HOT GAS CLEANING OF FURNACE OFF-GASES

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ABSTRACT

For the cleaning of the furnace off gas generated in a closed ferroalloy smelting process which is mainly carbon monoxide, the industry norm is to use a wet gas cleaning device i.e. a venturi scrubber or disintegrator where the solids are removed from the furnace off gas through contact with water injected into the gas stream inside the venturi in the case of a venturi scrubber or inside the rotor in the case of a disintegrator with the cleaned carbon monoxide gas conducted away from the venturi scrubber or disintegrator to either a flare stack for safe burning as a waste gas or to a power generation plant for burning as a fuel.

However, a few factors affect the suitability of the scrubbed gas for certain applications

- *Solids content in the cleaned gas - it normally varies between 10 to 50 mg/Nm^3, making the gas suitable for gas fired boiler applications but not internal combustion engines*
- *Moisture content in the cleaned gas – wet and saturated*
- *Unwanted components in the cleaned gas i.e. tar – more applicable in cases where high volatile reductants are used in the ferroalloy smelting process. The hydrocarbons present in the volatiles, result in unwanted water treatment problems and equipment maintenance problems*

This paper describes an alternative solution to wet scrubbing systems for the cleaning of the furnace off gas from ferroalloy smelting processes where low or high volatile reductants are used. It uses a separation technology whereby solids are collected and separated from the process gas by passing it through high temperature filtration elements that are periodically cleaned by using an inert gas. The resultant cleaned gas solid gas content is below 5 mg/Nm^3 and is suitable for direct use in any power generation or heating system. If high volatile reductants are used, the hot gas with tar in vapor form passes through the filtering section for cleaning before entering a suitable tar removal system prior to being used in any power generation systems or heating system. The collected tars from the tar removal systems can be used as a fuel or safely disposed of.

1. INTRODUCTION

A closed ferroalloy smelting process normally uses coal and coke as the main source of carbon for reduction reactions. The resulting furnace off gas produced from the smelting process is mainly carbon monoxide and hydrogen with temperatures ranging from 350 and 700^{o}C for a cold feed and 700 to 1000^{o}C for a hot feed operation, depending on the type of ferroalloy being produced. The furnace off gas normally has a solid content of typically 35 to 45 g/Nm^3 depending on the operating conditions in the furnace. The dust generated is mainly metallic oxides - magnesia - and silica.

This makes using wet gas cleaning systems in the form of venturi scrubbers, jet scrubbers or disintegrators ideal for cooling and cleaning the furnace off gas. The resulting fully saturated clean mainly carbon monoxide rich gas has a solid content of between 10 to 50 mg/Nm^3. Some smelter operators use a portion of the cleaned carbon monoxide rich gas for sintering and / or pre heating of the furnace feed material with the majority being flared to produce CO_2.

There have been a few smelter operators who have pursued the route of using the cleaned carbon monoxide rich gas in a co-generation application, the best-known operation being the gas fired boiler and turbine system. The definition of co-generation, for the purpose of this paper, is the use of carbon monoxide and hydrogen rich clean furnace off gas to produce electricity. The main reason for the success of this type of system is its ability to operate with variable gas qualities i.e. carbon monoxide and hydrogen compositions, relatively high solid content in the gas as well as unwanted components in the gas such as tars.

The increasing cost and dissipating supply of metallurgical grade coke have lead ferroalloy producers to search for alternative sources of carbon. Such alternatives include char, bituminous coal and anthracite, depending on the process. When a relatively high percentage of coal with a high volatile matter is used, tar vapours can be present in the furnace off gas. Cooling and cleaning of this furnace off gas in a wet gas cleaning system guarantees that these tars (mainly the heavy tars) will condense when the gas is in contact with colder surfaces or water, creating operating, maintenance and water treatment problems, i.e. heavy tars in suspension with light tars dissolved in the scrubbing liquor.

Combined with the constant rise in electricity prices, it has become necessary to investigate other means to overcome the challenges experienced with wet gas cleaning systems as summarized in table 1 and to consider utilizing all the gases as a source of fuel for producing electrical energy, thus becoming more energy efficient by operating a co-generation installation.

