Mitigating the emissions of acid pollutants from dry blast furnace gas cleaning plants

Given the improved operational economics and, in some areas, the physical or economic scarcity of water, steel producers are shifting towards the application of blast furnace gas cleaning systems, in which the wet scrubber has been replaced with a second, dry gas treatment stage. While in traditional systems, acid pollutants leave the system with the scrubbing water, dry gas cleaning systems need to incorporate additional measures such as absorbent injection to eliminate acid compounds.

This article evaluates several solutions for the dry elimination of pollutants such as hydrochloric acid, hydrogen fluoride and cyanides. Removal mechanisms of the different approaches are compared, as well as their efficiency and effectiveness with respect to the elimination and reduction of unwanted consequences downstream of the gas cleaning plant, such as acid-accelerated corrosion in ducting, or plant equipment and NOx emission from the hot blast system.

Overall, dry gas cleaning technology has great potential for cleaning blast furnace gas as it offers better energy efficiency, lower cost, uses less plot space and practically eliminates water consumption. The use of the Vertical Radial Injector ensures that the absorbent can be utilized most effectively, which reduces the amount of gaseous pollutants to safe levels.

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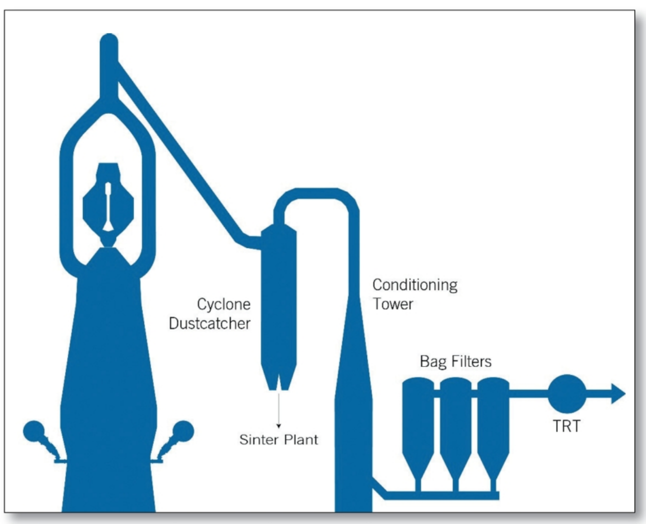

Fig 1 **Dry gas cleaning plant overview**

INTRODUCTION

In steel making, blast furnace gas is used as a fuel for different processes, most notably for the heating of the air supplied to the blast furnace itself. However, before it can be used as a fuel it needs to be conditioned and cleaned. Conventionally, a gravimetric dust catcher combined with a wet Bisschof scrubber and axial demister is used. But a relatively recent development is the shift towards dry gas cleaning plants. This system consists of a cyclone dust catcher, conditioning tower and a set of filter modules. Dry gas cleaning offers some clear benefits in comparison with wet cleaning systems namely:

- More thermal energy is available at the Top-Gas Recovery Turbine (TRT) and the gas has a higher calorific value for burning
- Elimination of the sludge and water processing plants
- Smaller physical footprint
- No water consumption

However, this technology also poses some challenges of which the main one is the removal of gaseous pollutants. *Figure 1* shows a quick overview of the layout of a dry gas cleaning plant.

Dry gas cleaning technology has been proven in the aluminum industry; the entire industry switched to dry cleaning technology in the 1980s. At Danieli Corus, with over 28 blast furnace gas cleaning projects and over 40 dry gas cleaning projects, all expertise necessary is present for the design of such a system **[1]**.

