a separate enclosure.
  The 2nd in-feed is the flow of coarse particles that stems from this separator/classifier.

  It is normal (with very few exceptions) that the necessary explosion isolation, or at least explosion de-coupling, that should be in place at mills' raw coal inlet is not in place, or not correctly designed.

  VRMs and HBMs have to be designed with EPSR. About the necessary degree of EPSR confusion exists. Some mill suppliers are speaking of EPSR good for 6 or 8 bar g, which clearly is unrealistic.
  The USAmerican code NFPA 85 demands EPSR good for 50 psi g (3.45 bar g), but an NFPA-internal investigation into the source of this requirement some years ago went without result.

  Serious calculations have resulted in the figure 2 bar g as the maximum (worst case) explosion pressure in the mill chamber of both typical VRMs and HBMs. One reason for this is that air-swept mills have a relatively large air inlet and relatively large air-ground fuel outlet, through which explosion pressure will dissipate into the larger volume of the system.

- **mill's air inlet**

  In some cases, explosion venting will be installed on the air inlet of a mill.

  This only makes sense when the distance between the mill and an upstream booster fan or air heater is so short that such equipment could be damaged by the possible explosion pressure in the mill.

  It will normally not be a problem to realise the necessary EPSR in the air duct.

Different from the air-ground fuel duct downstream of the mill, the only effects that are felt in the air duct upstream of the mill is explosion pressure and possibly a flash flame. The flash flame will not be able to ignite fuel and extinguish quickly, since on the air inlet side of the mill not sufficient fuel in form of fine coal particles is available.

Apart from protecting a booster fan or air heater, explosion vents on the air inlet side of a mill are not beneficial, for the protection of the system.

Should the explosion venting not be self-reclosing, e.g. by comprising rupture disks or rupture panels, the explosion venting would be counterproductive for the safety of the system. After having opened, ingress of atmospheric air and loss of emergency inerting gas through the venting orifice(s) would compromise the system's protection.

Most coal grinding systems have a remote-control valve in the air in-feed duct of the mill. Damper is an often-used name for this valve, but using the word damper is not very well suiting. This valve plays a role in the emergency inerting concept for the system inhibiting dissipation of CO_2 or N_2 into the larger system, where the gas would be useless.
This role of the valve has to be understood well by the process controllers and the controls that would enable the valve to play its role have to be in place.

Sometimes a misunderstanding exists. That the valve can serve as a blockade for explosion effects, even when designed as quick-acting is not true.
Special EPSR explosion isolation valves exist, but these are not available in the larger sizes that would be necessary. They are parts of explosion isolation systems that respond to a sensor that notices the start of an explosion. They have to close extremely fast. For the duct diameters of air-swept coal mill systems the moving mass of the valves' shutting mechanism would be too heavy as to be accelerated and decelerated fast enough as to be useful.

The quick-acting valves that can be found in the cement industry's coal grinding systems are far too slow as to ever function as explosion isolation system. They have their function in the emergency-inerting process and there is no need for them to be quick-acting.

- **mill's EPSR**

  As often can be noticed with older systems, the need of EPSR of the VRM's body, or of the HBM's inlet and outlet seal against the rotating cylinder is not always understood by the operators and their maintenance personnel.

  Retro-modifications and the tendency to shortcut the opening and closing of inspection orifices by leaving bolts or nuts away may dangerously compromise a mill's EPSR.

  The rejects ejection of VRMs also very often is not correctly designed or installed. Such a system has to have 2 interlocked valves with the necessary EPSR, of which only one can be open at any given time.

  In case the ejected rejects are transported by a conveyor, it has to be ensured that the explosion effects that could exit the VRM via this path can do no harm.
  A conveyor eliminates the need for personnel to remove the rejects from where they are ejected from the mill, for which it otherwise would be necessary for the personnel to work close to the mill. But the transition from the VRM's ejecting spout into the conveyor as well as the conveyor proper need to be protected against exiting explosion effects that could harm workers and passers-by.

  Correct solutions for the transition of the VRM's ejection into or onto conveyors are rare, in the industry.
  Lack of awareness of this need is ubiquitous.

- **VRM-to-DC or HBM-to-separator/classifier riser duct**

  For the presently usual designs, the connection between a coal mill and the next downstream process vessel in case of a VRM is the system's main baghouse (DC) and in case of an HBM the separator.

  Interconnected vessels are the reason why constructional explosion protection is not simple.
  Various conditions play a role in the development of violence, when an explosion in one vessel affects one or more connected vessels, of which the possible difference in volume of the interconnected vessels is only one.

  The most important and dangerous conditions in the VRM-to-DC riser duct and the HBM-to-separator riser duct are the following:

  - The explosion in the mill leads to pressure and a flame volume in the mill.
  - If an explosion was ignited in the mill, the O_2 percentage of the process air in the system must have been >13 % at the moment of the ignition and this O_2 level will also be available for the support of combustion in the riser duct.
  - The concentration of coal dust-in-air in the duct will be something like 500 g/m^3, which is in the most supportive section of the total range of dust-in-air explosivity (roughly 50 … 2,000 g/m^3).
  - All this will support the transition of the flame volume into the riser duct, where it will consume the available coal particles and O_2, developing heat/pressure and propagation speed.
  - The propagation speed development is a function of the length of the propagation path. More precisely, a function of the L/D (length/diameter) rate of the duct.