Table 1: Typical challenges and current solutions for co-generation installations with a wet gas cleaning system

Internal combustion engines*	**Solid content more than 10 mg/Nm^3**	**Wet gas filter**
	Unstable gas quality i.e. varying carbon monoxide and hydrogen	Large gas accumulator
	Moisture content of gas	Activated carbon filter
	Reduced operating hours and increased maintenance downtime due to unwanted tars present in gas	NO SOLUTION
	Inconsistent gas supply i.e. more than 10mbar/s pressure fluctuations, mainly due to variable gas volumes	Large gas accumulator
Gas fired boiler generator	Reduced operating hours and increased maintenance and downtime due to the presence of unwanted tars	No necessity to use any equipment to reduce the effect of tars
Organic Rankine Cycle power plant	Reduced operating hours and increased maintenance and downtime due to the presence of unwanted tars	No necessity to use any equipment to reduce the effect of tars

*For most applications, the total solution is a combination of equipment

Although it can be argued that the internal combustion engines should only be used for selected applications, it is likely that single or multiple internal combustion engines and ORC power plants will be preferred for installations where between 2 and 20 MW are to be generated, whereas individual steam cycle and gas turbines become more economical with size up to 300 MW. A factor in the selection of internal combustion engines is that small steam cycle and gas turbines are generally assessed, as having a capital cost that is around 25% to 45% higher than an internal combustion engine. However, operation and maintenance expenditure is typically greater for internal combustion engines in comparison to turbines. Turbines, and particularly steam cycle turbines, may be more tolerant of impurities in the fuel gas and the possibility of utilization of the steam may offer an additional benefit. Efficiencies of internal combustion engines are in the 37% range while that for turbines varies dependent on type and size, with the smaller turbines with low efficiencies starting from 25% for micro turbines to up to 40% for large turbines with good heat recovery systems.

2. OVERVIEW

In order to address the challenges described above, an alternative method and process to cool and clean the mainly carbon monoxide rich furnace off gas generated in a closed ferroalloy smelting process has been developed through the combination and modification of current technologies. The principle of the new development is to clean the process gas as hot as possible using a filtration separation technology. The target temperature is set at 350^{o}C as operating at this temperature can simplify the control of other pollutants as well as the removing of certain particulates – initially only tars, with the potential of allowing gases to be cleaned at optimum temperatures as well as acting as a medium to support a renewable layer of reagents. This technology has the following advantages over a wet gas cleaning technology:

- Reduction of the solid content in the cleaned process off gas to below 5 mg/Nm^3 as this technology has no equal where high removal efficiency is critical purely due to its operating principle.
- Reduction of the moisture in the cleaned process gas by reducing or eliminating the use of water.
- Elimination of the condensation of tars on colder surfaces for certain process off gases by operating above the tar dew point of the process gas.
- Elimination of the wet scrubber liquor water treatment system, which can be problematic when a process off gas with tars present is to be treated.

It is not the intention of the new development to eliminate the variations in the process gas supply as noticed in the gas pressure and quality – notably the carbon monoxide and hydrogen compositions - as these are related to the smelting operation and not the gas cleaning technology.

However, using the hot gas filtration technology has some challenges when compared to the wet gas cleaning technology, which required attention during the development process namely:

- Suitability of the technology to perform accurate furnace pressure control.
- Ability of the technology to handle process gas temperature spikes or increases.
- Ability of the technology to handle changing process dust properties.
- Optimization of the amount of inert gas required for cleaning, especially if it is not readily available.
- Reliable gas sealing during dust removal due to the explosiveness of the process gas.
- Ability of the dust handling equipment to operate at elevated temperatures.

3. PROCESS DESCRIPTION

The typical hot gas cleaning system as illustrated in figure 1 uses a process of extracting the furnace off gas from the closed ferroalloy smelting operation, reducing and controlling of the process gas temperature in a cooling section followed by a process of cleaning the process off gas in a gas cleaning section before the cleaned gas is supplied to a CO user or flare stack.

The furnace off gas is ducted from the closed ferroalloy smelting process typically through a water-cooled - or refractory lined off gas duct. This duct is usually removable duct for ease of cleaning. The duct diameter on the furnace side is enlarged to reduce the capture velocity sufficiently minimising the possibility of dust pick up due to high gas velocities.

In instances where it is required to maintain the process gas temperature above the tar dewpoint, the duct is internally lined with a suitable refractory lining and externally lagged with a low density insulation material covered with a weather protection. For plant start-up, additional energy in the form of a combusted fuel is injected into the duct through a start-up burner that is permanently connected to the duct and activated and controlled at a pre-determined temperature by the off gas temperature measurement in the duct after the burner.

The control of the process off gas temperature to achieve a target gas temperature of 350°C is performed in the gas cooling section by using either evaporative spray cooling or forced draft cooling. with the selection of the type of technology based on the criteria as listed in table 2 below.

