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The Materials and Energy Potential Method for the quantitative distinction between Valorization and Elimination in the Cement Industry

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Executive summary

This report proposes a quantitative method to distinguish between valorization and elimination of waste in a cement kiln. Examples are calculated to illustrate the consequences of the developed approach.

Valorization is defined as the processing of a waste in a cement kiln to substitute raw materials and/or fuels. In this case, the waste contributes, in a positive way, to the cement production process.

Waste combustion in a cement kiln without any substitution or process improvement and with the sole purpose of final waste processing is defined as elimination.

A review of proposed methods to define valorization shows that most approaches are based on the comparison of the waste with a fuel and that a clear appreciation of both the energy and the raw material value of a waste does not exist.

The method which has been developed in this report is based on the recognition that a specific waste can contribute to the cement-making process as an alternative raw material and, at the same time, as a source of energy. This is a specific advantage of waste processing in the cement process which is expressed in the assessment method: the Materials and Energy Potential (MEP) method.

Essential steps in the development of the proposed method are:

- division of the waste in a raw materials fraction and the rest fraction which is separately evaluated as a source of energy;
- measures for the raw materials content and the energy value of the rest fraction are developed;
- based on these measures, an assessment of waste processing as valorization or elimination is proposed.

Another essential aspect of the proposed method is the interpretation of the term “source of energy”. In this study, a “source of energy” is distinguished from a “fuel” with calorific values of 15 MJ/tonne up to 40 MJ/tonne (wood, coal, oil). The starting point chosen is that any energy contribution (to the cement process) is sufficient for the “energy source” classification.

First, the raw materials part is established. This fraction contains the components that are useful to (functional in) the cement process: CaO, SiO_2, Al_2O_3, Fe_2O_3 and SO_3. As the wet-cement process is discussed, up to 30 % water and a percentage of non-functional (inert and trace) elements are allocated to the raw materials fraction, comparable with the natural raw materials. In this report, max. 10% is used as an example for the non-functional part of the raw materials fraction. The weight fraction of this raw materials part is **M,** used as a measure for the raw materials value of the waste. In case a dry-cement process is considered, in analogy, a raw materials fraction can be defined with low water content or no water content (comparable with the natural raw materials).

Secondly, the energy value of the rest fraction (= waste minus raw materials fraction) is expressed in a measure **E**.

To evaluate the energy content, the combustion behaviour at the process conditions in the kiln is used as a starting point. More specifically, the maximum (autothermal) combustion temperature (T_{comb}) that the rest fraction can reach under the process conditions in the cement kiln is used as a measure for the energetic value of the waste or a waste fraction. As a reference temperature for full energy valorization, 1500 °C is proposed. This temperature is above the maximum solids temperature required in the cement process.

The other process conditions taken into account are: an oxygen concentration of 3 % (air excess value of 16.7 %), an inlet temperature of the air of 800 °C and an energy efficiency of 75 %.

Thus the **E** measure is defined as:

$$E = (T_{comb} - 800)/(1500 - 800)$$

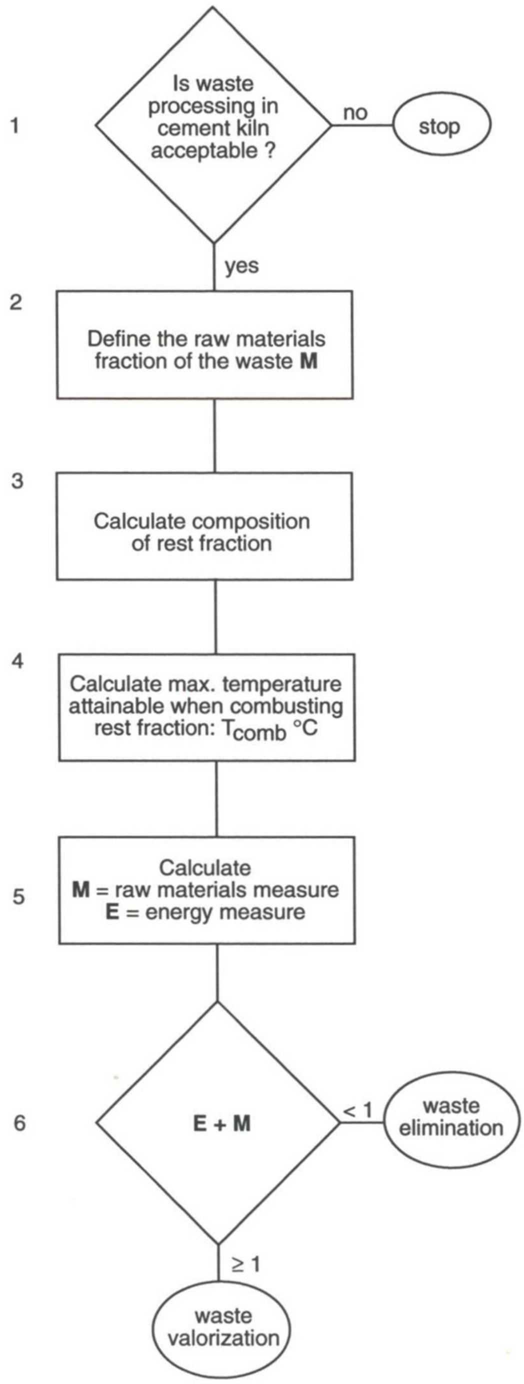
The Materials and Energy Potential of the waste is defined as the sum of **M** and **E**. It is proposed to consider processing of a waste in a cement kiln as valorization when

$$E + M \geq 1$$

Examples are calculated to show the consequences of this method that enables a quantitative distinction between valorization and elimination. For wastes with a **M** value of nearly 1, the formulated condition may be too strict.

Below, the decision scheme is presented to decide upon valorization or elimination of a waste in a cement kiln.

Decision scheme for waste valorization in a cement kiln.



Remarks:

Acceptable with regard to:
- health risks
- emissions
- technical produkt quality
- environmental product quality
- see Chapter 3.2

Raw materials fraction M:
- sum of CaO, SiO_2, Al_2O_3, Fe_2O_3 and SO_3
- with max. 30 % H_2O
- and max. 10 % other inorganics *
- see Chapter 3.3

* preliminary value

Calculate concentrations and heating value based on 100 % rest fraction

Process conditions:
- 75 % energy efficiency
- 3 % oxygen content
- air inlet 800 °C
- see Chapter 3.4

- **M** = raw materials fraction
- see Chapter 3.3
- **E** = $(T_{comb} - 800)/(1500 - 800)$
- see Chapter 3.4

The result of the appreciation of the raw materials aspect is that TNO's MEP method favours processing of wastes with a raw materials component in the cement kiln. The allocation of (part of the) water in the waste to the raw material fraction is specific for the wet-cement kiln process and favours the processing of wet wastes in this cement process.

In the following table, some calculations are presented as an example.

↓ → **waste** **characteristics**		**Organic solvent**	**Filtration earth**	**Artificial waste LFC**	**Filter cake**	**LD slag**
LHV *	(MJ/kg)	25	2.5	3.4	6	0
water	(%)	20	20	50	50	5
ash	(%)	–	50	20	20	95
M	(–)	0	0.71	0.29	0.29	1.0
T_{comb} (excl. raw materials fraction)	(°C)	18	1960	1130	1360	–
E	(-)	1.51	1.65	0.47	0.80	–
E + M	(-)	1.51	2.35	0.76	1.09	1.0
Valorization		YES	YES	NO	YES	YES

* Lower Heating Value of waste as such.

Contents

APPENDICES

1. Introduction

1.1 Valorization or elimination

In the classical cement manufacturing process, the raw materials and fuels used (such as limestone, marl, clay components and coals, fuel oil or natural gas) are of predominantly natural origin [4a]. By making controlled use of the known and proven process technology of the cement manufacturing process, these can be replaced by so-called secondary materials: waste materials from industrial production processes or from waste collection.

Secondary raw materials are therefore residues which can be used as alternatives to primary raw materials. Secondary fuels are combustible residues which represent alternatives to primary fuels. Some secondary materials can be classified as composed of an alternative raw material and of a fuel part.

Research and development in the cement industry have resulted in new sludge and solids handling systems to enable the handling of new materials [7].

In this report, the processing of a waste in a cement kiln to substitute raw materials and/or fuels is defined as the valorization of the waste. In this case, the waste contributes, in a positive way, to the cement production process.

Next to valorization of waste in a cement kiln, waste can be incinerated in a cement kiln as an alternative for waste combustion in a specialized waste combustion plant; the goal is the final treatment of the waste and there is no (or no significant) contribution to the cement production process. The high temperatures in the cement kiln, the alkaline environment, and the potential immobilization of ashes in the cement can make combustion in a cement kiln an attractive way for final treatment of a waste.

Waste combustion in a cement kiln with the sole purpose of final waste processing is defined here as elimination.

The differentiation between elimination and valorization is of importance as regulations distinguish between elimination and valorization of wastes. For instance, directives of the European Union allow the export of waste for the purpose of valorization.

The attraction of a cement kiln for the valorization or elimination of wastes and the importance of the difference has resulted in extensive literature and many proposals by authorities that often deal with the subject from different viewpoints emphasizing different aspects. Competition between cement kilns and the existing infrastructure of waste incinerators has led to discussions and proposals on the preference and admission of final waste treatment, either in cement kilns or in waste incinerators.

1.2 Goal and subject of the study

The goal of the study is to formulate criteria for the discrimination between valorization and elimination of waste in the wet-cement kiln process. If possible, this criteria should be quantifiable.

These criteria should be the result of technological considerations. Commercial and safety aspects are not considered in this study. Legal questions and contents of regulations are discussed only briefly.

1.3 Working method

In addition to views from literature, discussions with experts and authorities have been held to set up an overview of factors that are considered to determine the difference between valorization and elimination and of the (variation in) positions that can be taken.

Based on the wet-cement process of Ciments d'Obourg a quantitative method is proposed to distinguish between waste valorization and elimination in a cement process. The method is demonstrated by the calculation of the consequences for a number of illustrative wastes.

Ciments d'Obourg has a great deal of experience in using solid and liquid wastes in its cement process. In the Appendix A.1 the process, fuels, wastes and energetic and environmental aspects at the Ciments d'Obourg plant are presented as a case illustrating the potentials and environmental conditions in relation to waste usage.

2. Proposals to distinguish between valorization and elimination

2.1 Overview

The question 'valorization or elimination' should be decided by conditions on calorific value and raw materials content. In recent papers, a number of proposals are encountered for criteria based mainly on calorific value and raw materials content. The choices made are not all clearly founded and not always based on waste application specifically in the cement industry. Arguments, other than direct technological or ecological ones, are often considered, such as protection of the existing waste incineration infrastructure, maintainability and simplicity of regulations.

Examples of conditions on calorific value or raw materials content are:

- In Germany, according to the "Kreislaufgesetz", the energy content has to be larger than 11 MJ/kg and the fuel efficiency must be at least 75 %. Conditions on raw materials content are not published [19].

- The Ministry of the Environment (VROM) in the Netherlands sets a calorific value limit of 15 MJ/kg and states that only liquids can be processed (valorized) properly in a cement kiln (i.e. no sludges and no solids). In a former paper, a limit has been proposed of 18 MJ/kg or a useful ash content exceeding 50%.

- In France, based on EC Directive 94/67, energy recovery for the cement industry is recognized from 5 MJ/kg.

- In a proposal to BUWAL and in an OVAM paper, it is proposed that processing of a waste can only be regarded as valorization if the calorific value exceeds 25 MJ/kg and the contaminants in the waste do not exceed the given concentration limits or the calorific value exceeds 15 MJ/kg and the concentration of the contaminants in the waste do not exceed the limits and the total concentration of Ca, Si, Al and Fe is larger than 10 % [18, 20].

- Eurits (an organisation formed by the specialized waste incinerators) proposes calorific limits of 11.5 MJ/kg and 15 MJ/kg, depending on the chlorine content of the waste being smaller or higher than 1 % respectively [21]. Eurits promotes the application of its calculations for all co-combustion processes.

With the exception of the limits proposed in the Eurits paper, the calorific limits are based on values from fuels applied in cement kilns or in other applications.
The calorific values proposed by Eurits have a more technological base [21]. They are derived from EC conditions on incineration of hazardous waste in installations specializing in waste incineration (EC Directive 94/67/EG). These conditions are 850 °C at 6 % O_2 excess when the waste contains less than 1 % Cl and 1100 °C at 6 % O_2 excess when the Cl content exceeds 1 % (these considerations, however, are not valid for co-incineration in a cement kiln).

