Disposal of obsolete pesticides in cement kilns in developing countries
Lessons learned - How to proceed

Kare Helge Karstensen
The Foundation for Scientific and Industrial Research (SINTEF), Dept. Environmental Technology
P. O. Box 124, N-0314 Oslo, Norway
Phone: +47 22 06 73 00, Fax: +47 22 06 73 50, Email: Kare.H.Karstensen@chem.sintef.no

Introduction

The accumulation and bad management of obsolete pesticides constitutes a threat for health and environment, locally, regionally and globally. Estimates indicate that more than 100,000 tonnes of more or less toxic pesticides are accumulated globally, especially in developing countries (FAO 1999). Most of these pesticides are persistent and can be spread around the globe.

Obsolete pesticide stocks, particularly those in leaking and deteriorating containers, require immediate containment and disposal. Unfortunately, there are no easy disposal methods that are safe, cheap and generally applicable in developing countries. The preferred disposal option, high temperature incineration, is usually absent. Cement kilns, which can be a good alternative, are on the other hand usually available in most developing countries.

The United Nation Agriculture Program, FAO, recommends that local destruction solutions for obsolete pesticide stocks should be supported as and when appropriate, but must be developed as part of a national strategy for the management of hazardous waste. Such solutions must be based on social, economic and environmental acceptability (FAO 1999).

Unfortunately there are also many cement kilns, which should not be used for disposal of hazardous chemicals. An expert must assess the feasibility of using the kiln.

This paper presents a brief overview of finalised and planned disposal operations utilising cement kilns in developing countries. The lessons learned from these operations are used to develop a framework for the technical and institutional assessment of the suitability of a cement kiln and points out the necessary requirements, which should be fulfilled before a cement kiln is utilised for hazardous waste disposal. This framework is tailored to cover the destruction of obsolete pesticides but can also be used to assess the suitability for other hazardous wastes.

Incineration of hazardous waste

High temperature incineration involves a thermal destruction of the pesticide molecules, converting these into carbondioxide and water. To achieve a complete thermal destruction, sufficient temperature, oxygen supply, residence time and mixing conditions are needed (Brunner 1993; Dempsey 1993; Niessen 1995). Both dedicated hazardous waste incinerators and cement kilns can fulfil the necessary requirements with regards to performance, but normally cement kilns have higher temperature and longer residence times than dedicated hazardous waste incinerators. These advantages are widely utilised. More and more cement companies are turning to the use of hazardous waste for fuel replacement as seen in the U.S., Canada and in Europe (Karstensen 1998; Duda 1985).

In the existing European and US regulations, both dedicated hazardous waste incinerators and cement kilns are regarded to be suitable for hazardous waste disposal. Cement kilns usually burn hazardous wastes as a co-fuel only, normally limited up to maximum 40% of the heat requirement (European Union 1994; U.S. EPA 1991).

In Europe, cement kilns must comply with the emission limit values for several compounds laid down in the Council Directive 94/67/EC on Incineration of Hazardous Waste (European Union 1994). The emission limit values for dedicated incinerators are fixed in the Directive. Industrial facilities and cement kilns, which are co-incinerating hazardous waste limited up to maximum 40% of the heat input, need to determine appropriate emission limit values for the relevant pollutants emitted in that part of the volume of exhaust gas resulting from the incineration of the hazardous wastes.

Industrial facilities and cement kilns in the US incinerating hazardous wastes must comply with emission limit values laid down in the Resource Conservation and Recovery Act (RCRA) (U.S. EPA 1991). In addition, they also have to perform a Test Burn to demonstrate the incinerator performance on selected hazardous wastes. The rule requires that the facility demonstrate a 99,99% destruction and removal efficiency (DRE) for principal organic hazardous constituents (includes pesticides) in the waste stream. A DRE of 99.99% means that out of 1 tonne put into the system, less than 100 grams are actually emitted in the stack gas. Achieving this level of DRE "will ensure that constituents in the waste are not emitted at levels that could pose significant risk" (U.S. EPA 1991). On the other hand, a destruction and removal efficiency of 100% will never be possible to establish or demonstrate due to limitations in the analytical instruments. This means that a demonstrated DRE of 99.99% even can be higher in reality.

The principal organic hazardous constituents should be representative of the compounds in the waste stream that are the most abundant and the most difficult to destroy. Accordingly, chlorinated and aromatic compounds are often chosen because they are difficult compounds to destroy (Newman 1994).