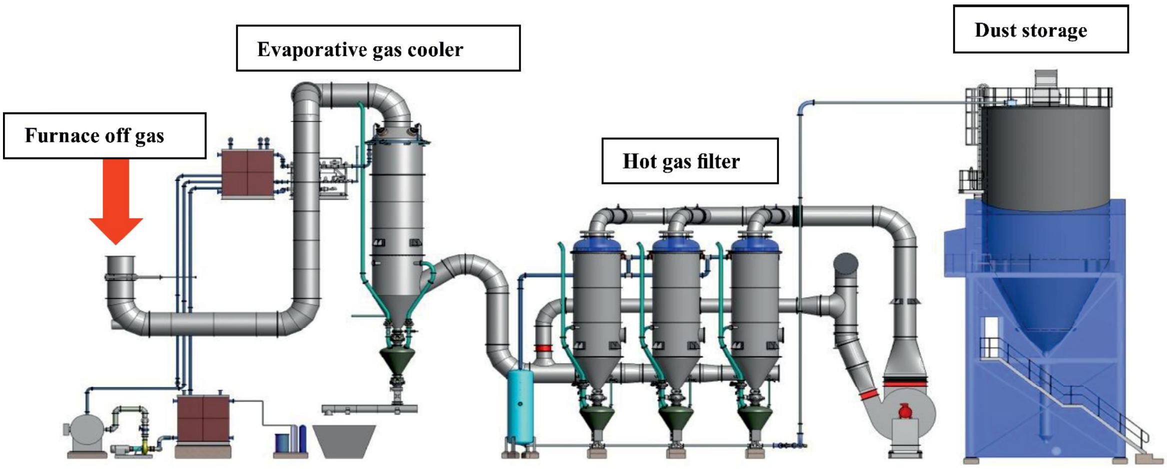

Figure 1: Illustration of a typical hot gas cleaning system

Table 2: Gas cooling technologies for different process gas temperature ranges

Process design gas temperature from furnace	Gas cooling technology to be used
$T_{gas} > 500°C$	Evaporative gas cooling
$300°C < T_{gas} < 500°C$	Forced draft cooling
$T_{gas} < 300°C$	None required

Evaporative cooling is the process where a liquid is injected into a process gas stream and evaporated to reduce the process gas temperature as the process gas flows through a large diameter vessel of a sufficient straight length. Pressurized water is normally used as the cooling medium which is finely atomized using compressed air through nozzles on a lance pipe in the hot gas stream. Due to the explosiveness of the process gas, an inert gas such as nitrogen is the most suitable atomizing medium, but high operating costs due to the volumes of inert gas required, makes it not a feasible solution. Steam is a more viable solution and although more difficult to use than compressed air, it performs well in laboratory tests and similar field applications.

Forced draft cooling on the other hand is the process where the process gas temperature is reduced by passing the process gas through the inside of a multiple banks of vertical tubes with cooling air as supplied by forced draft fans passed across the outside of the multiple bank of vertical tubes. The multiple banks of vertical tubes are fixed on the top and bottom tube sheets with the hopper at the bottom of the tube banks incorporated for dust collection. The process gas outlet temperature is controlled by changing the number of operating forced draft fans. A bypass duct with temperature control damper is used to by-pass the cooler in the event of low process gas temperatures.

It is expected that some dust in the process gas stream settles out of the process gas stream and is collected in the bottom of the evaporative spray cooler or forced draft cooler hopper. This settled out dust is regularly removed through a lock hopper system located on the bottom outlet. The locked hopper system is used as a sealing vessel between the CO rich environment inside the cooler and atmosphere, to prevent any air ingress into the system during the dust removal cycle. The removed dust is dumped into either a dense phase pneumatic or mechanical conveying system to a dust storage facility, the selection of which depending on the process design gas temperature.

3.1. Process gas cleaning

The capturing and removal of the particulate dust from the process gas stream is performed in the hot gas cleaning section mainly comprising a hot gas filter, housing the filter media. The media selection dictates whether any pollutant in vapour form (tars or sulphur dioxide) passes through or is captured and removed by the filter media.

The operating life of any filter media depends on:

- the dust characteristics (e.g., size, shape, and composition).
- the filter media's dust holding capacity and corresponding pressure drop.
- ability of the filter media to be cleaned, either on or off line.
- operating temperature range of the filter media.

Understanding the fundamental processes of particle removal as a gas stream passes through a filter media is thus critical to the optimum selection of the appropriate media and to the successful filter design and operation.

The further discussion on this section of the hot gas filter cleaning section is focused on understanding of the applicable filtration principles, the dust and filter media characteristics, in order to provide sufficient information for the specification of the filter design.

The dust samples from different ferroalloy operations were used to determine unknown parameters required as design parameters for the specification of the cleaning technology i.e. filter media and cleaning as well as to compare the effect of different properties on the plant design.

