

FROM WASTE TO ENERGY UP TO SUSTAINABLE DEVELOPMENT

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Abstract: Cement industry is one of the most intensive energy - consumer worldwide. In the same time, waste is an increasing flow in the actual consumer society coupled on the goods production and economic growth. 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. By using software from ANSYS, we have been able to analyse the effects of replacing 25 % of the traditional fuels used in an existing cement plant with alternative fuels from waste. One of the problems encountered was the calibration of existing plants with minimum costs in order to allow the use of solid wastes in 25 % as alternative fuels. For the implementation of the mathematical model and simulation of the processes at real scale with the possibility of varying the operational parameters of the system we used the latest bibliographic documents and modern computer simulation software – ANSYS – which conducted to reliable results effective immediately. The results of researches proved that the cement producers can successfully replace the traditional fossil fuels with financial and environmental benefits. Other gain obtained is greenhouse gases reduction, wastes being a green energy source. In conclusion, based on the simulations we proved that the cement producers can successfully replace the traditional fossil fuels with alternative secondary fuels having multiple benefits.

Key words: alternative fuel, renewable energy, rotary kiln, simulation, strategy, waste

Introduction

Substitution of traditional fuels by waste fuels is a necessity considering environmental impact and resource depletion also is an opportunity considering the price. Waste is a cheap perpetual and renewable energy source.

Using waste as alternative fuel comply with the Principle of sustainable use of resources which establish the necessity to minimize and effective use of primary resources, especially non-renewable resources, in order to conserve the natural resources, focusing on the use of secondary raw materials (ex. waste recovery).

The Principle of sustainable use of resources foreword is stated in the context of the broader concept of "sustainable development" (Rio Declaration on Environment and Development, Principle 3 – “The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations” [1]) and of the Thematic Strategy on the prevention and recycling of waste, planned in EC Communication, 2005 [2].

Following new European approach, taken in consideration biodegradable waste as renewable sources of energy, the path of using waste as energy source was opened. As mentioned, Directive 2009/28/EC on the promotion of the use of energy from renewable sources define biomass as biodegradable fraction of waste and residues from biological origin from agriculture, as well as the biodegradable fraction of industrial and municipal waste [3]. With European Directive transposition in national legislation by Law no. 220/2008 [4], using waste as energy source in Romania became more clearly. Energy recovery from waste is one of the basic options both of National Waste Management Strategy approved by Governmental Decision no. 1470/2004 [5] and of National Strategy for Energy Efficiency approved by Governmental Decision no. 163/2004 [6].

Last but not least, is to note the role of energy recovery from waste in reducing the emissions of greenhouse gases (carbon oxides, nitrogen oxides, sulphur oxides) and so implementing the United

Nations Framework Convention on Climate Change and The Kyoto Protocol Treaty [7]. The minimizing of greenhouse emissions (mainly on CO₂ reduction), due to the replacement of fossil fuels with waste, was revealed by extensive research developed on the national and international level [8 –11]. Use of waste as alternative fuels is reducing energy consumption and emissions (Figure 1).

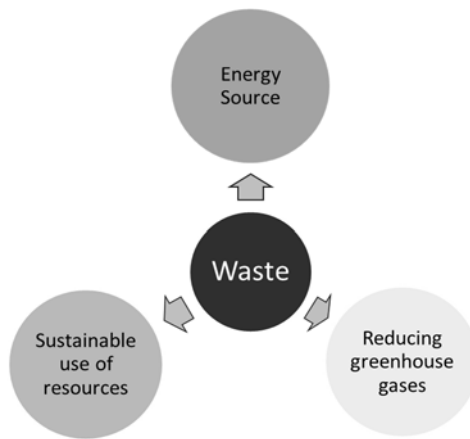


Fig.1. Global impact of waste to energy

It is important, in accordance with the waste hierarchy, and for the purpose of reduction of greenhouse gas emissions originating from waste disposal on landfills, to use bio-waste in order to produce energy (energy recovery from waste).