The Eurits paper formulates as a general criterium for co-incineration that the waste considered should be able to reach these temperatures autonomously. From this starting point, the calorific values mentioned above have been derived, assuming a waste with 25 % water and 35 % ash and 10 % energy loss.

The proposals mentioned are more extensively described in Appendix 2.

2.2 Discussion

Considering the proposals mentioned above, the following aspects deserve attention.
- The emphasis in the discussion on valorization is on the value of the waste as a substitute for fuel;
- Limits for the energetic value of the waste are often proposed based on comparison with calorific values of fuels. The energy contribution of the waste to the cement process is not evaluated directly, though the EC Directive mentions the use of the waste as “a source of energy”;
- Criteria for the raw materials content are mostly lacking or a limit value is arbitrarily set;
- The possible synergy in the cement process that a waste can contribute to the energy need as well as to the raw materials need is only appreciated to some extent in the OVAM proposal;
- In its EURITS paper the waste industry has proposed criteria derived from combustion properties and process conditions in a waste incinerator; not from the positive value as a raw material or a source of energy.

Most criteria are not specific for the use and functions of the waste in the cement process. In this aspect, the proposal in this study differs from others. The waste value for the cement process is chosen as the central criterion to distinguish waste valorization from elimination in the cement process.

3. Valorization or elimination

3.1 General

In this chapter, a method to distinguish between valorization and elimination is developed. The method is based on the recognition that a specific waste can contribute to the cement-making process as an alternative raw material and at the same time as a source of energy. This is a specific advantage of waste processing in the cement process that should be expressed by the assessment method.

Essential steps in the development of the proposed method are:

- division of the waste in a raw materials fraction and the rest fraction which is separately evaluated as a source of energy;

- measures for the raw materials content and the energy value of the rest fraction are developed;

- based on these measures, an assessment of waste processing as valorization or elimination is proposed.

The expression "source of energy" is used in the EC Directive 75/442/EC (Appendix A.2.2) An essential aspect in the proposed method is the interpretation of the term "source of energy". In this study, a "source of energy" is distinguished from a "fuel" with calorific values of 15 MJ/ton up to 40 MJ/ton (wood, coal, oil). The starting point chosen is that any positive energy contribution (to the cement process) is sufficient for the classification "energy source".

To evaluate the energy content, the combustion behaviour at the process conditions in the kiln is used as a starting point. More specifically, the combustion temperature that can be reached autothermally is used as a measure for the energetic value of the waste or a waste fraction.

Table 3.1 summarizes the decision scheme, elaborated in this chapter, to decide upon valorization or elimination of a waste in a cement kiln.

Table 3.1 Decision scheme for waste valorization in a cement kiln.

		Remarks:
1	Is waste processing in cement kiln acceptable ? — no → stop; yes ↓	Acceptable with regard to: - health risks - emissions - technical produkt quality - environmental product quality - see Chapter 3.2
2	Define the raw materials fraction of the waste **M**	Raw materials fraction M: - sum of CaO, SiO_2, Al_2O_3, Fe_2O_3 and SO_3 - with max. 30 % H_2O - and max. 10 % other inorganics * - see Chapter 3.3 * preliminary value
3	Calculate composition of rest fraction	Calculate concentrations and heating value based on 100 % rest fraction
4	Calculate max. temperature attainable when combusting rest fraction: T_{comb} °C	Process conditions: - 75 % energy efficiency - 3 % oxygen content - air inlet 800 °C - see Chapter 3.4
5	Calculate **M** = raw materials measure **E** = energy measure	- **M** = raw materials fraction - see Chapter 3.3 - **E** = (T_{comb} - 800)/(1500 - 800) - see Chapter 3.4
6	**E + M** — < 1 → waste elimination; ≥ 1 → waste valorization	

In the following parts of this chapter, the raw materials fraction is defined and a method is described to assess the energetic value of the rest fraction. Next, a decision parameter to distinguish between valorization and elimination of the total waste is proposed. But first a summary is given of general conditions that waste processing must fulfil.

3.2 General conditions for waste processing

In order to have an acceptable treatment of waste in a cement kiln, some general conditions have to be met:

- permit conditions and emission standards must be met;
- the quality of the cement must fulfil limits with respect to its structural capabilities and its environmental compatibility;
- the production process must not be impaired and the safety of the workplace must be ensured;
- an environmental assessment should show that the cement process must be the best way of handling the waste materials. In this assessment, the cement option should be compared with alternatives such as reuse, recycling, incineration in specialized waste combustion facilities or other facilities;
- the waste materials should not be mixed in order to reach the maximum allowable limits of contaminants in the waste.

These requirements result in criteria which limit the quantity of secondary materials used or even exclude them entirely. Several criteria are formulated in the literature [4a, 4b, 4c, 4d, 12, 14, 19, 20, 21, 22] and are related to gaseous emissions, cement quality, health standards, and reactor maintenance. These criteria are necessary conditions for the application of waste in general, but do not determine the difference between elimination of waste or valorization.

When these conditions are not met, the waste considered cannot be treated in a cement kiln: processing is not acceptable.

3.3 Definition of raw materials fraction

Generally, for the cement process, a waste can be described by the following fractions (see Figure 3.1):
- the organic fraction, constituting the energy source of the waste;
- an inorganic fraction, consisting of the useful, functional components;
- water;
- an inorganic fraction with the harmful compounds such as heavy metals (trace elements mostly);
- an inorganic fraction, consisting of neutral compounds without a positive or a negative contribution to cement production such as Mg-, P-, Na-, K-components.

Most of the water and the last two inorganic fractions mentioned are not functional for the cement production. For the assessment of the contribution of the waste to the raw materials, a raw materials fraction is defined, based on:

- the fraction useful compounds CaO, SiO_2, Al_2O_3, Fe_2O_3 and SO_3 in the waste and
- on the contents of other substances in the waste in comparison with those in natural raw materials.

As the wet-kiln process is considered in this study, the raw material fraction is assumed to contain 30 wt% water (or as a maximum the amount of water that is present in the waste material) in accordance to the natural raw material applied by Ciments d'Obourg (Appendix 1). In a similar way, percentages of the inert and trace elements inorganic fractions are allocated to the raw material fraction. These percentages should be based on the percentages occurring in natural raw materials. Schematically, this is depicted in Figure 3.1.

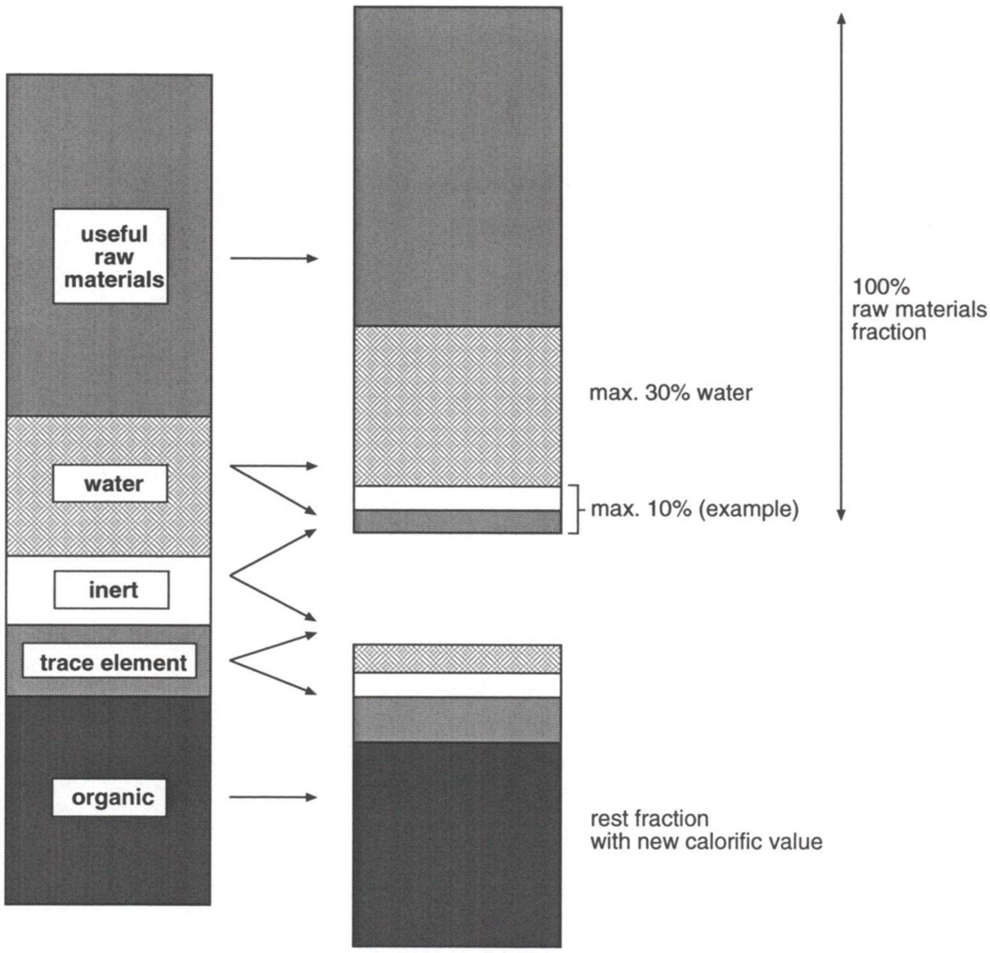


Figure 3.1 Partitioning of the waste in a raw materials fraction and a rest fraction

See, for example, the data in Table A.2.3: the raw material described here contains (in elemental form) approximately 5 % of inert natural and 0.2 % of trace elements.

An overview of concentrations occurring in natural Dutch clays [16] reveals approximately 3 % inerts, mainly Na_2O and K_2O, and 0.1 % of trace elements, mainly heavy metals.
Lime ($CaCO_3$) can contain 0.2 % inert material and 0.05 % of heavy metals [17].
LD slag, a commonly used raw material, contains approximately up to 10 % inert inorganic compounds, mainly as magnesia oxide and phosphorous oxide (see table 4.1).

Therefore, the raw materials fraction is defined so that, besides the useful components, it contains up to 30 % water, and up to 10 % of the inert components. If the waste itself does contain less than this quantity of water or components, the actual quantity in the waste is allocated to the raw materials fraction.

The max. 10 % inert in the raw materials fraction is mentioned as a possible example. A study of these non-functional components in natural raw materials could result in a better justified proposal.

In this study the value of the raw materials fraction of the waste is used as a measure for the value of the waste as a raw material.

The total waste minus the raw materials fraction is called the rest fraction.

3.4 Assessment of waste as a source of energy

It is proposed here to consider a material as a source of energy when, at the prevailing process conditions in the kiln, this material produces at least some surplus of energy.
In this respect, major process conditions to be considered are reaction temperature and air surplus in the kiln. (See Appendix A.1.1 for the wet-cement process conditions). The reaction temperature to be considered may depend on the feeding system options that are available. As an example, the mid-kiln feeding system that has been developed in the United States can be mentioned. Ciments d'Obourg will implement this system next year. It allows the feeding of material into the middle of the kiln where typically the decarbonization of calcium carbonates occurs, a major energy- demanding step in the process. Typical reactor temperatures at this point are 1100 °C in the gas phase and 800 °C for the solids (see Figure A.2). However, maximum temperatures in the kiln are 2000 °C in the gas phase and 1450 °C for the solids.

What situation should now be used to calculate the energy potential of the waste?

The ashes of the waste have to pass the zone where they are heated up to approximately 1450 °C whether they enter mid-kiln, at the feeding point of the fuel or at the solids entrance side.

Therefore, it is postulated that a substance is a source of energy when it is able to reach autothermally a combustion temperature of 1500 °C.
With respect to the conditions of the combustion to calculate this temperature, it is assumed that there is 3 % oxygen (approximately 16 % air surplus) and that the energy losses amount to 25 %.
The energy of the hot solids leaving the kiln is used to preheat the inlet air up to more than 800 °C. Therefore, a further premise for the calculation of the autothermal combustion temperature is an air inlet temperature of 800 °C.

These conditions ensure that the waste contributes positively to the energy demand of the cement process. In the next Section 3.5, a generalized evaluation is presented to distinguish between valorization and elimination. This generalized approach is based on the evaluation of the raw materials fraction and the rest fraction. This rest fraction is assessed as a possible source of energy.

3.5 Generalized assessment of a waste as a source of raw materials and energy

A generalized method to decide between valorization and elimination is described based on two measures that express the energy and the materials value of the waste respectively.

