Innovations in kiln gas bypass systems

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Summary

At Heidelberg Cement (HC) many (chlorine) gas bypass systems have been installed in the recent years. The first solutions simply aimed at dedusting. Later, via adding hydrated lime, SO_x was treated. Further steps were undertaken by adding raw meal to ease the dust handling. However, cost analysis showed that the most economic approach is SO_x treatment by recycling the gas within the kiln system and reducing bypass dust disposal by homogenisation & pre-separation. The initial additional investment for the equipment was swiftly recovered due to reduced operational costs. Though the operation is challenging - it is manageable. Looking forward the gas recycle back to the cooler and integral dust homogenisation are the dominant choice in the future.

1 Cause for a bypass

Bypass (BP) systems are predominantly used to control coating in the preheater towers. These blockage-causing coatings are to a high degree composed of chlorine and sulphur, incorporated into a calcium complex. To keep the coatings under control the hot meal chlorine (Cl) content should be around 1 – 1.5%. In the past the source of the chlorine has often been the raw material. Today the use of alternative fuels (AF) has increased and bypass system installations have also been on the increase in recent years. These (chlorine) bypass systems normally are operated at a relatively low rate of up to 5%, even though theory calls for larger design parameters. Therefore care is taken regarding input data selection for design optimisation.

2 Traditional bypass

Traditional (chlorine) bypass system gas train arrangements are simple: an air quenched mixing chamber (MC) with an electrostatic precipitator (EP) as bypass dust collector (see **figure 1**). The efficiency of the EP strongly depends on the dust properties. As a rule of thumb the chlorine content is supposed to be less than 5% to achieve dust emission less than 50 mg/Nm³.

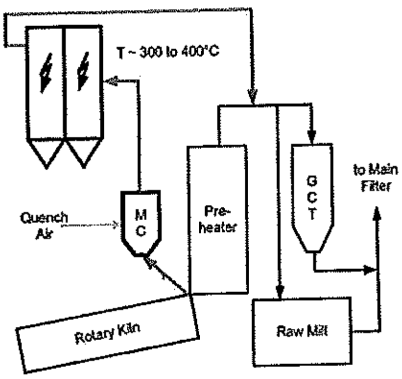

Figure 1 Traditional bypass system

A further relevant factor influencing dust collection is the temperature. Normally a (hot) EP is operated at 350 - 400°C – hence entering a favourable dust resistance temperature corridor. However, most operators were still struggling to keep emissions safely below design levels in the past. Therefore to improve EP performance gas conditioning towers (GCT) were optionally installed – ultimately operating in-between 150 and 200°C. But even then emission levels were not always able to meet the requirements safely. Subsequently fabric filter replaced EPs as these are less sensitive.

3 BP Dust Management

At the beginning of the millennium HeidelbergCement started to revamp many existing or install new bypass systems. Besides gas constituents bypass dust (BPD) generation has also been considered as a problematic case. At some plants it was possible to integrate all BPD without any quality impact on the cement. In some cases however, BPD had to be disposed. Therefore the task varied from plant to plant – and without considering BPD treatment a "standard" BP was not feasible. Nowadays bypass dust disposal costs are lower than they would have been without adapting the arrangements to the entire process. As shown in **table 1** the total ownership costs vary strongly - dependent on the arrangement between 0.5 and 1.2 €/t clinker – with SO_x abatement and BPD disposal being those variables that can be influenced the most.

Table 1 Cost for different bypass operation systems 2001 - 2006 [1]

Application Technique Location	DeSOx + MC + GCT + Filter Operation			
	System Operation	DeSOx Costs	BP-Dust Disposal	All incl. depreciation
Equipment in Arrangement	€ per ton of clinker			
MC + FF	0.08	0.20	0.40	0.91
MC+GCT+EP	0.05	0.05	0.51	1.01
MC + Cyclone + MC + FF	0.08	0.00	0.06	0.68
MC + GCT + FF	0.04	0.00	0.00	0.47
MC + FF Homogenisation	0.06	0.00	0.08	0.46
MC + GCT + FF	0.33	0.05	1.20	1.96
MC + FF + Dust-Homogenisation + Gas Recycle	0.07	0.00	0.00	0.47
MC + GCT + FF	0.08	0.30	0.40	1.16

MC = mixing chamber; GCT = gas conditioning tower; FF = fabric filter; EP = electrostatic precipitator; BP = bypass; $DeSO_x$ = desulphurisation

3.1 BPD dust flow reduction by pre-separation

BPD generation could be reduced by ~2/3rd with a special gas extraction point at kiln and cyclone as shown in **figure 2**. The valuable calcium oxide (CaO) compounds are sent back to the kiln, therefore reducing the loss of pre-calcined raw material. Despite this dust return, the goal to control chlorine (<1.5%) in the hot meal still can be successfully attained [2].

