ALTERNATIVE FUELS FROM WASTE – SPECIAL RECIPE FOR CEMENT KILNS

- CASE STUDY -

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Abstract: Waste recipe in cement production is one of the most closely guarded secrets. The type of waste used, and the percent of each type of waste in the mixture is confidential. The purpose of conducted research is to reveal the special recipe of mixture of conventional and alternative fuels used in clinkerization process having regard to constitute the base for further ecological solutions for conversion waste to energy in cement industry, including the optimization of the mixture of waste, from calorific point of view, and calibration of existing plants in order to allow the use of solid wastes as alternative fuels. By using CFD software from ANSYS, we successfully analysed the effects of replacing 25 percent of the traditional fuels by a special recipe mixture of wastes, ultimately revealing greenhouse gases reduction. The results of researches reveal that the substitution of traditional fuels with waste as alternative source of energy in the cement industry could be the most sustainable solution both for energy consumption and for waste recovery. Other environmental benefit is greenhouse gases reduction wastes being a green energy source with a low emission of CO2, NOx and CH4. In conclusion, the use of waste as alternative fuels, involve some special quality requirements, control and preparation but, following a special recipe, the cement producers can successfully replace the traditional fossil fuels with alternative secondary fuels having multiple benefits.

Key words: alternative fuel, greenhouse gases reduction, rotary kiln, simulation, waste recipe

Introduction

Waste recipe in cement production is one of the most closely guarded secrets. The type of waste used, and the percent of each type of waste in the mixture is confidential. Generally, the public information contain the list of wastes accepted for co-incineration (included almost 200 type of waste according with Waste European list approved by Commission Decision 2014/955/EU) and the total waste co-incineration capacity of the plant.

The clinkerization process uses a mixture of conventional and alternative fuels. The conventional (fossil) fuels are: natural gas, coal, and heavy oil. Alternative fuels accepted to be used in co-incineration are as follows: waste oils and emulsions, used tires, waste paper and cardboard, wood waste and sawdust, waste plastics, textiles, waste from catch pit (solid and liquid fractions), waste from petroleum refining, paints, varnishes, adhesives, solvents, sewage sludge from waste water treatment plants and from the production of paper.

The conducted researches hereof, in the preparation of waste alternative fuels in existing Romanian plants, has the main purpose to constitute the base for further ecological solutions for conversion waste to energy, including the optimization of the mixture of waste, from calorific point of view, and calibration of existing plants in order to allow the use of solid wastes as alternative fuels. The recipe can be used at large scale, in cement kilns, all over the world.

Criteria of waste selection

The use of waste as alternative fuels, involve some special quality requirements, control and preparation. Waste has to be suitable for co-processing from the technological, economic and environmental point of view.

1. In terms of environmental protection, the essential condition is: waste energy recovery does not lead to a significant increase in exhaust emissions (in the environment) and does not increase the content of hazardous substances in final product (cement).

- Waste co-incineration in cement plant should not lead to increasing pollutant emissions comparing with using conventional fuels.
- Waste combustion should have a low impact on the environment. This goal is achieved, inter alia, by limiting the quantities of pollutants contained in the waste for incineration. Those limits are established based on the specifics of each installation and technological process for clinker producing.

2. From the economical point of view, the thermo-energetic waste recovery in cement plants has to be profitable: waste has to be cheap, subtle process changes needed (ex. additional excess air supplying), and technological installation adjustments required by the use of new fuel do not involve massive spending.

- The investments for the installation required to prepare waste fuel has to be sustainable.

3. From the technological point of view, waste has to be feeded continuously and constantly.

- In terms of technology, waste must be supplied rhythmic delivered in sufficient quantities and present as small variations in quality. To verify, sampled waste are checked in the laboratory.
- The clinker product and cement obtained from incineration of waste must maintain the quality required by construction techniques.
- The waste that is to be used as fuel must have constant quality. In this regard, the implementation of the quality assurance systems is recommended in order to guarantee the characteristics of combustible wastes. This includes provisions for: sampling, sample preparation, analysis and external monitoring.

