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Destruction of concentrated chlorofluorocarbons in India demonstrates an effective option to simultaneously curb climate change and ozone depletion

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ABSTRACT

The Montreal Protocol aims to protect the stratospheric ozone layer by phasing out production of substances that contribute to ozone depletion, currently covering over 200 individual substances. As most of these compounds are synthetic greenhouse gases, there is an opportunity to curb both ozone depletion and climate change simultaneously by requiring Parties of both the Montreal and the Kyoto Protocol to destroy their existing stocks of concentrated chlorofluorocarbons (CFCs). Many emerging countries still possess stocks which need to be destroyed in an environmentally sound manner but costs may be prohibitive.

The UNEP Technology and Economic Assessment Panel identified in 2002 eleven destruction technologies which meet the criteria for environmentally sound destruction of chlorofluorocarbons. Cement kilns were among these, but no study has been reported in scientific literature assessing its destruction performance under real developing country conditions up to now. In contrast to incinerators and other treatment techniques, high temperature cement kilns are already in place in virtually every country and can, if found technical feasible, be retrofitted and adapted cost-efficiently to destroy chemicals like CFCs. India has the second largest cement industry in the world and several hazardous waste categories have been tested successfully in recent years.

The objective of this study was to carry out the first full scale demonstration involving high feeding rates of concentrated CFC-gases in a local cement kiln and to assess its feasibility and destruction performance. The test in Madhya Pradesh demonstrated that the kiln was able to destroy several concentrated CFC-gases effectively in an irreversible and environmental sound manner without causing increased releases of HCl, HF or PCDD/PCDF.

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The destruction and removal efficiency was >99.9999% and the overall environmental performance in compliance with Indian regulation and international best practice.

The test also revealed that cement kilns have a much higher disposal capacity than previously anticipated and that such undertaking can contribute significantly to reduce the release of both ODS and greenhouse gases; the destruction of 16.3 tonnes of CFCs done in this demonstration is equivalent to saving the release of 131,265 tonnes of CO₂ to the atmosphere.

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1. Introduction

Chlorofluorocarbons (CFCs) and halons (brominated fluorocarbons/CFCs) are potent ozone depleting substances (ODSs) and synthetic greenhouse gases (GHGs). All ozone depleting substances contain either chlorine or bromine; substances containing only fluorine do not harm the ozone layer but may still be a GHG. The interim replacements for CFCs are hydrochlorofluorocarbons (HCFCs), which deplete stratospheric ozone, but to a lesser extent than concentrated CFCs. Ultimately, hydrofluorocarbons (HFCs) will replace HCFCs.

The wide use of these chemicals has caused severe damage to the ozone layer and contributed significantly to the global warming. The global warming potential (GWP) refers to the amount of global warming caused by a substance and is the ratio of the warming caused by a substance to the warming caused by a similar mass of carbon dioxide; thus, the GWP of CO₂ is defined to be 1. The GWP of CFC-11 is 4750, CFC-12 10,890 and CFC-113 6130 over a time horizon of 100 years (WMO, 2010).

The *Montreal Protocol* on substances that deplete the ozone layer entered into force in 1989 and called for a phase out of all concentrated CFCs by 2010. There are however no provisions in the Montreal or in Kyoto Protocol (the United Nations Framework Convention on Climate Change, UNFCCC) to report on or to destroy existing stockpiles of concentrated CFCs, and quantities of current stockpiles are uncertain.

Many emerging countries, such as India, still possess stocks of concentrated CFCs which need to be destroyed in an environmentally sound manner but costs are prohibitive. Current accepted treatment technologies can be classified into two methodologies: destruction and conversion. In conversion processes, they are transformed into environmentally benign and in some cases chemicals of economic value, while CFCs and halons are converted into hydrogen halides and CO₂ in destruction processes (Hai et al., 2006). The UNEP Technology and Economic Assessment Panel (TEAP) task force on destruction technologies applied screening criteria to 45 identified technologies, where eleven met the qualification criteria for destruction of concentrated sources, i.e. CFCs and HCFCs (UNEP, 2002).