3.1.1. Filtration principle

The process gas produced in the closed ferroalloy smelting operation normally has a relatively high dust load (g/Nm^3). The preferred operative filtration mechanism for similar conditions is normally cake filtration and thus surface filtration rather than depth filtration with the cake removal via a pulse or blow back cleaning. A particle cake is developed on the surface of the filter media as illustrated in figure 2. This becomes the filtration layer which also causes the additional pressure drop.

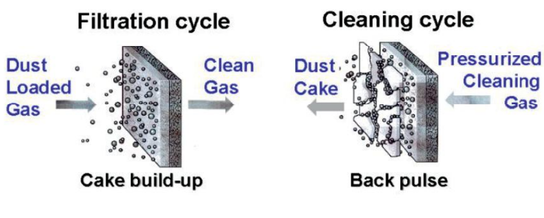

Figure 2: Particle loading during surface filtration and subsequent cake release during cleaning

The pressure drop increases as the particle loading increases as shown in figure 3. Once a terminal pressure is reached during the filtration cycle, the filter media is cleaned with a pulse of clean gas to dislodge the filter cake. With the correct selection of the filter media, the pressure drop can be recovered to the initial pressure drop. However, if particles become dislodged within the filter media, during the filtering, and progressively load the filter media, the pressure drop may not be completely recovered after the cleaning cycle. Figure 3 illustrates the recovery in the clean pressure drop. The optimal design application results in minimal increase in the clean (recovery) pressure drop after cleaning cycle, and more importantly, ensures an equilibrium operating condition after an initial series of cleaning cycles. The effectiveness of the cleaning cycle and the pressure drop recovery is a critical function of the properties of the filter cake and the media. The cake strength depends upon the particle morphology and size distribution, electrostatic and chemical interactions, and the cake moisture levels.

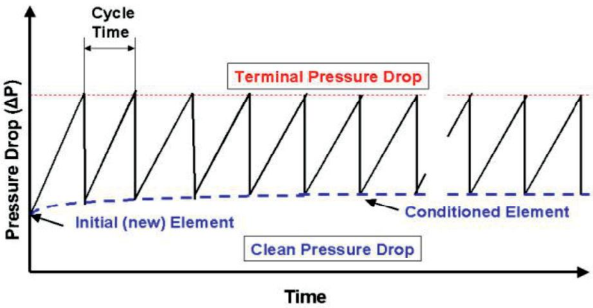

Figure 3: Typical pressure drop profiles during cake formation and periodic removal by cleaning

3.1.2. Filtration media

The proper selection of the filtration media with appropriate pore size, strength and corrosion resistance enables long-term operation with minimal downtime, closed and automatic operation with minimal operator intervention and infrequent maintenance. Two types of filtration media are considered for this technology namely sintered porous metal filter media and ceramic media.

[1] Sintered porous metal filter media: Filtration systems utilizing sintered porous metal filter media have been proven an effective and reliable choice for gas/solids (dust) separation in numerous industrial gas filtration applications in the chemical process, oil refining, petrochemical and power generation industries. Sintered porous metal filter media combine many different properties, including its outstanding filtration and cleaning characteristics, excellent chemical and thermal resistance, and its mechanical strength,

The properties of metal filters, fabricated from various metal alloys, for hot gas filtration applications allow their use in extreme conditions e.g. high temperature, high pressure and corrosive atmospheres. Sintered porous metal filter media are fabricated from metal powder or metal fibre. The main difference between the two products is the method of manufacturing i.e. metal powder is manufactured by pressing pre-alloyed powder either into tubes or porous sheet, followed by high temperature sintering, while metal fibre consists of very thin metal filaments uniformly laid to form a three dimensional non-woven structure sintered at the contact points. Figure 4 illustrates the difference between the two products. The filtration rating in gas ranges from 0.1 to $100\mu m$ for the sintered metal powder and 0.1 to $10\mu m$ for the sintered metal fibre. The drag coefficient K_1 of the filter media which is discussed later on is higher for the sintered metal powder compared to the sintered metal fibre due to the lower permeability, resulting in a higher clean element pressure drop for a specific filtering velocity.

The choice of sintered metal powder or sintered metal fibre is determined by the dust / cake properties, the target filtration velocity and allowable operating pressure drop.

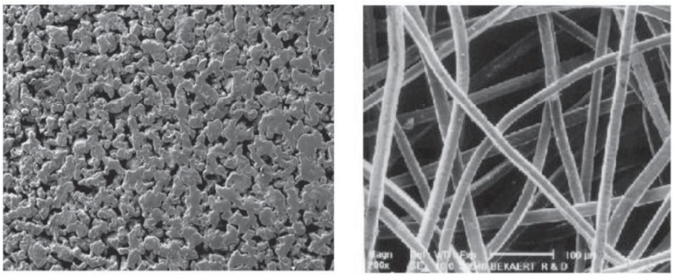

Figure 4: Photomicrograph of metal powder (left) and metal fibre (right)

[2] "Ceramic" candle media: The filter media is a high temperature media manufactured from CaO – MgO – SiO_2 high temperature glass fibres. The filter media has been proven an effective and reliable alternative for high temperature process conditions above the usual possibilities of textile filter media in the bio mass incineration, waste incineration, class recycling and wood gasification industries.

