CONVERTING WASTE TO ENERGY: AN INTEGRATED SOLUTION TO HAZARDOUS WASTE DISPOSAL

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1. INTRODUCTION

Just over one hundred years ago, the rotary cement kiln patented by Frederick Ransome, made its appearance[1]. With a length of 6.4m and diameter of 1.17m, producing about 1 ton per hour, it was a far cry from the long kilns of the 1950's and 1960's, and from the high capacity preheater and precalciner kilns of today.

The energy required for clinker formation requires a kiln burning zone temperature close to 1450°C. Energy saving has therefore been one of the main driving forces in developments in kiln technology and operation. More recently, apart from improved kiln design, an effective lowering of energy costs has been achieved by utilising the energy in certain waste materials. This is a global trend which started in England in the mid-1970's with the utilisation of municipal waste for kiln firing[2].

Cement kilns are ideally suited for this application because of the specific process requirements combining high temperatures and long retention time in an alkaline environment. Furthermore, any ash generated from the burning of waste is incorporated in the kiln product material, leaving no residue for disposal.

2. SUITABILITY OF CEMENT KILN FOR WASTE DESTRUCTION

2.1 RAW MATERIALS

The raw material composition and preparation have a strong influence on the capacity of a kiln to successfully burn a waste material.

Limestone, as a source of calcium, is the main raw material, with argillaceous materials such as shale or clay used as sources of silica, alumina, and iron.

The control parameter for the proportioning of the raw materials is the Lime Saturation Factor (LSF), which is defined as the ratio

$$LSF = \frac{CaO}{2.80\,SiO_2 + 1.18\,Al_2O_3 + 0.65\,Fe_2O_3}$$

where the denominator indicates the amount of lime theoretically required for saturation of the three oxides at clinkering temperature.

Final proportioning, together with fine grinding of the raw materials, takes place at the raw milling stage with an X-ray spectrometer linked to a computer used for chemical control. The fineness of grind is a critical aspect affecting the chemical reactions which take place in the kiln. Typically, the raw meal - as the finely ground raw material is known - will be ground to give a residue of 10% on a 90 micron screen.

2.2 THE CEMENT KILN

Chemical combination of the raw materials takes place in the rotary kiln which is refractory-lined and has a slope of 3-5 degrees. It is fired at the lower (discharge) end, with the feed entering at the opposite end. The kiln can be divided into a series of zones indicating the progressive change in the material passing through the kiln:

Drying
Preheating
Calcining
Clinkering
Cooling

Kiln developments, aimed at reduced energy consumption, have resulted in modern kiln systems utilising multi-stage cyclone towers for preheating and partial calcining. Preheated at a temperature of over 800°C is then fed to the short rotary kiln for conversion to clinker.

The latest kilns being built are rated for heat consumptions of 690-700 kcal/kg clinker, giving an overall thermal efficiency of just over 60%.

Fuels traditionally used for firing cement kilns are oil, gas, or coal - either singly or in combination using multi-channel burners. In South Africa, all cement kilns are fired with pulverised coal.

2.3 WASTE DESTRUCTION POTENTIAL

The essential characteristics of the cement kiln make it ideally suited for the destruction of wastes.

Temperature

A high burning zone temperature is needed to achieve formation of the calcium-based minerals which ultimately give cement its required performance. This temperature is about 1450°C while the flame temperature will be over 1900°C.

Residence Time

The kiln is designed to operate under oxidising conditions and therefore has sufficient retention time to achieve complete burnout of the fuel as well as to facilitate heat transfer between gas and material.

Kiln gas velocities are typically 10-12 m/second, giving a retention time of over 4 seconds in the high temperature area.

Turbulent Mixing

The rotary action of the kiln keeps the material load in motion exposing it to the kiln flame.

No Residue

When wastes are burnt in a cement kiln, any ash or residue formed is absorbed in the clinker mineral structure leaving no residue for disposal.