Despite the fact that cement kilns were among the methods recommended by UNEP TEAP in 2002, no study to assess their feasibility and destruction performance under real developing country conditions has been reported in the scientific literature up to now. The UNEP TEAP report mentions only one cement kiln test, conducted in Japan in 1997.

Cement kilns are currently used in many countries to recover energy and recycle materials in wastes, i.e. by substituting fossil fuels and virgin raw materials, to increase waste treatment capacity and subsequently reduce CO₂ emission from cement production. High temperature cement kilns have shown to be feasible to destroy many types of organic hazardous chemicals, and can constitute a sound and cost-efficient treatment option, especially for developing countries without dedicated technologies (Karstensen et al., 2006, 2010). The most modern and energy efficient and least polluting kilns, i.e. BAT/BEP, are today erected in emerging countries where cement and concrete are needed for infrastructure development.

India has the second largest cement industry in the world, with 181 kilns, and has recently been exploring the possibility to increase waste treatment capacity through co-processing of wastes in the cement industry (Kamyotra et al., 2013a) and several hazardous waste categories have been tested successfully (Kamyotra et al., 2013b).

The objective of this study was to carry out the first demonstration with high feeding rates of several concentrated CFC-gases in a local cement kiln, to assess its feasibility and destruction performance under real developing country conditions and to evaluate its effectiveness in curbing climate change and ozone depletion simultaneously.

2. Materials and methods

Co-processing of wastes in cement kilns is first of all about recovery of energy and recycling of materials in the waste, i.e. substitution of fossil fuel and virgin raw materials. However, given a lack of available treatment options and urgent needs, a feasible cement kiln can be used for treatment of organic hazardous constituents if done under strict control and Government guidance (Stockholm Convention, 2008; Karstensen, 2011).

2.1. CFCs destroyed

The CFCs destroyed in this investigation had been stored by Navin Fluorine in Mumbai for more than a decade waiting for a cost-efficient treatment option to emerge. The chemical and physical characteristics of the three CFC-gases are given in Table 1 (WMO, 2010).

2.2. Local cement plant in Madhya Pradesh

A technical feasibility study was conducted prior to the selection of the cement plant; ACC Keymore plant in the state

Table 1 – Characteristics of the CFCs destroyed.

Chemical name	% Cl	% F	Boiling point (°C)	Lifetime in the stratosphere (y)	CAS number
CFC-11 (CCl ₃ F) Trichlorofluoromethane	77.45	13.82	23.8	45	75-69-4
CFC-12 (CCl ₂ F ₂) Dichlorodifluoromethane	58.68	31.40	−29.8	100	75-71-8
CFC-113 (C ₂ F ₃ Cl ₃) 1,1,2-Trichlorotrifluoroethane	56.80	30.39	47.7	85	76-13-1

of Madhya Pradesh was found to be feasible for carrying out a demonstration disposal with CFCs. All aspects of transportation and receiving of the CFC-tanks, handling, storage and introduction of the CFC-gases as well as the power and water supply were considered to be stable, safe and adequate.

The rotary kiln at ACC Keymore is 66 m long, 4.35 m in diameter and has a production capacity of 4626 tonnes of clinker per day. From the top of the cyclone preheating tower, the alkaline limestone based raw meal powder is fed counter currently with the hot kiln exit gases from the kiln, i.e. functioning as a large dry lime scrubber. The raw meal is calcined as it moves down the preheating tower and the kiln towards the burning zone where the material melts to form clinker at a temperature of 1450 °C. The clinker is cooled by air in a cooler and the hot air is recovered in the process. The exit gas from the kiln and the preheater is normally directed through the raw mill and the coal mill for drying purpose. The plant is equipped with state-of-the-art process control equipment, the latest technology in air pollution control, i.e. electro static precipitators (ESP) and bag-house filters, as well as on-line emission monitoring of gross air pollutants. All dust collected in the air pollution control devices are recovered and fed back in the process; i.e. the plant does not produce any residues which need to be disposed of.

The gas residence time inside the hot clinkerization zone of the kiln is approximately 6.5 s, at a temperature above 1300 °C. The CFC-gases were fed through the main burner, a Swirlax FLS multichannel burner with a primary air volume of 9576 Nm³/h. The average exit gas volume out of the main stack was measured to be 446,473 Nm³/h with a stack gas temperature of 140–149 °C.