    The velocity of the process air in the duct is usually roughly 19 m/s. With some duct length and a sufficiently high L/D rate, the flame front propagation in the duct will easily accelerate to a value like 200 m/s. This equals 720 km/h.
    It is not hard to imagine that anything in the way of a burning pressurised air mass that moves through a duct at this speed will be exposed to violence.

    How to deal with this?

  - Don't allow high pressure to build up where the propagation starts.
  - Lead flame volume and pressure effectively into the atmosphere before the accelerating flame front propagation starts.
  - Use a self-reclosing explosion vent for this that closes immediately upon having vented.

  This is not done effectively by using 'a' vent and by putting it 'somewhere'. The vent has to be positioned correctly and the geometry of the duct and the explosion vent have to ensure diversion of the pressure and a large portion of the flame volume into the atmosphere. This requires specialist design.

  The explosion vent has to have a very low activation pressure to be effective, which must not be a problem, since the duct is operated under negative pressure.

  The consideration that has to be prioritised is effectiveness of the diversion. Should the optimal conditions for the diversion be hindered by considerations like the desire to simplify the installation or to protect people, such considerations have to rank lower and solutions have to be found. The effectiveness of the diversion comes first, in order for the protection of the system to be real.

  In the industry, in many cases such a diverter vent is not in place, of the wrong type, incorrectly positioned, or left without the necessary regular maintenance. Often, the recoil force that is caused by explosion venting is not included in the design strength of the supporting structure.

- **for HBM systems only: the separator or classifier**

  The separator is an enclosure with a volume of several m^3. This enclosure has 3 connections: HBM-to-separator riser duct (from below), separator-to-DC riser duct (upward) and separator to HBM inlet, for the transport of the separated coarse coal particles (downward & lateral).

Explosive combustion can run into the separator both from below, if an explosion had been ignited in the HBM, or from above, if an explosion had been ignited in the DC.

An initial explosion can also be ignited inside the separator

The other way around there is the connection between the separator and the HBM's inlet, through which also explosion effects can be transmitted.

Without the mitigating diversion of the beginning flame front propagation described above (under *VRM-to-DC or HBM-to-separator/classifier riser duct*), the violence of the unmitigated flame front propagation toward the separator could lead to a violent secondary explosion in the separator's volume.

Should this happen, the secondary explosion would be an explosion under what is called the *elevated initial pressure* condition. When the flame front enters the separator from below it is already compressing the air in the system ahead of it, the effect of which is called *pressure piling*. The flame front is a powerful ignition source and the pressure that develops during an explosion under the condition elevated initial pressure will rise to a value above the value it would normally reach. The combustion then will intensify the way in which combustion in an internal combustion motor can be turbo-charged.
The entering flame front will also cause turbulence in the separator. All these effects, plus the fact that the volume of the separator is smaller than the volume of the HBM in which the explosion started, form the potential for a kind of supercharged secondary explosion in the separator.

In case of flame front propagation that starts in the DC and runs downward to the separator the same conditions as mentioned before will define the violence. But since most DCs have a rectangular shape without a high degree of EPSR, the capacity of their explosion venting system to mitigate the explosion pressure will, if correctly designed, ensure a much lower explosion pressure in the DC than the possible maximum explosion pressure (2 bar g) in the HBM.

Most coal grinding systems with an HBM have a connection between the separator and the HBM inlet that is not protected against the explosion effects that can originate both in the HBM or in the separator.
Necessary are:

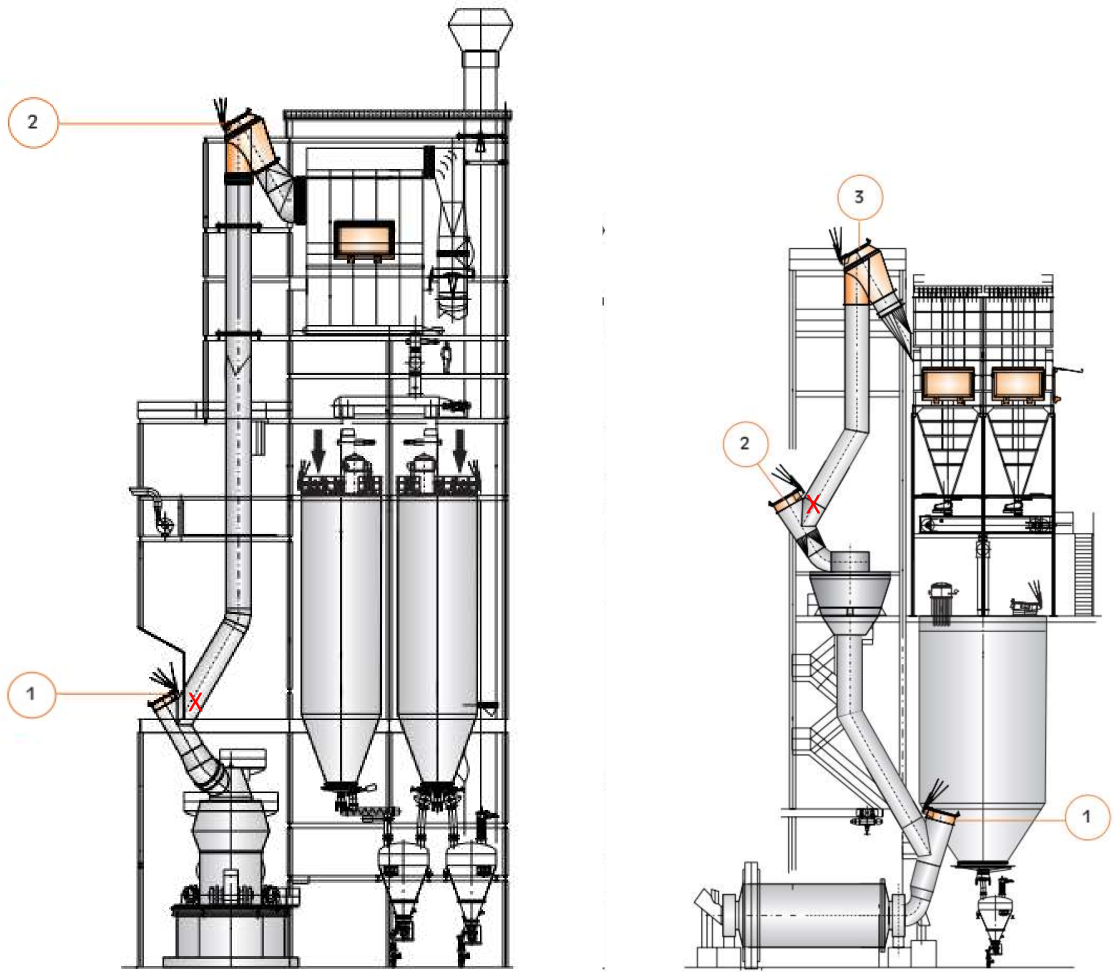
- explosion isolation between the HBM inlet and the conveyor for the separator's coarse rejected particles
- Explosion isolation between the separator and the conveyor