A special permitting process exists for the incineration of "dioxin-listed" wastes. These wastes actually include two distinct classes of compounds, polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofuranes (PCDFs), usually mentioned together as PCDD/Fs. These wastes are considered to be acutely hazardous and the DRE requirements are 99.9999% (U.S. EPA 1991).

Disposal of obsolete pesticides in cement kilns in developing countries

Only three disposal operations of obsolete pesticides in cement kilns in developing countries are reported in the literature. Some of the available information is not complete.

The Deutsche Gesellschaft für Technische Zusammenarbeit, GTZ, gathered its first experience with the incineration of obsolete pesticides in Malaysia. US-AID carried out a disposal operation in Pakistan and GTZ carried out a disposal operation in Tanzania.

Disposal of obsolete pesticides in a cement kiln in Malaysia

In the middle of the eighties GTZ carried out the first disposal operation of obsolete pesticides in a cement kiln in Malaysia (Schimpf 1990). The cement plant was located 24 km north of Kuala-Lumpur and had a rotary kiln with a diameter of 4.3 meter and a length of 73 meter. The plant was equipped with electrostatic precipitator and produced 3,800 tonnes of clinker per day (Schimpf 1990).

A waste introduction-system was designed for the introduction of liquid wastes into the kiln. Solid and concentrated liquid wastes were dissolved or diluted in kerosene or fuel oil in a 5 m^3 storage tank with an agitator and fed through the oil-burner into the kiln. The cost for the introduction system was estimated to be 12,000 USD (Schimpf 1990).

A mixture of 2,4-D and 2,4,5-T with a known quantity of active ingredients was incinerated. Before, during and after the incineration, dust samples were taken from the electrostatic precipitator and analysed for 21 isomers of PCDD/FS. No PCDD/Fs where found (Schimpf 1990).

Pesticide disposal in a cement kiln in Pakistan

A total of 17,000 litre of organophosphate (OP) and organochlorine (OC) pesticides mixtures were incinerated in a modern cement kiln in Pakistan in 1987 (Huden 1990). The pilot project was done under developing country conditions without modifications of the facility.

Stack gases were sampled and analysed to determine particulate, chloride, and oxides of sulphur and carbon monoxide emissions. The results met post-1990 standards of the Environment Protection Agency (EPA) of Punjab. Products of Incomplete Combustion (PIC) were examined via GC/MS, but no unexpected PICs were detected. Analyses of process samples, raw meal feed, clinker and ESP dust showed no detectable pesticides (Huden 1990).

The cement plant was a modern, 4-cyclone, pre-heater dry process plant built in 1986 with a clinker production of 2,000 tonnes per day. The plant used Number-6 fuel oil with an approximate heating value of 10,700 kcal/kg and a sulphur content of 2.9 percent. Fuel oil was fed to the kiln through a Pillard burner at a rate of 7.3 tonnes per hour. The inside diameter of the kiln was 4.3 meter and the length 78 meter. Kiln inclination was 4 degrees and normal operating speed was 1+1/3rd revolutions per minute. Air from the raw material crushing and blending operation was combined with the kiln gases and exhausted to an electrostatic precipitator. The outlet of the electrostatic precipitator was connected to a 35-meter high stack. The average volumetric flow rate was measured to be approximately 204,000 Nm^3/hour (Huden 1990).

Feasibility decision of the Test Burn assumed that sufficient quantity (a minimum of 12,000 litre) of one organophosphate (OP) and one organochloride (OC) pesticide would be made available. For the purposes of the Test Burn it was essential to have a product of reasonable quality, which is with an active ingredient close to the original formulation but not less than 25% and of a viscosity close to that of water. Early sample analysis, however, indicated poor quality, with an active ingredient in the zero to 10% range and high viscosity. In order to work with a sufficient quantity the team realised that a "cocktail" of various OPs and OCs was inevitable. This, of course, added innumerable unknowns and analytical and process challenges to the task (Huden 1990).

All the collected pesticides had been sampled and analysed for active ingredient and other physical characteristics beforehand, and declared fit for use. They represented best available grades within a reasonable transport radius from the plant (Huden 1990).