The most important parameters for combustible waste characterisation are: calorific value, and burner adequacy – waste with an adequate calorific value can replace the primary fuels in kilns

Preparing the Alternative Fuels from Solid Waste

The large solid waste is manually loaded on a conveyor roller and feeded to the cold end of the kiln, in the specific quantities prescribed (following the recipe) in the control room. The small solid waste (wood waste, plastics, textiles) are grounded in a special yielding fragments of about 25 mm which are then transported by means of compressed air systems in the kiln.

Scrap tires, from ELV dismantling, and spare parts replacing, are unloaded on the reception area and stored until recovery (Figure 2). They consist of platforms with special facilities for downloading tires and placing them on a conveyor belt (Figure 1).

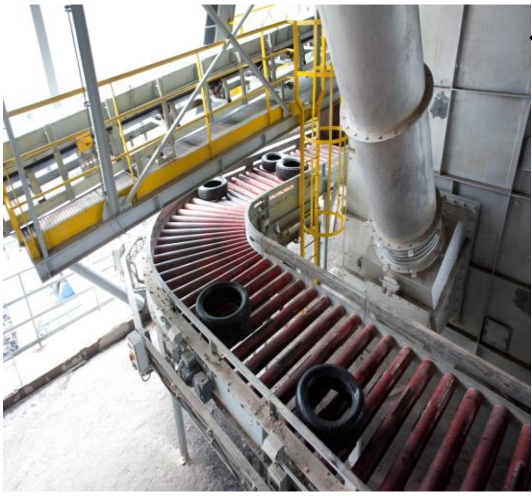

Figure 1

Automated conveyor transports of the scrap tires to the injection point in the kiln system

Figure 2

Scrap tires storage

Figure 3 System for processing of large tires to be used as alternative fuels in cement kilns

Large scrap tires are shredded and grounded by a special hydraulic system followed by dosing and the subsequent transport to the conveyor belt (Figure 3). Weighing and supply of tires in kilns is done by automated systems. The entire system is fully supervised and monitored both the video and the historical activity data.

Using scrap tires as alternative fuel is recommended both because of high calorific value similar to that of brown coal, and because of their availability in significant quantities. An additional advantage of using scrap tires is steel insertion. The steel can substitute, in part, or all, for the iron requirement in the raw meal recipe thereby reducing the raw meal cost. The steel insertion do not adversely affect the quality of clinker and the operation of cement kiln, as is clear from previous scientific research [1], [2], [3].

Waste plastics, paper and cardboard, resulted from industrial activities and from sorted household waste are grinded in a special yielding fragments of about 25 mm which are then transported by means of compressed air systems in the kiln.

Figure 4 System for processing of plastics, paper and cardboard to be used as alternative fuels

The systems (figure 4) are flexible and can be used also for other types of alternative fuels (eg. sawdust impregnated) due to a well-established recipe for the finished product, and due to the performant dispensers of materials.

Waste wood, from agriculture, forestry, and wood processing industry, are ground in special equipment (Figure 5) and loaded in the kiln according to the recipe.

Figure 5 System for processing of wood, to be used as alternative fuels in cement kilns

The sawdust is impregnated with oil, varnish, paints or oil waste. Once collected from generators, wood undergoes special treatment. Impregnated sawdust has to be handled and transported with special care due to the potential risk of pollution.

Preparing the Liquid Alternative Fuels

The alternative liquid fuels follow the route: unloading, storage, fuel supply. Particular attention is paid to transport waste oil and solvents derived from the automotive and chemical industries because of the chemical composition and the risk of explosion. It is also required close supervision of the transport of waste oil from current activities of the oil industry. The liquid alternative fuels are injected in the kiln by the main burner, following the recipe.

The Composition of Fuel Mixture

In most cases, waste alternative fuels are prepared from a specific prescription and usual, are fuelled in the same time with traditional (fossil) fuels.

In the case study we considered the following mixture of fuels:

- 75% traditional fuels and
- 25% alternative fuels from waste.