The primary benefits of the "ceramic" candle filter media are its high thermal resistance up to 850°C, spark resistance, non – flammability, self-supporting structure, high chemical resistance, light weight and low emission level of less 1 mg/Nm^3 (depending on dust properties). It is however sensitive to process gases containing hydro fluorides due to the reaction with the SiO_2 in the filter media as well as operating below the process gas dew point as the condensation can actually dissolve the fibre material, leading to a diminishing wall thickness.

3.1.3. Dust/cake properties

The dust properties and particle size distribution are influencing factors on the degree of dust capture on the filter media. The cake strength depends upon the particle morphology and size distribution, electrostatic and chemical interactions, and the cake moisture levels. Table 3 summarizes the laboratory results obtained [3] for test work performed on one of the dust samples - bulk densities, particle size distribution and cake densities for specific cake thicknesses:

Table 3: Laboratory test results – ferromanganese

Bulk density (kg/m^3)	1,060
Particle size distribution	
Size range (µm)	0.67 to 300
Mean size (µm)	54.1
Median size (µm)	40.8
Cake density for	
2.5 mm cake (kg/m^3)	682
5.1 mm cake (kg/m^3)	682
7.62 mm cake (kg/m^3)	908

Using a single element of sintered metal powder media of different grades (as determined by the particle size distribution), actual filtration tests were also performed on a laboratory scale filter to determine actual total pressure drops (for a clean and clogged element) for different filtering (approach) velocities and specific cake thicknesses.

These results were used to derive empirical relations for the element drag (K_1) for each filter media grade and filter cake (K_2) resistances for each dust sample required, these used in calculating the approximate filter pressure drops for variable cake thickness as determined by the cleaning cycle differential as well as filtering velocities for larger scale installations.

The relations below were derived for ferromanganese:

$$\Delta P_{grade\ 2\ media} = 0.0093\ V^2 + 0.8251\ V \quad (1)$$

$$K_1 = {\Delta P_{grade\ 2\ media}}/{V} \quad (2)$$

$$\Delta P_{6.35\ mm\ cake} = 0.0442\ V^2 + 1.4414\ V \quad (3)$$

$$Areal\ cake\ density = Cake\ density\ x\ Cake\ thickness \quad (4)$$

$$K_2 = {\Delta P_{6.35\ mm\ cake}}/{(V\ \ x\ areal\ cake\ density)} \quad (5)$$

where $V = filtering\ velocity\ ({m}/{min})$

Figure 5 presents the actual filtration test results for ferromanganese and filter media grade used. The recovery pressure drop after cleaning as well as the downstream air quality for each dust sample was also determined using a laboratory gas/solids venturi system to understand what the expected clean (recovery) pressure drop after cleaning is, how well does the filter media “cleans”, the degree of penetration by the dust e into the filter media pores as well as what the expected solid content in the exit process gas is. Table 4 summarizes the calculation results for K_1 and K_2.:for ferromanganese. Table 5 summarizes the results of the recovery pressure drop and downstream air quality test work for ferromanganese.

Table 4: Calculation results for K_1 & K_2 for FeMn

Filter media grade *	**Grade 2**
K_1 ($mmH_2O/(m/min)$)	74 - 76
K_2 ($mmH_2O/(m/min.kg/m^2)$)	11 – 14

*The filter media grade refers to the average pore size of the media e.g. grade 2 refers to a media with an average pore size of 2 μm

Table 5: Clean pressure drop recovery & downstream air quality for FeMn

Filter media grade	**Grade 2**
Pressure drop recovery (mmH_2O)*	2.54 – 12.7
Downstream air quality (mg/m^3)**	**6.5. – 0.05** ***

*Pulsing / blowback pressure = 4 bar. Variances are due to the increased filtering velocity as some of the dust re deposit on the filter media at higher filtering velocities as well as th e increased cake thickness