The measures are:
- the raw materials fraction, expressed as a weight fraction of the waste. This fraction, defined in 3.3, is smaller than or equal to 1 and denoted further as **M**;
- the energy value, expressed as the quotient of the maximum combustion temperature, T_{comb}, achievable by the rest fraction, and the desired temperature of 1500 °C. This quotient is denoted further as **E**.
  A reference temperature level is chosen of 800 °C, being the air inlet temperature and therefore:

$$\begin{aligned} \boldsymbol{E} &= (T_{comb} - 800)/(1500 - 800) \\ &= (T_{comb} - 800)/700 \end{aligned}$$

For an (almost) pure inorganic raw material **E** = 0 and **M** = 1.

According to the statement in 3.1, the waste processing should be classified as valorization, when there is a raw materials fraction (**M** > 0) and **E** is larger than 1. In this case, the waste consists of two fractions that both contribute to the cement production process in a positive way.

When **E** < 1, there is not sufficient energy in the waste to produce some energy surplus at 1500 °C. For a classification as valorization, this should be compensated by the importance of the raw materials factor **M.**

It is proposed to generally classify waste processing in a wet-cement kiln as valorization, as opposed to elimination, when:

$$\boldsymbol{E} + \boldsymbol{M} \geq 1$$

This relation is the basis for the Materials and Energy Potential method developed in this study.
The defined measures have been calculated for a number of wastes (see Chapter 4) and plotted in what is called a Materials and Energy Potential Scheme or a MEP scheme (Figure 4.1). The aim is to illustrate the consequences of this assessment method, summarized in Table 3.1.

Some features of the method developed are discussed in Chapter 5.

4. Calculations and sensitivity analysis

4.1 Calculations for some example wastes

The method described in Chapter 3 to distinguish between valorization and elimination is illustrated by calculations on four wastes and on medium-quality coal, all applied at Ciments d'Obourg. The compositions of these wastes and the coal, as given by Ciments d'Obourg, are presented in Table 4.1.

In Table 4.2, some artificial wastes have been defined, mostly low calorific variants of the actually applied wastes from Table 4.1 (the organic fraction is supposed to be cellulosis and the lower heating values are calculated by the Michel formulae).

The Tables 4.3 and 4.4, respectively, present the calculated **M** and **E** measures, based on the following premises:
- oxygen concentration for incineration: 3 % oxygen (air surplus 16.7%);
- energy efficiency 75 %; 25 % loss;
- raw materials fraction: raw materials including up to 30 % water (see 3.3)

Allocation of part of the inert fraction and/or the hazardous fraction to the raw materials fraction has been disregarded.

To calculate the combustion temperature, it is necessary to estimate the composition of the organic fraction of the waste since no data is available. The organic fraction of the low calorific waste examples is supposed to be cellulosis.

Table 4.1 Composition of waste examples HPC, FE, FC, DSS and medium coal.

	Unit	HPC solvents	FE filtration earth	FC filter cake	DSS dry sewage sludge	PC poor coal	LDS LD-slag
LHV (*)	MJ/kg	25	2.5	6.0	11.0	16.2	–
H_2O	%	20	20	50	22	0	5
Ash	%	0	50	20	44	50	95
S	%	1	1	1	1	1.5	0.2
CaO	% ash	0	25	25	11	7	46
SiO_2	% ash	0	45	5	51	46	12
Al_2O_3	% ash	0	15	15	16	26	2.5
Fe_2O_3	% ash	0	5	45	9	8	32
SO_3	% ash	0	10	10	3	7	0.5

* LHV = Lower Heating Value

Table 4.2 *Composition of artificial waste examples LPC, LFE, LFC, and LSS and wet sewage sludge WSS for theoretical calculations.*

	Unit	LPC	LFE	LFC	LSS	WSS
LHV (*)	MJ/kg	11.7	6.2	3.4	4.7	2.9
H_2O	%	20	20	50	22	70
Ash	%	0	50	20	44	10.2
S	%	1	1	1	1	1
CaO	% ash	0	25	25	11	11
SiO_2	% ash	0	45	5	51	51
Al_2O_3	% ash	0	15	15	16	16
Fe_2O_3	% ash	0	5	45	9	9
SO_3	% ash	0	10	10	3	3

* LHV = Lower Heating Value

Table 4.3 *Results of calculations of Materials and Energy measures for air inlet temperatures of 25 and 800 °C (raw mat.=sum of useful oxides)*, T comb = combustion temperature.

air inlet temperature 25 °C

	Unit	HPC solvents (a)	FE filtration earth	FC filter cake	DSS dry sewage sludge	PC poor coal	LDS LD-slag
T_{comb} waste as such	°C	1440	1265	905	1252	1419	–
Useful * oxides	(-)	0	50	20	40	47	88
M measure	(-)	0	0.71	0.29	0.57	0.47	1.00
T_{comb} rest fraction	°C	1440	1484	1030	1688	1532	–
E measure	(-)	0.91	0.98	0.33	0.93	1.05	
Calorific value	MJ/kg	20.3	12.5	6.0	11.0	16.2	–
calculated **	MJ/kg	20.3	43.4	8.7	26.3	35.1	–

Air inlet temperature 800 °C

	Unit	HPC solvent s	FE filtration earth	FC filter cake	DSS dry sewage sludge	PC poor coal	LDS LD-slag
T_{comb} waste as such	°C	1863	1662	1210	1646	1876	–
Useful oxides *	(-)	0	50	20	40	47	88
M measure	(-)	0	0.70	0.29	0.57	0.47	1.00
T_{comb} excl. raw materials fraction	°C	1863	1958	1360	1975	2037	–
E measure	(-)	1.51	1.65	0.80	1.68	1.78	–
E + M	(-)	1.51	2.35	1.09	2.24	2.25	1.00

* only raw materials as such: CaO, SiO_2, Al_2O_3, Fe_2O_3 and SO3

** upper value: for waste as such; lower value: for rest fraction = waste minus raw materials fraction

Table 4.4 Results of theoretical calculations of Materials and Energy measures for artificial waste examples for air inlet temperatures of 25 and 800 °C (raw mat. = sum of useful oxides).

Air inlet temperature 25 °C

	Unit	LPC	LFE	LFC	LSS	WSS
T_{comb} waste as such	°C	1376	1030	700	930	590
Useful * oxides	(-)	0	50	20	40	09
M measure	(-)	0	0.71	0.29	0.57	0.12
T_{comb} rest fraction	°C	1376	1460	880	1330	630
E measure	(-)	0.82	0.94	0.11	0.76	-
Calorific value **	MJ/kg	11.7	6.2	3.4	4.7	2.9
calculated	MJ/kg	11.7	22.3	5.1	11.7	3.4

Air inlet temperature 800 °C

	Unit	LPC	LFE	LFC	LSS	WSS
T_{comb} waste as such	°C	1751	1449	980	1421	840
Useful * oxides	(-)	0	50	20	40	09
M measure	(-)	0	0.70	0.29	0.57	0.12
T_{comb} excluding raw materials fraction	°C	1751	2003	1130	1802	897
E measure	(-)	1.36	1.72	0.47	1.51	0.15
E + M	(-)	1.36	2.42	0.76	2.08	0.27

* only raw materials as such: CaO, SiO_2, Al_2O_3, Fe_2O_3 and SO_3

** upper value: for waste as such; lower value: for rest fraction = waste minus raw materials fraction

The Materials and Energy measures are plotted in Figure 4.1 with the line

$$\boldsymbol{M} + \boldsymbol{E} = 1$$

From the data, it is concluded that combustion of actually processed wastes as filtration earth, poor coal, dry sewage sludge, HPC and filter cake (just) should be valued as valorization.

From the artificial wastes, WSS (very clearly) and LFC are examples of waste elimination. LPC (just), LFE and LSS are shown to be wastes that can be valorized in a wet-cement kiln.

must be at least some energy surplus. Therefore, there seems to be no clear objection against defining such a case as valorization realizing that it is a bottom limit. Possibly, however, there are more attractive ways of co-incineration or processing these wastes.

For wastes with a **M** value of nearly 1 and no organic fraction (E approx. 0), the condition $\mathbf{M + E \geq 1}$ can be too strict and should possibly be reconsidered. The condition $\mathbf{M + E \geq 1}$ can be distinctive as is shown by the following. The calculated examples show that wastes with a substantial raw materials fraction have an advantage above wastes without. Compare for example LPC and LSS in Table 4.4. LPC is only just a valorization case (**E** = 1.36, **M** = 0), despite the heating value of 11.7 MJ/kg, that would make it a fuel according to the German law. LSS with a much lower heating value of 4.7 MJ/kg is even more clearly valorized (**E** = 1.43, **M** = 0.57). The latter is due to the raw materials. An additional reason for this strong effect is that part of the water fraction is allocated to the raw materials fraction (both wastes have a water fraction of approximately 20 %.)

The actually applied wastes and the coal (filtration earth, dry sewage sludge and the poor coal) score relatively high too because of their raw materials fraction.

These examples further show that the proposed MEP method to distinguish between valorization and elimination favours the strong point of waste processing in a cement kiln, that is, the energy as well as the ash content of a waste can be used.

6. Conclusions

- The main types of criteria for waste treatment in a cement process discussed in literature are conditions from emission standards, limits on concentrations of contaminants in the waste and limits with respect to cement quality. These aspects do not distinguish between valorization and elimination; cement processes in which wastes are used (waste which is valorized and waste which is eliminated) have to respect these limits.

- Generally, it can be concluded that in Germany, Belgium and The Netherlands, the issue of valorization and elimination has not been worked out on process technological considerations only which explains the widely different ranges of criteria.
  Proposed conditions are mainly based on limits to heating values. Raw material aspects are hardly discussed.
  The approach developed by Eurits (the specialized waste incineration organization) to assess co-incineration is based on process conditions during waste combustion in hazardous waste incinerator processes and is therefore not applicable to waste processing in a cement kiln.

- A Materials and Energy Potential (MEP) method is proposed that can distinguish quantitatively between valorization and elimination in case of waste processing in a cement kiln.

- The MEP method is specifically developed for the wet-cement process but can be modified easily in a way that it can be used for dry or semi-dry-cement processes as well.

- The method is based on the recognition that a specific waste can contribute to the cement-making process at the same time as an alternative raw material and as a source of energy. This is a specific advantage of waste processing in the cement process.

- Essential steps in the development of the proposed method are:
  - division of the waste in a raw materials fraction and the rest fraction which is separately evaluated as a source of energy;
  - measures for the raw materials content (**M**)and the energy value of the rest fraction (**E**) are presented.

- It has been a starting point that the rest fraction of the waste can be classified as a source of energy if this fraction produces some energy surplus at the process conditions in the cement kiln. In this approach, comparisons to the heating values of fossil fuels are superfluous.

- The defined reference process conditions for waste combustion in a cement kiln are:
  - an oxygen concentration of 3 %;
  - a maximum solids temperature of 1500 °C;
  - an air inlet temperature of 800 °C;
  - an energy efficiency of 75 %.

  These conditions are more strict than actual conditions (oxygen 2.5 %, 1450 °C max. solids temperature) in a cement kiln.

- The measures **E** and **M** are defined in the following way:
  - **M** is the raw materials fraction, expressed as a weight fraction of the waste. This fraction is defined so that it can contain up to 30 % water and a fraction of non-functional elements in accordance with natural raw materials applied in cement making;
  - the energy value **E** is defined as the quotient of the maximum combustion temperature, T_{comb}, achievable by the rest fraction, and the desired temperature of 1500 °C. This quotient is denoted further as **E**.
    A reference temperature level is chosen of 800 °C, being the air inlet temperature and therefore:

    $$E = (T_{comb} - 800)/(1500 - 800)$$
    $$= (T_{comb} - 800)/700$$

- Based on these measures, a general condition is formulated for the assessment of waste processing as valorization:

  $$E + M \geq 1$$

- The allocation of (part of the) water in the waste to the raw material fraction is specific for the wet-cement kiln process and favours the processing of wet wastes in this cement process.

- The MEP method favours processing of wastes with a raw materials component in the cement kiln.

- Non-functional compounds (Mg-, P-, Na-, K-components and trace elements) are allowed in the raw materials fraction up to a preliminary maximum of 10 %. A better justified value has to be the result of a study of amounts occuring in natural raw materials.

- It is shown that the thermal analysis and limits proposed by TNO result in approximately the same judgement as the Eurits approach. The difference is the result of the appreciation of the raw materials aspect in TNO's MEP method.