The alternative fuel has the following composition (figure 6):

- 61% liquid waste – liquid waste resulted from oil refining, waste from paints; vanishes, adhesives and solvents, sewage sludge, oily sludge, liquid waste from catch pits, waste oil, and emulsion;
- 26% waste wood and small solid waste – paper, cardboard, plastic, textiles, solid fraction of waste from catch pits;
- 13% waste tires and other large solid waste

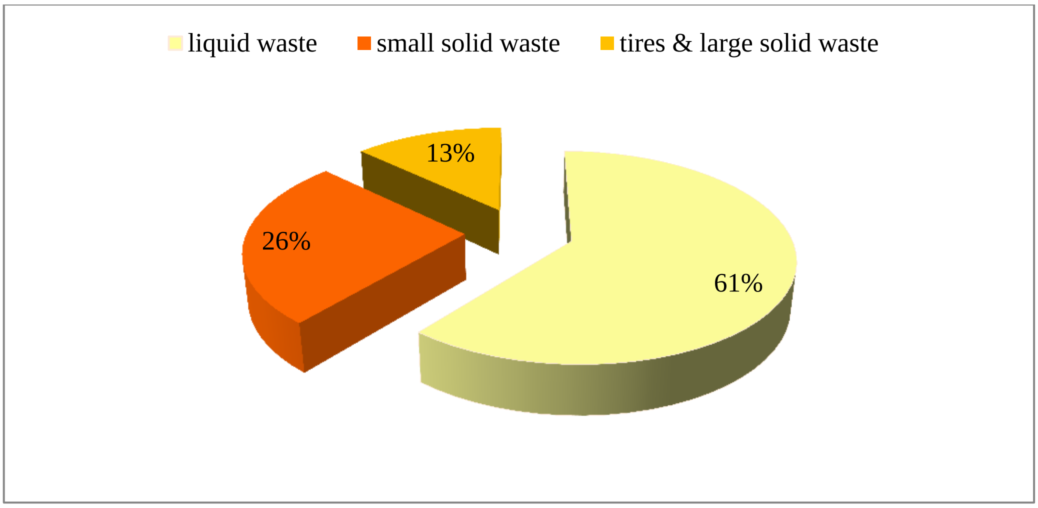

Figure 6 Composition of waste mixture

The composition of real fuels is not precisely (it can vary in some range), and many chemical reactions occur during the combustion. In this respect, is recommended to use the concept of heat of combustion, called the calorific value. Calorific value is the amount of heat produced by burning a kg of fuel and is determined experimentally. These experimental values are averages, and are released in the form of intervals (Table 1.).

Table 1 Calorific value of the traditional fuels [4]

Type of Fuel	Calorific value MJ/kg
Natural gas	50
Coal	26-30
Heavy oil	40-42
Mixture - weighted	33,5

For a mixture of fuels we can determinate the calorific value as weighted average of the calorific value of the components. The weights are holding mass or volume of components after András Kakucs. [5]

$$Q_i = \sum_i g_i \cdot Q_{ii} \qquad (1)$$

By correlating the calorific value of alternative fuels shown in Table 1 with the share of waste recipe, e.g. 26% of small solid waste, 13% large solid waste (including tires), 61% liquid waste, shown in Figure 6, we calculate calorific value of the mixture of waste as a weighted average calorific fractions of waste. The results are shown in Table 2.

Table 2 Calorific value of the waste mixture

Type of waste	**Calorific value MJ/kg**	**Share in the mixture %**
Liquid waste	25	61
Small solid waste and wood waste	27	26
Tires and large solid waste	26	13
Mixture	**25,65**	100

For the 3 major types of waste (small solid, large solid and liquid), the main criterion followed in the waste mixture, within the category, is the availability.

Sometimes, a certain amount of fuel gas is introduced, in addition to air, at the burning of fuel (liquid or solid) mixture. In this case, the calorific value will be:

$$Q_{it} = Q_{is} + Q_{ig} \qquad (2)$$

Where:

Q_{it} = total calorific value, Q_{is} = calorific value of solids, Q_{ig} = calorific value of fuel gas

The calorific value of traditional fuels used in clinkering process is presented in Table 1, the calorific value of each fraction of the mixture of waste is shown in Table 2 and the calorific value of the traditional and alternative fuel mix of presented in Table 3.