**Each test started with a clean element

***The increased cake thickness reduce the penetration of dust into the filter media, yielding improved air quality

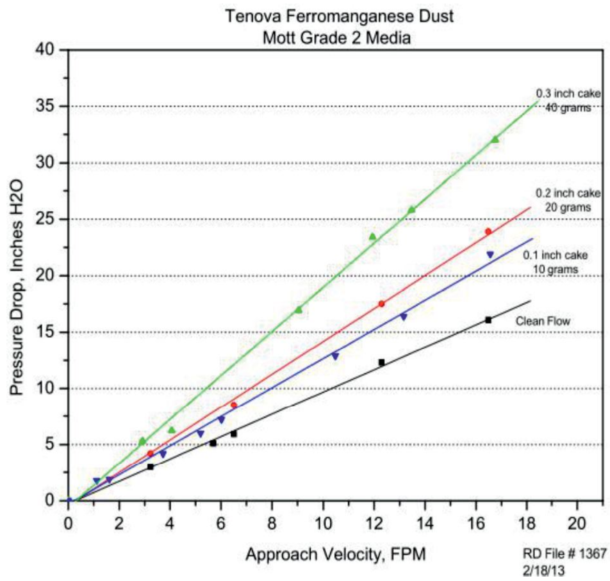

Figure 5: Total pressure drops for different filtering velocities (FeMn)

3.1.4. High volatile gas properties

Where a relatively high percentage of reductant with a high volatile matter is used, tar vapours are present in the process off gas. Operating at temperatures below the tar dew point of the process gas creates a risk that these tars (mainly heavy tars) will condense. In order to determine the tar concentrations and composition in the process gas generated when using a high volatile reductant in a smelting process, reductant samples were pyrolyzed in a laboratory scale gasification system followed by a two staged tar removal system for collection of the removed tars as well as to determine whether the tar removal system is suitable to the clean the tar containing gas.

Although positive analytical and visual results [5] were obtained, the produced gas contained a high concentration of tars and a selection of unknown tar components, which require further investigation. Although not designed for handling this specific kind of process gas, the tar removal system performed satisfactorily in removing a large portion of the tars with relatively light (low boiling temperatures) components still present.

3.1.5. System operating pressure

The selection of the appropriate filter media and target filtering velocity based on dust / cake properties influences the operating pressure drop of the filter, which in turn is the largest contributing factor to the total system operating pressure, which ultimately affects the furnace pressure control. Although the system pressure drop is the summation of a series of pressure drops from the inlet to outlet of the filter, the pressure drop across the filter media and cake is the focus as the others are relatively constant for a specific velocity. Knowledge of these factors and how they influence the filter operating pressure drop is critical for good furnace pressure control. It also greatly assists in estimating the cleaning / blowback gas consumption where it affects the operating expenditure of the plant as well as for optimizing the plant operating parameters during the plant design.

The results of the aforementioned laboratory tests and calculations were used to estimate the total pressure drop of the filter [4] for target filtering velocities and cleaning cycles.*

$$\Delta P = K_1 V + K_2 C_1 V^2 t \tag{6}$$

where $\Delta P = Pressure\ drop\ across\ filter\ (mmH_2O)$

$K_1 = drag\ of\ a\ dust\ free\ (cleaned)\ filter\ media\ (mmH_2O/(m/min))$

$V = average\ or\ design\ filtering\ velocity\ (m/min)$

$K_2 = dust\ cake\ flow\ resistance\ (mmH_2O/(\frac{m}{min}.kg/m^2)$

$C_1 = inlet\ dust\ concentration\ (\frac{kg}{m^3})$ $\quad t = time\ interval\ between\ cleaning\ cycles\ (min)$

*The effect of dust re depositing on adjacent filter media is neglected due to the design of the hot gas filter housing, which promotes the downward flow of the dust, as well as method of cleaning, which is described later

Figure 6 illustrates the results of the estimated filter pressure drops for different cleaning cycle differentials and test filter media at a constant inlet dust concentration (C_1) of 100 g/m^3. It clearly highlights the importance of the known dust properties, selection of the target filtering velocity and filter media and grade on the estimated operating pressure drop of the filter as well as the running costs of the system i.e. more frequent cleaning / blow back increases the cleaning / blow back gas consumption.

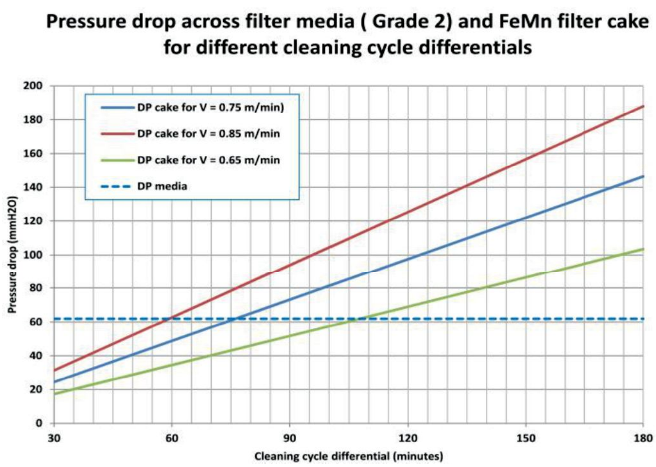

Figure 6: Total pressure drop for different filtering velocities (FeMn)

Table 6 summarises the design parameters that can be typically obtained from the test work results.