The pesticide delivery system was designed for free flowing liquids. Waste pesticides were pumped from a tank truck and injected at an average rate of 294 litres per hour for OPs and 46 litres per hour for OCs. The injector achieved fine atomisation using 60 psi of compressed air. The system was tested successfully with diesel fuel. The "cocktail" of pesticides, however, contained sludge that settled to the bottom of the tank truck, causing viscosity to fluctuate depending on temperature and degree of agitation. These unanticipated conditions caused a variety of problems (Huden 1990).

The kiln met RCRA standards for particulate concentrations (183 mg/m^3). DRE results were very close to RCRA standards. HCl emissions limits were not met (Huden 1990).

The author speculated that the concentration of pesticides in the feed were too low for instrumentation to measure a DRE of 99.99%, probably due to a combination of low active ingredient and low feed rate. Had it been possible to feed a higher concentration to the kiln, the desired DRE, which may actually have been achieved, could have been demonstrated instrumentally. Measured HCl emissions were substantially higher than RCRA tolerances, but may have been anomalous (Huden 1990).

Disposal of Dinitro-o-Cresol in a cement kiln in Tanzania

57,500 litres of Dinitro-o-Cresol where disposed of by GTZ in a cement kiln in Dar Es Salaam, Tanzania in 1996 (Schimpf 1998).

4,6-Dinitro-o-Cresol (DNOC) with the sum formula (C7H8N2O5) belongs to the group of nitro-compounds and is classified in group lb (highly hazardous) in accordance with the WHO classification. The insecticide is highly toxic to fish. DNOC is explosive in its dry form. Chemical analyses revealed that the DNOC found in stock was dissolved in diesel.

The calorific value of the 50/50 DNOC/diesel-mixture was assumed to be approximately 11,000 kcal/kg and thus 1,300 kcal/kg above the calorific value of the fuel oil normally used in the cement plant (Schimpf 1998).

The cement kiln belongs to Twiga Portland Cement Co. Ltd and is located 30 km west of Dar-Es-Salaam. The cement plant has three heat-exchanger kilns of different sizes, each with a 4-stage heat exchanger. Kiln 3 was assumed to be suitable for incinerating the DNOC (Schimpf 1998).

The Ministry of Agriculture was the formal owner of the DNOC and was responsible for the administrative processing within Tanzania. It filed an official application for incineration of the DNOC in the cement plant to the Ministry of Environment in 1992. The incineration permit was issued by the National Environmental Management Council and the Chief Government Chemist four years later, in 1996 (Schimpf 1998).

Waste introduction system

A waste introduction system was designed and consisted of a high-pressure pump resistant to chemicals, storage and mixing tank with integrated filter system and all the necessary safety components.

The system consisted of a steel tank with a capacity of 4.4 m^3, an agitator motor (2.2 kW, 1,500 rpm, 220/380 V), a level indicator (minimum and maximum) with an automatic switch-off system, a Maxroy diaphragm high-pressure pump (rating up to 32 bar) with pressure display and amper (rating: 120 l/h - 600 l/h), a Krone flow meter, a pressure monitor for automatic switching off of the pressure in the event of a sudden pressure rise or pressure drop, various safety valves, including a flame check valve and a full splash protection in the form of a Plexiglas wall. All the relevant parts of the system consisted of explosion-proof components (Schimpf 1998).

This waste introduction system was placed in a 20-foot container and installed in a steel drip tray so that any possible leaks of the contents of the tank could be caught in the tray. The container itself was equipped with a forced ventilation system and placed about 15 meters from kiln 3. The DNOC was diluted with 50% diesel oil in the tank to a concentration of below 10% active ingredient and then fed automatically and continuously directly into the flame at high pressure via the fuel lance (Schimpf 1998).

The tank of the waste introduction system was filled from the exterior. For this purpose the DNOC-drums were transferred with the aid of a forklift truck from the intermediate store to a (second) drip tray, which was installed directly next to the waste introduction system. The DNOC and the same quantity of diesel was pumped into the waste introduction system tank and agitated. The mixture was pumped, with a diaphragm pump at a pressure of 30 bar, through the oil lance into the kiln. The pump rate was adjusted to 320-350 litres per hour. The fuel oil was heated to a temperature of approx. 130°C, and pumped at a rate of 3,300-3,500 litres per hour into the kiln (Schimpf 1998).

More than 57,500 litres DNOC 20% were incinerated in kiln 3 within a period of about 7 weeks. The DNOC was diluted with the same quantity of diesel oil, and in addition, approximately 4,500 litres diesel oil was used to clean the drums and test the waste introduction system. Thus, altogether, approximately 115,000 litres DNOC-diesel were introduced into the cement kiln and incinerated. The old DNOC drums were melted and recycled as iron for construction purposes (Schimpf 1998).