Cement kilns have limited tolerance for chlorine and fluorine and the total input needs to be controlled carefully to avoid process disturbances and negative impacts of the product quality. The tolerance for extra chlorine and fluorine of the actual kiln was established by analysing all input materials.

2.3. Circulation of volatile components

Volatile components such as alkalis, sulphur and chlorine introduced with raw materials and fuels may give rise to problems in kiln operation when present in high concentrations. Depending on their volatility, alkalis, sulphur and chlorides evaporate in the sintering zone of the rotary kiln and re-condense at cooler parts of the system either on the raw meal particles or on the surrounding walls. With the raw meal, they are reintroduced to the sintering zone again thus establishing a permanent internal cycle of volatile circulating elements. By reaching equilibrium between input and output, a major part of the volatile components will finally leave the system incorporated in the clinker.

Part of the volatile components however, may form new compounds such as alkali chlorides or alkali sulphates and other intermediate phases such as spurrite, which will then contribute to the build-up phenomena mentioned above by producing a sticky raw meal adhesive to the walls of the cyclones, the ducts or the kiln tube. A small part only of the circulating elements leaves the kiln with the exit gas dust and is precipitated in the dedusting device of the system.

2.3.1. Chlorine limitations

Chlorine is regarded as an unwanted constituent because it creates operating problems; newer pre-heater/pre-calciner dry process kilns have the lowest tolerance for chlorine. Cyclone preheater kilns with 4–6 cyclone stages, with or without a precalciner, but without dust extraction or bypass, will be able to tolerate a chlorine input of 300 g per tonne of clinker. If dust from the filters are not recycled back to the process, but extracted, the tolerance for chlorine will increase to 300–400 g per tonne of clinker. If the kiln is equipped with a by-pass, which extracts parts of the hot kiln gases at the kiln inlet, it would allow an additional chlorine input of 100 g per tonne of clinker for each percent of bypass rate, e.g. 8% bypass, 800 g per tonne of clinker would be the limit (applicable for 5–10% bypass rate). The maximum amount of chlorine allowed by cement standards for quality cement is 1000 g of chlorine per tonne of cement; also this limit is identical for all types of kilns.

If the feeding limits are not followed, the process will be disturbed by a build-up of coatings, cyclone blockages, and loss of kiln production which can finally stop the kiln. Severe corrosion and refractory damage can be expected, and last but not least, high chlorine levels in cement may affect the quality, e.g. steel reinforcement corrosion.

2.3.2. Fluorine tolerance

In the clinker burning process, fluorides promote the formation of tricalciumsilicate (alite) and reduce the temperature for stabilisation of alite, meaning that the sintering temperature can be reduced. For this reason calcium fluoride is used at some cement plants as a sintering auxiliary material.

Fluorides will preferentially be bound in the cement clinker as calcium fluoride, which can affect the cement properties. If the concentration of fluorine is higher than approximately 0.35% in cement it will reduce the early strength and increase the setting time of the cement, as well as reduce the lime saturation factor, increase the silica and the alumina ratio, and finally change the colour of the cement to pink.

2.4. Design of feeding system for CFC-gases

The CFC-gases are semi-liquid at ambient temperature and the gas cylinders needed to be heated in a water bath to