Table 6: Design parameters for FeMn hot gas filter

Filter media grade	**Grade 2**
Target filtering velocity (m/min)	0.65
Target filter differential operating pressure drop (mm H_2O)	20
Estimated cleaning cycle differential (min)	35
Comparative cleaning / blow back gas consumption	Highest

3.1.6. Hot gas filter design

The hot gas filter consists of a single or series of vertical cylindrical cells each comprising (from bottom to top):

- A conical shaped dust hopper.
- A dirty gas plenum with a single side entry gas inlet extending into a vertical centre duct with outlet at the top end of the dirty air plenum.
- A filter element bundle consisting of a tube sheet with a number of filter elements with internal venturi compartmentalized through internal divider plates.
- A clean air plenum, similarly compartmentalized as the filter bundle but individually sealed with each having blowback nozzles equal in quantity to the corresponding filter elements, with a single top exit gas outlet nozzle.
- A blow back system consisting of quick opening blow valves for each clean air plenum "compartment", a blow back controller and a blow back gas accumulator tank.
- A lock hopper system.

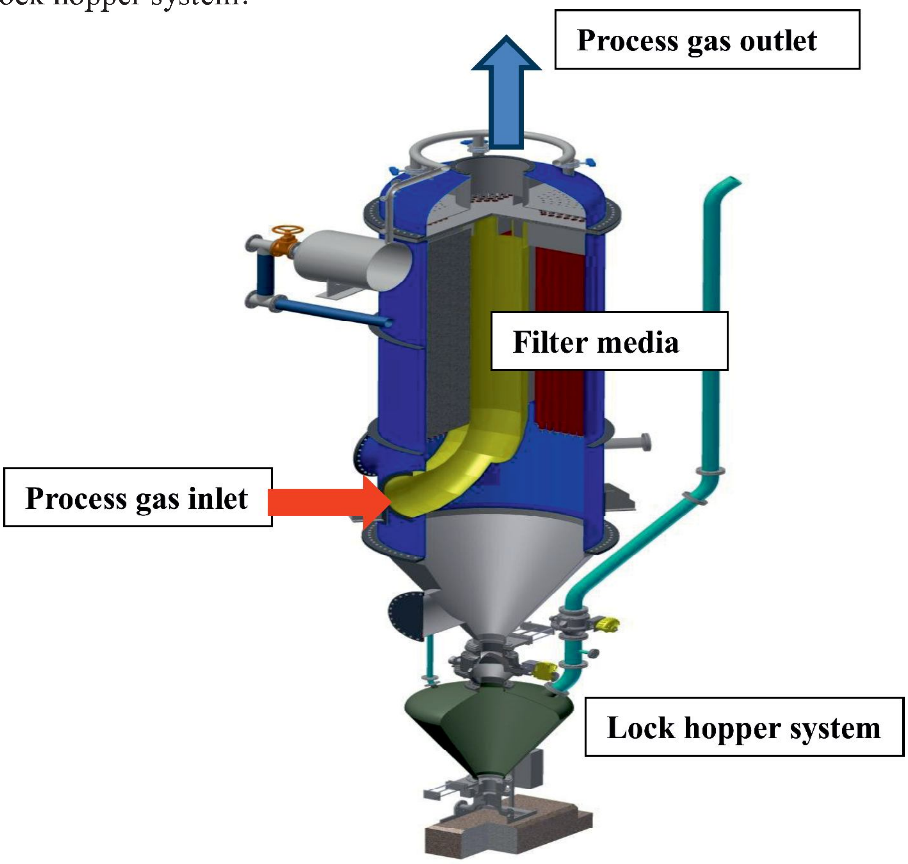

Figure 7: Partial cross section of the hot gas filter vessel

Pressure sensing devices are mounted on each cell to sense the filter pressure differential between the dirty air plenum and clean air plenum. The output of this device is used in the control circuit of the blow back controller for a specific cell as well as the complete hot gas filter controller. A similar pressure sensing device is also used to sense the filter pressure differential between inlet and outlet duct of the hot gas filter dirty air plenum. The output of this device is used in the control circuit of the furnace pressure control controller.

The dust laden gas enters each of the hot gas filter vessels and exits at the top of the centre duct, from where gas is dispersed into the compartmentalized dirty gas plenum, passed through the filter element bundle and exits the clean air plenum. The dust remains on the outside of the element and is regularly removed to prevent blinding of the elements.