Chemical analysis

Clinker and filter dust samples were taken before, during and after the test run. The samples were analysed at two laboratories for DNOC residues. A heated measuring probe sampled flue gas 70 metres up in the stack and measured CO, CO_2, O_2, NO_x and the temperature continuously. The composition of the flue gas and the temperatures fluctuated greatly. During the test run no DNOC residues were detected in the clinker or the filter dust (Schimpf 1998).

Problems faced

A series of technical problems led to delays, especially during the testing phase. The kiln "broke down" regularly during the incineration of the DNOC due to several problems. The refractory of the kiln was damaged; the outer wall of the satellite cooler burned through, the power fluctuated and went down now and then and the raw meal feed was disrupted (Schimpf 1998).

At the beginning, during the preparatory phase, the workers at the cement plan viewed the activities of the team very sceptically. Directly before the start of the test run there was a "strike" by the workforce, they wanted to prevent the incineration. After discussions with the union leader, it turned out that the responsible liaison officer commissioned by the management had not carried out his tasks and the workers had not been informed correctly of the proposed measure. Their behaviour altered as soon as the representatives responsible for the project explained the project and the task of the waste introduction system to the workers in an information session. After this the negative attitude changed to support (Schimpf 1998).

Other planned disposal operations

Several other projects have been planned to utilise the benefits of the cement kiln to incinerate obsolete pesticides. In most cases, the cement kiln option has been evaluated to be attractive because such solution also could constitute a permanent disposal facility in the future.

Mozambique

In 1997 the Danish Government started a project involving the collection, treatment and final disposal of obsolete pesticides in Mozambique. Almost 1,000 tonnes of pesticides were collected throughout the country and transported to a purpose made waste station in Matola, outside Maputo and near the cement plant, Cimentos de Mozambique. The intention was to upgrade the cement kiln at Cimentos and to incinerate the organic obsolete pesticides there. After the finalisation of the disposal the intention was to leave behind a permanent facility for sound hazardous waste incineration in Mozambique in the future. However, NGOs in the community of Matola started to oppose and question the intention of the cement kiln disposal. The project became controversial and the media gave the project a bad and unfair mention. The political pressure in Copenhagen increased and finally in July 2000, the Danish Government decided to stop the cement kiln upgrading in Mozambique and to export all the pesticides to Europe.

Nepal

In Nepal, 114 tonnes of obsolete pesticides were "disposed" of by burying, spreading over land or reformulating in 1991. In 1998 two cement plants, in Hetauda and Jaljale, were investigated for the purpose of incineration of the remaining 70 tonnes of obsolete pesticides. In a preliminary feasibility study both were regarded to be suitable in principle. In 1999 this disposal option was abandoned due to negative perceptions, lack of knowledge and high cost estimates. Approximately 20 tonnes were then disposed of by land application and burial in the Bardia district. Presently, approximately 51 tonnes of pesticides are stored at Amlekhgunj warehouse "waiting" for export.

Eastern Europe

In Belarus, the Ministry of Natural Resources and Environmental Protection has made an inventory of obsolete pesticides. More than 2,000 tonnes are assumed to be obsolete and since 1997 the intention has been to utilise the Grodno Interkolkhoz cement plant for the disposal. So far, "nothing" has happened due to negative perceptions.

The situation is more or less identical in Ukraine, apart from the fact that the amount of obsolete pesticides is assumed to be ten times as high.

Lessons learned

Despite the fact that inventories for obsolete pesticides has been performed in more than 44 countries since FAO initiated the work in 1992, only a few disposal operations have been completed. The majority of these disposal operations have involved shipping the waste to developed countries and high temperature incineration there. Such a solution does of course solve the immediate risks of the obsolete pesticides, but on the other hand, the solution is not in agreement with the intention of the Basel Convention and does not leave any capacity behind. Developing countries will need their own facilities for disposal of hazardous wastes in the future and this should be kept in mind when dealing with obsolete pesticides.

So far, only three disposal operations utilising cement kilns are reported. Unfortunately, none of these reports provide scientifically valid data on the suitability of incinerating obsolete pesticides in cement kilns.

