

Hot Gas Filters for Control of Emissions to Atmosphere

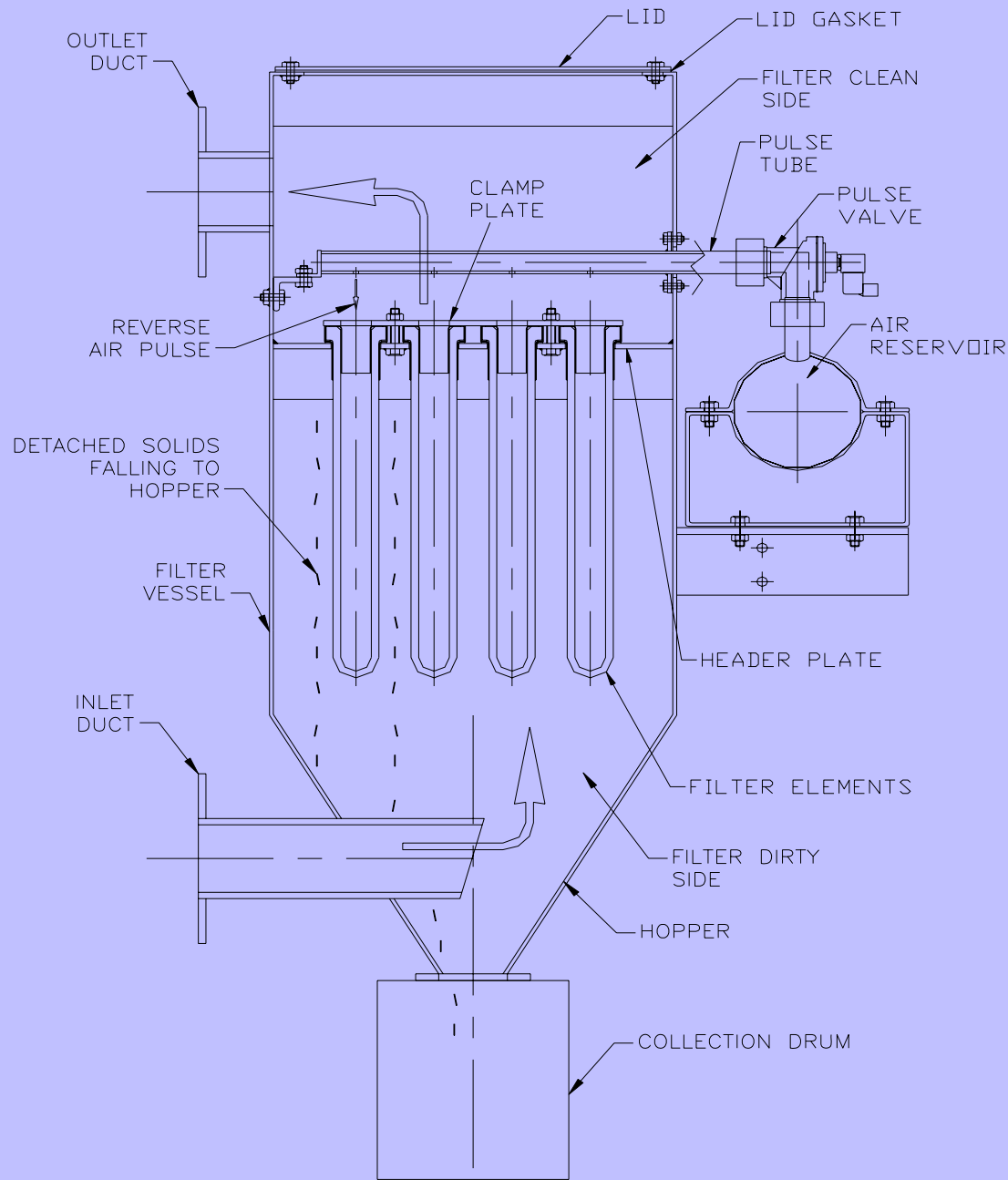
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The Case for Hot Gas Filters – Part 1

- ⇒ Most controlled processes emit a mixture of pollutants to atmosphere
- ⇒ Very often particulates constitute an important part of the mixture
- ⇒ Particulates can be satisfactorily controlled only by barrier filtration
- ⇒ Conventional barrier filters - bag filters - operate only at temperatures $<200\text{ C}$
- ⇒ The use of higher temperature barrier filters, such as ceramic filters, can simplify the control of other pollutants as well as removing the particulates