The filter elements are cleaned on line by a blow back system, which is activated based on the measured differential pressure between the dirty air plenum and clean air plenum. A blow back duration is approximately between 0.5 to 1 seconds in which time the "compartment" is pressurised before the blow back gas is injected into the filter element, with a delay of 10 - 15 s between compartment blow backs. An inert gas which is nitrogen in this case, is used as blow back medium.

The dust dislodged from the elements is collected in each cell conical hopper. The collected dust is periodically removed through a locked hopper system connected to the outlet of the conical hopper.

System pressure control

The furnace freeboard pressure in a closed ferroalloy smelting operation is normally controlled between -5 to 5 mm H_2O to limit the amount of carbon monoxide escaping from the furnace free board or atmospheric air from entering the furnace free board. The furnace pressure control is achieved by using a modulating pressure control damper in the recycling gas line connecting the hot gas filter Main ID fan outlet to the hot gas filter inlet duct as well as a variable speed drive for the hot gas filter Main ID fan motor as illustrated in figure 1 with the furnace free board pressure measurement used as control input variable to the modulating control damper and fan speed control.

3.1.7. Safety Devices

The main gas components – CO, CO_2, H_2 and O_2 - are monitored on line with a gas analyser located in the connecting duct between the hot gas filter and Main ID fan, to provide information about the furnace conditions and entire hot gas cleaning filter as well as alarm and shut down signals in the event of undesired O_2 and H_2 levels.

A fully automated isolation and purging system is used to purge the gas cleaning system in the event of detecting undesired high levels of oxygen levels during normal plant operations as well as during plant start-up and shutdown. This system is integrated into the overall plant control system with little or no operator intervention required.

3.2. Other hot gas cleaning components

The outlet of the hot gas filter is ducted to a single Main ID fan, used to draw the process off gas from the furnace free board. The fan speed is controlled through a variable speed drive for furnace pressure control. The fan outlet is ducted to the hot gas filter inlet (recycling gas line) used for furnace pressure control and one of the following options depending on the preferred gas use:

Table 7: CO gas supply options (Power generation)

Internal combustion engines (tar free gas)	Gas / water cooler
	CO gas booster fan
Internal combustion engines (tar gas)	CO gas booster
	Tar removal system
Waste heat boiler / turbine	CO gas booster
ORC power plant	Combustion chamber

Any excess CO gas that can't be processed in any of the options as summarized in table 7 is supplied to the flare stack through a reflux device, which primary function is to ensure that a gas seal is maintained between the CO rich gas environment within gas cleaning plant and atmosphere. Instances where it is required to maintain the process gas temperature as hot as possible, for e.g. above the tar dew point of the process gas and for personnel protection, the equipment is externally lagged with a low density insulation material covered with a weather protection.

4. CONCLUSIONS

High temperature dry gas cleaning is a viable alternative to wet scrubbing of furnace gases, producing a cleaner gas that is directly usable in a number of co-generation plant options. The significant reduction in water consumption presents an ecological benefit in areas where water is in short supply.

The test work performed on each of the dust samples indicates that:

- the sintered porous metal filter media is a suitable filter media, although a different grade is required determined by the particle size distribution.
- the dust from ferrochrome, silicon-manganese and ferromanganese furnaces exhibits significantly different properties, but all can be successfully cleaned with the appropriate choice of filter media.
- the blowback / cleaning of the element is effective in removing the cake.
- the increase in filter media pressure drop after blow back is acceptably low, but depends on the filtering velocity as a certain amount of dust is redeposit onto the media at high velocities.
- the downstream air quality of less than 5 mg/Nm^3 is possible.
- test work is required for any unknown dust type in order to determine the dust properties and other design parameters.
- future work is required for the "ceramic" candle filter element.

The test work performed on the high volatile reductant indicates that:

- heavy tars are present in a filtered process gas from a smelting operation operating on a high volatile reductant can be successfully removed with a tar removal system with lighter tars of low concentrations still present, which should not be problematic in the end utilization of the process gas in an internal engine.
- further test work for longer durations is required to obtain a more accurate composition of the tars present in order to optimize the tar removal system for improved efficiencies.

The abovementioned conclusions from the test work together with the research and development done on the hot gas cleaning process to date strengthen the argument that this hot gas cleaning process is a suitable alternative and in some instances, the only alternative solution for the conventional wet gas cleaning system, specifically in the following applications:

- Medium off gas volumes at high gas temperatures.
- Off gas containing unwanted components e.g. tars.
- Specific clean gas properties are required.
  - Low moisture content.
  - Low solid content.
  - Gas temperature above the dew point for further processing / cleaning.

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4. REFERENCES

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