Lessons learned in Malaysia

In the report from Malaysia (Schimpf 1998) there is no information about the amounts of pesticides incinerated, the concentration of the active ingredients, the feed rate into the kiln, the oil consumption, the chlorine tolerance of the kiln, the destruction and removal efficiency etc. The project in Malaysia is clearly based on the assumption that the DRE of 2,4-D and 2,4,5-T would be satisfactory in any cement kiln. The analysis of PCDD/Fs in EP dust does not verify the performance of the kiln and the negative results could be expected beforehand. Unfortunately, the study is insufficiently documented and does not support cement kiln disposal.

Lessons learned in Pakistan

For the purpose of the pilot burn in Pakistan, the author (Huden 1990) summarised that it might have been wise to insist on using a uniform, higher grade waste pesticide and restricting the burn to one compound in each pesticide group, as had been intended. Uncertainty of availability of the ideal test candidate, likely long haul transport, and need to get on with the job, forced the team into a truly real case waste disposal situation, the complexity of which did not become apparent until they were well committed and could not turn back.

Better early sampling of candidate pesticides could have told the team more of what was ahead as well as determined a better choice of pesticides for the burn. The choice of laboratory is of course also important.

Further on, Huden also claims that in selecting a cement plant for waste disposal, the power supply reliability is essential. The actual plant was plagued by many power interruptions.

When designing the waste injection and delivery system, the team expected to work with free flowing liquids but received sludge, which caused numerous problems. The waste products should have been blended in a dedicated tank, equipped with an agitator and fed to the fuel line, which should have been equipped with a cut-off valve (Huden 1990).

The team was affected by management changes in some of the ministries; the acceptance and easy approval process at the feasibility stage did not automatically guarantee approval from the new generation of bureaucrats. Agreements in principle should have been formalised early so that promises once made represented institutional instead of individual commitment.

According to Huden, the important public relations issue was given short shrift. To assume that a potentially touchy subject best be kept quiet, is dangerously naive. The press, community leaders and labour unions can quickly turn into enemies when they are not informed of the intent of such an undertaking. With proper care, popular acceptance is much more likely than not, particularly when the benefit of participating in risk reduction can be understood. The heating value of the waste as fuel should also be stressed as a contribution to resource recovery and conservation of natural resources (Huden 1990).

Lessons learned in Tanzania

Obviously, the kiln chosen for the disposal operation of DNOC in Tanzania (Schimpf 1990) was not a good choice. The kiln broke down regularly during the disposal operation, the refractory of the kiln was damaged, the outer wall of the satellite cooler burned through, the power fluctuated and the raw meal feed was disrupted.

There was no sampling of DNOC in the exit gas, i.e. no possibility to determine the destruction and removal efficiency of DNOC in the process. To measure DNOC in EP dust and clinker is not enough, the exit gas is the most important. The measurement of CO_2, O_2, and NO_x in the exit gas does not give any information about the DRE.

The project also clearly shows the need for transparency, information and good communication.

Lessons learned in Mozambique

The planned upgrading and disposal in the cement kiln of Cimentos de Mozambique failed due to lack of public information and awareness raising. Knowledge, good communication and transparency are certainly the key.

Assessment of the suitability of cement kilns

The three disposal operations just described may have assumed that any cement kiln will be suited for the purpose. Even though any cement kiln needs a high temperature to produce cement, far from all are suited. The feasibility has to be assessed case by case, and will be dependent on process type, waste types, raw materials, location, infrastructure etc.

It should also be kept in mind that cement kilns are not a universal disposal option for hazardous wastes and not as versatile with regard to acceptance of different wastes as a dedicated hazardous waste incinerator. A cement kiln is for example not an option for disposal of heavy metal containing pesticides or whole drums of pesticide wastes. Certain cement kilns also have a low tolerance of chlorine. Ideally, the wastes should be liquid organic hydrocarbons, which could be pumped into the high temperature zone of the kiln together with the conventional fuel.

A complete assessment of the suitability of a particular cement kiln for the incineration of obsolete pesticides should ideally comprise three parts; first an introductory investigation into the amounts and types of obsolete pesticides/ hazardous wastes which need to be disposed of. If this investigation shows that an incineration in a cement kiln can be an option, the second step would be to perform a thorough feasibility study of the cement kiln(s) in question. If the feasibility study indicates a good candidate, a Test Burn with selected obsolete pesticides/principal organic hazardous constituents should be carried out to verify the performance. The results of the Test Burn will constitute the foundation in the decision making process, on whether or not to implement the incineration in the cement kiln.