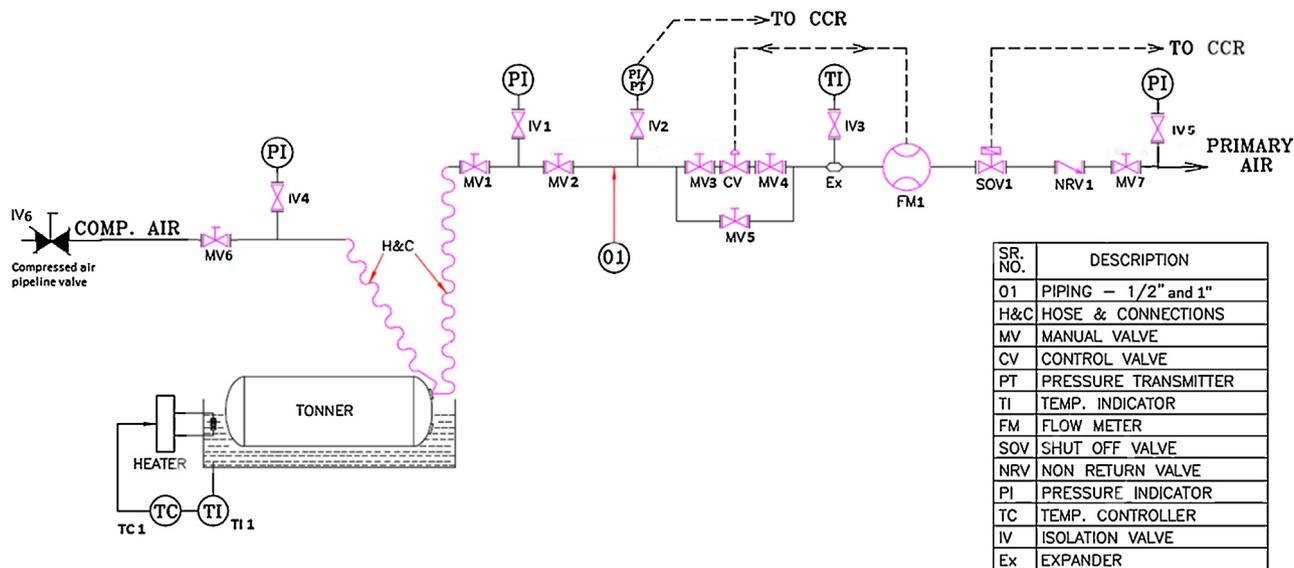


Fig. 1 – CFC feeding system (tonner is the steel cylinder with CFCs).

volatilise the gases. CFC-12 does not require heating as the boiling point is -29.8°C .

CFC-gas from the steel cylinders was pumped through a train of manual valves, pressure and temperature indicators with control valves and gas flow metres, shut off valves and finally a non-return valve. The desired feeding rate for CFCs was maintained by a logic control between the control valve and flow metre operated through central control room. Start-up and stop operation of the feeding was interlocked with the operation of primary air blower, kiln bag house fan, continuous emission monitoring system (CEMS), positive draft blower, and primary air blower pressure. The feeding system was designed for a maximum gas flow rate of 50 kg CFC/h.

The steel cylinders were placed in the heated water bath and connected to the valve train with a flexible hose arrangement with gas flowing through a pipeline connected to the inlet manifold of primary air blower to the main burner, exposing the gases to a temperature of 2000°C . The feeding lines were provided with heating coils and insulation to avoid condensation. Compressed air was used to flush the system ensuring that no CFCs were left into the system. The feeding system was carefully calibrated before use (Fig. 1).

2.5. Test outline and process conditions

To prove and verify that the destruction efficiency is adequate, real performance verification needs to be

conducted. Concepts for testing cement kilns are described in details elsewhere (Basel Convention, 2011; Karstensen et al., 2006, 2010).

The qualification test was carried out in kiln #1 over four days, 4–7 December 2012 and aimed to compare the emissions under Baseline conditions, i.e. when feeding coal only, with the emissions when CFC were fed in at a rate of 30–40 kg/h together with coal, amounting to approximately 23 kg chlorine and 4–13 kg fluorine per hour (corrected for density). The main burner was fired with pulverised coal at an average feeding rate of 11,746 tonnes/h, constituting the main flame. In the burning of clinker it is necessary to maintain material temperatures of up to 1450°C in order to ensure the sintering reactions required. This is achieved by applying peak combustion temperatures of about 2000°C with the main burner flame. An excess of oxygen – typically 2–3% – is essential for the formation of the clinker phases and for the quality of the finished cement (Table 2).

2.6. Safety measures

The process chemistry had been evaluated and considered to be feasible for carrying out the test. The following preconditions had been set:

- CFC should only be fed through the burner flame; not during kiln start-up, shutdowns or major upsets;

Table 2 – Test outline.