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8. List of Abbreviations

Buwal	Swiss Bundesumweltamt
E	Measure of energy value
Eurits	European Union for Responsible Incineration and Treatment of Special Waste
HHV	High heating value
LHV	Lower (net) heating value
LUA NRW	Landesumweltamt Nordrhein-Westfalen
M	Measure of raw materials content
MEP	Materials and Energy potential
OVAM	Flemish Waste Authority
RM	Raw materials fraction
T_{comb}	Combustion temperature
VROM	Netherlands Ministry for Housing, Spatial Planning and the Environment

9. Authentication

Name and address of the sponsor
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Names and functions of the contributing personnel

J.A. Zeevalkink	Project leader
Mrs. M.M.C. Alkemade	

Names of establishments to which parts of this research were sub-contracted
–

Period in which the research took place
1996

Signatures	**Approved by**
J.A. Zeevalkink	J. de Koning
Project leader	Head Department of Thermal Conversion Technology
Date: 19-11-1996	Date: 19-11-96.

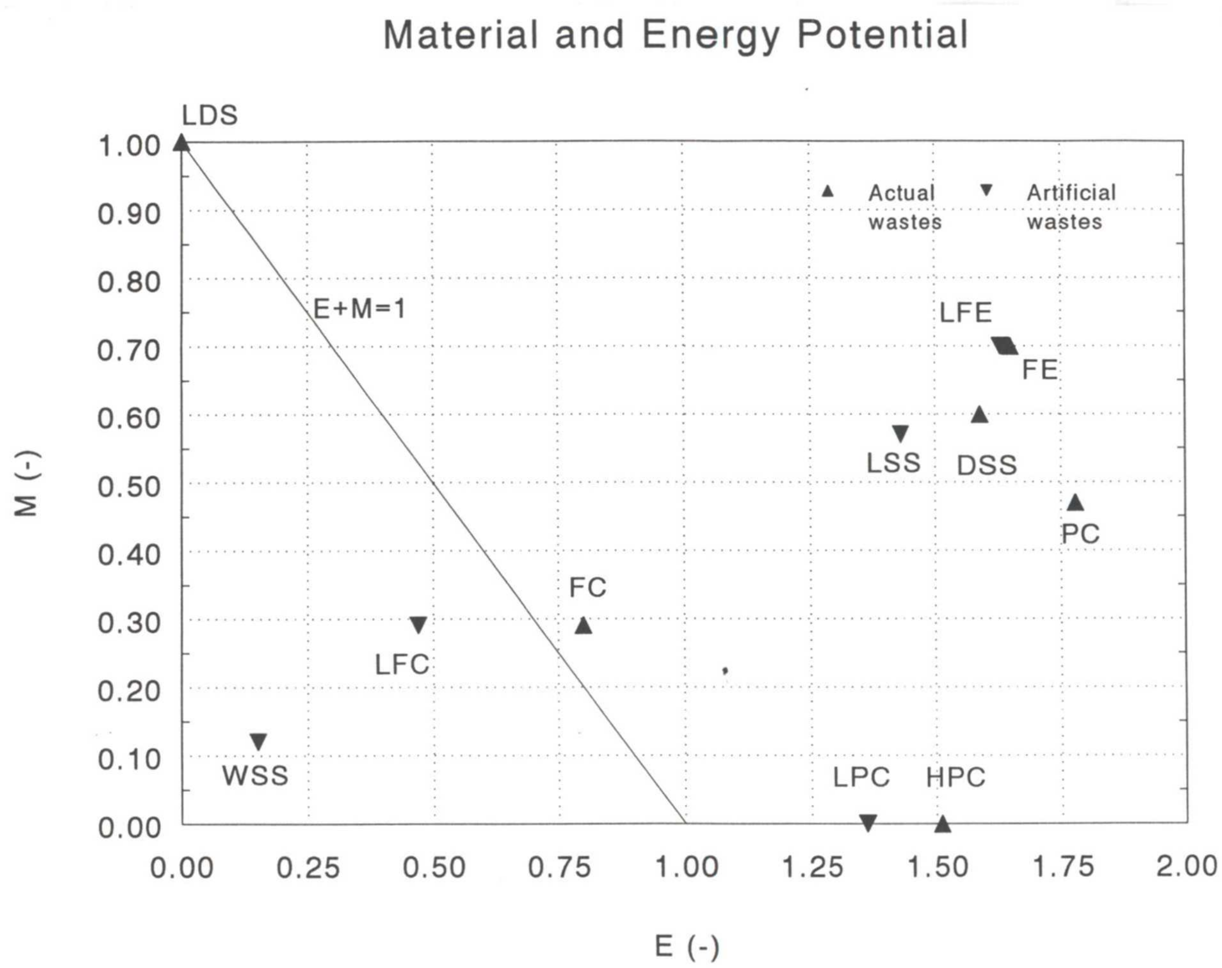


Figure 4.1 *MEP scheme: Materials and Energy Potential scheme. Values from Tables 4.3 and 4.4 are used*

4.2 Waste pre-treatment and valorization

In Chapter 4.1, the Materials and Energy Potentials (MEP-values) for dry sewage sludge (DSS) and wet sewage sludge (WSS) are calculated to illustrate the MEP-method. It is concluded that DSS processing is definitely valorization and WSS processing should definitely be classified as elimination.

What influence has pre-treatment, drying in this case, in the MEP-method?

Three aspects are of interest:

- generally, sewage sludge has to be dried to 50% dry solids or higher to make it acceptable for disposal or incineration in a waste combustion facility. Therefore, it is acceptable to consider the dried sewage sludge to calculate the MEP-value;
- it could be reasoned that it is efficient to feed the wet sewage sludge directly into the kiln to integrate drying and combustion in the cement kiln. Efficiency of processing wet sewage sludge may improve from an economical point of view but also energetically (and thus environmentally). In other words, it may be more favourable to process WSS in the cement kiln than processing WSS via an external drying followed by processing inn a cement kiln;
- to assess the environmental consequences of this approach is not within the scope of the MEP-method. It requires an in-depth environmental analysis (for example an approach by Life Cycle Analysis methods) to evaluate this working method.

The MEP-method quantifies whether waste pre-treatment results in a waste that can be valorized in the cement process. Whether the waste should be evaluated before or after pre-treatment should be based on other considerations.

4.3 Theoretical wastes and MEP values

For a number of theoretical waste compositions MEP values have been calculated to show some relations and sensitivities. For simplicity, the waste is composed of an ash fraction, water and an organic fraction. The ash fraction is supposed to consist completely of useful components. The organic fraction constitutes the energetic value of the waste. A complete review of the results is shown in Appendix 3.

The following cases have been calculated:

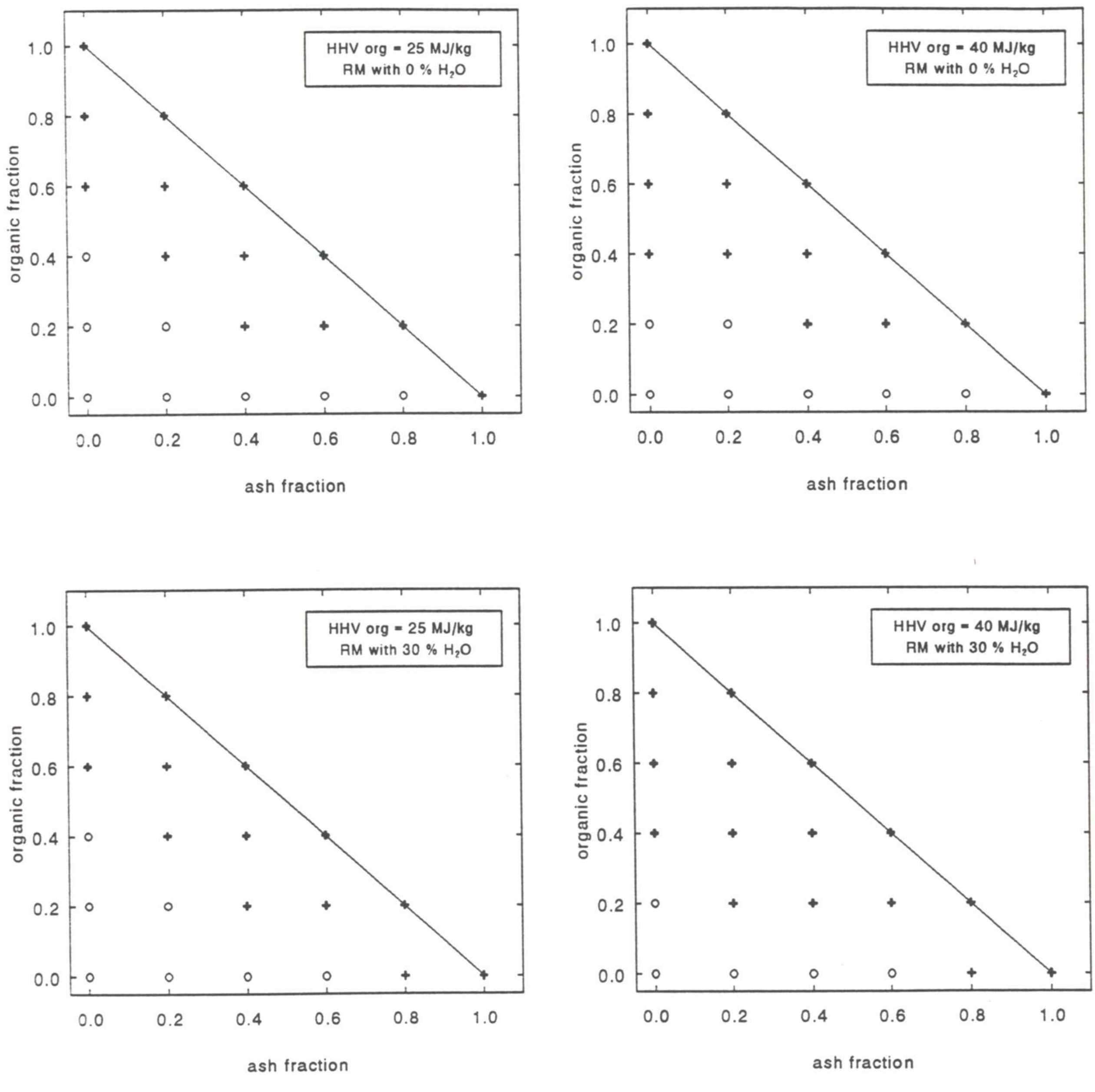
- with an organic fraction with a low High Heating Value (HHV=25 MJ/ton) and with a high HHV (40 MJ/ton);
- with a raw materials fraction with up to 30 % water as defined in the standard approach of TNO for the wet-cement process and with a raw materials fraction containing 0 % water. The latter case is illustrative for the results of the MEP method when applied to the dry-cement process.

In Figure 4.2 the resulting conclusions from the MEP method is illustrated in graphs showing areas of waste compositions that are valorized or eliminated, respectively.

In Appendix 3, results are included of combustion temperature calculations based on the Eurits approach (see Chapter 2 and [21]) for hazardous waste. According to this approach waste co-icineration is acceptable if the waste as such can reach a combustion temperature of 1100 ^{0} C at 6 % O_2 and 10 % energy loss. It is shown in the Appendix 3 that the results of the thermal analysis of the MEP largely coincides with the Eurits method, the difference being that the MEP method first sets apart the raw materials fraction. In Table 4.5 the waste compositions are summarized that result in different conclusions for both methods. It can be seen that these differences occur for waste compositions with a high ash content.

Table 4.5 Waste compositions resulting in different conclusions between MEP method on valorization and Eurits approach on co-incineration (HHV = High Heating Value of organic fraction)

ORGANIC FRACTION	HHV MJ/kg	WATER	ASH FRACTION	MEP METHOD	EURITS on co-incineration	NUMBER (see appendix 3)
0.20	25	0.40	0.40	valorization	no	13
0.20	25	0.20	0.60	valorization	no	16
0.00	–	0.20	0.80	valorization	no	19
0.20	40	0.60	0.20	valorization	no	28
0.20	40	0.40	0.40	valorization	no	32
0.00	–	0.20	0.80	valorization	no	38



+ = valorization o = elimination

Figure 4.2 *Results of MEP method for theoretical waste compositions containing ash, water and an organic fraction (RM = 30% for the wet cement process, RM = 0% for the dry cement process). The HHV o the organic fraction is indicated.*

5. Discussion of the method and the results

M is defined in a way that it indicates, per ton of waste, the saving in tons of raw materials. The water and other components introduced in the wet-cement kiln with the primary raw materials are included in the definition of the raw materials fraction. The water fraction involves that the definition of **M** is specific for the wet-cement process.
For a dry-cement process, this water fraction would not be included and as a consequence, the wet-cement process has an advantage for wet wastes in this approach.
Allocation of (a part of) the water fraction to the raw materials fraction promotes a judgement in favour of valorization. First, the measure **M** increases and, second, the combustion temperature rises because the rest fraction contains less water. This effect is most clearly seen for wastes with a high ash content.