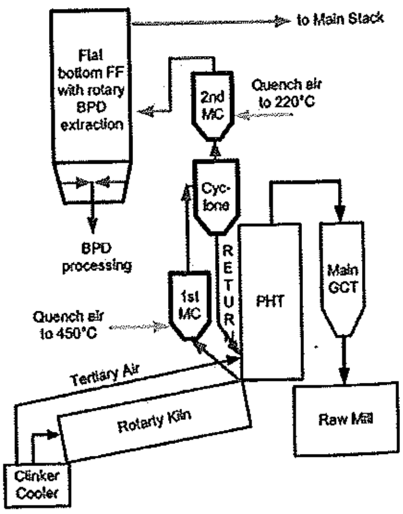

Figure 2 Plant with pre-separation

For more technical and operational data see **table 2**.

Table 2 "high dust" smoke chambers with & without pre-separation 3,200 tpd kiln

Bypass rate	7 – 8%		
Bypass gas flow	$60\ kNm^3/h$		
Cl in hot meal:	up to 2.5% prior installation	~1% after installation	
SO_x emission from main stack < $50\ mg/Nm^3$			
Mode	Chlorine	SO_3	Dust purge
no pre-separation	4.5%	1 – 2%	~ 30 tpd
with pre-separation	12 – 18%	4 – 6%	~ 10 tpd

tpd = tones per day

However, a disadvantage is that the dust itself is composed of up to 60% of alkali salts – and these are difficult to handle. This requires a special technology such as flat bottom hoppers with rotary scrapers.

Nevertheless – due to stringent quality standards for cement – bypass dust is disposed – though much less than without this arrangement adaptation.

The following **figures 3** and **4** show a bypass arrangement and the pre-separation cyclone in detail.

3.2 BPD Homogenisation for improved incorporation in cement mill

The requirement is to assure that the Cl content does not exceed 0.1% in the final product. Therefore the dosing has to be very accurate as the Cl content in the BPD - due to the nature of the kiln operation - varies strongly. As a consequence this often leads to BPD disposal. However, via BPD homogenisation this obstacle can be (partially) overcome, but earlier approaches resulted in quite large homogenisation silos.

Previously it was also often necessary to add raw meal to the BPD to ease the handling. By homogenisation alone however, handling is eased with comparably less raw meal added. If it is not possible to incorporate (all) the BPD in the cement mill – the lesser raw meal is added – this approach is also the more economic.

Separate homogenisation and raw meal dosing resulted however in extensive equipment. HeidelbergCement started to homogenise the dust within or at the dust collector and to minimise the raw meal dosage.

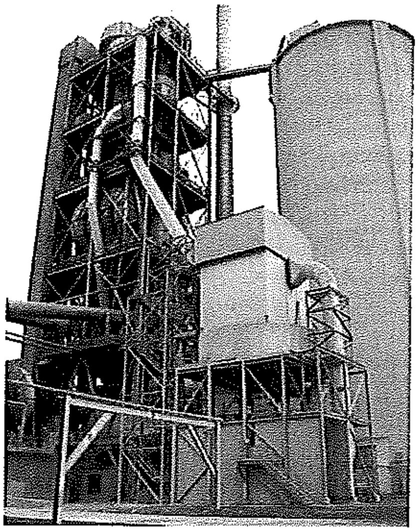

Figure 3 Bypass arrangement

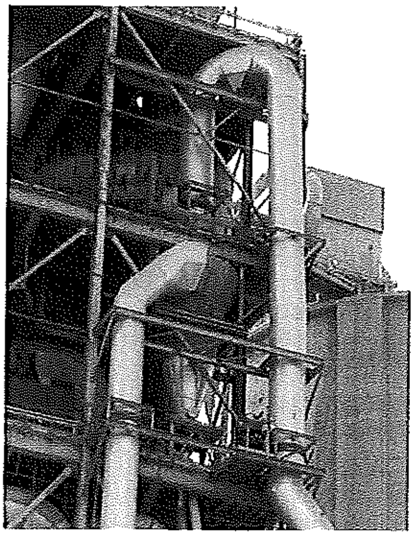

Figure 4 Detail pre-separation cyclone

Now - with some experience in operation - bypass dust is partially sold as a soil stabiliser, hence replacing quick lime as a building material.