Most conveyors used for the connection between separator and HBM inlet are U-through screw conveyors. U-through screw conveyors have the disadvantage that their flat covers make EPSR difficult to achieve.
U-through screw conveyors also have the disadvantage that above the flight (screw) and under the flat covers an air channel exists, through which explosion effects can transit. This ubiquitous situation harbours the risk that in case of an explosion in the HBM or in the separator the explosion pressure will deform or open the flat covers of the U-through screw conveyor.
Although the screw conveyor doesn't transport dust (only coarse particles) the amount of dust that could exit the screw conveyor as the result of damaged or open flat covers of the U-through and then would become air borne and form an explosive atmosphere in the vicinity of the screw conveyor potentially is available.
Should the dust-in-air concentration be sufficient, an equipment-external, (building) structure-internal dust explosion could follow.
Should people be present, this could be lethal.

Between separator and screw conveyor an airlock is installed. In almost all cases this airlock doesn't qualify as explosion isolation system. This airlock has to qualify as explosion isolation system.

In some cases, a rotary valve is installed between the screw conveyor and the HBM inlet. Although, according to the rules of constructional explosion protection, in these cases the rotary valve should qualify as explosion isolation system, it normally will not qualify as such.
Even if the rotary valve qualified as explosion isolation system, the features it needs to have in order to qualify would soon be lost, due to wear. Rotary valves through which coarse raw coal particles are transferred will suffer wear.
Since the gap width between the rotor vane tips ad the rotary valve's body's bore needs to be extremely narrow, wear will cause the flame and pressure stopping feature to be lost soon.

From the explosion protection point of view this situation is not a problem. Flame front propagation from the HBM inlet into the screw conveyor would be extremely unlikely, due to lack of coal dust. But the screw conveyor needs to be protected against the possible 2 bar g explosion pressure in the HBM. For this purpose, a rotary valve not qualifying as explosion isolation system, but with sufficient EPSR and some wear protection has to be installed.
This situation could be called a grey zone, in the rules for constructional explosion protection.



most common correct self-reclosing explosion vent/diverter configurations in VRM (left) and HBM systems courtesy Thorwesten Vent GmbH

- **for HBM systems only: the separator or classifier-to-DC riser duct**

  The separator constitutes an extra interconnected vessel, when comparing HBM systems with VRM systems.

Since a dust explosion can happen in the separator (running in from below, running in from above, as well as initiated inside) both upward (to the DC) and downward (to the HBM) flame front propagation are possible.

Due to the volume of the separator (several m^3), the explosion in the separator can become a major contributor to the violence of the overall explosion scenario and this has to be included in both the system's and the separator's protection design.

Under the header *VRM-to-DC or HBM-to-separator/classifier riser duct* the need to install an explosion vent cum diverter close to the mill outlet has been explained. For exactly the same reasons such a vent cum diverter has to be installed close to the separator's air-ground fuel outlet. This explosion vent also has the function of mitigating the explosion pressure in the separator.

Both the explosion vent cum diverter at the mill outlet and at the separator outlet also have to mitigate pressure build-up in the riser duct sections above and below the separator, should flame front propagation in the opposite direction take place.

Often, the recoil force that is caused by explosion venting is not included in the design strength of the supporting structure.

The downward flame front propagation in this section of the riser duct also has the tendency to accelerate, but the violence of his scenario will be considerably less than in the scenario in which the initial explosion takes place inside the HBM.
Reason: The relatively low explosion pressure in the rectangular (weak) DC construction, about which more can be read further down.

The diverter configurations at the HBM outlet and the separator outlet have to be optimised for the diversion of flames and pressure that come from below. This means that their geometry will not be optimal for diversion of flames and pressure that run in the opposite (downward) direction.

With the lower violence that comes with this downward flame front propagation and with the risk that downward flame front propagation occurs at all being so much lower, the mitigation that is achieved by the non-optimal geometry of the explosion vents cum diverter configurations at the separator and HBM outlet is sufficient.