The MEP-methods allows up to 10 % (as a preliminary value) of non-functional inorganics in the raw materials fraction. One might think that as a result, a very high concentration of heavy metals is allowed in the waste. Therefore, it is emphasized that the general conditions, mentioned in Chapter 3.2, should be fulfilled: emission, product quality health aspects etcetera should be within the existing limits. As a consequence, there will be limits to the amounts of heavy metals.

E is an indicator of the energy contribution (or need) of the non-raw materials fraction, the rest fraction, of the waste.
If $\mathbf{E} \geq 1$, the rest fraction can produce an energy surplus at the process conditions in the kiln. The waste can be regarded as the sum of two fractions, both contributing to the cement process: one fraction is a substitute for natural raw materials, the other produces energy. In this case, the waste as such can be processed in the kiln with a positive contribution to the cement-making process and it is proposed to see this as a clear case of waste valorization.

In case $\mathbf{E} < 1$, **E** indicates to what extent the rest fraction is self-supporting with respect to the energy demands of the cement process. In this situation, the raw materials fraction should be so important that it compensates for the energy shortage of the rest fraction. Weighing of these energy and mass aspects against each other may be possible in specific cases by a Life Cycle Analysis approach. Here, as a general arbitrary starting point for discussion it is chosen that for valorization: $\mathbf{E} + \mathbf{M} \geq 1$.

With **M** approximately 0 and **E** equal to 1 or slightly higher (the LPC waste is almost an example), the contribution to the cement production is small and it may seem questionable that this is valorization. However, the waste can be processed without energy demand and the conditions are formulated so that there

Appendix 1 The wet-cement process of Ciments d'Obourg

The present cement production at Ciments d'Obourg has been used as a case study to illustrate the present situation of waste valorization and elimination.

A.1.1 The production process

The cement production can be divided into two main parts: (1) heating of raw materials to form clinker which is cooled and (2) grinding of the clinker and mixing with a small amount of gypsum, fly ashes and other materials to produce cement [8].

The heating process occurs in the cement kiln. At Ciments d'Obourg, two kilns are used (length 202 and 227 m, respectively, and diameters of 6.75 and 7.16 m, respectively) to produce about 1,500 ktons of clinker per year. The rotating cylinders are lined with heat-resistant bricks. The residence time of the raw materials in the kiln is about two hours and 45 minutes. Figure 2.1 gives a process scheme.

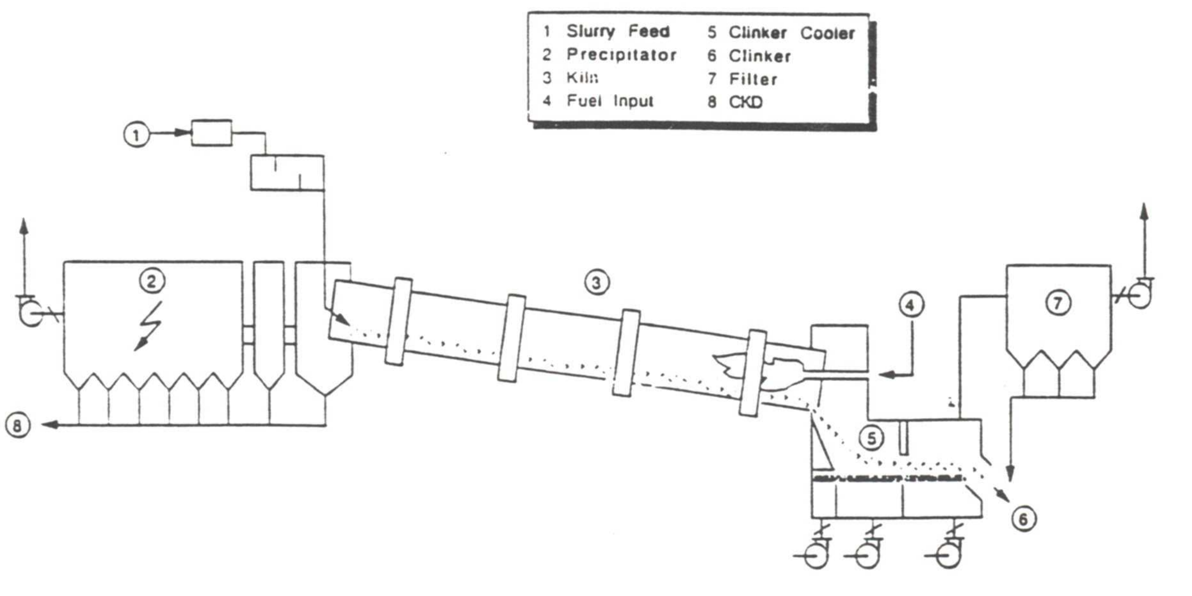


Figure A.1 Typical Wet Process Cement Kiln.

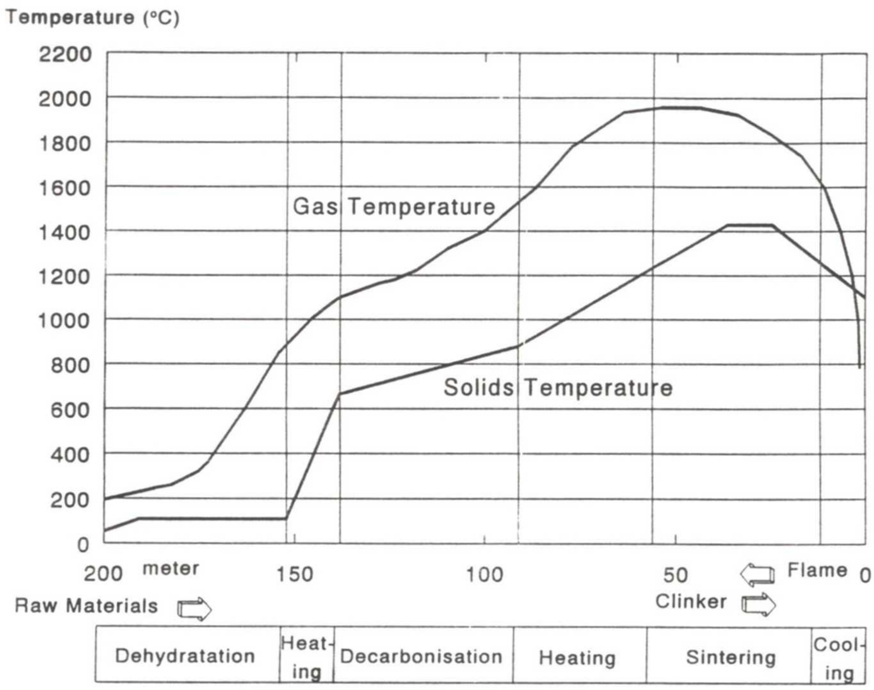


Figure A.2 Temperature profiles in cement kiln

Clinker is produced by feeding blended and ground raw materials (such as limestone, clay, sand and iron ore) into the cement kiln and burning them under controlled high-temperature conditions. The raw materials are fed at the elevated end and, through the rotations of the kiln, move slowly down towards the firing end where heat is applied with coal, gas or oil flame.

Clinker may be produced by one of three different processes: the wet, semidry, or dry process. The Ciments d'Obourg process is a wet process, since the limestone near Ciments d'Obourg contains about 30 % water. In the wet process, the slurry is fed directly into the inclined end of the kiln. The water promotes homogenization of the mixture. Evaporation of water from the kiln feed requires both a cement kiln with a long dry and preheating zone and a substantial energy requirement.

The temperature profile of the cement kiln is depicted in Figure A.2. Waste materials can be fed at the low temperature end or the high temperature end of the kiln. Wastes containing volatile organics are fed with the fuel replacing wastes at the high temperature zone. Ciments d'Obourg is currently introducing a mid-kiln feeding device enabling waste feeding in batches in the middle of the kiln.

Besides the clinker, residues such as smoke chamber dust, ESP filter dust and stack dust are generated. The smoke dust and ESP filter dust are partly recycled in the cement kiln and (to prevent accumulation of volatile metals as Hg and

Tl) partly mixed in the second part of the cement production: clinker, gypsum and dust mixing. None of the generated dusts are landfilled or otherwise handled outside Ciments d'Obourg.

Scoribel (51 % owned by Ciments d'Obourg) pretreats some of the waste materials before feeding them into the cement kiln. Scoribel delivers waste materials only to Ciments d'Obourg which uses these materials as a fuel for the cement process. Scoribel can be characterized as a pre-treatment center for small waste flows. It takes care of the commercial aspects, legislation and chemical analysis of small waste streams which cannot be fed directly into the kiln at Ciments d'Obourg because the waste streams are typically:
1. too small in volume and/or
2. impossible to feed directly because of the material's physical structure.

Scoribel provided about 24,000 tons of 'waste fuel' to Ciments d'Obourg; about 166,000 tons of fuel material are fed directly to the cement process.

A.1.2 Raw materials (primary and secondary)

The production of cement requires the following components: calcium carbonates, silica, alumina and iron oxide. To obtain the desired composition of the components, the following raw materials are used:

- limestone (> 95 % d.s. calcium carbonate and up to 30 % water)
- coal ash (providing silica and alumina)
- LD steel slag (providing iron oxide).

The proportion of the raw materials in the second part of the cement production depends on the type of cement that is being produced. Portland cement requires a clinker to gypsum ratio of 14 to 1. Composite cement (also produced at Ciments d'Obourg) consists of clinker, blast furnace slag, ESP fly ash and gypsum. One of the requirements of European regulation is a maximum chloride content in all cement of 1000 mg/kg.

The mixture of energy sources must have an energy content of about 15.5 - 16.4 MJ/kg. For this, the actual situation is (average 1995):
1. % coal
2. % hazardous waste
3. % crude oil or gas.

Ad 1. Rich coal as well as poor coal is used. Poor coal consists of 55 % ash and 10-15 % volatiles and has an energy content of 10-12.5 MJ/kg. The rich coal ash contains only 40-42 % ash and 20 % volatile, while the energy content is substantially higher (17 MJ/kg) than for poor coal. The ash in the coal is beneficial as raw material.

Ad 2. Typically 10 % solvent and 20 % solid waste fuel are used. The mixture of waste fuel is produced at Scoribel. As given in the permit, the amount of solvent is limited to 50,000 tons annually. However, the market is limiting the use to 25,000-27,000 tons a year. Therefore, primary fuel and gas are still needed at Ciments d'Obourg.

Ad 3. For temperature reasons (flame temperature more than 2000 °C, material at 1450 °C), fuel or gas with a high calorific value is required. At least 20 % of the total energy must have a calorific value of over 25 MJ.

Besides these materials, used water (maximum 20,000 tons/year) is injected in the flame, although water elimination is not an interest of Ciments d'Obourg. The total amount of water (used water, water in liquid fuel and solid fuel) is at most 7 % per unit of clinker produced.

Examples of waste that are used at Ciments d'Obourg include:

In liquid form
- solvents (up to 6 % Cl), aliphatics and aromatics
- used oils
- paints, glue, grease, hydrocarbon sludges.

In solid form
- all types of sludges, organics, minerals
- distillation bottoms in sludge and solid form
- absorbent, used catalysts, contaminated soils, filtration earths
- contaminated plastics, rubber, wood, textiles.

Waste materials which may be used in the near future are:
- non-hazardous waste: plastics, paper, textiles, waste wood
- sewage sludge;
- R.D.F. from municipal refuse.

A.1.3 Acception criteria

Depending on the type of waste, different restrictions are made by Ciments d'Obourg:

Waste used as a secondary fuel
- minimum calorific value for autothermal energy recovery: 10.5 MJ/kg; below this value, it is difficult to maintain a flame.

Waste recycled as alternative raw material, either purely mineral or mixed mineral organics
- if the waste contains organic compounds it is only injected in the burning zone;
- ash content between 5-100 %;
- ash chemical composition: $CaO + SiO_2 + Al_2O_3 + Fe_2O_3 + SO_3 > 80$ %
  (if SO_3 is available in the ash, less gypsum is needed. On the other hand, the amount of SO_3 is limited because of emission legislation).

Waste elimination without energy recovery or raw material supply
- injected only in the burning zone, as a separate stream
- used only as part of a solution for a local/regional waste problem
- if no better economic and ecological solution is available.

The actual legal approval at Ciments d'Obourg (October 1994) is delivered by the Walloon Ministry of Environment to enable Ciments d'Obourg to handle hazardous waste up to:
- for waste valorization: 180,000 tons/y in solid form
  50,000 tons/y in liquid form
- for waste elimination: 20,000 tons/y as used water

The alternative fuels are controlled using several tests, as stated in Table A1.1.