Typical Hot Gas Filter

The Case for Hot Gas Filters – Part 2

⇒ Hot gas filters can:

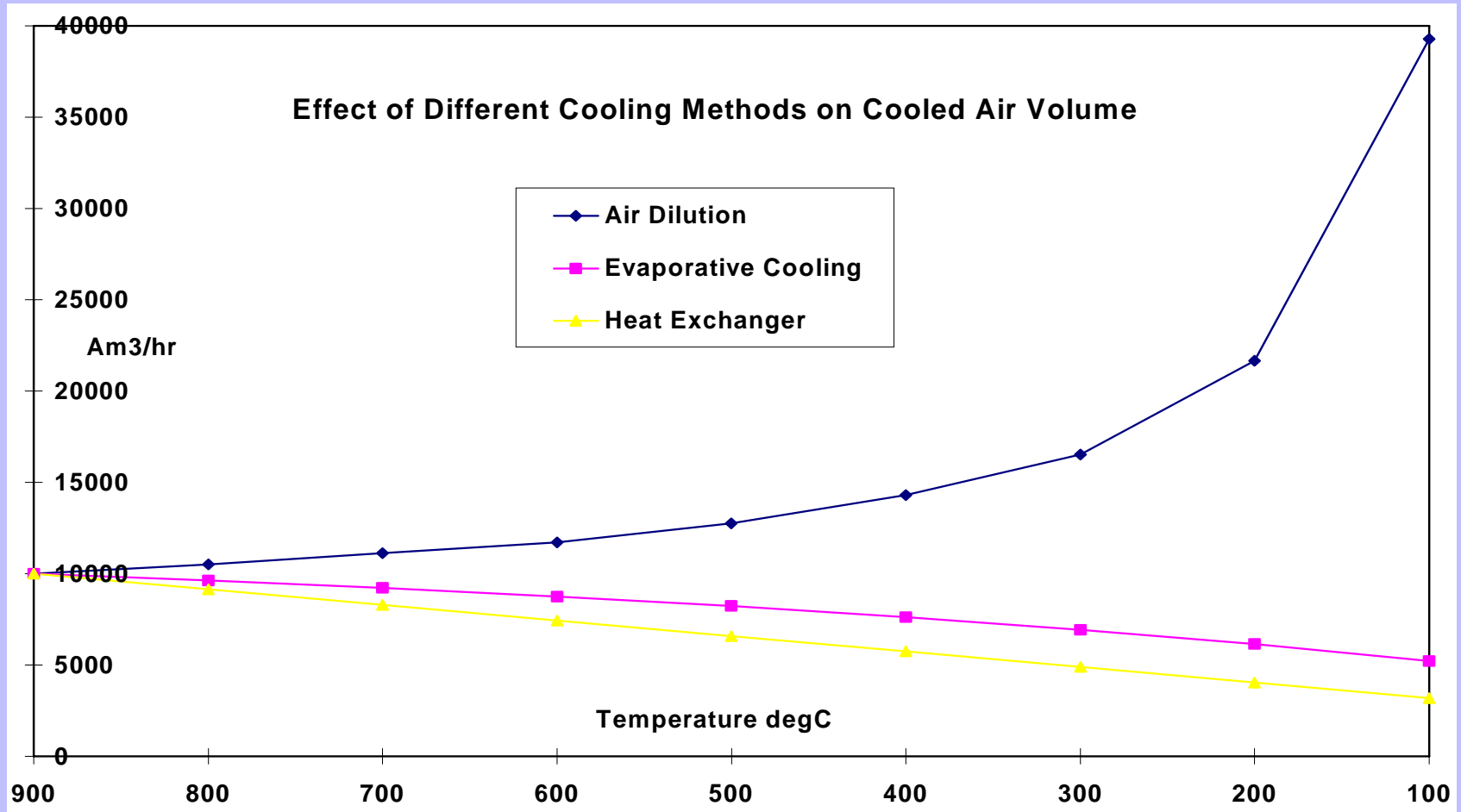
- allow gases to be filtered at the optimum temperature
- provide support for a renewable layer of reactant
- remove all the particulate from the gas stream

⇒ Sometimes this means that all the emission control processes can be performed by a single hot gas filter operating at ca. 425 °C