Table 3 Calorific value of the fuel mixture

Type of fuel	Fuel	Calorific value MJ/kg	Percentage in the mixture
Traditional	Natural gas	50	75 %
	Coal	26-30	
	Heavy oil	40-42	
	Mixture - recipe	**33,5**	
Alternative	Liquid wastes	30	25 %
	Wood waste and other solid waste small dimensions	27	
	Tires and large solid wastes	26	
	Mixture - weighted	**25.65**	
Calorific value of the mixture		**31.54**	100 %

As we can see in table 3, the calorific value of waste fuel mix (25.65 MJ/kg) is lower than the calorific value of traditional fuel mix (33,5 MJ/kg). In order to maintain the temperature distribution inside the kiln, we have to compensate the difference of the calorific value of the fuels: 33.5 MJ/kg of the fossil fuels and 31.54 MJ/kg of the mixture of wastes and fossil fuels.

Following the BREF [6] recommendation, we have to choose between two operational changes:

- increasing the amount of secondary fuels (from waste) that have to be used in order to achieve the thermal energy demand, or

- Intensifying the oxidation inside the kiln by supplementing the air flow in order to enhance the oxidizing conditions in the sintering zone of cement kiln.

The option considered to offer the sound solution for maintaining the shape of combustion temperatures inside the kiln is to introduce an excess of air in the system by changing the operating parameters of the oven. In this way we avoid increasing the amount of waste used, for not exceed the capacity of processing plant.

In addition to the calculation of the calorific value and heat released, we have to determine the quantity of oxygen and, therefore, the amount of air necessary to complete combustion. An excess air means a loss of heat discharged with heated gases, but not involved in combustion, ex. nitrogen and oxygen that fall outside the reaction. Flue gas volume and heat escaping shall be calculated after equations proposed by Nicolae Antonescu and others (Table 4) [7].

Table 4 Air flow and combustion gas flow related to the flow of waste and calorific value [7]

Waste flow [t/h]	**Flue gas temperature T_1 [°C]**	**Calorific value**					
		2300 kJ/kg		**2510 kJ/kg**		**2720 kJ/kg**	
		V_{aer} [m^3_N/h]	**V_{gaze} [m^3_N/h]**	**V_{aer} [m^3_N/h]**	**V_{gaze} [m^3_N/h]**	**V_{aer} [m^3_N/h]**	**V_{gaze} [m^3_N/h]**
4.5	840	4600	8600	4800	8800	5000	9000
4.75	855	4800	9100	5000	9800	5300	9500
5.0	840	5000	9600	5300	9800	5600	10000
5.25	850	5300	10000	5600	10200	-	-

The minimum amount of air necessary for combustion of a kg of waste, VO [M3N / kg], and the minimum amount of waste gases from the combustion of theoretical, per unit amount of waste Vg [M3N / kg] (see table 4), are to a good approximation, linear function of the calorific value of the waste Hi [kJ / kg] and can be determined by relations indicated by Nicolae Antonescu and others [7]:

$$Vo = 0.26\frac{Hi}{1000} + 0.4 \text{ [m}^3{}_N\text{/kg]}, \quad (3)$$

$$Vg = 0.215\frac{Hi}{1000} + 1.42 \text{ [m}^3{}_N\text{/kg]}, \quad (4)$$

The calorific value of the fuel mix and the excess air will be used for the 3D simulation of thermal processes in rotary kiln incineration plant.

Since we can't perform practical experience on the system studied, being an industrial plant in operation, the validation of theoretical hypothesis will be performed after the simulation, by comparing the temperatures simulated in the initial conditions with temperatures simulated with added waste fuel and with temperatures measured directly with the 5 optical pyrometers present in the system. The temperature measurement is performed in normal working regime of the industrial plant.

Results and Discussions

The immediate result is to increase the combustion gas temperature and decreasing the flow of hot gases discharged from the plant. Finally the resulting intensification of heat transfer between the flue gas and the bed, as well as a reduction of heat losses. Previous research results reveal a decrease in specific consumption of heat when using oxygen (air) in addition to burning [6] [8 - 11].