Introductory assessment

The first step in the assessment would be to look into the amount and types of obsolete pesticides/hazardous wastes, which shall be disposed of in a particular scenario.

Liquid obsolete pesticides are easiest and safest to handle in a cement kiln scenario. It can usually be pumped through the main burner lance directly into the high temperature zone of the kiln together with coal or heavy oil.

Solid obsolete pesticides are more difficult, but can in some instances be blended/mixed with different liquids, kerosene, diesel etc. Attention should be given to particles in the liquid mixture, which can clog hoses and wear pumps. Introduction of solid obsolete pesticides without prior conversion to a liquid form is not yet demonstrated in a cement kiln disposal operation.

The following points are relevant to investigate:

Amount of obsolete pesticides, formulation, composition and characteristics, i.e. content of chlorine, alkalis, sulphur, phosphorus, heavy metals, water, calorific value, ash, reactivity/ burnability and the need for pre-treatment.

Other future needs for high temperature disposal options should also be included in the analysis, i.e. the availability of other sources of wastes and the national strategy for management of hazardous waste.

Feasibility of a particular cement kiln

If the initial investigation shows that an incineration in a cement kiln can be an option, the second step would be to perform a thorough feasibility study of the cement kiln(s) in question. Such a feasibility study will consider all aspects of the cement plant, the process and product quality requirements, the location and infrastructure of the plant, occupational health and safety, and institutional and legal aspects.

Process and product quality

The first step of a feasibility study would be to start with the technical, physical and chemical aspects of the process itself and of the product quality requirements. The following points are relevant to investigate:

Process type (wet, dry, preheater, precalciner), raw material sources, consumption and handling, emissions to the environment, exit gas cleaning devices and conditioning, clinker cooler;

Raw material composition, i.e. first of all the content of alkalis, chlorine and TOC. A calculation of the chlorine tolerance of the process.

Fuel type(s), sources, composition (calorific value, ash), consumption and handling (capacity of for example coal mills);

Product types and quality requirements, for example with regards to the content of chlorine, alkalis, heavy metals, setting time, fineness etc. Product storage and handling.

Plant location and infrastructure

The second step in the feasibility study would be to consider the plant location and infrastructure. The following issues are relevant:

Cement plant location (rural vs. urban/densely populated area) and general logistics on site;
Possibilities for waste handling and introduction;
Access for waste transport and for emergency aid (fire, hospital etc.);
Dominating wind direction and nearby water sources and other resources;
Stability of power (electricity) and water supply.

Occupational health and safety aspects

The third step in the feasibility study would be to consider occupational health and safety aspects and management attitude. The following issues are relevant:

The waste receiving, storage, handling and introduction process on-site. This should be assessed to be stable, safe and robust (continuous vs. batchwise);
The availability of safety and emergency equipment (fire extinguisher and first aid);
Safety and emergency plans, implementation and training;
The availability of personal protective gear and equipment/material for cleaning up spills;
Training of personal.

Institutional and legal aspects

The fourth step in the feasibility study would be to consider what could be called institutional and legal aspects. The following issues are relevant:

National strategy for the management of hazardous waste;
Public information, risk communication and awareness raising (transparency);
Incineration criteria and performance verification (independent assessment);
National licence conditions and regulation;
Liability;
Sustainability and owner-ship, i.e. future needs and plans.

Test Burn

If the feasibility study indicates a good cement kiln candidate, a Test Burn with selected obsolete pesticides should be carried out (Newman 1994).

The Test Burn will constitute the foundation in the decision making process, to continue the incineration in the cement kiln or not. However, emission standards for incineration of hazardous waste in cement kilns are usually not available in developing countries. Therefore, it is necessary to implement some criteria that must be demonstrated and fulfilled in a Test Burn before it is decided to carry on with incineration of the obsolete pesticides in the particular cement kiln.

The two following performance criteria is suggested:

1) The destruction and removal efficiency (DRE) for the introduced pesticides in the particular cement kiln should demonstrate to be 99.99%.
2) The cement kiln should comply with the EU-Directive with regards to emissions of PCDD/Fs, i.e. 0.1 ng TEQ/Nm^3.

If the particular cement kiln does not meet the criteria, a tuning of the process could be performed and the Test Burn repeated. If the criteria are not met in the second Test Burn, the incineration should not be performed in the particular cement kiln.

Prior to the actual Test Burn a Test Burn Plan should be developed.