Here the description of needs that need to be taken-into account in case of typical HBM system configurations can end. Downstream of (above) the points X in the illustration above the needs for protection of HBM and VRM systems are identical.

In many coal grinding systems, the explosion vents cum diverters described above are not installed. If they are, they are often not correctly positioned and correctly designed.

Without the correctly designed and installed explosion vents/diverters described above the protection of the system is not effective and the danger for people and the possibility of un-necessary damage is real.
Unfortunately, it is normal that people believe their system to be protected when they see explosion vents in it. This belief is unjustified. Often many things are wrong, with configurations meant to provide for safety.

- **the final (upper) section of the mill-to-DC riser duct**

  Downstream of (above) the explosion vent cum diverter at the outlet of the VRM and the outlet of the HBM system's separator, respectively, the conditions under which explosion effects will be felt or will develop are similar.

  The conditions for upward flame front propagation are given, but mitigated and taken care of.

  The more unlikely conditions for downward propagation, with much less drive behind in it, also are given.

  What needs to be done here is to ensure that whatever flame front propagation toward the DC inlet still occurs is diverted into the atmosphere.

The explosion diverter at the inlet of the DC, marked '2' and '3' respectively in the illustration, has to be very effective and its venting mechanism has to be self-reclosing.

An explosion diverter at the inlet of the DC will be found in many coal grinding systems. But in most cases, one or more of the following things will be wrong with them:

- non-self-reclosing venting mechanism
- wrong geometry, especially internally
- in wrong position, at too long distance from the DC or otherwise wrong
- not supported as for their support to withstand the enormous recoil (reaction) force in the direction opposite to the venting blast
- not subject to the compulsory regular maintenance
- too high activation pressure p_{stat}

Even ideally positioned explosion diverters with ideal geometry internally and externally and with a low activation pressure will not vent & divert the flame front into the atmosphere completely. The low activation pressure is essential for the fast opening that is essential for effective venting.
Always a part of the flame body will enter the DC, but without high pressure behind it. The 2nd reason for the activation pressure of the explosion diverter having to be low is that this inhibits pressure piling ahead of the flame front propagation.

When everything has been designed and installed correctly, but only then, the explosion vents of the DC normally can handle explosion pressure that builds up inside the DC, even when the conditions are worsened as the result of approaching flame front propagation.

- **DC**

Most DCs have a rectangular geometry. Various versions of DCs exist. Some of them have twin bag house chambers. Especially Chinese designs have multiple funnel hoppers.
The EPSR has to correspond with:

a) installed capability (dimensioning and efficiency) of the explosion venting configuration
b) the explosion characteristics K_{St} and p_{max} of the fuel in a 21 % O_2 atmosphere
c) the geometry of the DC

The K_{St} and p_{max} value are laboratory-evaluated values. These values can only be evaluated by specialised laboratories and are mostly unknown to the coal suppliers and the users. Over the years some values for some types of coal have been found by tests of various types of coal and can be applied as rough assumptions for comparable coal.

The K_{St} value defines the rise of pressure per unit of time under certain standardised test conditions and stands for potential violence of an explosion.
The p_{max} value defines the maximum explosion pressure under certain standardised test conditions and also stands for potential violence.
Both K_{St} and p_{max} are dust-specific values. The VM percentage, the particle size and particle size distribution, the dust-in-air concentration, the particles' humidity, the ignition energy, the turbulence and the geometry of the enclosure in which the explosive combustion takes place all play a role in the development of explosion pressure, but the K_{St} and p_{max} values, if evaluated using a representative sample, will cover all this.

In order to calculate the necessary explosion venting capability (dimensioning and efficiency) equations are provided by the European (EN) standard 14491 and the USAmerican standard NFPA 68.

The equation needs the following input and is to be applied assuming the normal 21 % O_2 content of the explosive atmosphere:

- volume and geometry information (re the vessel to protect)
- K_{St} and p_{max}

- EPSR expressed as p_{red}, in which p_{red} is the design-defined strength that will withstand the maximum mitigated explosion pressure that will be the result of the explosion venting

In many cases, the EPSR of the DC is not known. It is not easy to calculate the strength that the typical DC geometries with rectangular sections in them have. Only in very rare cases the manufacturers of bag houses had their bag house designs' strength tested, normally by using modular designs and testing module combinations.

This is what often goes wrong:

- A standard DC design (as used for dust-air separation with non-combustible dusts) is used and just a couple of explosion vents are installed on it.
  In practise, in many cases, all kinds of designs are realised without their real EPSR (p_{red}) being known.
- The negative effects of filter bags being in the way of the explosion venting are not accounted for. EN 14491 and NFPA 68 approach this differently.
  Bags in the way of explosion venting are a design fault.
- The more complicated geometry of DCs with multiple funnel hoppers is not accounted for, simply due to the fact that the responsible designers are completely ignorant of the fact that they have to look into this not-so-easy-to-deal-with condition.
  EN 14491 and NFPA 68 don't mention this difficult design issue.
- The explosion vents don't qualify as such (have not been type-tested) and are non-self-reclosing. Many phantasy-designs exist, some of them are very dangerous, will not work effectively, or both.
- The explosion vents have been positioned incorrectly and will vent the venting blast into a dangerous direction.
- The recoil force has not been taken-into-account in the design of the DC's support.
- The penthouse covers are not EPSR or after maintenance work on the DC have not been put back into place correctly.
- The extraction screw conveyor doesn't have the necessary EPSR, e.g. in its flange connection with the DC bag house. If not strong enough, the flange connection could open like a zipper, when exposed to explosion pressure.
- The screw conveyor connection of the DC with (a) downstream pump pre-hopper(s) or, if connected directly, for gravity in-feed, with (a) PF silo(s), doesn't have the necessary explosion isolation system(s) installed in it and lack(s) EPSR, or both.