	Baseline 4 December 2012	CFC-12 5 December 2012	CFC-11 6 December 2012	CFC-113 7 December 2012
Feeding of coal (tonne h^{-1})	11.704	11.791	11.648	11.841
Feeding of CFC (kg/h)	0	40	30	40
Amount of chlorine (kg/h)	0	23	23	23
Amount of fluorine (kg/h)	0	13	4	12
Exhaust gas volume (Nm^3/h)	446,498	446,898	456,498	436,446

- the process should be run in compound mode operation, i.e. the exit gas directed through the raw mill and under identical process conditions all days;
- alternative fuels and raw materials should not be used, only coal;
- all involved personnel should have been trained prior to the test.

System controls were implemented to provide for automatic shutdown of the CFC-gas feed if any of the following conditions occurred:

- Interruptions of the coal feeding;
- interruptions in combustion air flows;
- kiln inlet temperature below 900 °C and outlet temperatures below 1300 °C;
- positive pressure in the burning zone of the kiln;
- kiln inlet oxygen content less than 2.5%;
- refractory damage, ring formation in the kiln or cyclone blockage.

The entire test was inspected by local university experts, central and provincial authorities, ACC and Geocycle personal and third party experts.

2.7. Sampling and analysis of CFCs

CFCs were sucked non-isokinetically through a sampling train from a hole in the upper part of the stack. Two sorbent tubes connected in series were used for adsorption of CFCs in the sampling train according to US EPA Method 0030; 1st trap contained Tenax and 2nd trap a combination of Tenax and Charcoal. Each sampling campaign implied 60 l gaseous samples through 3 pairs of sorbent cartridges; i.e. each of CFC-11, CFC-12 and CFC-113 were collected in triplicate. One sample was collected under normal baseline conditions, i.e. with no CFC feeding.

Analysis of the CFCs was done by thermal desorption coupled with Purge and Trap GCMS; Agilent 7890A GC with 5975C mass spectrometer coupled with Stratum Purge and Trap (Teledyne Tekmar) using DB-VRX capillary column (20 m × 0.18 mm × 1.0 μm). Oven programme was set at 40 °C for 5 min with 20 °C/min ramp to 250 °C and flow of helium through column was adjusted to 1 ml/min. Synchronous SIM/SCAN data acquisition method was adopted with following target and qualifier ions respectively: CFC-11, 101 and 103; CFC-12, 85 and 87; CFC-113, 101 and 103, 151 and 153.

Calibration curves were constructed with spiked samples at 4 times concentration levels (1, 2, 5 and 10 ng) and peak area was plotted. Analytes present in the samples were confirmed through QEdit and quantified against the calibration curve. Reporting limits were fixed at 1 ng, i.e. a concentration below 1 ng was declared as non-detection. Stack gas volume was converted into standard normal conditions (11% O₂) to quantify the concentration in ng CFC/Nm³.

2.7.1. HCl and HF

Gaseous HCl and HF were absorbed into a medium containing pure triple distilled water at a sampling rate of 2 l/min using 2 impingers in series. A heated sampling probe with glass liner

was used to trap the analyte. The probe and filter were heated up to 190 °C with an automatic temperature controller system; a glass fibre filter was used to collect particulates/dust.

The exit gas was dried using Silica Gel and cooled to below 20 °C before entering to dry gas flow metre. The entire sampling train was rinsed with triple distilled water; the volume of absorbing solution and rinse solution was measured. Collected samples were transported to the laboratory in cooled HDPE bottles and analysed according to the US EPA Method 26.

2.7.2. PCDD/PCDFs

An Apex Isokinetic Source Sampling Kit was used to sample PCDD/PCDFs isokinetically according to US EPA Method 23. Samples were ducted through a heated sampling probe with glass liner and adsorbed in XAD 2 resin. Probe and filter was heated up to 120 °C with Apex Source Sampler.

The glass fibre filter were removed from the filter holder box and transferred into clean containers. Material deposited in the nozzle, probe liner, probe transfer line and front half of the filter holder was transferred into a separate container by rinsing three times each with acetone, toluene and hexane. The back half of the filter holder, the connecting line between the thimble holder and condenser were washed similarly and the washing solution was collected in the same container.