The product itself – even though there is still a variation in Cl content present (deviation in a 5 h test less than 0.5%) - fulfils the quality requirements in cases where high grade quick lime is not necessary (see section 4.3.1).

The homogenisation is easily arranged by recycling the BPD from the fabric filter (FF) back to the raw gas duct prior to entering the FF (see **figure 5**). Even if the dust load in the FF increases fivefold the FF only has to have 10% more filtration area than usual. The bypass dust is extracted by an overflow system. The pneumatic dust transport from the filter to the feeding silo of the mill can now convey BPD with higher Cl contents – as Cl peaks are equalised. Previous reasons for transport blockages are now reduced (see **figure 5** and **table 4** for a similar application). In one case potential SO_x emissions are controlled together with the kiln off gas in a wet flue gas desulphurisation (FDG) and converted to gypsum. In another arrangement the BP gas is taken back to the clinker cooler (see **figure 9** and **table 4** for a similar application).

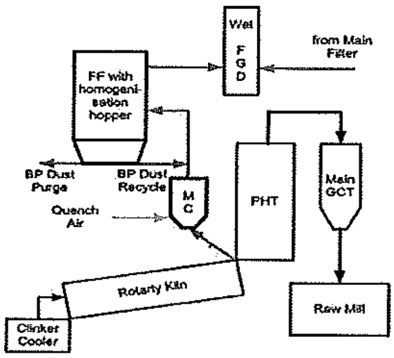

Figure 5 Bypass with integrated homogenisation and storage in FF hopper

4 Control of Gaseous BP Emissions

Along with the extracted bypass dust, SO_x and also hydrochloric acid (HCl) escape. These two compounds can often be observed in a resulting fairly high corrosion rate of the dust collector, especially on the dedusting equipment when GCTs are used.

By the use of primary measures such as low sulphur fuels and optimised burning conditions, SO_x can partially be controlled. In some cases duplex stainless steel is still applied to counter corrosion, but this does not limit the emissions.

Earlier studies [1] have revealed that the costs for SO_x (and HCl) absorption can be up to 0.3 €/t clinker. Therefore optimised process systems are needed to keep these costs under control.

4.1 Suppressing POP formation

On (hot) EP systems - due to the de novo synthesis - persistent organic pollutants (POP) often developed, therefore forcing some of these arrangements to be withdrawn or redesigned. The reason for this is that due to the rather long retention time (~ 10 s in an EP) - paralleled by an operation temperature around 350°C - dioxins can develop. In some bypass gas the concentration exceeded TEQ (toxic equivalent) 0.1 ng/Nm³ (10% O_2 relation). The general idea, also supported by the Stockholm Convention, is to avoid formation of POPs and contamination of the bypass dust.

It can be assumed that the Kel-Chlor-Deacon reaction, taking place at a temperature of 250 to 450°C and in the presence of copper-chloride as a catalyst, fertilises dioxin and furan (D/F) formation [3, 4]. The reaction equation is:

$$4\,HCl + O_2 \rightarrow 2\,Cl_2 + 2\,H_2O$$

It is the Cl_2 that reacts swiftly with aromatic precursors to dioxins or furans – faster than the HCl itself. However, research in this area is still going on.

Further, according to the reaction above, the presence of water vapour depresses the Cl_2 formation – thus shifting the reaction to the left. Potentially the chlorination aromatic precursors are additionally inhibited. Therefore water injection probably helps to avoid D/F formation. However, fast cooling via "large" mixing chambers solely with air also fulfils most needs.

Subsequently one of the first goals that was tackled was fast cooling within the gas train system. Particularly the temperature corridor of 450 - 250°C had to be passed rather quickly. Here either an extra large mixing chamber or an additional GCT was required. The choice was made for smaller bypass rates - a simple arrangement with a MC and a FF. For larger plants (and BP rates) a GCT as an additional cooling step seemed to be more adequate. In both cases the formation of POPs is successfully suppressed to below TEQ 0.1 ng/m³.

4.2 Controlling SO_x and HCl

The issue with other gas constituents such as SO_x and HCl however remained. It had been realised that kiln designs with a high dust load from the kiln inlet chamber - hence in the riser duct - had significantly less acid gas components compared to low dust kiln inlet arrangements. This issue can be explained by the presence of active free lime. Here less than 50 mg/Nm³ of SO_x had been frequently measured in the exhaust gas. A disadvantage, however, is the larger quantity of BPD generated, which cannot in all cases be consumed in the cement mills.