Development of a Test Burn Plan

The purpose of the Test Burn Plan is to provide a clear delineation of the incinerator system, the nature of the obsolete pesticides, sampling and analytical techniques, and proposed operating conditions for the cement process and control equipment. The plan identifies how the incinerator will be tested. The relevant authorities must approve the Test Burn Plan before the Test Burn can be performed.

The Test Burn Plan should include at least the following components:

Incinerator process and control system description

Incinerator process and control system description, i.e. a technical adequate description of the plant. This description should contain capacities of prime movers (including RPM, volumetric flow rates etc.), dimensions of facility showing feed locations, burner design, description of automatic waste feed cut-off system, description of pollution control equipment, location of temperature, pressure, flow rate and other process monitoring systems, stack gas monitoring systems (including calibration procedures) and determination of the amounts of obsolete pesticides that will be incinerated during the Test Burn.

Obsolete pesticide characterisation

It is necessary in the Test Burn Plan to describe as completely as possible all obsolete pesticides that are planned to be combusted during the Test Burn. At a minimum, the information listed in Table 1 below should be presented for each of the obsolete pesticides.

Table 1. Obsolete pesticide analysis data

Heating value (kcal/kg)
Viscosity (liquids)
Chlorine content
Alkali content (Na is most critical)
Sulphur and phosphorous content (estimation)
Ash content
Analysis of primary organic constituents & concentrations
Confirmation of the absence of heavy metals
Particles (liquid pesticides)

After the obsolete pesticides have been defined and all of the principal organic hazardous constituents in each have been identified, it will be necessary to select one or several of these constituents as *principal organic hazardous compounds* to demonstrate the incinerator destruction and removal efficiency (DRE).

The compound, which is present in the highest concentration, and the compound which ranks highest on the U.S. EPA incinerability hierarchy, should be selected for the Test Burn. It is desirable to select principal organic hazardous compounds with different types of molecular structures.

When selecting principal organic hazardous compounds, careful consideration should be paid to adequate sampling and analysis of the compound. The assessment of possible formation of products of incomplete combustion during the combustion process should be considered carefully when selecting principal organic hazardous compounds to ensure that the selected compounds are not likely to be present in the incinerator exhaust as a product of incomplete combustion of some other compound.

Provisions for sampling and monitoring of incinerator process

The Test Burn Plan should define very clearly and completely the sampling and analysis and process monitoring procedures that will be used during the Test Burn program. The plan should include descriptions of the stack testing procedures and process monitoring procedures. It is important to tell the authorities what procedures will be used for sampling and analysis of the stack gas and to present the rationale for selection of each procedure.

Samples that must be collected and analysed along with the stack gas include a sample of the obsolete pesticide, which are fed to the incinerator, the raw meal, the main fuel source, electro precipitator dust and clinker. At a minimum, the parameters presented in Table 2 must be analysed for each of these samples. This section of the Test Burn Plan must describe what samples will be collected, how these samples will be collected, what parameters will be analysed and what analytical procedures will be used (the principles).

The third area to be addressed in this section of the Test Burn Plan is how the operation of the kiln and all associated control equipment will be monitored during the test program. Examples of the types of process data that must be recorded are presented in Table 3. The way in which each parameter will be monitored must be specified. When in-line process monitors are to be used, data must be presented on the make and model number of each monitor and the calibration procedures and frequency of those monitors.

Table 2. Parameters for analysis

Sample	Parameters
Exit gas	Principal organic hazardous compounds (DRE of pesticides) PCDD/Fs Temperature Gas volumes CO, O_2, CO_2 HCl Dust Heavy metals
Obsolete pesticide feed	Principal organic hazardous compounds Heating value (kcal/kg) Viscosity Chlorine content Alkali, sulphur and phosphorous content Ash content Heavy metals
Raw meal	Principal organic hazardous compounds Chlorine content Alkali, sulphur and phosphorous content Heavy metals
Fuel	Principal organic hazardous compounds Heating value Chlorine content Ash content
Electro precipitator dust	Principal organic hazardous compounds
Clinker	Principal organic hazardous compounds Alkali, sulphur and phosphorous content Heavy metals Other relevant quality indicators

Table 3. Process date requirements

Incinerator temperature (kiln inlet, clinker cooler, cyclones, EPS and stack)
Fuel feed rate
Raw meal feed rate
Clinker production rate
Obsolete pesticide feed rate(s)
Combustion airflow rates (air volumes)
Cooling water feed rate
RPM kiln