The exit gas was cooled to below 20 °C before passing to XAD 2 resin by using a condenser. Hot gas was dried using Silica Gel. The XAD-2 trap was cleaned with acetone, toluene and hexane three times; all washings were combined and concentrated to 5 ml in a rotary evaporator below 37 °C. The concentrate was added to the container containing filter and XAD-2.

3. Results

3.1. Destruction of CFC

The TEAP recommends that facilities used for the destruction of concentrated CFCs should be able to demonstrate destruction and removal efficiency (DRE) of 99.99% for each chemical tested (UNEP, 2002). This test showed a DRE > 99.9999 for all gases (Table 3).

3.2. Reduction of global warming potential

The GWP of the CFC tested varies from 4750 to 10,890 over a time horizon of 100 years; see Table 4. With 16.3 tonnes of concentrated CFCs destroyed in this campaign, this is equivalent to saving the release of 131,265 tonnes of CO₂ to the atmosphere. The bulk of the gases were destroyed after the destruction performance had been verified.

3.3. Emission of other air pollutants

CFCs contain high amounts of chloride and fluorine, which will either be converted to hydrochloric and hydrofluoric acid, or adsorbed in the alkaline lime-based raw meal and subsequently be part of the final cement clinker. The emissions of HCl and HF were below 1.5 and 0.5 mg/Nm³

Table 3 – Main results of test burn (corrected to 11% O₂ and standard conditions).

	Baseline 4 December 2012	CFC 12 5 December 2012	CFC 11 6 December 2012	CFC 113 7 December 2012
CFCs (ng/Nm ³) (three samples)	ND/ND/ND	24/23/30	5/ND/ND	ND/ND/ND
% DRE of CFC	>99.9999	>99.9999	>99.9999	>99.9999
HCl (mg/Nm ³)	<1.5	<1.5	<1.5	<1.5
HF (mg/Nm ³)	<0.5	<0.5	<0.5	<0.5
PCDD/PCDF (ng I-TEQ/Nm ³)	<0.003	<0.003	<0.003	<0.003

Table 4 – Reduction in global warming potential.

Chemical name	Quantity (kg)	GWP ₁₀₀ (WMO, 2010)	Equivalent amount of CO ₂ (kg)
CFC-11	3880	4750	18,430,000
CFC-12	7678	10,890	83,613,420
CFC-113	4767	6130	29,221,710
Sum (tonnes)	16,325		131,265,130

respectively the three test days and no correlation between the feeding of CFCs and the emissions of HCl or HF could be identified. The emissions of NO_x, dust, TOCs, O₂ and CO were all within normal ranges and in compliance with regulatory requirements.

The emissions of PCDD/PCDFs were below 0.003 ng I-TEQ/Nm³ all days, i.e. in compliance with the most stringent requirements internationally available.

4. Discussion

The UNEP TEAP (2002) recommends the following technologies for the destruction of concentrated CFCs; Cement Kilns, Liquid Injection Incineration, Gaseous/Fume Oxidation, Reactor Cracking, Rotary Kiln Incineration, Argon Plasma Arc, Inductively-Coupled Radio-Frequency Plasma, Nitrogen Plasma Arc, Microwave Plasma, Gas Phase Catalytic Dehalogenation and Super-Heated Steam Reactor.

In contrast to incinerators and other treatment techniques, cement kilns are already in place in virtually every country and can, if found technical feasible, be retrofitted and adapted cost-effectively to destroy chemicals like CFCs. Recent studies have shown that costs for destruction of hazardous chemicals in cement kiln can be attractive/competitive (Basel Convention, 2011).

The UNEP TEAP (2002) description of cement kilns is based on a single study, the test conducted by Ueno et al. in a Japanese cement kiln in 1997. Despite the fact that the test was successful, the mentioning of the potential in the TEAP report may have been discouraging, claiming that feeding rates of CFCs to cement kilns will be at the lower end (<10 kg/h); that hazardous waste feeding cement kilns emit much higher PCDD/PCDFs than others and that only 60 kilns would be available around the world for such destruction.