Gas Scrubbing Effect

With finely milled limestone as the main raw material, the kiln system effectively scrubs the exhaust gases neutralising acidic vapour which might be formed during combustion. As a result of this, cement kilns are able to burn wastes with a fairly high sulphur content without SO_2 emission problems.

Auto Regulation

The clinker produced by the kiln is the major component of the finished cement. Cement quality requirements therefore impose close operating limits on the kiln to ensure product quality and consistency. These in turn result in a self-regulating system which ensures complete combustion of any waste introduced into the kiln.

2.4 LIMITATIONS

While the controlled use of combustible industrial waste provides an opportunity for optimising the cost of firing a cement kiln, careful attention must be paid to the following aspects.

- Full compliance with environmental regulations must be maintained at all times;
- Kiln operation and product quality must not be compromised in any way.

Components in the waste that can critically influence the clinker properties are

Alkalis
Chlorine
Sulphur.

Chlorides increase the volatilisation of alkalis in the kiln, resulting in increased circulation and the formation of buildups which obstruct gas and material flow[3]. Limits are set for the chloride content in concrete to avoid attack of reinforcing steel[4].

Heavy metals which may be present in the ash formed in the combustion of waste can adversely affect the setting time of cement. This can occur when the concentration of certain metals exceeds 0.1% in the final cement[5].

3. WASTES BURNT IN CEMENT KILNS

A range of solid and liquid waste materials which can be burnt in cement kilns as partial fuel replacement is illustrated in Table 1[6].

TABLE 1: Solid and liquid wastes used for firing cement kilns.

Solids		Liquids
Paper wastes Wastes from the paper industry	Wood wastes (Bark, shavings, sawdust Rice chaff	Tar Acid Sludge Used oil
Petroleum coke	Olive kernels	Petrochemical wastes
Graphite dust	Coconut shells	Paint industry wastes
Charcoal Plastic residues	Household refuse Refuse-derived fuel	Chemical wastes Solvent wastes
Rubber residues	Oil-bearing earths	Distillation residues
Old tyres Battery cases Activated bentonite	Sewage sludge	Wax suspensions Asphalt slurry Oil sludge

The essential requirement for waste to be utilised in this way is that it must be combustible and have a significant energy content. From a cost point of view, the waste must be more economical than the conventional fuel which it is replacing[7]. Transport costs will often result in a cement plant utilising waste materials generated in fairly close proximity. Local knowledge will sometimes lead to the burning of less common wastes. For example, at a cement plant in Paulding, Ohio the range of wastes utilised includes cosmetics, perfumes, pharmaceuticals, hairspray, and bad batches of tequila![8].

4. WASTE BURNING PROGRAMME AT JUPITER

4.1. PLANT SELECTION

At PPC, the application of hazardous waste fuels in the cement industry was studied extensively, with visits being made to several plants in Europe and North America for a first-hand assessment.

During 1992, the decision was taken to proceed with a programme which could lead to implementation of hazardous waste burning at the Jupiter plant situated on the Johannesburg/Germiston boundary. The plant was selected in view of its proximity to major chemical industries, and the suitability of its process equipment. The Jupiter kiln, which was commissioned in 1971, is classed as a long dry kiln and has an effective length of 146m. This gives the kiln an extended retention time making it ideally suited for waste burning application.

4.2 TEST REQUIREMENTS

In South Africa, cement kilns are listed as scheduled processes in the Atmospheric Pollution Prevention Act[9]. An operating permit issued by the Air Pollution Control Directorate of the Department of National Health is therefore required.

For the burning of waste, a cement kiln must also comply with the recently-published guidelines for the design, installation and operation of incinerators which were drawn up by the Air Pollution Control Directorate[10]. These require compliance with the following:

- A destruction and removal efficiency (DRE) of 99.99% on each principal organic hazardous constituent (POHC) in the feed waste;
- Emission concentration limits

<0.05mg/Nm³	for	Cd,Hg,Tl
<0.5mg/Nm³	for	Cr,Be,As,Sb,Ba,Pb,Ag, Co,Cu,Mn,Sn,V,Ni
<30mg/Nm³	for	Chloride as HCl, HF, SO_2

Limits are also specified for emissions of dioxins and furans;

80ng/Nm3 total dioxins and furans.