BLAST FURNACE GAS AND ITS PROBLEMS

To understand the requirements for the cleaning process we first need to know what we are starting with. Blast furnace

Main components	Formula	mol%
Nitrogen	N2	45-58
Carbon monoxide	CO	20-25
Carbon dioxide	CO_2	17-25
Hydrogen	H_2	1-5
Trace components	Formula	Amount
Dust	–	20-40g/Nm³
Moisture	H_2O	20-115g/Nm³
Hydrogen chloride	HCl	< 800mg/Nm³
Hydrogen fluoride	HF	< 80mg/Nm³
Hydrogen cyanide	HCN	< 150mg/Nm³
Carbonile sulfide	COS	< 70mg/Nm³
Hydrogen sulfide	H_2S	< 50mg/Nm³

Table 1 **Main components of blast furnace gas**

gas is a byproduct of producing steel, it consists mainly of nitrogen, carbon monoxide, carbon dioxide and hydrogen. Aside from these main components, there are pollutants present in the form of dust, and gaseous pollutants such as HCl, HF, HCN, and CNS. *Table 1* gives an overview of the typical composition of blast furnace gas **[2]**.

The main components of blast furnace gas are:

- **Hydrogen chloride:** HCl will increase the corrosion of metals which may lead to shortened life times of the stoves. This effect is further enhanced by higher temperatures **[3]**.
- **Hydrogen fluoride:** HF will have similar effects to HCl albeit in a smaller way since it is present in smaller quantities.
- **Hydrogen cyanide:** HCN will increase NOX emissions due to it decomposition products.
- **Carbonile Sulfide:** Increases SOx emissions due to its decomposition products.

While the amount of pollutants is relatively small, the potential effects on the rest of the cleaning system can be catastrophic when not mitigated. In a study by Chen et al **[4]** it was found that after four years of operation the wall thickness of a pipe downstream of the dry scrubber had reduced from 8mm to less than 3.4mm. The system they tested was a blast furnace which used a dry de-dusting system, followed by a spray tower in which they injected an undisclosed alkaline medium into the gas stream. The measurements were done downstream of this spray tower.

Recently there has been a push in regulations for reduced NOx emissions in the European Union. In traditional wet gas cleaning systems, cyanide removal is very limited, with typical removal efficiencies lower than 50%. Cyanides will break down into NOx emissions in the stove burner. Limiting the amount of NOx formed as a byproduct of the cyanides in the burner allows the stoves to operate at a higher temperature. This in turn may lead to an improved overall system efficiency.

In the *Best Available Techniques Reference Document for Iron and Steel Production*, the following emission levels are detailed for hot blast stoves **[5]**:

Dust : < 10 mg/Nm³
SOx : < 200mg/Nm³
NOx : < 100mg/Nm³

While this document is not legislation itself, it is often used as a basis for legislation in different countries and can be seen as a standard with which technologies have to comply. The proposed system makes sure that pollutant levels in the supply gas for the stoves are low enough to meet these targets.

Another interesting field of study is the removal of CO_2 from the waste gas stream. This is also mainly driven by ever-increasing regulations, such as a proposed CO_2 tax in the Netherlands. Danieli Corus is currently investigating different methods of CO_2 removal, such as CO_2 mineralization, but in this paper we will focus on the removal of acidic pollutants.

DRY GAS CLEANING PROCESS DESCRIPTION

As explained in the introduction, the dry gas cleaning process consists of three main process steps:

- Dust removal using a cyclone
- Conditioning tower to ensure a safe temperature for the filter modules
- Filter modules for the remaining dust removal and other pollutant removal using an absorbent

A short overview of these elements is given below.

The dust cyclone

The dust cyclone is the first step in the dry gas cleaning process. In comparison with conventional technology, the gravimetrical dust catcher, the removal efficiency is increased from 50% to 85%. The dust removed is relatively coarse and contains mainly iron oxide and carbon. This fraction can be recycled through the sinter plant without any further treatment. The finer fraction of the dust which is intentionally not captured, contains elements such as zinc and lead and will first be directed to the conditioning process and then towards the fine dust removal step. *Table 2* shows an overview of the most important design parameters of the cyclone.