Test schedule

It is necessary to include a proposed schedule in the Test Burn Plan. An *example* of such a schedule is presented below:

Day 1	Arrive on-site / Briefing
Day 2	Equipment set-up
Day 3	Conduct preliminary and reference measurements
Day 4	Conduct Test 1 obsolete pesticide
Day 5	Conduct Test 2 obsolete pesticide
Day 6	Conduct Test 3 obsolete pesticide
Day 7	Conduct Test 4 obsolete pesticide
Day 8	Conduct reference measurements
Day 9	Ship samples for analysis / Debriefing
Day 10	"Pack" equipment (to be left on site) and depart
Day 30	Assess results and write report

OR Return back and Tune the process (4 days)

Day 35	*Conduct reference measurements*
Day 36	*Conduct Test 1 obsolete pesticide*
Day 37	*Conduct Test 2 obsolete pesticide*
Day 38	*Conduct reference measurements*
Day 39	*Ship samples for analysis / Pack equipment / Leave site / Debriefing*
Day 58	*Sample analysis complete*
Day 75	*Submit Final Report*

This schedule must be revised to include actual dates when a firm test date is established.

Test Burn protocol

The Test Burn protocol is the section in the Test Burn Plan in which the operating conditions of the incinerator and control system during the Test Burn are selected and discussed. This section of the plan is extremely important because the conditions at which the incinerator is operated during the Test Burn could become operating restrictions. As a result, these conditions must be carefully selected.

Conditions should be selected which provide a maximum degree of flexibility for future incinerator operations. This flexibility can be achieved by testing under worst case conditions; i.e., maximum expected hazardous waste feed rate, maximum expected concentration, maximum expected ash content, maximum tolerated chlorine content and "minimum expected incinerator temperature".

Quality assurance and quality control

Quality assurance and quality control (QA/QC) activities must be an integral part of a Test Burn program from the beginning of the effort through to the end. A complete QA/QC plan must be included as part of the Test Burn Plan (Newman 1994).

This plan must be prepared in detail because it will be used as a way to measure the quality of the data generated during the Test Burn, and as a result, the acceptability of the test report.

The preparation of a comprehensive Test Burn Plan must detail the nature of the actual Test Burn as well as technical considerations of the process and the obsolete pesticide streams.

Report the Test Burn and make recommendations

The final report must include a thorough documentation of the incinerator performance at the actual plant and provide scientific valid data on the suitability of the cement kiln to incinerate obsolete pesticides in an environmentally acceptable and sustainable manner. The final report will constitute the foundation in the decision making process, on whether or not to continue the incineration in the cement kiln.

The report should also include documentation on the following preconditions:

1) The technical process is assessed to be feasible for the disposal operation, i.e. adequate temperature, oxygen content, residence time and mixing conditions.
2) The power and water supply is assessed to be stable and adequate.
3) The waste receiving, handling, storage and introduction process is assessed to be stable, safe and robust.
4) The staff and technicians at the cement plant have received adequate information and training in handling hazardous waste.
5) Emergency procedures are implemented and followed, i.e. personal protective gear is in use and fire extinguishing and equipment/material for cleaning up spills are available.
6) Procedures for stopping waste feed in the event of an equipment malfunction or other emergency are to be implemented. The set points for each operating parameter used with this system must be specified. These are the levels that would activate feed cut-off.

Conclusion

Experiences from many countries indicate that it can be a good investment to follow the proposed framework for the assessment of the suitability of a cement kiln in a disposal scenario. Many potentially good projects have failed due to poor technical preparation or public perception. A well-operated and suited cement kiln can constitute a sustainable and environmentally sound option for destruction of hazardous wastes in many developing countries. More than three million tonnes of hazardous wastes are co-incinerated annually as a fuel substitute in cement kilns in industrialised countries.

A prerequisite for attaining trust and confidence is to perform an independent, substantial and comprehensive technical assessment. An open and informative process, with good communication is as important to the success of the operation as the technical planning or any other aspect of pesticide disposal.

The stage is set to initiate better-planned Test Burns elsewhere, refine techniques and get on with large-scale implementation. More than 100,000 tonnes of persistent pesticides constitutes a serious threat for health and environment. A suitable cement kiln can be a good alternative for the disposal of these, but also for other hazardous chemicals in the future. The benefits of the cement kilns should not be restricted to industrialised countries.

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