Table A1.1 Maximum limits for alternative fuels at Ciments d'Obourg.

General parameters	Maximum limit	Heavy metals	Maximum limit
flash point	> -10 °C	cadmium	100 mg/kg
total chloride	6 %	mercury	10 mg/kg
F + Br + I	2000 mg/kg	thallium	100 mg/kg
sulfur	3 %	beryllium	50 mg/kg
total cyanides	100 mg/kg	arsenic	200 mg/kg
nitriles	800 mg/kg	cobalt	200 mg/kg
PCB	30 mg/kg	nickel	1000 mg/kg
selenium	50 mg/kg	tellurium	50 mg/kg
antimony	50 mg/kg	lead	1000 mg/kg
chromium	1000 mg/kg	copper	1000 mg/kg
vanadium	1000 mg/kg	zinc *)	5000 mg/kg

*) this zinc limit implies that used tyres cannot be used.

Appendix 2 Interviews with experts

To gain information about the points of view regarding valorization/elimination of hazardous waste in cement kilns, several prominent people have been interviewed. The results of the interviews are given in this appendix.

A.2.1 Proposal from the Landesumweltamt Nordrhein-Westfalen (January 1996)

Mr H.D. Winkler[1] has been interviewed to explain the viewpoint held by the Landesumweltamt Nordrhein-Westfalen. This is a governmental department in Germany concerned with environmental aspects. Mr H.D. Winkler is specifically concerned with air polluting emissions. In his position, he is also concerned with the question of whether a material can be regarded as a waste material or as a secondary material.

In Germany, more and more alternative materials are used in the cement incinerators *e.g.* municipal waste (without non-burning wastes), tires, plastics and diapers. These materials are used as alternative fuels and as alternative raw materials. In Germany, it is permissible to incinerate up to 25 % alternative materials in a cement kiln. If more alternative materials are used, stringent (emission) measurements must be made.

Materials cannot be exported abroad if they are considered waste materials. However, if the materials are seen as secondary materials, export permissions can be given.

In this respect, the 'Landesumweltamt' wants to have a clear view as to which materials can be appointed as secondary materials. The following idea has therefore been worked out.

Point of view

In Germany, a separation has been made between materials which can be seen as substitutes of primary fuels and materials which can be seen as substitutes of raw materials.

To understand in which case a material can be considered a secondary fuel, the following scheme has been developed.

---

1 Dipl.-Ing. H.D. Winkler, Landesumweltamt Nordrhein-Westfalen, P.O.-Box 10 23 63, 45023 Essen, Germany

1. Is the material a commonly used fuel ?
   In case a material is included on the list of 'Common used Fuels', it is not necessary to test the material in this scheme. It can be used as common fuel.
   In case it is not a commonly used fuel, it has to be determined if it can be seen as a secondary fuel.

2. Is the material a waste material or not ?
   To test in which class the material has to be classified, three aspects are important:

   2a. Kind and amount of pollutants
   This aspect depends on product characteristics. The amount of pollutants is related to the energy content of the product [mg/MJ]. This amount has to be compared with the given limits (Table A.2.1). These limits are based on the amount of pollutants per energy content in natural fuels. For every element the highest amount of element per energy content found has been chosen.
   If the alternative fuel meets the limits, it can be used as an alternative fuel in every kind of incineration process.

   2b. The amount of waste of the process
   This aspect does not depend on the product, but on the process in which the material will be handled. In the case of the cement industry, no waste materials are expected.

   2.c. Emissions
   The amount of emissions may not exceed the maximum allowable limits. To translate this criteria into the maximum values of pollutants in the waste, the following train of thought has been made:

The gaseous limits of elements and the amount of gaseous emission of a cement process give the amount of elements which may leave the process [amount/time]. This amount has to be related to the amount of elements in the starting material. The volatility of the different elements has been used for this: a percentage of each element which is probably going into the air, regarding the circumstances in the cement process, has been determined[1].
If the amount of an element which may leave a process via the air is known [amount/time] and if it is known which percentage of an element will leave the process via gaseous emissions [percentage via gas], the amount of each element in the starting material can be calculated:

---

1 For example, it is expected that about 99 % of the amounts of Hg and T in a starting material will go out of the system via air. This amount will be less for Cd and Pb (about 20 %). Other elements like Be, Cr, Ni, V and Zn are even less volatile; only about 10 % will leave the system via the air.

$$AS = AA / P * 100\ \%$$

in which:
AS = amount of element in starting material per time unit
AA = allowable amount of an element in gas per time unit
P = percentage of the element which will leave the process via gas

The gaseous-emission levels of heavy metals strongly depend on the used fuels as well as on the process. Therefore, the calculations have to be made for every kind of process separately. It has been calculated by Landesumweltamt Nordrhein-Westfalen for the cement industry exclusively. To meet the calculation errors, 50 % of the calculated amount of elements in the starting material has been given as the limit.
This limit is public since February 1996 (Table A.2.2).

2d. The use of the material has to be within the legal limits.

2e. A contamination of elements in the system is not allowed.

If a material meets all the criteria stated above, it has to be tested further, based on more politically-based aspects (point 3):

3. Is the material a secondary fuel or a secondary raw material?
   This question has to be answered in four parts:
   3a. Is the energy content larger than 11 MJ/kg
       It is determined by law that a fuel material has to have at least an energy content of 11 MJ/kg. Otherwise, it cannot be characterized as a fuel.
   3b. Amount of fuel content that can be used
       The amount of the fuel content which is used in the total handling system must be at least 75 %. This is given by law. Ciments d'Obourg reaches 92 % [15].
   3c. Is the heat which is generated in the incineration process recovered and used (within or outside the process)
   3d. Can all waste that is generated during processing, be handled?

Finally, a material is considered a secondary fuel if it can also fulfil these four aspects (3a-d).

The quality of the clinker and the cement itself (DIN-1164-1) is not a point of consideration, according to the 'Landesumweltamt'. It is felt that this aspect is not their concern, but rather that of the cement industry.

The formulation of rules to determine whether a material can be seen as a secondary **raw** material or as a waste material is not yet finalized. It is expected that it will have the same kind of design as Scheme 1 (i.e., based on emission limits). As a starting point it is said that waste materials which are added to the cement kiln and as a result substitute primary raw materials (even as low as 0.01 % !) can be regarded as valorization as long as the gaseous emissions do not exceed the maximum allowable limits. The quality of the clinker and the cement are again of concern of the cement industry itself.

Some final remarks:

- some materials have a combined function in the cement kiln: raw materials substitution as well as fuel substitution. The German law has no rules with respect to valorization and elimination of these kind of materials;

- the amount of chlorides has to be limited also because of the risk of too much chloride-containing components at the kiln wall;

- materials may be mixed with saw dust if this is technologically needed.

Table A.2.1 Limits for alternative fuels based on contaminants in commonly used fuels.

Element	Limits [mg/MJ]
Be	0.13
Cd	0.3
Hg	0.06
Tl	0.15
As	1.9
Co	1.2
Ni	3.5
Se	0.2
Te	0.04
Sb	0.07
Pb	10
Cr	3.7
Cu	3.7
V	6.7
Sn	0.4
Zn	8
S	740
Cl	60
F	14

Table A.2.2 Limits for alternative fuels based on expected gaseous emissions.

Element	Limits [mg/MJ]
Be	3
Cd	6
Hg	0.6
Tl	5
As	25
Co	20
Ni	40
Se	2
Te	2.5
Sb	10
Pb	80
Cr	60
Cu	80
V	70
Sn	30
Zn	800
S	1500
Cl	2500
F	2500
PCB	50 mg/kg
PCP	5 mg/kg
Calorific value	11 MJ/kg

A 2.2 Directives from and discussions in the European Union

EC Directive

The industrial countries are more and more considering the fact that natural resources are limited and that protection of our environment is a necessity. In the legislative fields, this has led to a European Directive 75/442/EEC on waste specifying that

'Members States shall take appropriate measures to encourage:

- firstly, the prevention or reduction of waste production and its harmfulness, in particular by:
  - development of clean technologies more sparing in their use of natural resources,
  - technical development and marketing of products designed so as to make no contribution or to make the smallest possible contribution, by the nature of their manufacture, use of final disposal, to increase the amount of harmfulness of waste and pollution hazards,
  - the development of appropriate techniques for final disposal of dangerous substances contained in waste destined for recovery;

- secondly:
    - the recovery of waste by means of recycling, re-use or any other process with the view
    - to extract raw materials, or,
    - the use of waste as a source of energy'.

According to EU directives, waste treatment, recycling and energy recovery should be promoted with the following priorities:

1. Waste minimization
2. Waste re-use
3. Waste recycling
4. Waste incineration with energy recovery
5. Waste incineration
6. Landfilling

In DG XII of the European Commission, a discussion is going on with external representatives and is organised in the 'Forum on Waste'. Their (possible) approach was discussed with Mr Bemtgen of DG XII. Major aspects concerning the cement industry are given below [10].

- When ranking waste management systems:
    - landfill must receive the lowest priority, and will be completely banned except for fatal waste, at the horizon 2002;
    - prevention is the most recommendable practice;
    - it is impossible to establish a rational hierarchy between the other routes for waste management, at the present level of development of analysis tools.

- Any waste management process must aim at maximizing the socio-economic added value and minimizing the environmental impact.

- When considering the 'energy from waste' route its environmental impact must be evaluated by subtracting from the impact of the operation, the impact of fossil fuel combustion and the impact of dumping, composting, recycling etc. the waste (its normal fate if not burnt).

- The APAS Clean Coal Technology programme (EC, DG XII) has shown clear evidence of synergistic effects when co-firing or co-gasifying waste and fossil fuel, for both the emissions and the effluents.

- It has also be shown that the management of reuse of solid by-products (slag, fly-ash, gypsum, sulphur and other solid residues) resulting from co-firing waste and fossil fuel stays under control.

- Co-firing in large scale units is technically, environmentally and economically more attractive than mono-firing in smaller units or incineration with low energy recuperation.

- For technical reasons (ash handling, fuel feeding etc.) co-firing of waste with coal is preferred to gas or oil.

- Co-firing in existing cement kilns saves fuel. The inclusion of fly ashes in the clinker also saves feedstock and eliminates the dumping of the ashes and may improve the product quality.

On the basis of these points, a concept of consecutive utilization is proposed [2]. The added value from a given product over its whole life is gradually reduced and at its end it is converted back to fuel, e.g.:

wood → paper → low-grade paper → cardboard → insulation material → combustion with electricity generation → heating with waste heat oil → plastic → low-grade plastic → combustion with electricity generation → heating with waste heat

It is concluded that neither the origin nor chemical or physical, nor technical nor economic arguments permit to clearly distinguish between fuels and wastes. All those involved will have to co-operate to optimize the full chain from the primary product through all possible transformation stages up to the very final energy recovery.

A.2.3 Discussion paper Dutch Ministry of Environmental Affairs (January 1996)

Mr H. Meijer of the Ministry of the Environmental Affairs (VROM) in the Netherlands has been interviewed to give the point of view of this ministry[1].

Mr Meijer has been working on the subject of discriminating between elimination and valorization of wastes in thermal processes. As a result of internal discussions and studies, a draft proposal has been formulated that defines criteria for the difference.

The proposal has been prepared to have a framework for the evaluation of requests to export waste for treatment abroad. Generally, export is only considered when there is a lack of waste treatment capacity in the Netherlands or if treatment abroad can be considered a valorization of the waste. Valorization of waste is considered to be more valuable than elimination and in these cases export can be allowed.

[1] Mr. Meijer has another function at the moment; his successor is Mr. C. den Herder.

However, in the case that product recycling in the Netherlands is possible, export will not be allowed even if valorization abroad is an option. Product recycling, for example the distillery of solvents, is seen as a "higher" stage of treatment. This policy is formulated in the "Meerjarenplan verwijdering gevaarlijk afval (Mjp-ga)" (Long-term plan for the elimination of dangerous wastes).

The use of a waste is considered to be a form of valorization in case the waste is directly used in a production or treatment process to replace fuels. The waste must have a calorific value of at least 15,000 kJ/kg.

This criteria is based on a minimum positive contribution of the energy need and the temperature of the waste to the cement process.

In all cases of valorization of the waste, the relevant regulations should be fulfilled. However, the testing and enforcement of the regulations is in the hands of the local authorities (within the European Union).