4.1. Comparing the Indian results with the test in Japan

The test was carried out in Chichibu Plant No. 2 in Saitama Prefecture and used a kiln 5.5 m in diameter and 83 m long, with a manufacturing capacity of 5000 tonnes clinker/day. 3.5 kg/h CFC-12 were fed to the kiln achieving a DRE of 99.99%;

the emissions were 0.04 ng I-TEQ PCDD/PCDF/Nm³, 0.5 mg HCl/Nm³ and 0.3 mg HF/Nm³ (UNEP, 2002).

The test in India was conducted in a similar but using a slightly smaller 4000 tonnes clinker/day kiln, but with a feeding rate more than ten times higher, 40 kg/h CFC-12, and achieving a better DRE of 99.9999%; the emissions were in the same order of magnitude, i.e. less than <0.003 ng I-TEQ PCDD/PCDF/Nm³, <1.5 mg HCl/Nm³ and <0.5 mg HF/Nm³.

4.1.1. Flow rates, sampling and analysis

Ueno et al. (1997) reported an exit gas flow rate of 5750 m³/min, or 345,000 m³/h. The average exit gas volume from cement kilns is normally 2300 Nm³/tonne clinker (IPPC, 2010), indicating that the flow rate measured in the Japanese test was underestimated; it should have been around 480,000 m³/h according to IPPC (2010). The average exit gas flow rate measured in the Indian kiln was 446,473 Nm³/h.

The Japanese test used evacuated stainless steel tanks for sampling of CFC in the exit gas while the Indian test used two absorbent tubes with Tenax and a combination of Tenax and Charcoal connected in series. The Japanese test analysed the trapped CFC-12 with a gas chromatograph equipped with an electron capture detector while the Indian test used a GC-MS.

4.1.2. Emissions of CFCs

The average emission rate of CFC-12 measured in the Japanese test was 0.007 g/min during the baseline and 0.011 g/min under the CFC-feeding. With the flow rate mentioned above, this amounts to 1217 ng CFC-12/m³ during the baseline and 1913 ng CFC-12/m³ under the CFC-feeding. The Indian test measured 23–30 ng CFC-12/Nm³ with the two different absorbents used; one sample identified CFC-11, at 5 ng/Nm³, while CFC-113 was not detected.

The Japanese test achieved a DRE of 99.99%, after subtracting the baseline emission of 1217 ng CFC-12/m³. The Indian test achieved a DRE >99.9999% without subtracting the baseline emission.

4.1.3. Theoretical destruction capacity within the cement industry

Ueno et al. (1997) claimed the cement kiln used could treat up to 25 tonnes of CFC-12 per year with the same feeding rates;

extrapolating to the total cement production in Japan of 98 million tonnes in 1994, the maximum capacity for CFC destruction in the Japanese cement industry would have been about 1500 tonnes per year.

The Indian kiln with its higher feeding rate could destroy up to 1 tonne a day, or more than 300 tonnes a year.

An annual global cement production of approximately 3600 million tonnes in 2011 (Cembureau, 2011) would imply the production of approximately 2880 million tonnes of clinker, with an average clinker factor of 0.8 in cement. If we for simplicity reasons anticipate that an average kiln produces 4000 tonnes of clinker per day, or approximately 1.4 million tonnes a year, this implies that more than 2000 such kilns are in operation worldwide. If all of these can feed the same amount of CFCs as we did in India, the cement industry would be able to destroy more than 600,000 tonnes of concentrated CFCs annually. If we assume that the CFCs would have an average GWP of 5000, such an amount could theoretically save the release of 3 billion tonnes of CO₂.

4.1.4. Formation of PCDD/PCDF in hazardous waste feeding cement kilns?

The UNEP TEAP report claims that hazardous waste feeding cement kilns emit much higher PCDD/PCDFs than non-hazardous waste feeding kilns. This information comes from the testing of wet kilns co-processing hazardous waste in the US in the 1980s and the 1990s, often without exit gas quenching and tested under “worst case scenario conditions”, which could mean high temperature in the APCD – conditions today known to stimulate dioxin formation (Karstensen, 2006).