The Case for Hot Gas Filters – Part 3

- ⇒ Cooling a gas to 200 °C is a lot more problematic than cooling it to 400 °C
- ⇒ Acid gas sorbents react better at higher temperatures
- ⇒ Operating at 300°C+ avoids acid gas condensation
- ⇒ Operating at 300 - 400°C provides optimum conditions for SCR NO_x control
- ⇒ Operating at 400 °C+ avoids 'de novo' dioxin formation
- ⇒ Discharging gas at 300°C+ avoids stack plume

Cooling of Hot Gases



Problems of Cooling Gas to 200 °C

- ⇒ Using air dilution – gas volume increases to 2.25x
- ⇒ Using evaporative cooling – wet solids and plume formation
- ⇒ Using heat exchanger / boiler
 - Acid gas condensation causing corrosion
 - Solids condensation / adhesion causing gas flow path blockage
 - Regular cleaning / maintenance required
 - '*De novo*' dioxin formation
- ⇒ All methods
 - Equipment is a lot larger than for 400 – 450 °C

Controlled Emissions to Atmosphere (based on incineration guidelines)

- ⇒ Particulate matter
- ⇒ Acid Gases
 - HCl, HF, SO_x
 - NO_x
- ⇒ Heavy Metals
- ⇒ CO & VOCs
- ⇒ Dioxins & Furans
- ⇒ CO₂ & Water

Control of Particulate Matter

- ⇒ All hot gas filter media comply with emission guidelines
- ⇒ Ceramic filters are especially efficient
 - Often downstream solids are not detectable
- ⇒ Hot gas filters are reverse pulse cleaned on-line, without disruption to the process
- ⇒ Collected solids are normally dry and free-flowing

H₂SO₄, HCl and HF Removal

- ⇒ Removed by reaction with sorbent
 - Sorbent powder is dispersed and blown into gas stream
 - Powder collects on surface of filter element to form a renewable fixed bed
 - Gas passes through fixed bed - reactive components are absorbed
 - Spent powder is blown off elements and discharged

- ⇒ Two main sorbents are used
 - Hydrated lime – Ca(OH)₂
 - Sodium bicarbonate – NaHCO₃

- ⇒ Only the reaction on the element is important
 - There is much too little contact between reactants in dilute phase systems

Comparison of Sorbents

⇒ Sodium bicarbonate (NaHCO_3)

- Stoichiometry 2.30 kg / 1kg HCl
- Price £225 / tonne (25 kg bags)
- Cost at 100% efficiency £517 / tonne HCl
- Typical temp. of use 200 °C

⇒ Hydrated lime (Ca(OH)_2)

- Stoichiometry 1.01 kg / 1kg HCl
- Price £198 / tonne (25 kg bags)
- Cost at 100% efficiency £200 / tonne HCl
- Typical temp. of use 400 °C

⇒ Removal efficiency

- Depends on sorbent excess (molar ratio)