Major points of discussion could be:
- The "simplicity" rule results in criteria that are not differentiated with respect to the considered thermal process. The criterium for energy valorization in a power station is the same as for the cement process.
- Furthermore, wastes that combine an energetic value with a substantial content of raw material are not considered.

These options have been considered but rejected because they are considered to be too complicated for a sufficiently practicable application and enforcement.

Another ongoing discussion closely related to this subject is the definition of a waste as a secondary raw material. This problem is currently being discussed with a number of industries and industrial organizations who have the opportunity to comment on this subject.

A general criterium could be that a waste is defined as a secondary raw material when the application in a production process is ensured.

A.2.4 Discussion paper of OVAM (February 1996)

With representatives of OVAM, the Flanders Waste Authority, the problem of valorization in the cement industry has been discussed in an informal way. OVAM has produced a discussion paper proposing conditions for valorization of waste.

Basic principles are:
- no distribution of harmful components in the environment;
- mixing of materials to meet acceptance limits is not allowed;
- the calorific value of waste should be sufficient to reach the required temperature level.

Heavy metals and acids, absorbed in the clinker, do not positively contribute to the cement quality. Therefore, the principle of non-dilution applies.
A waste with a calorific value above 25 MJ/kg is valued positively, with 15 to 25 MJ/kg it is valued neutral, and below 15 MJ/kg negatively.
For a positive contribution as a source of raw materials, it is demanded that the ash residue (at 600 °C) contains more than 10 % Si, Ca, Al, and Fe.
This discussion paper then summarizes that wastes processing in a cement kiln is considered to be valorization, if:
- the calorific value exceeds 25 MJ/kg and the concentration limits in table 5.5.1 are met;

or
- the calorific value is more then 15 MJ/kg, the concentration in the waste of Ca, Si, Al, and Fe is more than 10 % and the concentration limits are not exceeded.

Table A.2.3 Limits for valorization of wastes in cement kilns proposed in the OVAM-discussion paper.

Elements	Limits
Cl	1 %
F+BR+I	1 %
S	3 %
N	1 %
Na	1.5 %
K	1.5 %
Cd	10 mg/kg
Be	10 mg/kg
Hg	2 mg/kg
Sb	10 mg/kg
Zn	500 mg/kg
Pb	200 mg/kg
V	200 mg/kg
Cu	200 mg/kg
Co	200 mg/kg
Cr	200 mg/kg
Ni	200 mg/kg
Ash residue, excluding Ca, Si, Al, Fe	200 mg/kg

If these conditions apply, waste incineration is considered to be valorization. Nevertheless, a waste tax applies to stimulate the recycling of wastes, e.g. of solvents.

If the conditions do not apply, processing in a cement kiln can be acceptable, but is considered to be elimination of the waste.

A.2.5 Viewpoint of Ciments d'Obourg

In conformity with the EU directives, Ciments d'Obourg wants to promote waste recycling and energy recovery.

For Ciments d'Obourg, this implies that, for valorization, waste has to give an added value to the cement production. Specialized incinerators are important tools in waste management with respect to waste elimination.

Ciments d'Obourg promotes and follows a clear and transparent policy: all information is available to the authorities and the neighbourhood.

Technical principles
The technical starting points stated by Ciments d'Obourg can be summarized as follows:
- Ciments d'Obourg has to apply a wet process since the limestone contains 30 % water.
- Pretreatment of waste, whenever necessary, ensures optimum combustion and raw material recovery.
- Pretreatment will never be applied to enable waste to be treated in an environmentally less favourable way.
- Ciments d'Obourg takes care that residual pollutants (trace elements) from wastes which are bonded mineralogically in the clinker stay within traditional ranges.

Criteria for energy and material recovery
Ciments d'Obourg classifies a material as energy valorization from the first calorie useful for the clinker processing. Types of fuels and secondary raw materials which are currently used in the cement industry are given in the following table.

Table A.2.4 Types of fuels and secondary materials.

Energy content	Remarks
3 MJ/kg	minimum energy content for energy recovery (maximum required for water evaporation)
7 MJ/kg	self-combustion
16 MJ/kg	average calorific value of mixed fuels for clinker production
25 MJ/kg	20 % of the total energy must be supplied by fuel with a calorific value > 25 MJ/kg

With respect to the raw material part of a (secondary) material, it is stated that every amount of raw material which has positive value to the production process is considered recycling in the cement process.

Waste impact on cement/concrete qualification
Cement and concrete have, in any case, to fulfil all existing norms on quality and environmental aspects, *e.g.*:
- setting and strengths development;
- all normalised leaching tests for building materials must be investigated.

The pollutants are bound mineralogically in the clinker and have to stay within traditional ranges of concentrations.

Pre-treatment of waste is done when necessary to ensure optimum combustion and raw material recovery. Pre-treatment will never be applied to enable waste to be treated in a less environmentally favourable way.

Emission standards
For specific process emission parameters, Ciments d'Obourg applies BATNEEC. This implies that for some parameters, it is not economically reasonable to reach the emission norms which are common for the specialized incinerators. These parameters are:
- dust;
- NO_x;
- pollutants mainly coming from oxidation on natural compounds in raw materials: CO, TOC SO_2.

For other pollutants, the EU directive 94/67 (December 1994) concerning hazardous waste incinerators, is followed. The pollutants are:
- gaseous compounds such as HCl, H_2S, HF, etc.
- heavy metals
- dioxins and furanes.

The emissions are controlled continuously for dust, CO, O_2, SO_2, NO_x and TOC. The gaseous compounds and heavy metals are measured every month. Furthermore, the complete heavy metal balances are made annually.

Waste composition

The starting points are:

- clinker production of 1500 000 tons annually,
- the average heavy-metals content of the alternative fuel is similar to the actual situation,
- the maximum limit proposed is based on maximum clinker pollutants concentration following Buwal (Swiss Government of Environmental Affairs) [18] and Graf comments, October 1994,
- the maximum limit is calculated separately for the Scoribel entrance and CDO entrance.

The following train is made (cobalt is described as an example):

- It is said that in 1994 the average alternative fuels comprise, among other heavy metals, 22.9 mg/kg cobalt. In case the 185 000 tons of alternative fuel have to be substituted by coal (45.11 mg/kg cobalt) 200 000 tons of coal are needed.
- The clinker of Ciments d'Obourg presently contains 30.3 mg/kg cobalt, which is partly due (11.8 %) to the alternative fuel.
- If fuel containing 45.11 mg/kg instead of 22.9 mg/kg cobalt is used, the cobalt content in the clinker from the coal will be about 22 % ((45.11 / 22.9) * 11.8 %).
- In 185 000 tons of alternative fuel, 22.9 mg/kg cobalt is present (total of 4.2 tons) and in 1500 000 clinker, 30.3 mg/kg cobalt is present (total 45.45 tons). So, 45.45 minus 4.2 tons cobalt (41.35 tons) originate from other resources. Calculations show that 90.6 % (41.35 / 45.45) of the cobalt originate from the other raw materials.
- Therefore, 90.6 % of the cobalt originate from the other raw material containing a certain amount of cobalt and 9.4 % of the cobalt originate from the alternative fuel containing 22.9 mg/kg cobalt. The clinker contains 30.3 mg/kg cobalt.

This gives the following equation:

$$0.094 * 22.9 + 90.6 * x = 30.3,$$

resulting x = 31.06 mg/kg (= cobalt in the other raw materials).

- If coal is used instead of alternative fuel, the same equation as above describes the cobalt content in that case; 32.9 mg/kg cobalt will be present.
- The maximum limit proposed by BUWAL [18] is 50 mg/kg.

– Starting from the maximum limit of 50 mg/kg, the train can be made in the opposite direction, and the amount of cobalt in the starting materials can be found.

This gives an idea of the maximum amount of different metals in the starting materials which can be used, without the risk that the amount of the metals in the clinker will pass the limit given by Buwal.
In other research work it has been found that the emissions do not increase if alternative fuels are fed into the process.

Appendix 3 More examples of MEP calculations and comparison with Eurits method

A number of theoretical waste compositions have been calculated to show some sensitivities and to compare the conclusions on valorization with the conditions formulated by Eurits for co-incineration. For simplicity, the waste is composed of an ash fraction, water and an organic fraction. The ash fraction is supposed to consist completely of useful components. The organic fraction constitutes the energetic value of the waste.
The results are shown in Tables A.3.1 to A.3.4.

The following cases have been calculated:

- with an organic fraction with a low High Heating Value (HHV=25 MJ/ton in Tables A.3.1 and A.3.3) and a high HHV (40 MJ/ton in Tables A.3.2 and A.3.4);

- with a raw materials fraction of 30 % as defined in the standard approach of TNO for the wet-cement process in Tables A.3.1 and A.3.2 and with a raw materials fraction containing 0 % water in Tables A.3.3 and A.3.4. The latter case is illustrative for the results of the MEP method when applied to the dry-cement process.

The tables contain the following information:

- the mass fractions organics, water and ash;

- the resulting raw materials measure **M**;

- the conclusions of the MEP method with respect to valorization or elimination and of the Eurits method on co-incineration;

- the composition of the rest fraction as defined in the MEP method: the waste minus the raw materials fraction;

- the autothermal combustion temperature of the rest fraction for the reference conditions defined in the MEP method and its heating value, followed by combustion temperatures calculated at deviating conditions to show some sensitivities;

- the combustion temperature of the waste as such under the conditions defined in the Eurits approach for co-incineration of hazardous waste and the heating value of the waste as such. The Eurits condition for co-incineration is that this temperature is above 1100 °C;

- the **E** and **E** + **M** values, following from the MEP combustion temperature.

From the calculation examples 3 and 4 (Table A.3.1) and 23 (Table A.3.2), it can be seen that the thermal limits of the two methods almost coincide. Apparently, the thermal MEP limit of 1500 °C (at 3 % O_2, air temperature 800 °C, 25 % energy loss) gives approximately the same result as the Eurits limit for co-incineration of hazardous waste (1100 °C at 6 % O_2, air temperature 25 °C, 10 % energy loss). Therefore, the difference between the two methods is mainly the result of the appreciation of the raw materials contribution of a waste in the MEP methodology. This is illustrated by the examples 13, 16 and 19 in Table A.3.1.

This result is confirmed by other calculations such as the waste example in the Eurits paper to illustrate the 1100 °C limit. Under the standard conditions of the MEP method, the autothermal combustion temperature of this waste just exceeds 1500 °C.

Allocation of (a part of) the water fraction to the raw materials fraction promotes a judgement in favour of valorization. First, the measure **M** increases and, second, the combustion temperature rises because the rest fraction contains less water. Again, this difference is most clearly seen in the wastes with a high ash content.

HHV Organ fractie 25,00 MJ/ton
RM 30,00 % water

ORG.FR	WATER	ASH	M	TNO Valo-Elim	Eurits Co-incin.	REST water	FRACTION org.fract	LHV rest	T comb	T comb	T comb	T comb	T comb	T comb	T comb	T comb	T comb	T comb	T comb	Eurits T comb	Waste as such Eurits LHV	TNO E	TNO E+M	No.
								O2 in %	3	0	6	3	3	3	3	3	3	0	6	6				
								T inlet air C	800	800	800	25	500	800	800	25	25	25	25	25				
								E efficiency	75	75	75	75	75	50	100	50	100	100	100	90				
1,00	0,00	0,00	0,00	valo	yess	0,00	1,00	22,80	1961	2136	1780	1518	1780	1650	>2500	1293	1873	2113	1634	1498	22,90	1,66	1,66	1
0,80	0,20	0,00	0,00	valo	yess	0,20	0,80	17,80	1835	1981	1684	1425	1665	1550	2318	1211	1745	1944	1534	1408	17,80	1,48	1,48	2
0,60	0,40	0,00	0,00	valo	yess	0,40	0,60	12,70	1654	1763	1533	1280	1501	1405	2047	1089	1557	1716	1387	1275	12,80	1,22	1,22	3
0,40	0,60	0,00	0,00	elim	no	0,60	0,40	7,70	1372	1438	1299	1044	1240	1171	1673	889	1267	1374	1145	1053	8,00	0,82	0,82	4
0,20	0,80	0,00	0,00	elim	no	0,80	0,20	2,60	829	841	815	565	724	706	1006	480	688	732	637	582	2,60	0,04	0,04	5
0,80	0,00	0,20	0,20	valo	yess	0,00	1,00	25,00	1961											1466		1,66	1,86	6
0,60	0,20	0,20	0,29	valo	yess	0,16	0,84	20,60	1864											1343	13,10	1,52	1,81	7
0,40	0,40	0,20	0,29	valo	yess	0,44	0,56	12,90	1608											1139	8,20	1,15	1,44	8
0,20	0,60	0,20	0,29	elim	no	0,72	0,28	5,20	1101											704	3,10	0,43	0,72	9
0,00	0,80	0,20	0,29	elim	no	1,00	0,00	-2,50	800											0		0,00	0,29	10
0,60	0,00	0,40	0,40	valo	yess	0,00	1,00	25,00	1961											1415	13,70	1,66	2,06	11
0,40	0,20	0,40	0,57	valo	yess	0,07	0,93	23,17	1924											1228	8,70	1,61	2,18	12
0,20	0,40	0,40	0,57	valo	no	0,53	0,47	10,33	1488											826	3,60	0,98	1,55	13
0,00	0,60	0,40	0,57	elim	no	1,00	0,00	-2,50	800											0		0,00	0,57	14
0,40	0,00	0,60	0,60	valo	yess	0,00	1,00	25,00	1961											1325		1,66	2,26	15
0,20	0,20	0,60	0,80	valo	no	0,00	1,00	25,00	1961											964	4,10	1,66	2,46	16
0,00	0,40	0,60	0,90	elim	no	1,00	0,00	-2,50	800											0		0,00	0,90	17
0,20	0,00	0,80	0,80	valo	yess	0,00	1,00	25,00	1961											1111		1,66	2,46	18
0,00	0,20	0,80	1,00	valo	no	0,00	0,00	0,00	800											0		0,00	1,00	19