At the time of planning the Jupiter waste burning programme there were no specific regulations for the permitting of hazardous waste burning in cement kilns in South Africa. PPC therefore elected to follow the procedures of the US Environmental Protection Agency.

The US EPA has classified a cement kiln as an industrial furnace[11]. This requires a cement kiln using hazardous waste as supplemental fuel to achieve compliance with the Boilers and Industrial Furnaces (BIF) rule. The BIF rule requires a plant to demonstrate a DRE of 99.99% for principal organic hazardous constituents in the waste stream[12]. By following US EPA procedures, compliance with South Africa's guidelines for incinerators has been achieved.

An important aspect included in the guidelines for incinerators is that the handling and transport of waste is regulated by the Department of Water Affairs and Forestry. While cement kiln operation is regulated by the Air Pollution Control Directorate of the Department of Health, it is therefore necessary, in addition, to have approval by the Department of Water Affairs and Forestry for the system and procedures to be used to supply and transport waste to the kiln plant.

4.3 TEST PROGRAMME

PPC contracted the Analytical Technology Division of the Atomic Energy Corporation, working in co-operation with C and M Consulting Engineers, to conduct the required sampling and analytical work. A manual of sampling and test methods and a quality management system for the project were drawn up by AEC.

A three-stage test programme was set up:

Base-line study -	to provide information on the background distribution of metals and organic compounds in feed materials, emissions, and the clinker produced by the kiln.
Test burn -	using carbon tetrachloride to demonstrate the destruction and removal efficiency (DRE) of the kiln.
Trial burn -	to assess the efficiency of waste co-processing in an extended test.

The base-line study and test burn were conducted during February and March 1993, with the trial burn being completed by mid-August of that year.

For the test burn, carbon tetrachloride was injected into the kiln flame at a rate of 100kg/h. Carbon tetrachloride has been used as the principal organic hazardous constituent for DRE testing in the USA as its thermal stability makes it difficult to combust and destroy[13].

A pumpable phenolic distillation residue from a chemical plant was used for the trial burn, with provision being made to burn up to 1000 tons of this material over a 5-week period. This material was injected into the kiln flame by means of a burner lance fitted to the coal firing pipe. Metering and flow control equipment was installed and linked to the kiln control system. Automatic control interlocks were set up to regulate the waste feed, as follows:

- The waste fuel could only be added when the kiln was at or above 90% of normal output i.e. at steady state conditions.
- The waste fuel feed could not be started unless the coal firing system was in operation.
- a maximum waste fuel feed rate was set.

An operating permit for the test period was obtained both from the Air Pollution Control Directorate of the

Department of Health and from the Department of Water Affairs and Forestry.

4.4 SAMPLING AND ANALYSIS

Samples from the process streams entering and leaving the kiln system were taken as indicated in the flowsheet in Figure 1. The sampling programme included measurement of the gas flow rate at the kiln stack and at the hot gas duct which returns waste gas to the raw mill for utilisation in drying.

The analytical procedures used are outlined in Tables 2 and 3[14]