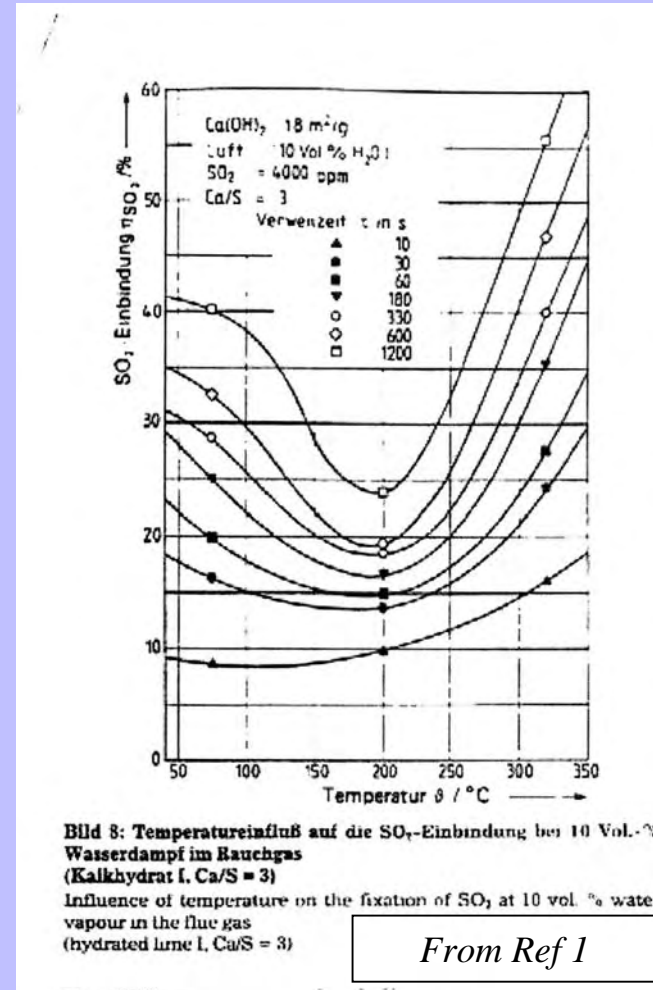
Removal Efficiencies

- ⇒ Typically using sodium bicarbonate at 200 °C gives 85% SO₂ and 95% HCl removal efficiencies at a 1:1 molar ratio.
- ⇒ Typically using hydrated lime at 400 °C gives 85% SO₂ and 95% HCl removal efficiencies at a 2:1 molar ratio.
- ⇒ Combining the molar efficiencies with the stoichiometric equivalents and the cost / tonne gives removal costs
 - £517 / tonne HCl removed using sodium bicarbonate
 - £400 / tonne HCl removed using hydrated lime

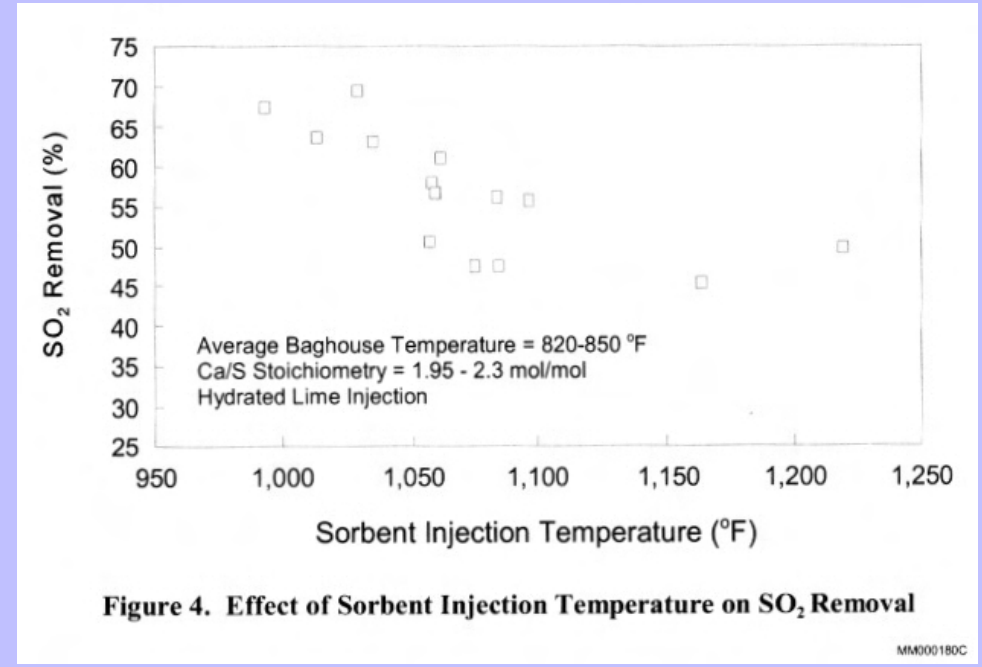
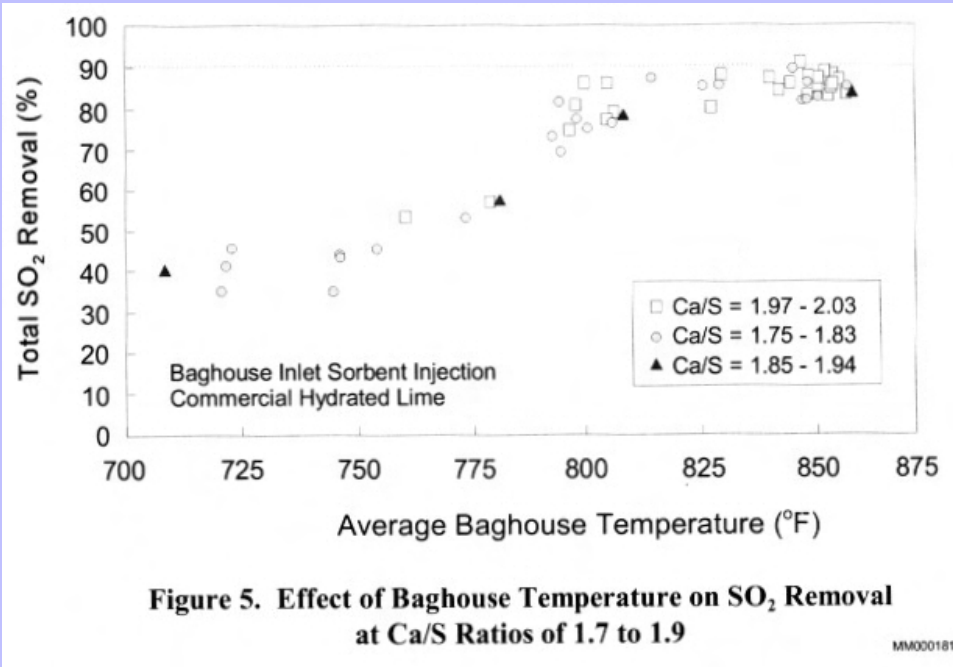
Reactivity of Hydrated Lime 1