TABLE A.3.1 CALCULATIONS OF COMBUSTION TEMPERATURES AND LIMITS FOR THE ASSESSMENT OF VALORIZATION OR ELIMINATION.
Raw materials fraction with 30 % water

HHV Organ fractie 40,00 MJ/ton
RM 30,00 % water

ORG.FR	WATER	ASH	M	TNO Valo-Elim	Eurits Co-incin.	REST water	FRACTION org.fract	LHV rest	TNO T comb	T comb	T comb	T comb	T comb	T comb	T comb	T comb	T comb	T comb	T comb	Eurits T comb	Waste as such Eurits LHV	TNO E	TNO E+M	No.
								O2 in %	3	0	7	3	3	3	3	3	3	0	6	6				
								T inlet air C	800	800	800	25	500	800	800	25	25	25	25	25				
								E efficiency	75	75	75	75	75	50	100	50	100	100	100	90				
1,00	0,00	0,00	0,00	valo	yess	0,00	1,00	37,10	2027	2240	1824	1548	1828	1695	>2500	1311	1907	2181	1647	1508	37,10	1,75	1,75	20
0,80	0,20	0,00	0,00	valo	yess	0,20	0,80	29,20	1938	2121	1758	1483	1748	1628	>2500	1258	1820	2061	1583	1451	29,20	1,63	1,63	21
0,60	0,40	0,00	0,00	valo	yess	0,40	0,60	21,30	1809	1956	1657	1382	1633	1528	2282	1177	1691	1893	1485	1363	21,30	1,44	1,44	22
0,40	0,60	0,00	0,00	valo	yess	0,60	0,40	13,30	1597	1699	1484	1212	1440	1356	1968	1033	1479	1628	1313	1207	13,30	1,14	1,14	23
0,20	0,80	0,00	0,00	elim	no	0,80	0,20	5,50	1149	1191	1102	835	1024	981	1395	710	1014	1094	923	849	5,50	0,50	0,50	24
0,80	0,00	0,20	0,20	valo	yess	0,00	1,00	37,10	2034											1491	29,80	1,76	1,96	25
0,60	0,20	0,20	0,29	valo	yess	0,16	0,84	31,00	1962											1411	21,80	1,66	1,95	26
0,40	0,40	0,20	0,29	valo	yess	0,44	0,56	19,80	1778											1270	13,90	1,40	1,68	27
0,20	0,60	0,20	0,29	valo	no	0,72	0,28	8,70	1380											940	6,00	0,83	1,11	28
0,00	0,80	0,20	0,29	elim	no	1,00	0,00	-2,50	800											0		0,00	0,29	29
0,60	0,00	0,40	0,40	valo	yess	0,00	1,00	37,10	2034											1458	22,30	1,76	2,16	30
0,40	0,20	0,40	0,57	valo	yess	0,07	0,93	34,50	2003											1332	14,40	1,72	2,29	31
0,20	0,40	0,40	0,57	valo	no	0,53	0,47	16,20	1687											1034	6,50	1,27	1,84	32
0,00	0,60	0,40	0,57	elim	no	1,00	0,00	-2,50	800											0		0,00	0,57	33
0,40	0,00	0,60	0,60	valo	yess	0,00	1,00	37,10	2034											1397	14,90	1,76	2,36	34
0,20	0,20	0,60	0,80	valo	yess	0,00	1,00	37,10	2034											1134	7,00	1,76	2,56	35
0,00	0,40	0,60	0,90	elim	no	1,00	0,00	-2,50	800											0		0,00	0,90	36
0,20	0,00	0,80	0,80	valo	yess	0,00	1,00	37,10	2034											1242	7,40	1,76	2,56	37
0,00	0,20	0,80	1,00	valo	no	0,00	0,00	0,00	800											0		0,00	1,00	38

TABLE A.3.2 CALCULATIONS OF COMBUSTION TEMPERATURES AND LIMITS FOR THE ASSESSMENT OF VALORIZATION OR ELIMINATION.
Raw materials fraction with 30 % water

HHV Organ fractie 25,00 MJ/ton
RM 0,00 % water

ORG.FR	WATER	ASH	M	TNO Valo-Elim	Eurits Co-incin.	REST water	FRACTION org.fract	LHV rest	TNO T comb	T comb	T comb	T comb	T comb	T comb	T comb	T comb	T comb	T comb	T comb	Eurits T comb	Waste as such Eurits LHV	TNO E	TNO E+M	No.
								O2 in %	3	0	7	3	3	3	3	3	3	0	6	6				
								T inlet air C	800	800	800	25	500	800	800	25	25	25	25	25				
								E efficiency	75	75	75	75	75	50	100	50	100	100	100	90				
1,00	0,00	0,00	0,00	valo	yess	0,00	1,00	22,90	1965	2240	1824	1548	1828	1695	>2500	1311	1907	2181	1647	1498	22,90	1,66	1,66	39
0,80	0,20	0,00	0,00	valo	yess	0,20	0,80	17,80	1835	2121	1758	1483	1748	1628	>2500	1258	1820	2061	1583	1408	17,80	1,48	1,48	40
0,60	0,40	0,00	0,00	valo	yess	0,40	0,60	12,80	1654	1956	1657	1382	1633	1528	2282	1177	1691	1893	1485	1275	12,80	1,22	1,22	41
0,40	0,60	0,00	0,00	elim	no	0,60	0,40	8,00	1372	1699	1484	1212	1440	1356	1968	1033	1479	1628	1313	1053	8,00	0,82	0,82	42
0,20	0,80	0,00	0,00	elim	no	0,80	0,20	2,60	829	1191	1102	835	1024	981	1395	710	1014	1094	923	582	2,60	0,04	0,04	43
0,80	0,00	0,20	0,20	valo	yess	0,00	1,00	22,90	1965											1466		1,66	1,86	44
0,60	0,20	0,20	0,20	valo	yess	0,25	0,75	16,60	1796											1343	13,10	1,42	1,62	45
0,40	0,40	0,20	0,20	valo	yess	0,50	0,50	10,20	1531											1139	8,20	1,04	1,24	46
0,20	0,60	0,20	0,20	elim	no	0,75	0,25	3,90	1011											704	3,10	0,30	0,50	47
0,00	0,80	0,20	0,20	elim	no	1,00	0,00	-2,50	800											0		0,00	0,20	48
0,60	0,00	0,40	0,40	valo	yess	0,00	1,00	22,90	1965											1415	13,70	1,66	2,06	49
0,40	0,20	0,40	0,40	valo	yess	0,33	0,67	14,50	1723											1228	8,70	1,32	1,72	50
0,20	0,40	0,40	0,40	valo	no	0,67	0,33	6,00	1236											826	3,60	0,62	1,02	51
0,00	0,60	0,40	0,40	elim	no	1,00	0,00	-2,50	800											0		0,00	0,40	52
0,40	0,00	0,60	0,60	valo	yess	0,00	1,00	22,90	1965											1325		1,66	2,26	53
0,20	0,20	0,60	0,60	valo	no	0,50	0,50	10,20	1531											964	4,10	1,04	1,64	54
0,00	0,40	0,60	0,60	elim	no	1,00	0,00	-2,50	800											0		0,00	0,60	55
0,20	0,00	0,80	0,80	valo	yess	0,00	1,00	22,90	1965											1111		1,66	2,46	56
0,00	0,20	0,80	0,80	elim	no	1,00	0,00	-2,50	800											0		0,00	0,80	57

TABLE A.3.3 CALCULATIONS OF COMBUSTION TEMPERATURES AND LIMITS FOR THE ASSESSMENT OF VALORIZATION OR ELIMINATION.
Raw materials fraction without water

HHV Organ fractie 40,00 MJ/ton
RM 0,00 % water

ORG.FR	WATER	ASH	M	TNO Valo-Elim	Eurits Co-incin.	REST water	FRACTION org.fract	LHV rest	TNO T comb	T comb	T comb	T comb	T comb	T comb	T comb	T comb	T comb	T comb	T comb	Eurits T comb	Waste as such Eurits LHV	TNO E	TNO E+M	No.
								O2 in %	3	0	7	3	3	3	3	3	3	0	6	6				
								T inlet air C	800	800	800	25	500	800	800	25	25	25	25	25				
								E efficiency	75	75	75	75	75	50	100	50	100	100	100	90				
1,00	0,00	0,00	0,00	valo	yess	0,00	1,00	37,10	2027	2240	1824	1548	1828	1695	>2500	1311	1907	2181	1647	1508	37,10	1,75	1,75	58
0,80	0,20	0,00	0,00	valo	yess	0,20	0,80	29,30	1942	2121	1758	1483	1748	1628	>2500	1258	1820	2061	1583	1451	29,20	1,63	1,63	59
0,60	0,40	0,00	0,00	valo	yess	0,40	0,60	21,30	1811	1956	1657	1382	1633	1528	2282	1177	1691	1893	1485	1363	21,30	1,44	1,44	60
0,40	0,60	0,00	0,00	valo	yess	0,60	0,40	13,30	1597	1699	1484	1212	1440	1356	1968	1033	1479	1628	1313	1207	13,30	1,14	1,14	61
0,20	0,80	0,00	0,00	elim	no	0,80	0,20	5,50	1149	1191	1102	835	1024	981	1395	710	1014	1094	923	849	5,50	0,50	0,50	62
0,80	0,00	0,20	0,20	valo	yess	0,00	1,00	37,10	2034											1491	29,80	1,76	1,96	63
0,60	0,20	0,20	0,20	valo	yess	0,25	0,75	27,30	1914											1411	21,80	1,59	1,79	64
0,40	0,40	0,20	0,20	valo	yess	0,50	0,50	17,30	1720											1270	13,90	1,31	1,51	65
0,20	0,60	0,20	0,20	elim	no	0,75	0,25	7,50	1306											940	6,00	0,72	0,92	66
0,00	0,80	0,20	0,20	elim	no	1,00	0,00	-2,50	800											0		0,00	0,20	67
0,60	0,00	0,40	0,40	valo	yess	0,00	1,00	37,10	2034											1458	22,30	1,76	2,16	68
0,40	0,20	0,40	0,40	valo	yess	0,33	0,67	24,00	1861											1332	14,40	1,52	1,92	69
0,20	0,40	0,40	0,40	valo	no	0,67	0,33	10,70	1489											1034	6,50	0,98	1,38	70
0,00	0,60	0,40	0,40	elim	no	1,00	0,00	-2,50	800											0		0,00	0,40	71
0,40	0,00	0,60	0,60	valo	yess	0,00	1,00	37,10	2034											1397	14,90	1,76	2,36	72
0,20	0,20	0,60	0,60	valo	yess	0,50	0,50	17,30	1720											1134	7,00	1,31	1,91	73
0,00	0,40	0,60	0,60	elim	no	1,00	0,00	-2,50	800											0		0,00	0,60	74
0,20	0,00	0,80	0,80	valo	yess	0,00	1,00	37,10	2034											1242	7,40	1,76	2,56	75
0,00	0,20	0,80	0,80	elim	no	1,00	0,00	-2,50	800											0		0,00	0,80	76

TABLE A.3.4 CALCULATIONS OF COMBUSTION TEMPERATURES AND LIMITS FOR THE ASSESSMENT OF VALORIZATION OR ELIMINATION.
Raw materials fraction without water