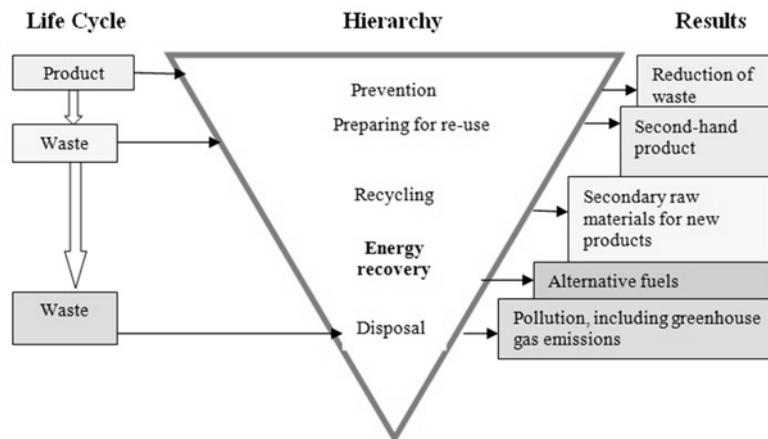


Fig.2. Waste hierarchy

The waste hierarchy provided in new waste framework Directive (Directive 2008/98 [14]) shall apply as a priority order in waste prevention and management legislation and policy (Figure 2).

Diverting municipal solid wastes from landfill minimize the greenhouse gas emissions affecting the climate change and, in the same time, conserve natural resources by using waste as secondary raw material and alternative fuel.

The international latest researches were also focussed on using waste as alternative fuel in cement industry [12], and waste incineration in rotary kilns [13]. In this respect, waste-to –energy systems has been widely debated.

The purpose of present paper is to analyse the effect of using waste as alternative fuel in cement kilns concerning the temperature distribution inside the kiln and, thereby, on the clinker and environment quality.

Experimental Research – System under Study

In Romania is a very strong opinion about municipal solid waste being not suitable for energy recovery. In the meantime new technologies were already implemented by the foreign companies in order to replace traditional fuels with alternative fuel from waste. In fact, only a very small quantity of municipal solid waste is used for energy recovery even if a selective waste collection was implemented and new sorting stations were developed near the waste landfills.

Using waste as alternative fuel in cement kiln is the main solution for recovery of energy from waste implemented in Romania so far. For example, an existing cement plant with a production capacity of 3,000,000 t / year has environmental permit for maximum 46 t/hour (about 400,000 t / year) waste used as alternative fuel and currently use only 30,000 t / year.

Condition of approval stipulated by integrated permit [15] is to respect the proportion of 25% alternative fuels (waste) and 75% conventional fuel in the mixtures for incineration. Therefore, according

to the environmental permit, alternative fuel (waste) should be increased from 3.5 t / h to 46 t / hour. In Germany, some cement plants already replaced traditional fuel with alternative fuel - waste fuel in proportion of 80% to 100% [16].

For the purpose of this paper were used the calorific values of Romanian waste fractions measured by Romanian researchers [17].

The studied system consists of: a heat exchanger (cyclone pre-heater), a clinker kiln and a grate cooler. The waste replacing traditional fuels are feed by the upper chamber (at the cold end of the kiln) and by the main burner (at the hot end of the kiln) – Figure 3.