4.2.1 Improving SO_x absorption by increased water injection

Tests additionally revealed that free lime in the BPD had an increased SO_x absorption activity when the amount of water injection was maximised.

Investigations showed that at 150°C or less, the SO_x absorption rises again [5]. This led to the application of a water injection not only to the GCT but also in the MC – increasing the water dew point (see **figure 6**). It was proved that it is possible to abate the SO_x without additional injection of calcium hydroxide ($Ca(OH)_2$). A pre-condition is that enough active CaO is present in the BPD. In some cases, however, due to space restrictions, the arrangement did not allow for water injection in the MC.

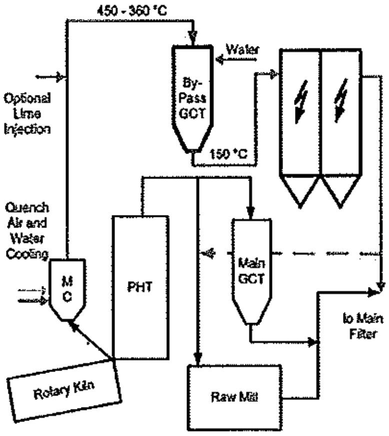

Figure 6 Bypass with dual water injection and optional lime addition

If not enough active CaO is present, $Ca(OH)_2$ has to be injected. Operational results have shown that it is more economic to use high grade $Ca(OH)_2$ with BET surfaces >35 m²/g. The hydrated lime stoichiometric ratio drops below < 4 mol/mol by operating the GCT with 150°C rather than 180°C. Furthermore SO_x can be well absorbed in the raw mill – once again dropping hydrated lime demand.

4.2.2 BP Gas treatment in an absorber

As shown below in **figure 7** and **8**, since 1992, HC has been operating an alkali bypass system with integrated fluidised bed absorber (GSA). In the mixing chamber the gas is cooled from 1,150 to 275°C; and by adding water to the absorber, temperature drops to 180°C before the FF. The bypass off gas is mixed with the kiln off gas before the stack. The initial EP was exchanged by a FF in 1999, as it no longer fulfilled emission requirements. Long term experience has shown that the P84 bags of the FF last a mere 2 years and the mixing chamber occasionally blocks. Nevertheless the operation has been managed largely successfully for 17 years.

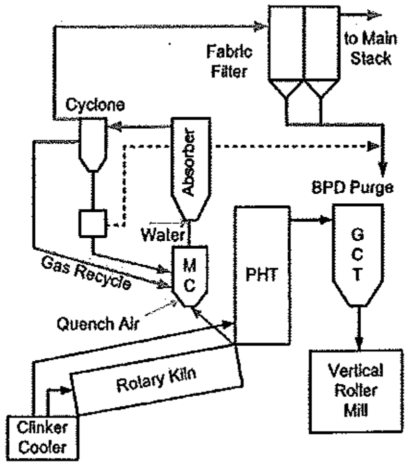

Figure 7 Bypass with fluidised bed absorption

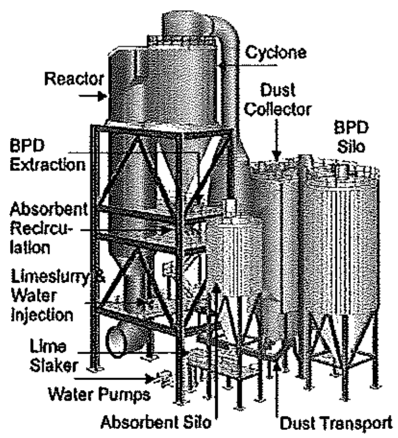

Figure 8 Gas Suspension Absorber arrangement by FLSmidth Airtech [6]

The system is designed for a bypass rate of 60%, but it is operated at 25% (see **table 3**). The reason for this is that the promised alkali reduction in the clinker could not be reached. The post design thereafter called for a gas recycle back to the MC to provide for enough vertical velocity in the mixing chamber and GSA.

Even though the GSA is designed as a semi-dry SO_x scrubber, it is not operated as such. Currently no hydrated lime is added to the GSA as the SO_x absorption capabilities meet the emission requirements of <400 mg/Nm³ already by the free CaO in the BPD. A test run with lower temperatures resulted in moist filter dust which is likely to be due to the content of soluble salts. Optimisation of $Ca(OH)_2$ injection and lowered off gas temperature is needed to improve the SO_x scrubbing [6, 7].