The conditioning tower

The conditioning of the blast furnace gas is required in case the temperature of the gas is over 180°C or below 100°C. Mostly, this high temperature is caused by an offset or a slip of the burden within the blast furnace. A conditioning ▷

Parameter	Typical	Reason
Removal efficiency	85%	More than 85% removal efficiency increases the zinc content in the recovered dry dust significantly resulting in zinc-related process problems in the blast furnace
Down-comer angle	>40°	Below 40° dust can settle in the down-comer causing blockages
Dust storage capacity	72hr	Hopper below the cyclone could store dust up to 3 days to allow for bad weather conditions, or weekend production capacity
Discharge height of dust	5m	Dust discharge should have sufficient height to allow train wagons to fit underneath

Table 2 **Cyclone design parameters**

Fig 2 **Vertical radial injector**

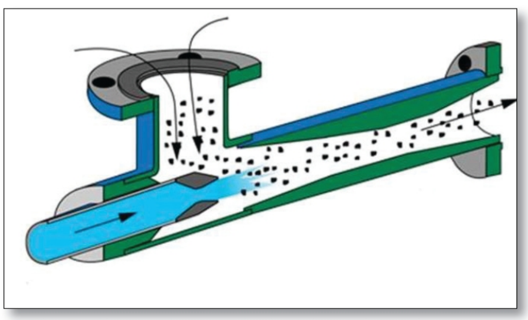

Fig 3 **Eductor for fresh absorbent injection**

tower is foreseen in the design where the blast furnace gas enters at the top of the tower and water is injected in co-current flow. Water is injected with nitrogen to produce a water mist, with droplets of ~150µm diameter. The residence time within the tower is such that all the droplets are fully evaporated at the outlet of the conditioning tower. The temperature of the BF gas leaving the conditioning tower is approximately 150°C. Where the temperature of the blast furnace gas is below 100°C a burner provides hot combustion gases that are mixed with the blast furnace gas to maintain a temperature of 130°C. This reheat is required to prevent condensation of moisture further down in the installation. Under normal operating conditions of the blast furnace neither cooling, nor heating is necessary.

The spray nozzles used to atomize the water are configured such that the whole circumference in the inlet duct is covered. The construction material of the spray lances is Hastelloy®, in order to withstand the harsh conditions of the blast furnace gas. The turndown ratio of the nozzle is 1:6 without compromising the droplet diameter. Furthermore, the nozzles can be switched on independently, allowing an even larger turndown ratio. If the lances are not operated, a small nitrogen flow prevents blocking of the nozzles due to dust. The lances can easily be removed from the outside of the tower. A platform and inspection hatches are provided.

Absorbent injection

To remove gaseous pollutants an absorbent must be injected. This is done at the bottom of the filter modules using a Vertical Radial Injector (VRI). The VRI (*Figure 2*) ensures that there is an even distribution of the absorbent through the gas and that the contact area is maximized.

A large part of the absorbent, combined with caught dust, is recycled through the VRI while an eductor (*Figure 3*) keeps a steady supply of fresh material. The fresh material is added above the VRI, further along the stream, to ensure that fresh material absorbs the final pollutants.

The material used for absorption is an alkali, of which lime is most often used. This gives the best result for the removal of all acidic components. An online gas monitor for HCl controls fresh absorbent feed rate, as this is the main pollutant. This ensures that no fresh absorbent is wasted and helps reduce the running costs of the system. The removal efficiency of HCN is expected to be much higher using this system than the wet system, leading to a significant reduction of NOx emissions. *Figure 4* shows a filter module including the absorbent injection and recycle system.

Currently, testing is being done to measure the effectiveness of different absorbents. The test equipment is continually being developed together with TNO and Lhoist and can be seen in Figure 5. The most recent development is the artificial addition of HCl into the process stream, since the amount of pollutant at Tata steel IJmuiden was too low to be able to do accurate tests.

Low pressure pulse filter modules

The conditioned blast furnace gas and the injected absorbent are directed to a number of filter modules, in which filter bags take care of the separation of the dust and the clean gas. The filter bags are configured in a circular array, so as to fit as many filter bags as possible in the round pressure vessels. This arrangement allows more square-meters of filter cloth per module. Due to the use of the Low Pressure (LP) pulse cleaning system, the filter bags can be made longer than standard High Pressure (HP) pulse cleaning designs. These longer filter bags also contribute to the overall square meterage within each module. Therefore, the Danieli Coris design requires fewer filter modules than competing systems.