It is important that the penthouse is kept clean. Damaged bags will cause deposits of coal dust to form in the penthouse. Depending on the thickness of the coal dust layers that have formed and the characteristics of the coal, auto-ignition that leads to a fire can occur. And, in case of an explosion in the bag section of the DC, coal dust deposits in the penthouse may become part of a scenario for which the protection of the DC was not designed.
Monitoring of the clean air's cleanliness is necessary to know about bag damage and to be able to do what is needed then. And that has to be done then!

Most coal grinding systems have a remote-control valve in DC-to-main fan clean duct. Damper is an often-used name for this valve, but using the word damper is not very well suiting. This valve plays a role in the emergency inerting concept for the system inhibiting dissipation of CO_2 or N_2 into the clean air duct, where the gas would be useless.
This role of the valve has to be understood well by the process controllers and the controls that would enable the valve to play its role have to be in place.

- **DC-to-pump pre-hopper transfer or DC-to-PF silo transfer**

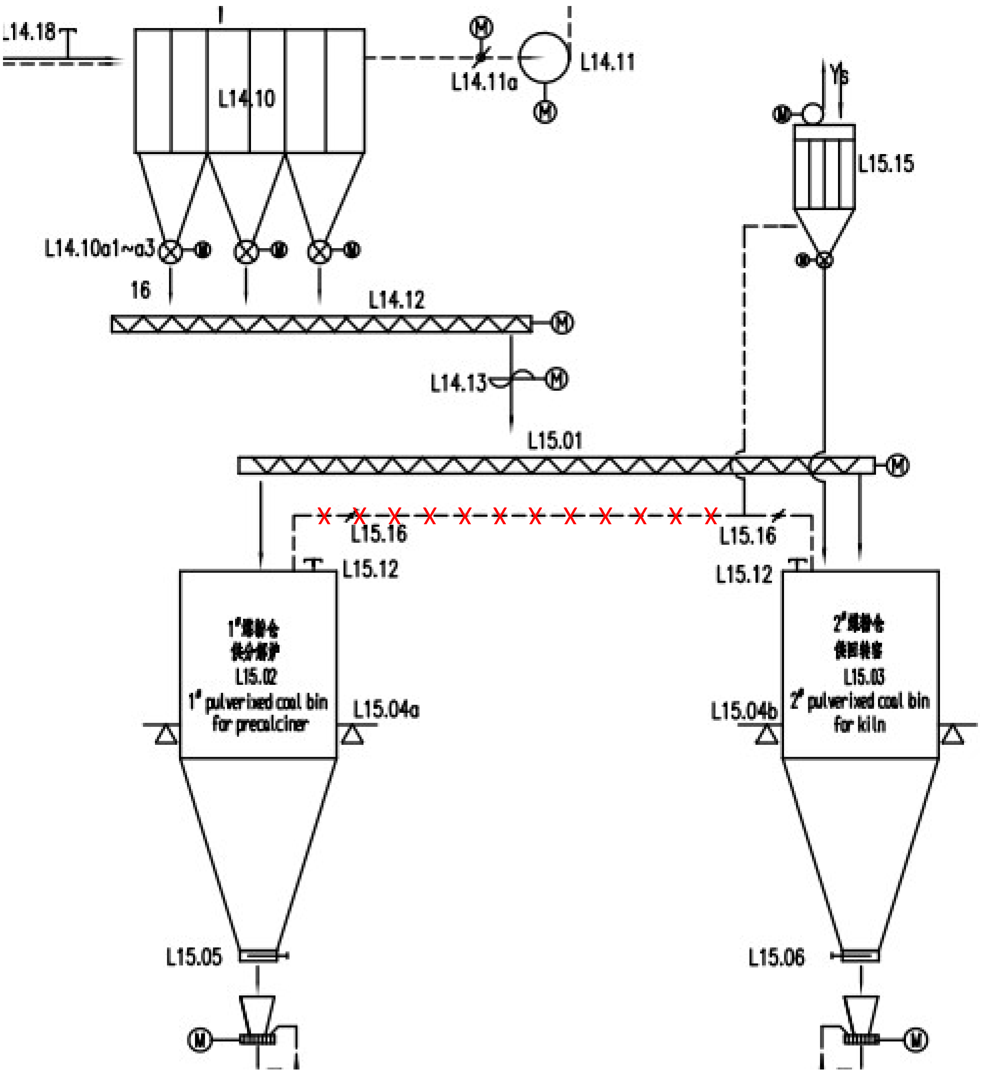
  It is normal for **pump pre-hoppers** to have no explosion protection. Some are, as they should be, EPSR for unmitigated explosion pressure, that is good for 9 or 10 bar g. Often pumps with a pre-hopper without EPSR can be found, which is wrong.

Due to the possibility that a dust explosion is ignited in a pump pre-hopper, it is necessary to install effective explosion isolation in the connection between the DC and the pump pre-hopper.