By using CFD software from ANSYS (Figure 7 and 8), we successfully analysed the effects of replacing 25 percent of the traditional fuels by a mixture of wastes, ultimately revealing greenhouse gases reduction. More details about simulation were published by the authors in a previous paper [12].

The combustion of fuel mixture (special recipe for cement kilns), with excess air, lead to a diminish NO_x emissions to 0.04 kg/m^3 shown in Fig. 7, below actual emission level from traditional fuels combustion.

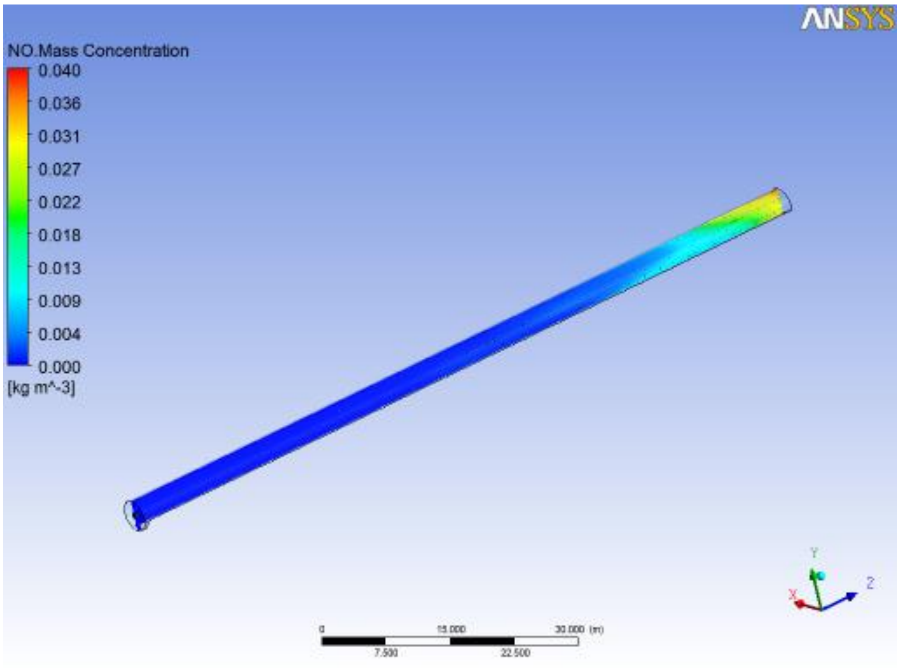

Figure 7 Simulation of NOx emissions

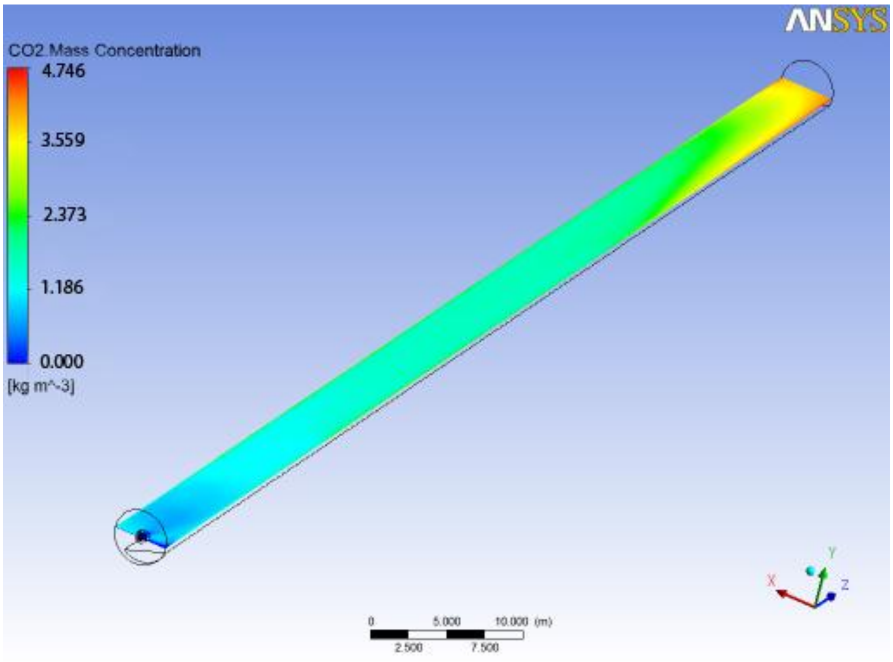

Figure 8 Simulation of CO_2 emissions from burning

Analysing simulation results, shown in Fig. 8, we can conclude that the replacement of traditional fuels with the special recipe of waste can diminish CO_2 emissions from burning to 4.74 kg/m^3. Without the replacement of traditional fuels with alternative fuel from waste, CO_2 emissions varies, according the measurements records, between 5.42 kg/m^3 and 65 kg/m^3.