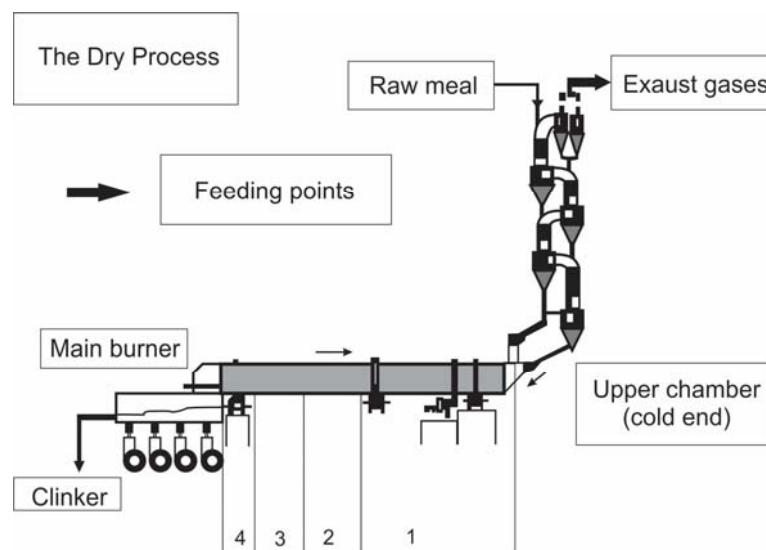


Fig.3. Technological process and the main zones of rotary kiln

Temperatures kiln control profile lead to maintain a high quality of clinker. For burning purposes the liquid fuels (heavy oil), gassy fuels (natural gas), solid fuels (coal), alternatives (solid and liquid wastes) or a mixture of those. According to the reactions within the kiln and resulting compound, we can distinguish the following zones of the rotary kiln:

- Calcination zone (decarbonization) where the alkaline carbonates are decomposed at temperatures comprised between 800°C – 1000 °C. At this temperature, CO₂ is released in the gas phase, obtained from CaCO₃ and MgCO₃ (zone 1 of the Figure 3);

- Transition zone where the first mineralogical clinker compounds are formed through solid phase reactions at temperatures between 1000°C and 1350 °C (zone 2 of the Figure 3);

- Sintering zone (clinkerization zone) where the clinker is formed from the liquid phases at temperatures between 1350°C and 1500°C in these zone develops tricalcium silicate (alit), the most valuable compounds of clinker (zone 3 of the Figure 3);

- Cooling zone where the temperature drops from 1450°C to 1250°C and mineralogical compounds occurs. Burned gases are circulated into the kiln backwards, in counter-current to the clinker (zone 4 of the fig. 3).

Primary energy consumption per cement unit is composed by: traditional fuels (tar, natural gas and pet coke), alternative fuels (waste) and electric energy. The case study is focused on thermal processes in the rotary kiln, and the system boundary is the constructive limit of the kiln.

Using alternative fuels in the rotary kiln we can diminish the amount of fossil fuels and, in the same time, decreasing the primary energy due to 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. In order to maintain the temperature distribution inside the kiln, following the BREF [16] 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 selected for actual research was the injecting of excess air, mainly because a higher quantity of mixt fuels could exceed the constructive limit of the plant. We calculated that the increasing the excess air from 4.5 % to 12% we can solve the problem of decreasing the calorific value. Taking into account these premises, we applied both variable conditions (excess air and calorific value) on the simulation.

Simulation Model

Model validation techniques include simulation model under known input conditions and comparing model output with system output. First of all we have to analyse the processes involved in order to create the mathematic model.

Clinker manufacturing in rotary kiln of an existing plant is a complex process very difficult to analyse and control because of the complex heat and mass transfer, chemical reaction scheme and dynamics of the functional model.

Thermal process modelling in rotary kiln could be split in three different sub-models:

- The model of the hot flow which take into account the heat transfer and phenomena in the gas flow;
- The model of the solid bed including heat transfer clinker – gas and clinker – refractory;
- A model of the kiln wall – refractory model.

From a thermodynamic point of view, it can be distinguish three different mechanism of heat transfer in the rotary kiln: convection, conduction and radiation (the main mechanism of heat transfer). The radiation heat transfer prevails in the energy transfer mechanism to the processed material because the rotary kilns are operated at high temperatures with intense flame combustion. Thermal radiation is maximized by the cylinder structure of the kiln and by the presence of free space.

The model (figure 4) takes into account the major phenomena of interest including the gas flow, all modes of heat transfer and the thermal effects of the refractory.