The maximum explosion pressure in the DC depends on the DC's EPSR (good for a p_{red} value) and explosion venting concept. The highest value for p_{red} of a rectangular DC geometry designed by a serious manufacturer will be 0.4 bar g. For most DCs the value for p_{red} will be considerably lower, if known at all.

This means that the explosion isolation between the DC and the pump pre-hopper needs to be capable to be effective against any value between 0.1 bar g and 0.4 bar g from above and for 9 or 10 bar g from the pump pre-hopper below.

Explosion isolation by definition has to completely block the passage of flames and pressure. This requirement is not easy to fulfil.



A completely unacceptable design as result of the idea to use 1 de-aeration de-dusting filter for 2 PF silos. Interconnected vessels are either not acceptable, in constructional explosion protection, or only with lots of additional protective systems, which have not been included in the above design.

As mentioned earlier, the qualification of rotary valves as explosion isolation system depends, apart from some other features, primarily on the gap width between the tips of the rotor vanes and the body bore, which must not exceed some hundreds of a mm.

Qualifying rotary valves with the correct EPSR for this application are available on the market. However, the problem with all of these is that the gap width will widen as the result of wear, albeit slower than in case or raw coal. The maintenance that would keep the isolation feature effective typically cannot be provided for by the maintenance personnel of a cement plant.

Other types of explosion isolation equipment the market doesn't offer, presently. Possible would be EPSR valve locks with 2 valves with alternating valve movements that ensure that always one of the 2 valves is closed at any given time. Presently no supplier has worked out the design and done the necessary type tests that would make qualifying equipment available to the market.

This means that the explosion isolation system between DC and pump pre-hopper(s) presently only can be a rotary valve, with the necessary gap width feature being lost over time.

What needs to be done here is to ensure that the screw conveyor connection between the DC's funnel hopper and the vertical drop pipe above the pump pre-hopper is an EPSR pipe screw conveyor and not a U-through screw conveyor. In many cases the screw conveyors for the transfer of the DC's output are U-through screw conveyors without EPSR, which are not suitable for the application.

The reasons have already been given in the text above: Due to their flat covers U-through screw conveyors will not have EPSR. Deformation or separation of their flat covers from their basis will lead to the formation of a dust cloud in the vicinity of the damaged spot. The air borne ground coal is perfect fuel for explosive combustion outside of the screw conveyor and often the location will cause the dust cloud to form inside a structure or building.

The 2nd reason why U-through screw conveyors should not be used for PF is that above the flight (screw) there is an unobstructed channel for the transfer of explosion effects through the screw conveyor.

Screw conveyors with a pipe body and the necessary EPSR are what has to be installed.

The combination of EPSR pipe body screw conveyors with a rotary valve that qualifies as explosion isolation system when new is an acceptable solution. After the gap width between rotor vane tips and body bore has widened as result of wear the combination of rotary valve and EPSR pipe body screw conveyor will still provide for less than perfect but still sufficient explosion isolation. Again, this then is in the grey area of constructional explosion protection.

In case of multiple DC funnel hoppers, the screw conveyor configuration will be complex and explosion isolation in most cases will have to be installed under each funnel hopper outlet, which is another reason why DC's with multiple funnel hoppers should not be installed, in coal grinding systems.

Often, pump pre-hoppers are connected with a filter for the de-dusting of the de-aeration air.
This is wrong, since the result of it is that another set of interconnected vessels in which a dust explosion can be ignited is created. This seems not to have been understood by most system designers.
In order for such a configuration to be protected correctly, a number of explosion isolating and explosion de-coupling features would have to be installed.
What should be done is installing a small filter with the necessary EPSR directly on the pre-hopper. Such filters are available on the market. A vessel like a pre-hopper with EPSR good for 9 or 10 bar g should not be connected with another vessel. That the screw conveyor connection between the DC and the pre-hopper needs explosion isolation in it is challenging enough.

In case of DC-to-**PF silo** screw conveyor systems, the situation is slightly different. PF silos normally are equipped with explosion vents and designed for the resulting worst case mitigated explosion pressure p_{red}.

According to EN 14491 the highest acceptable value for p_{red} is 2 bar g. NFPA 68 has stopped to give a limit for p_{red} some years ago, but the limit set by EN 14491 (2 bar g) is suitable for cylindrical PF silo designs.

What this means for the necessary explosion isolation in the transport connection between the DC and the PF silo(s) is that, different from connections with pump pre-hoppers with 9 or 10 bar g EPSR, the explosion isolation system in the connection with the PF silo has to be capable to stop explosion effects between 0.1 and 0.4 bar g from above and 2 bar g from below.

Another incorrect design is given when one or more PF silos are interconnected via an air duct. See the illustration above.

- **sampling facilities**

  Often it is overlooked that sampling facilities will be exposed to explosion pressure. In case of an explosion in the system, flames and pressure may exit through them, and parts of them may turn into a missile. Both the design of such facilities systems and their position in the system have to ensure safety.

- **PF silo** or **PF silos**

  First of all, PF silos should never be installed inside a building or a partially enclosed structure. There is no need for that. A good design with good rain drainage of the roof or the roof platform will not suffer from rain, even not from very hard rain.

  Since PF silos normally have constructional explosion protection in form of **explosion venting** installed and since the direction of the venting blast normally is upwards, the location of silos inside buildings or partially enclosed structures demands a change of direction of the venting blast that ensures the explosion effects' exit from the building or structure without causing hazards or damage.