The results of the research (Figure 9) reveal that the substitution of traditional fuels with waste as alternative source of energy in the cement industry could be the most sustainable solution both for energy consumption and for waste recovery. Other environmental benefit is greenhouse gases reduction wastes being a green energy source with a low emission of CO2, NOx and CH4.

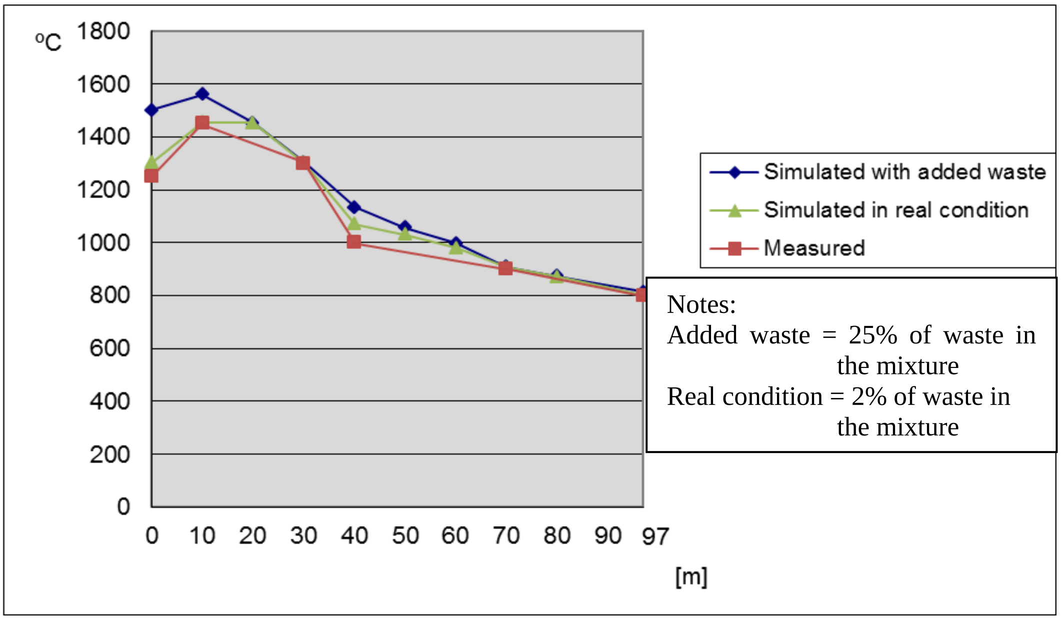

Figure 9 Results validation

Conclusions

In conclusion, the use of waste as alternative fuels, involve some special quality requirements, control and preparation but, following a special recipe, the cement producers can successfully replace the traditional fossil fuels with alternative secondary fuels having multiple benefits.

The research results can be used by the managers of the cement industry in order to extend the quantity and the variety of waste prepared as alternative fuels and, also to optimize waste burning in rotary kilns. The other interest on the research results may be from the part of the environmental authorities in order to include the new approach into the national waste management plan.

For further research we can vary the percent of wastes in the mixture and analyse what's happen with calorific value of the alternative fuel and the green houses emissions of the plant.

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