Table 3 Bypass system with fluidised bed absorption on 1,700 tpd PC kiln

Bypass rate		20 – 25%	
Bypass Off Gas Flow		86 kNm³/h	
Gas Recycle to MC		35 kNm³/h	
Species in BPD after FF	HCl in BP gas	SO_x in BP gas	BPD Dust Purge
2% Cl 10% SO_3 35 CaO	up to 10 mg/Nm³	av. 300, peaks up to 1,000 mg/Nm³	~40 tpd

4.3 Passive gas cleaning

Passive gas cleaning is avoiding emissions without adding any absorbent or a decisive gas cleaning technology. Predominantly the bypass gas is kept within the kiln system and is not released separately.

4.3.1 Gas recycle to the clinker cooler

This passive possibility to avoid SO_X-emissions consists of locking SO_x into a gas cycle from the kiln riser duct back to the clinker cooler (CC) under the grate (first chambers). Most of the sulphur species is SO_2 and the corrosion potential is minimised by keeping the water vapour content low. Hence for such a bypass gas recycle system, only quench air is used for providing the applicable FF inlet gas temperature of < 220°C. Here the clinker cooler has to be designed to accept hot recycled gases – therefore only non-sensitive cooler parts should be located underneath the grate.

A plus is that the bypass gas heat content is largely recovered and typical heat losses are minimised. Furthermore NO_x in the bypass gas (as originating from the burner) cannot exhaust: the latter is especially valuable for low NO_x emission demands. A flow chart of this bypass gas recycle system is given in **figure 9** and technical data is shown in **table 4**.

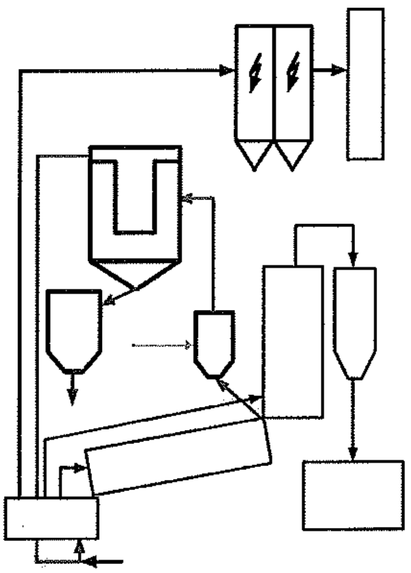

Figure 9 Bypass off gas recycle to clinker cooler

Table 4 Bypass system with gas recycle to clinker cooler and homogenisation of a 3,500 tpd kiln

Bypass rate		6 – 7%	
Bypass Gas Flow		45 kNm³/h	
Species variation in BPD after homogenisation	HCl in BP gas	SO_x in BP gas	BPD Dust Purge
4 – 5% Cl 4 – 6% SO_3 30 – 35% CaO 16 - 17% SiO_2	up to 500 mg/Nm³	up to 5000 mg/Nm³	~ 20 tpd

As shown in **figure 5** and described in chapter 3.2, due to homogenisation the bypass dust composition varies much less than usual and is now considered as a product.

1/3rd of the BPD is sold as a lime substitution product – the latter financing the disposal costs. This is thanks to the homogenisation and a screening system for extraction of coarse particulate. Now quality has improved to customer satisfaction. Currently the excessive BPD is used in a sub-terrain limestone mine to fill up caverns and stabilise these.

Reports from the plant have in no case shown an influence on the clinker quality – despite the cooling air temperature being higher. Even though a fabric filter is applied, fine particulate accumulation at the grate can be observed. Analysis suggests that the composition is a complex containing sulphur and chlorine as well as substantial clinker phase. It can be assumed that an additional gas phase reaction takes place after the FF, fertilised due to the high concentrations of SO_x and HCl found in the bypass gas.

Fortunately the cooler plates did not block and the cooler efficiency did not suffer, provided that the plates were swept every couple of months. However, due to a temperature of ~100°C of the gas under the grate and the desublimate potential, the drives have to be placed appropriately outside.

It is conceivable, that too narrow slits can close faster. Soon there will be more experience from other gas recycle systems with narrow slit cooler plates. Up to now no excessive corrosion in the CC has been reported.