“The efficiency of lime is high when the temperature of the gas is just over the dew point, with figures of 75% SO_2 removal efficiency being reported using a lime to acid gas stoichiometric ratio of 1. As the temperature rises, the efficiency reduces until typically, it reaches a minimum efficiency at $190^\circ C$, at which point it increases until at approximately $350^\circ C$ the efficiency has recovered. Above $500^\circ C$ the efficiency increases dramatically.”

Frank Emerson, Technical Manager,
Buxton Lime



Reactivity of Hydrated Lime 2



Effect of Temperature on SO₂ Removal with Lime (Ref 4)

NO_x Control Measures

- ⇒ Primary measures involve control of primary and secondary combustion conditions to minimise NO_x production
- ⇒ Secondary measures involve reducing the NO_x to nitrogen and water using a NH₂-X compound either without or with the help of a catalyst (SNCR or SCR)
- ⇒ SNCR (selective non-catalytic reduction) is performed at 850 – 900 °C, i.e. upstream of the hot gas filter.
- ⇒ SCR (selective catalytic reduction) is performed at 300 – 400 °C.
- ⇒ Filtering the gas before the catalyst will substantially improve the catalyst performance, by eliminating blockage with solids
- ⇒ Alternatively catalyst-impregnated filter elements such as TopKat can be used
- ⇒ Either way, filtering the gas at high temperature facilitates secondary NO_x control

Heavy Metals

⇒ May be removed as particulates

- Hot gas filtration will remove only the solids from the gas stream, not the vapour
- Without another abatement stage the vapour will be emitted to atmosphere
- As long as there is metal present in sufficient concentration, the amount emitted as a vapour will depend on the equilibrium vapour pressure at the filtration temperature
- 0.001Pa vapour pressure is approx. 0.035 mg/Nm³ (+/- 60%)

⇒ Limits are:

- Hg 0.05 mg/m³
- Cd and Tl (together) 0.05 mg/m³
- Sb, As, Pb, Cr, Co, Cu, Mn and V (together) 0.5 mg/m³

Periodic Table of Elements

1	IA																0															
1	H	IIA																5	6	7	8	9	10									
2	Li	Be																	B	C	N	O	F	Ne								
3	Na	Mg	III B	IV B	V B	VI B	VII B	VII				IB	IB	Al	Si	P	S	Cl	Ar													
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr														
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe														
6	Cs	Ba	* La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn														
7	Fr	Ra	+ Ac	Rf	Ha	106	107	108	109	110																						

* Lanthanide Series

58	59	60	61	62	63	64	65	66	67	68	69	70	71
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu

+ Actinide Series

90	91	92	93	94	95	96	97	98	99	100	101	102	103
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Mn	Lr	

Legend - click to find out more...