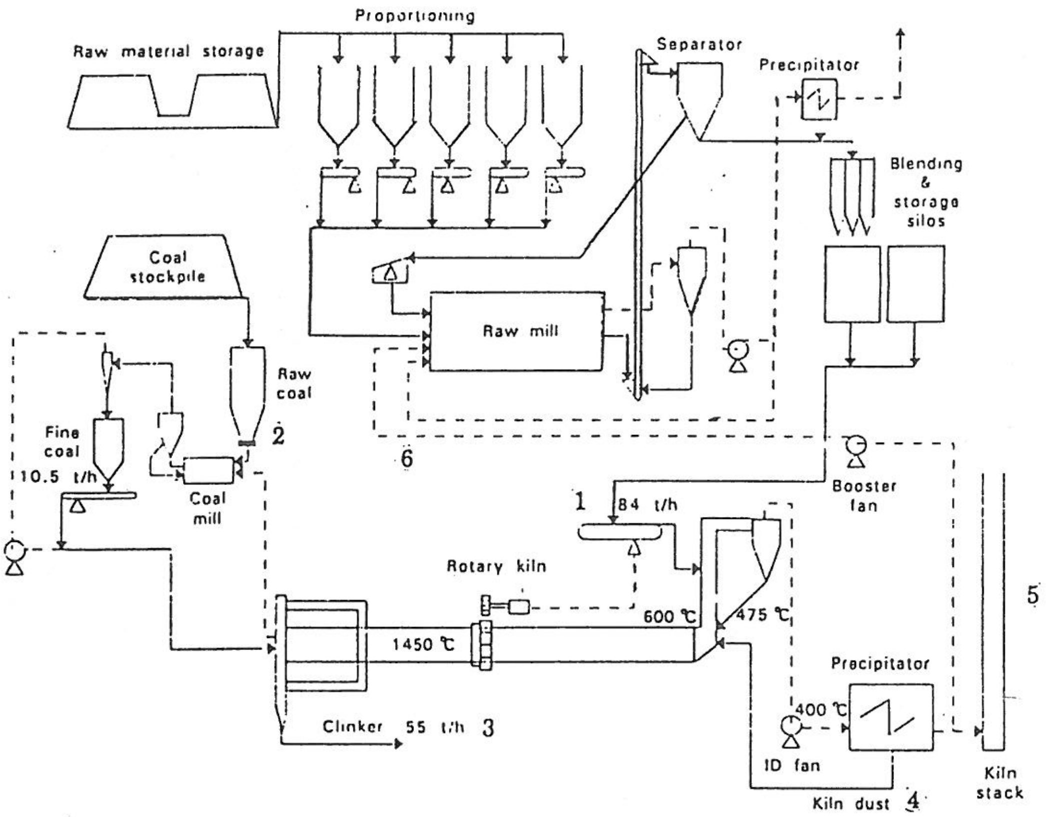

FIGURE 1: Jupiter Kiln Flowsheet.
Sampling points: 1. Raw meal; 2. Coal; 3. Clinker; 4. Precipitator dust; 5. Kilnn Stack; 6. Hot gas duct.

TABLE 2: Inorganic Analytical Techniques

Inorganic materials	Technique
Ba,Be,Cd,Tl,V, Cr,Pb,Zn,Ni	Inductively coupled plasma atomic emission spectroscopy (ICP-AES)
Hg,As,Se,Sb	Hydride generation analyser (HGA)
Cl	Ion Chromatography (IC),Spectrophotometry
S	Pyrometric elemental combustion
SO_2	Titrimetric
Cr^{6+}	Spectrophotometry

TABLE 3: Analysis of volatile and semi-volatile organic compounds

Volatiles: thermal desorption	Gas chromatograph-mass spectrometer (GC-MS) No.1
Semi-volatiles: analysis	GC-MS No. 2
Qualitative analysis:	Analyte identified by com parison of the sample mass spectrum with standard reference mass spectra (NBS library).
Semi-quantitative analysis:	Peak areas of the identified compounds integrated and the relative amounts calculated.

4.4.1 Destruction and Removal Efficiency

The Destruction and Removal Efficiency (DRE) was determined twice during two test runs i.e. a total of four determination.

In each test, carbon tetrachloride (CCl_4) levels were above the detection limits for the analytical technique. A DRE of 99.999% was recorded in each test.

4.4.2 Trial Burn

A comparison of the elemental compositions of the waste fuel and the coal used for firing the kiln is given in Table 4.