More than 2200 PCDD/PCDF measurements were recently assessed from cement kilns around the world, representing most technologies and waste feeding scenarios (Karstensen, 2008). They generally indicated that most modern cement kilns today can meet an emission level of 0.1 ng I-TEQ/m³, when well managed and operated. The data showed an average flue gas concentration of 0.021 ng I-TEQ/m³ for PCDD/PCDFs, also when co-processing wastes and treating hazardous wastes. The Stockholm Convention acknowledge that hazardous waste feeding cement kilns do not emit higher PCDD/PCDFs than cement kilns not feeding hazardous waste; i.e. the statement of UNEP TEAP is outdated (UNEP Toolkit, 2013).

4.2. Need for continuous destruction of ODS

There are no requirements in the Montreal or in the Kyoto Protocol to destroy CFCs despite the fact that many of the ODS have a huge GWP (UNFCCC, 2013). Many ozone depleting chemicals are today traded illegally around the world and several compounds with known or suspected ozone depleting potential are not subject to a phase-out timetable under the Montreal Protocol (Norman et al., 2008). New ozone-depleting chemicals will be developed and even chemicals currently in use but not listed by the Protocol may be found to be ODSs and to have a global warming potential.

Norman et al. (2008) reported that more than 100,000 large centrifugal building chillers using CFC-11 as a working fluid were still in use, causing a minimum leakage of 1 tonne of CFCs for every 20 chillers/year. The IPCC/TEAP Special Report

(2005) estimates emissions from stationary air conditioning related to the use of CFCs, HCFCs, and HFCs to constitute about 0.4 Gt CO₂-equivalents/year by 2015 under a business-as-usual scenario.

There is obviously both an urgent need and a huge untapped potential in reducing the release of ODS and greenhouse gases by requiring Parties to the Montreal and the Kyoto Protocol/UNFCCC to destroy end-of-life stocks of CFCs on a continuous basis.

4.3. Need for better coordination

The clean development mechanism (CDM) under the Kyoto Protocol allows emission-reduction projects in developing countries to earn certified emission reduction (CER) credits, each equivalent to one tonne of CO₂. These CERs can be traded and sold, and used by industrialised countries to a meet a part of their emission reduction targets. The mechanism stimulates sustainable development and emission reductions, while giving industrialised countries some flexibility in how they meet their emission reduction limitation targets.

The provision of the Montreal Protocol's phase-out process that allows developing countries to increase their production and use of HCFCs through 2013 was decided from an ozone-only perspective, but in conjunction with provisions of the Kyoto Protocol it can create perverse incentives (Gillenwater and Seres, 2011). A developing country can expand production of HCFC-22 beyond its needs, in order to obtain CDM credits under Kyoto by destroying the HFC-23 (GWP 12,000) that is a by-product of the HCFC-22 production process. The IPCC/TEAP Special Report notes that “destruction of by-product emissions of HFC-23 from HCFC-22 production has a reduction potential of up to 300 Mt CO₂-eq/year by 2015”.

A joint cap and trade system where permits are required for both ozone depleting and global warming effects of all emissions would potentially be beneficial. The UNFCCC might begin by closing the CDM loophole that yields cheap carbon credits for production of otherwise unnecessary ODS. The possibility of using destruction credits to manage the phase-out of such ODSs would increase transparency and avoid unnecessary emissions.

5. Conclusion

No studies have up to now investigated the potential of using cement kilns for destruction of CFC in developing countries. The test demonstrated that the local Indian cement kiln using high feeding rates was able to destroy several concentrated CFC-gases effectively in an irreversible and environmental sound manner, without causing any increased release of HCl, HF or PCDD/PCDF. The DRE was demonstrated to be >99.9999% for all CFC-gases, better than recommended by UNEP TEAP; other emissions and the overall environmental performance were in compliance with Indian regulation and international best practice.

The demonstration indicates that cement kilns have a much higher disposal capacity that previously anticipated and that such undertaking can contribute significantly to reduce the release of greenhouse gases; destruction of 16.3 tonnes of

CFCs in the Indian cement kiln is equivalent to save the release of 131,265 tonnes of CO₂ to the atmosphere.

The parties to the Montreal and the Kyoto Protocol should be required to report and destroy their stocks of accumulated ODS on a continuous basis, and curb climate change and ozone depletion simultaneously. The availability of technology is no longer an issue.

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