  Although there are possibilities to design the explosion venting configuration in a way that the venting blast is deflected as to safely exit, multiple possibilities to get that wrong exist. Unfortunately, things are going wrong often, as can be seen in the industry.

  The first industrially produced explosion vents for silos were for silos for coal and they were explosion doors. Different from rupture disks or panels, explosion doors, when correctly designed and positioned, will re-close. Their venting element is a hinged lid that will fall back into its closed position by gravity.

  Unfortunately, a multitude of wrong explosion door designs exist and numerous examples of such ineffective and often dangerous designs can be found in the industry.

  It was understood early that silos, after a venting occurrence, have to be closed again. After an explosion venting occurrence, a fire in the silo has to be expected. That fire should not be supported by the O_2 of the ambient air and/or by chimney effects.
  Should CO_2 or N_2 be applied for emergency inerting, the gas should not be lost to the atmosphere.

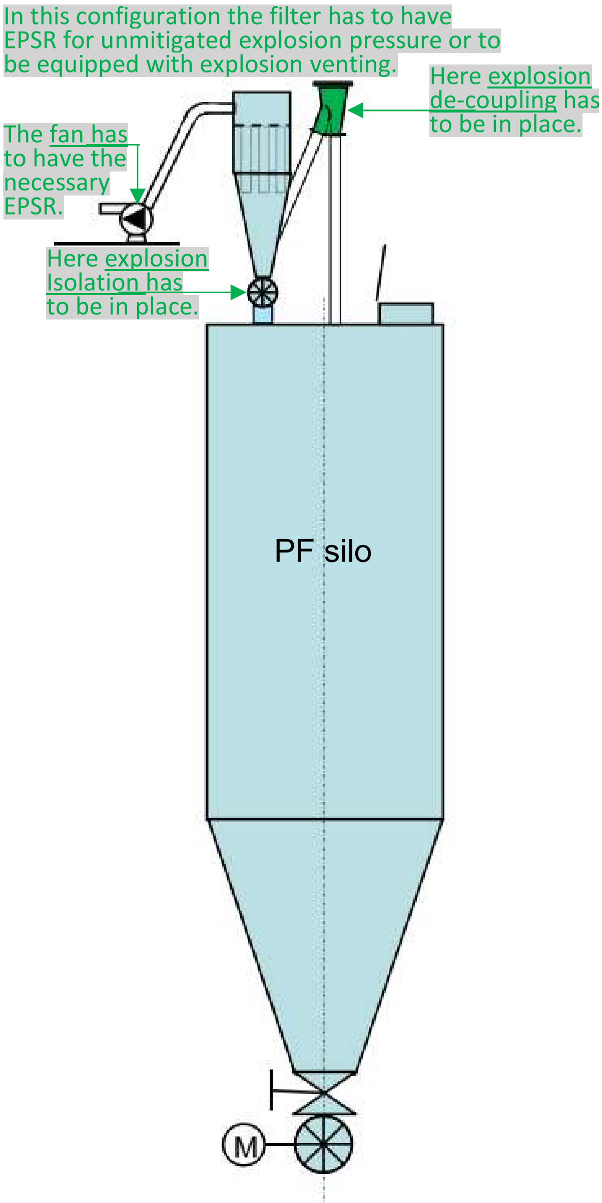
  The self-re-closing explosion vents require a feature that prevents the protected silo from taking damage as result of negative pressure after the explosion venting has taken place and the vent(s) has(ve) reclosed.

  The main reason for negative pressure in the silo is that a part of the original air volume above the column of coal under atmospheric pressure was pressed (vented) out of the silo as the result of its heat-induced expansion.
  E.g.: The explosion pressure was mitigated by the explosion venting but still reached 1 bar g, meaning that the volume of the air above the column of coal doubled.
  After the vent(s) has(ve) closed, roughly 50 % of the expanded hot air will have been vented. The remaining 50 % will cool down rapidly and shrink. Ergo: Negative pressure in the silo, for which the silo needs to be sufficiently vacuum resistant, which is difficult to achieve.

Good explosion door designs therefore will comprise spring-loaded inwardly opening flaps in their body. Such flaps are called vacuum breakers. EN 14491 offers an equation for the dimensioning of vacuum breakers.

The need for explosion isolation in the in-feed of the silo when the in-feed is by means of a mechanical conveying system has already been discussed. See *DC-to-pump pre-hopper transfer or DC-to-PF silo transfer*.

Should the in-feed be by means of pneumatic conveying (usually positive pressure), no cyclone should be used. Silo and cyclone then would constitute interconnected vessels, which would make constructional explosion protection complicated. Should a cyclone have been installed, the explosion protection of the silo usually is incorrect.



This is a complicated way to install the PF silo's de-aeration de-dusting filter. It needs additional explosion isolation, explosion de-coupling, CO monitoring and a connection with the emergency inerting system. The filter also needs one or more explosion vents and EPSR.

The simple way is to integrate the filter in the silo. The silo's CO monitoring and emergency inerting include the filter.

A bagfilter will be used for the de-dusting of the displaced air that has to exit the silo during in-feed. Small quantities of displaced air in case of in-feed by means of mechanical conveying. Larger quantities in case of in-feed by means of positive pressure pneumatic conveying.