The following **figures 10** and **11** show dust agglomeration underneath the grate as well as on the grate cooler slits.

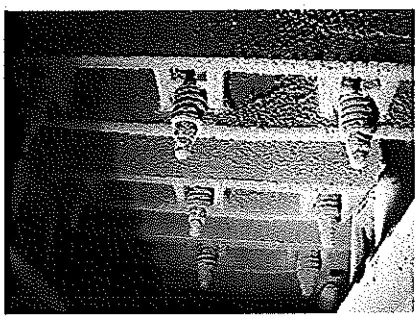

Figure 10 Dust agglomeration underneath the grate of the clinker cooler

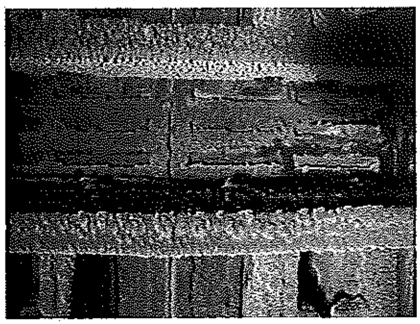

Figure 11 Dust agglomeration on the grate cooler slits

4.3.2 Gas recycle to the combustion chamber

Another passive SO_x control measure is to return the de-dusted gas to the precalciner. Additionally a large portion of quench air is replaced with water and gas recycling (see **figure 12** and **table 5** for technical data).

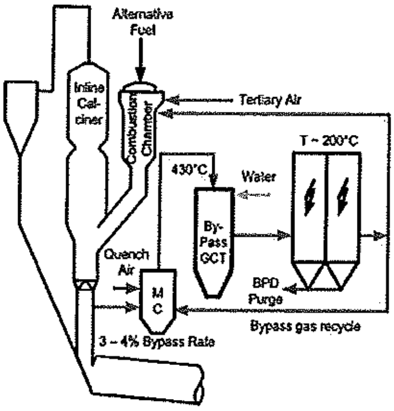

Figure 12 Bypass gas sent to precalciner

Table 5 Bypass system with gas recycle to combustion chamber of a 2,700 tpd PC kiln

Bypass rate	3 – 4%
Bypass Gas Flow to PC	10 kNm^3/h
Bypass Gas Flow back to MC	6 kNm^3/h
BP Dust Purge Composition	BP Dust Purge
20 – 30% Cl 5 – 15% SO_3 <10% CaO (free) 10 – 30% Na&K	~ 20 tpd

Here it has to be considered that the water dew point increases dramatically from 45°C to >70°C, hence an immaculate insulation is needed to avoid water condensation and subsequent corrosion. Despite all these precautions, the corrosion still occurred. Furthermore, coatings appeared in the GCT outlet and on the impeller of the EP ID-Fan, hence illustrating the challenging properties of the dust and off gas.

Due to the fact that besides SO_x, also NO_x is returned to the kiln, a NOx leakage without passing the SNCR is avoided.

The equipment is not trouble-free to operate. Especially as, due to the low bypass rate, the alkali salt concentration is rather high. However, it is in compliance with the requirement to generate as little BPD as possible. Currently, because of corrosion, false air in the EP hampers a "perfect" operation. The introduction of the gas stream into the combustion chamber also has to be chosen carefully.

5 Conclusion

It has been a long tramp from the traditional bypass system with a MC and EP to the customised systems. Today HC has a tool box of techniques allowing an adaptation to most situations.

This development has been propelled by environmental awareness (SO_x and POP control) and the use of AF. But economic considerations also contributed to the development in order to harvest the merits of an increased AF use rather than to surrender them to the operational costs of a bypass system.

Out of all possible arrangements, the gas recycle back to the clinker cooler is currently the most common choice. And this despite the fact that the clinker cooler design features - namely the grate drives and cooler plates - have to accommodate the hot grate air and therefore possible de-sublimation.

The gas recycle to the clinker cooler system has the following advantages:

- Sulphur is kept within the kiln system and eventually taken out with the clinker or BPD – but not as gaseous emission
- No leakage of NO_x emissions – this is especially valuable where lower emissions are foreseen in the near future
- Minimisation of heat losses due to bypass operation – hence meeting a more energy efficient operation

Last but not least, also dust homogenisation to smooth the varying Cl content - allowing a maximised BPD incorporation - is a "must" to minimise disposal of excess BPD.

Since mid 2009 HC has 4 kilns in operation with gas recycle to the cooler. And more are currently in preparation.

References

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