TABLE 4: Elemental compositions of Waste Fuel and Coal[15,16]

Component	Waste Fuel	Coal
Sulphur	5.7%	0.7%
Chlorine	44mg/kg	108mg/kg
Arsenic	0.2	1.1
Barium	7	156
Beryllium	<0.5	2
Cadmium	<1	1
Chromium	101	18
Mercury	<0.1	<0.1
Lead	<0.5	20
Antimony	0.1	0.1
Selenium	0.1	0.4
Thallium	24	15

The main organic compounds present in the waste fuel were:

Phenol
Isomers of 3 alkylphenols
Alkyl siloxane compounds

At 20% replacement of coal, the effect of the waste fuel on the clinker heavy metal content is illustrated in Table 5[17].

The changes in clinker composition are in line with the differences in the waste fuel and coal elemental compositions. The levels of Thallium and Chromium have increased while there is a reduction in Barium and Lead content. Overall, the waste fuel had no significant effect on the metal composition of the clinker.

In spite of the high sulphur level in the waste fuel, there was no significant concentration of SO_2 in the kiln stack gas, confirming the ability of the kiln to scrub SO_2.

TABLE 5: Comparison of heavy metal concentrations in Jupiter clinker

Metal	Normal fuel (Coal) mg/kg	Trial burn mg/kg
Antimony	0.4	0.2
Arsenic	0.04	1.2
Barium	735	573
Beryllium	1	1
Cadmium	9	7
Chromium	105	165
Lead	153	59
Mercury	0.15	0.04
Nickel	49	49
Selenium	<0.1	<0.1
Silver	4	5
Thallium	98	145
Vanadium	86	100
Zinc	42	28

4.4.3 Risk Assessment

The scope of the sampling and analytical programme included dispersion modelling of the kiln stack exhaust gas, using the US EPA Industrial Source Complex Dispersion Model[18]. Meteorological data for the period 1987 to 1991 were used to simulate average ground level concentrations, within a 10km radius of the kiln stack, for the following time periods:

8-hourly
Daily
Annually.

Risk assessment was conducted in accordance with US EPA risk assessment protocols, characterising health risk in terms of:

Exposure to non-carcinogens
Exposure to carcinogens.

In order to include dioxins in the assessment, samples of the kiln stack gas were taken for dioxin determination, during the trial burn. This task was carried out by the Atomic Energy Corporation working jointly with Triangle Laboratories, USA, and represents the first plant scale dioxin testing done in South Africa[19].

Evaluation of emissions from kiln operation with coal firing and with coal/waste fuel firing indicated that the waste had no effect on both cancer and non-cancer health risks to the community. Cancer risk was less than one in a million.

5. COMMUNICATION

A project feasibility study usually has two generally accepted components:

Technical
Financial.

Growing awareness of environmental impact has resulted in the inclusion of additional critical components in project evaluation. For the Jupiter waste burning programme to be developed into a full-scale project, communication and community involvement are vital factors influencing feasibility. The test programme therefore fulfilled a dual role to:

Establish technical viability
Gather information for communication.

Interested and affected parties were identified as follows:

PPC employees at the Jupiter plant
Employees at other PPC plants
The community around Jupiter
Municipal departments
Government departments
Environmental groups.

Prior to initiating the formal communication process, a comprehensive set of information material, suitable for several applications, was prepared. This included the following:

5.1 INFORMATION MATERIAL

(i) Exhibition poster set.

Printed in colour, these posters provided some background information on waste generation and explained the operation of a cement kiln and its suitability for burning flammable wastes. An outline of the Jupiter test programme was included, together with some comparative international information.

(ii) Video: "Making Waste Work".

With a duration of 12 minutes, this included coverage of the trial burn, together with discussion and comment by several environmental experts. A summary of the comments was printed in a Z-fold colour leaflet.

(iii) Information sheet
For distribution by knock-and-drop.

(iv) Press advertisement.

(v) Press briefing material.