H - gas

Li - solid

Br - liquid

Tc - synthetic



Non-Metals



Transition Metals



Rare Earth Metals



Halogens



Alkali Metals



Alkali Earth Metals



Other Metals



Inert Elements

Vapour Pressures of Heavy Metals @ 400 °C

Heavy Metal	Symbol	VP @ 400 °C Pa
Mercury	Hg	690,000
Cadmium / Cadmium oxide	Cd / CdO	760 / .0007
Thallium	Tl	.007
Antimony	Sb / Sb ₂ O ₃	.035 / 2
Arsenic / Arsenic oxide	As / As ₂ O ₃	2,400 / 72,400
Lead	Pb	.00002
Chromium, Cobalt, Copper, Manganese, Nickel, Vanadium	Cr, Co, Cu, Mn, Ni, V	<10E-07

1 Pa = 10E-05 bar, so 1 Pa = 10ppm v/v. 1 ppm v/v = between 2 & 7 mg/Nm³

Problem Heavy Metals

- Mercury (Hg)
 - ⇒ Will probably be present as the element
 - ⇒ Has a vapour pressure of nearly 7 bar
 - ⇒ If there is enough mercury in the gas stream the emission limit will be exceeded
- Antimony (Sb)
 - ⇒ Will probably be present as the trioxide, Sb_2O_3
 - ⇒ The vapour pressure of 2Pa indicates an equilibrium concentration of 70 mg/ Nm³
 - ⇒ If there is enough antimony in the gas stream the emission limit will be exceeded
- Arsenic (As)
 - ⇒ Will probably be present as the trioxide, As_2O_3
 - ⇒ Has a vapour pressure of 0.7 bar
 - ⇒ If there is enough arsenic in the gas stream the emission limit will be exceeded
- Cadmium (Cd)
 - ⇒ Will probably be present as the oxide, CdO
 - ⇒ The vapour pressure of .0007 Pa indicates an equilibrium concentration of .02 mg/ Nm³
 - ⇒ Whatever the concentration of Cd, the emission will be below the emission limit
- If there is a substantial quantity of Hg, Sb or As then hot gas filtration is probably not the best solution

CO and VOCs

- ⇒ Removal is by oxidation to produce CO₂ and H₂O
- ⇒ This oxidation is often part of upstream combustion processes
- ⇒ If further oxidation is required, catalytic oxidation at 350 degC is effective
- ⇒ Hot gas filtration before the catalyst is essential for catalyst longevity

Dioxins and Furans

- ⇒ Requirement is to deal with '*de novo*' formation
- ⇒ Hot gas filtration achieves this by
 - Filtering at a temperature that is at the top of the '*de novo*' formation temperature window
 - Using lime to neutralise the HCl required for the reaction
 - Removing all the particulate from the gas stream
- ⇒ Conventional systems capture the dioxins with activated carbon, for disposal to landfill
- ⇒ Hot gas filtration avoids the formation of the dioxins and avoids the need for landfilling

References

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2. Josewicz & Gullett. Reaction mechanisms of dry Ca-based sorbents with gaseous HCl *Ind. Eng. Chem. Res. 1995, 34 607-612*
3. Hemmer, Kasper, Schraub & Wang. Removal of particles and acid gases (SO₂ or HCl) with a ceramic filter by addition of dry sorbents. *Proc. 'High Temperature Gas Cleaning' 5th Intl. Symposium, Morgantown USA 2002*
4. SOx-NOx-Rox Box Flue Gas Cleanup Demonstration – A DOE Assessment
<http://www.osti.gov/bridge/servlets/purl/771594-aF2roy/webviewable/771594.PDF>
5. Yan, Chin et al. Kinetic Study of Hydrated Lime Reaction with HCl *Environ. Sci. Technol. 2003, 37 2556-2562*
6. Emerson. Hydrated lime, sodium carbonate and sodium bicarbonate in flue gas treatment. *Private correspondence with author*

Further Reading

- ⇒ EA Guidance Notes for Waste Incineration (download)
<http://www.environment-agency.gov.uk/business/444304/444641/595811>
- ⇒ Environmental Data Services (ENDS) – authoritative journal
<http://www.ends.co.uk/>
- ⇒ Caldo Ceramic Filters <http://www.caldo.com/>
- ⇒ Cerafil Ceramic Filter Elements <http://www.madisonfilter.com/cerafil/>
- ⇒ Air Pollution Control Postgraduate Courses
<http://www.gees.bham.ac.uk/courses/postgraduate/dehrm/airpoll.htm>
- ⇒ Book – Gas Cleaning in Demanding Applications
<http://www.amazon.co.uk/exec/obidos/ASIN/0751403512/qid%3D1112884532/026-6376597-5152444>
- ⇒ Gas Cleaning at High Temperatures Symposium Sept 2002
http://www.netl.doe.gov/publications/proceedings/02/GasCleaning/gas_clean02.html