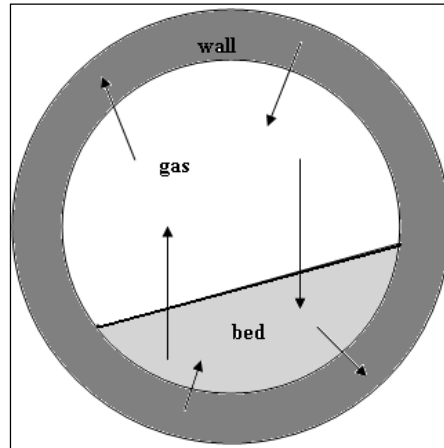


Fig.4. Cross section of the kiln

From a hydrodynamic point of view, we have a turbulent flow mixing of droplet (for liquid fuels) and pulverized coal particles (solid fuels) in air flow. Temperatures in the kiln varying between 800°C at the cold end and 2000°C at the hot end (burner zone). The material mixture (bed) circulate between cold end to the hot end and the gas flow moving from the hot end to the cold end in counter-current blown by fans. Entire kiln became thus a heat exchanger in counter-current; the solid fee is progressively heated as it moves into the kiln chemical reactions being thus activated. This situation is used in model formulating the base operations so that it can be applied generally to all the clinker burner processes.

Computer modelling use the CFD (Computational Fluid Dynamics) code in a multiphase flow model, involve equations for conservation of mass, momentum and energy – based on the turbulent Navier–Stokes equations. The Navier–Stokes equations were further developed by Boateng [18] being associated with equation of mixture fractions model by Wang [19], and for combustion chemistry of the

mixture fraction model (Gibbs). Numerical solutions are sought by discretizing equations and integrating over each control volume represented by the mesh.

Simulation Experiment

A 3D simulation of thermal processes in rotary kiln incineration plant should be used to obtain valid results along the entire length of the kiln. The first step in simulation is the geometry definition (figure 5) followed by mesh generation.

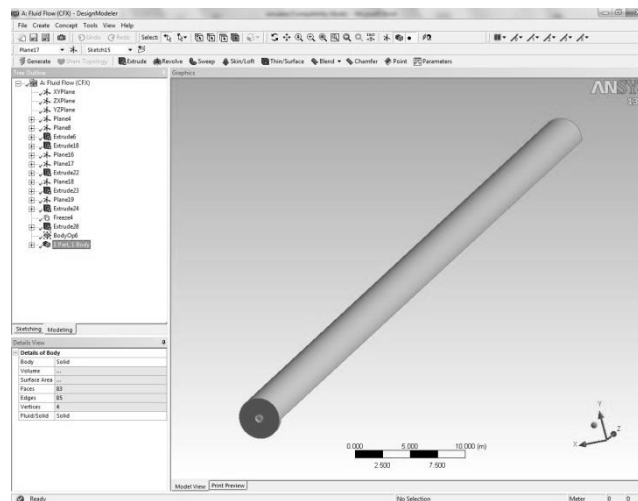


Fig.5. Geometry creation

To simplify the model the following assumptions are considered:

- The inside and outside diameters of the kiln are constant;
- The specific and reactions heats are independent of the temperature and constant along the axial direction;
- Conduction in gases, in solid materials and in the axial direction of the wall is neglected;
- The height and speed of solid materials are constant;
- Radial and angular variations of the wall temperature are neglected;
- The combustion is complete and producing carbon dioxide and water.

After geometry creation the next step is Mesh generation (Figure 6). The quality of the finite element has a directly influence on the computation and results – the reliability of simulation.

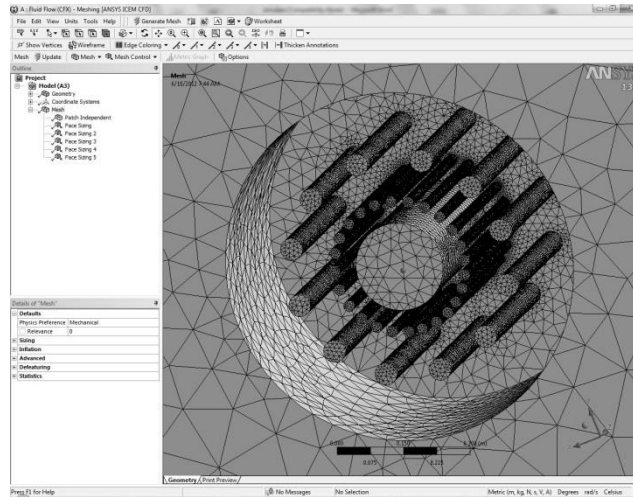


Fig.6. Mesh generation

The initial and boundary conditions are set. Boundary condition concerns the construction limits of the kiln, temperature limits, the mass flow of air and fuel, as follows:

a) Technical characteristics of the rotary kiln

- Length = 97 m
- Internal kiln radius = 1.9 m
- External kiln radius = 2.9 m
- Inclination = 3 %
- Refractory thickness = 0.9 m
- External shall thickness = 0.1 m
- Burner diameter = 0.8 m
- Length of burner = 6 m
- Temperature of flame = 2000°C