Another limiting factor in the design is the can velocity, the upward gas velocity between the filter bags, which has to be low enough to prevent pulsed dust being captured by the upcoming gas stream and re-deposited onto the clean filter bag. Within the Danieli Corus design the incoming gas rises in the empty centre and in the open area near the wall, ensuring an undisturbed deposit in the hopper.

Each module is equipped with an inlet and outlet goggle valve so that maintenance on the module can be executed during production. The N-1 design allows one module to be taken out of operation for a maintenance bag change without influencing the gas quality, or blast furnace operation. Broken bags can be found by the use of broken bag detectors in the outlet of each module. The injection of fluorescent powder upstream of the filter bags makes the search for the broken bags easy. An ultraviolet lamp detects the broken bags straight away. Each module is also equipped with a nitrogen flush, so that the modules can be opened and vented safely before entering.

Low pressure pulse cleaning system

The filter bags within the filter modules need to be cleaned frequently to remove the layer of dust which is deposited over time. With the LP pulse cleaning system, a large volume of gas is brought into the filter bag which is inflated. Due to this inflation the dust on the outside of the bags is ejected from the bags. The gas, which is used for the pulsing, is clean blast furance gas boosted to a pressure of approximately 0.8bar. The use of blast furnace gas as the pulsing gas does not cause dilution of the blast furnace gas, as is the case with competing technologies which use costly nitrogen. These competing technologies use medium, or high pressure pulsing which creates a shockwave that travels down the pulsed bag while discharging the dust. However, the energy of the shockwave is lost as it travels down the bag. Effective bag cleaning with medium or high pressure pulse cleaning is therefore limited to between 4 and 4.5m of bag length. The Danieli Corus low pressure pulse cleaning system uses bags of 8m in length. Within cement applications, low pressure pulse cleaning filter bags of 10m are already in use.

The distribution of the blast furnace pulse gas is done with a slow rotating device which has three arms on which the gas injection nozzles are placed (*Figure 6*). The use of

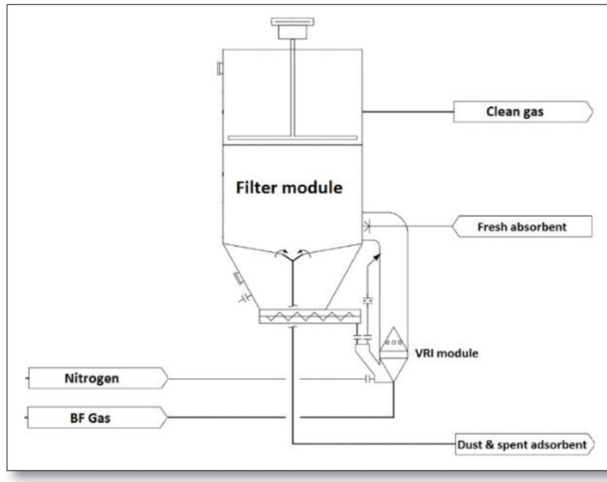

Fig 4 **Overview of a filter module including absorbent injection system**

Fig 5 **Absorbent test setup**

the rotating arm allows for easy access to the filter bags. Where there is a broken bag under one of the arms, the arm can be pushed away easily. Removal of pulse pipes is therefore not required for this design.

The cleaned BF Gas exits the module through the outlet goggle valve to the outlet plenum where the gas from all modules in collected. From the clean gas header a portion of clean gas is fed to the blast furnace gas booster. This pressurized blast furnace gas is used for pulsing the filter modules and fluidization of the VRI injectors. If required, this boosted blast furnace gas can also be used in the reheat burner in case the blast furnace gas is too cold.