Often it is not understood that if the bagfilter is not an integrated part of the silo the installation constitutes interconnected vessels. In that case the filter has at least 2 and very often 3 connections that need special protection:

- The suction connection of the filter with the silo needs at least explosion de-coupling.
- The discharge connection of the filter into the silo needs explosion isolation.
- If the fan has no EPSR, the connection between the bag chamber and the fan needs at least explosion de-coupling, since an explosion in the bag chamber is possible.

Different from the integrated filter, the non-integrated filter needs both explosion vents and EPSR. The integrated filter only needs EPSR, since the silo has explosion vents. Should the non-integrated filter also be connected with other equipment, which often is the case, additional explosion isolation or at least explosion de-coupling is necessary.

Unfortunately, silo-filter combinations of this kind practically never are designed correctly.

The filter's clean air exhaust has to have a remote control valve that enables isolation of the silo from the atmosphere, in order to inhibit the loss of inerting gas (CO_2 or N_2).

During CO_2 or N_2 inundation some pressure will build up. This has to be limited to a value below the value at which the explosion doors would open. For this, the remote control valve in the filter's exhaust needs to be controlled by a pressure transducer, which causes the valve to be open as long as a certain pressure value in the silo is exceeded.
The control function shall only become active during emergency inerting.

Something else that often goes wrong is that the filter's fan causes such a strong negative pressure in the silo that the explosion doors' vacuum breakers are continuously open. Very often the fan's capacity and its power consumption needlessly are way too high.

- **instrumentation and emergency inerting relevant for fire and explosion protection**

Apart from metal detectors and metal separation mechanisms on the raw coal side sometimes a sprinkler system for fire extinguishing on top of conveyor belts is in place.

Smoke detectors in belt transition point de-dusting filters almost never are installed.

Nothing can be said against having a sprinkler system installed and keeping it well maintained. But when a fire develops on top of a raw coal conveyor belt, coal undergoing intensified oxidation may already have been dropped in a raw coal silo, meaning that something that should not go wrong has gone wrong.

It has to be made the task and the responsibility of the raw coal yard personnel to ensure that coal undergoing intensified maintenance never reaches a raw coal silo, where it could become the source of very dangerous scenarios.

In plants in which intensified oxidation of the raw coal in the yard is expected from time to time, vigilance may be in place. But such vigilance very rarely is subject to written rules that help meet the need for effective reactions being the consequence of such a situation. The requirements of certified QA (quality assurance) cannot be met, without written rules being in place. The certifiers may have spent no thoughts on this.

Pt 100 temperature sensors

Pt 100 sensors only give fully reliable information when they are measuring the air temperature, e.g. in a silo.

When the sensor is surrounded by coal, the temperature it reliably measures is only the temperature of coal in the area that is less than roughly 120 mm away from the sensor's probe. Coal is a bad thermo conductor. This means that some interpreting is always necessary, when reading the temperature that is measured in a column of bulk coal. 'The picture' is never complete.

gas analysers

The minimum is to have gas analysers monitoring O_2 and the CO of the process air as follows:

- O_2 in air inlet of mill
- O_2 in air outlet of DC
- CO in air outlet of DC
- CO in top of PF silo(s)

To use 'chemical' gas analysers means that frequent recalibration is required. Chemical analysers have a life span of only a very few years. In the industry it can be seen very often that the 'chemical' gas analysers are not recalibrated often enough or have surpassed their useful life. 'IR' (infrared) gas analysers should be used.

When a system is good it will take care of the cleaning and dehydration of the air that passes through the analysers and ensure that the air intake from the coal grinding system's spots is kept clean. An O_2 and a CO analyser can be installed in line downstream of one cleaning/dehydrating unit.

If the suction lines for the air are not too long it is possible to use one set of analysers for the monitoring of 2 or 3 pieces of equipment (e.g. PF silos). An alternating sequence can then be arranged for.

When, e.g. in case of high VM coal, the raw coal silos are connected with the emergency inerting system it makes sense to install a combined CO and O_2 analyser. The progress of an emergency inerting process is indicated by the O_2 value. To know the O_2 value and to see it decline in an emergency situation can be helpful.

The same is true for the monitoring of PF silos.

emergency inerting

The inerting medium, gaseous CO_2 or N_2, has to be available in sufficient quantity and with a sufficient output from the storage at all times. Many systems with insufficient and unreliable monitoring of the available quantity can be found, in the industry. Only when the tank or the bundles of gas cylinders are installed with a weighing feature the indication of the storage is reliable.

CO_2 needs to properly evaporate, before it is sent into the distribution lines.

CO_2 and N_2 systems come under various names, mostly with something like fire extinguishing in it.
The only suitable name and the only suitable set-up is emergency inerting system. The main function of the system always is to quickly reduce the O_2 in the piece of equipment or in the section of the system into which the inerting medium is injected.

The gas storage and distribution systems in the industry often come from sources with insufficient know-how.

The number of inadequate systems in the industry is legion.

Emergency inerting has to be included in the controls of a coal grinding system. The concept behind these controls has to be well-thought. E.g. it must be possible to isolate certain not-too-voluminous sections by means of valves.
The concept must be well known by the operators and they must be trained to do the right things when emergency inerting becomes necessary. Alternatively, the emergency inserting process can be fully automated.

pressure transducer

Equipment in which, as the result of emergency inerting, the pressure could rise as to open explosion vents has to be equipped with a pressure transducer that only during emergency inerting controls a relief valve in a well-chosen position.
The relief has to be organised on the basis *as much as necessary* (as to not open the explosion vents) and *as little as possible* (as to not waste emergency inerting medium).