5.2 IMPLEMENTATION

The communication process was implemented in a structured manner, starting with internal briefing of employees at the Jupiter plant. A Managing Director's Brief was sent to other PPC plants and communicated to employees through the team briefing system.

This was followed by briefing sessions for people in the environmental field and for the press.

The process was officially launched with a poster exhibition at the International Executive Communications Annual Waste Management Symposium held in January 1994. Media coverage was arranged to coincide with the official launch. At the same time, the knock-and-drop distribution of 60 000 leaflets to homes and businesses within a 5km radius of the Jupiter plant was carried out.

Press advertisements and the knock-and drop papers extended an invitation to the public to visit the Jupiter plant on two open days. This demonstrated transparency in the communication process.

5.3 OUTCOME

Through the communication process, the public was being informed of a potential project before its implementation. This resulted in a very positive response, including requests to meet with environmental groups and to participate in environmental exhibitions.

From meetings and contact with the public, several concerns and comments were raised. These included the following:

(i) Transportation of waste to the Jupiter site

(ii) Odours

(iii) Health aspects with regard to kiln stack emission

(iv) Monitoring and auditing.

The transportation operation must be well-managed and documented. This remains the responsibility of the plant, even though deliveries may be handled by a transport sub-contractor.

A facility for storing and blending pumpable wastes prior to use as supplementary kiln fuel must be designed to meet the required environmental standards. This includes the provision of scrubbing and filtering equipment for control of odours which can arise, for example, from the displacement of air during pumping to closed tanks. Experience with existing disposal sites has indicated that odours can draw regular complaints from the public.

Information from the risk assessment study enabled direct answers, based on measured data, to be given in reply to health-related questions.

As outlined in section 2.3, cement quality requirements demand close operating limits on a kiln. These ensure that conditions required for complete burnout of waste used as fuel are consistently maintained. Auditing by an external authority should nevertheless be carried out as a check on plant operation and management systems.

6. CONCLUSIONS

The waste-burning programme at PPC's Jupiter plant has completed the test requirements for permitting the burning of flammable hazardous waste as partial replacement of the coal used as the normal kiln fuel.

The test work has been conducted in three phases, in line with US EPA requirements:

Base-line study
Test Burn (DRE testing)
Trail burn.

This has made a contribution to the setting of standards for the permitting and regulation of hazardous waste treatment in South Africa.

The Jupiter kiln achieved a Destruction and Removal Efficiency of 99.999% which is better that the standard set by the US EPA. This is also better than the standards set in the recently published South African guidelines for the design, installation, and operation of incinerators.

In the trial burn, a waste with 5,5% sulphur was burnt. There was no measurable SO2 emission form the kiln system and no adverse effect on the final product.

Stack dispersion modelling was utilised in a health risk assessment, which indicated that the waste used as partial fuel replacement had no effect on either cancer or non-cancer risks. Dioxin analysis of the kiln stack gas represented the first plant scale dioxin testing done in South Africa.

Community involvement is a vital factor in a project of this nature. The communication process drew strong support from the public and from environmental groups. Useful input for plant design was gained through comments and concerns raised by the public.

The cement kiln is not a universal remedy for dealing with the hazardous waste problem, as wastes used must be flammable and must not have any adverse impact on product quality. The kiln provides an opportunity to move away from the disposal of flammable wastes in the ground.

Wastes have to be tested and blended, prior to being fed to the kiln, in order to ensure stable kiln operation. This requires an investment in a laboratory and storage/blending facility which must be designed and constructed in compliance with environmental requirements.

While the co-processing of waste contributes to process energy requirements, the cost of the waste handling system has to be met by an appropriate disposal fee structure.

In the competitive global marketplace, South African exporters will increasingly come under scrutiny by competitors checking on environmental management and compliance with international environmental standards.

Cement kiln provide a means of recovering energy from hazardous waste in a process which

meets with public approval,
leaves no residue, and is
environmentally acceptable - internationally.

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