Description	Amount		Savings per year	
		@35/MWh	@60/MWh	@85/MWh
Increased BF gas temperature	4100 kW	1,435,000	2,440,000	3,445,000
Decreased moisture content BF gas	80 kW	30,000	50,000	70,000
Evaporation	400 kW	140,000	240,000	335,000
Lower power Cold Blast	120 kW	40,000	70,000	95,000
TRT	3900 kW	1,365,000	2,320,000	3,275,000
Reduced water consumption @ 10ct/m^3	Approx. 225 m^3/h	200,000	200,000	200,000
No water chemicals (2ppm @ 1,200m^3/h @ 10/kg)		-200,000	200,000	200,000
Absorbent	100kg/h	-100,000	-100,000	-100,000
Total		3,310,000	5,420,000	7,520,000

Table 2 **Cost comparison of a dry and wet gas cleaning system**

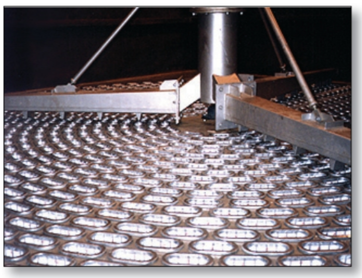

Fig 6 **Low pressure pulse system**

After this step the blast furnace gas is fed towards the TRT for expansion and energy recovery. Due to the higher blast furance temperature the output of the TRT is around 25% to 35% higher compared with a wet scrubber.

CAPEX AND OPEX

Table 3 gives an overview of the potential yearly savings for a dry gas cleaning system. It is based on a plant generating 600 000Nm^3/h of blast furnace gas. Some points of attention are the price of water which in this overview is set at 10ct/m^3. This is a realistic price when water is readily available. However, water is not always readily available and prices up to ten times as high might be possible in some locations, which improves the business case even further. Three different cases for the price of energy are given. One is based on a very low price point at €35/MWh where power is available from, for example other nearby industry, or is generated on site, another is at €60/MWh which is representative of the United states and finally one at €85/MWh, which is an approximation of the price point of European countries. Even with the relatively low price of water and at the lowest price of energy, it is clear that significant savings can be made by choosing, or switching to a dry gas cleaning plant in comparison with a wet gas cleaning plant. It is expected that the return on investment of a dry gas cleaning system will be approximately two years, and in some cases even less.

CONCLUSIONS

Dry gas cleaning technology offers many advantages over the more traditional gas cleaning technology. It is more energy efficient, more cost-effective, has a smaller physical footprint, especially if water treatment facilities and sludge handling equipment are included, and almost completely eliminates water consumption. While gaseous pollutants are a cause for concern, the use of the VRI ensures that absorbent is effectively dispersed in the gas stream, which in turn reduces the amount of pollutants to safe levels. **MS**

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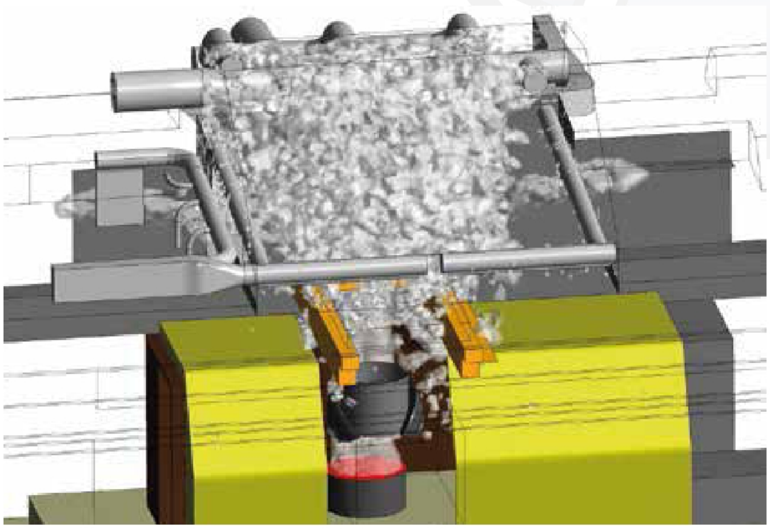

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