- Length of flame = 20 m – if the flame is shorter, with intensive burning the NO_x emissions increasing and if the flame is longer the temperature for clinkerization is not attained.

- Clinker temperature under the flame = 1450 °C

b) Operational variables

- Temperature of clinkerization = 1300 °C

- Velocity of kiln = 1,9 rpm

- Temperature of feed meal at the entrance of the kiln = 800 °C

- Excess air = 4,5 % - 12%

- Thermal transfer coefficient α for (S1) = 20 W/K·m² where S1 – outer surface as interface between shell and environment

- Thermal transfer coefficient α for (S3) = 350 W/K·m² where S3 – inner surface interface between refractory and gas

- Thermal transfer coefficient α for (S2) = 0,5 W/K·m² where S2 – surface interface between bed-gas and bed-refractory

- Emissive coefficient $\beta = 1$

- Thermal conductivity

- in bed = 0.693 W/K·m

- in gas = 0.8 W/K·m

- in shell = 10 W/K·m

- in refractory = 0.04 W/K·m

c) Fuel properties

- Fuels mass flow is 25,55 kg/s, fractional flow of the mixture being variable as follows:

- 24.578 kg/s traditional fuel and 0.972 kg/s fuel from waste, respectively

- 19.16 kg/s traditional fuel and 6.39 kg/s fuel from waste.

- Fuel calorific value is presented in Table 1.

Table 1 Calorific value of the traditional and alternative fuels 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 %

d) Air mass flow and temperatures shown in Table 2.

Table 2 Air mass flow and temperatures

Air stream		Mass flow rate (kg/s)	Temperature (°C)
Primary air	Coal carrier air	0,579	70
	Swirl air (tangential air)	0,279	70
	Axial air	1,18	80
Secondary air		25,97	800

The next step in CFD simulation is Post-Processing. The common post-processor for all ANSYS [20], delivers everything needed to visualize and analyse fluid dynamics results. These capabilities include image generation to communicate results visually, qualitative post-processing to display and calculate data, automation to ease repetitive tasks, and the ability to run in batch mode.

Analysing post processing results (Figure 7 and Figure 8) showing thermal processes inside the oven, can observe a uniform combustion, this means a steady conditions maintained throughout the whole kiln. Also we can conclude that is sufficient supply of air for oxidation to take place obtaining optimal

reaction products. Similarly, cross-sectional temperature profile shows a uniform combustion with controlled turbulence.

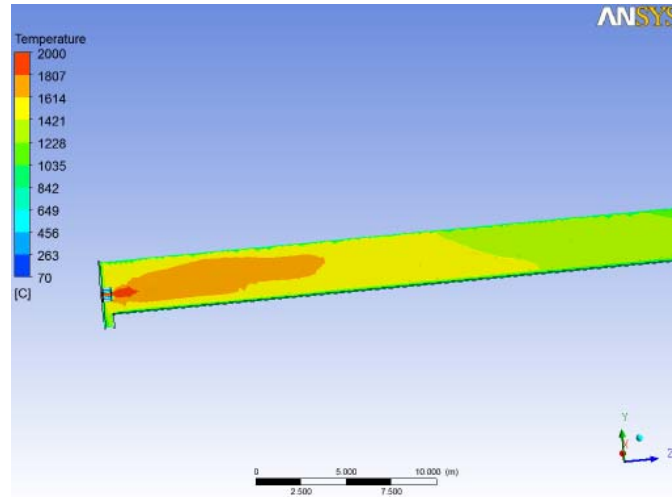


Fig. 7. Temperatures profile in longitudinal section

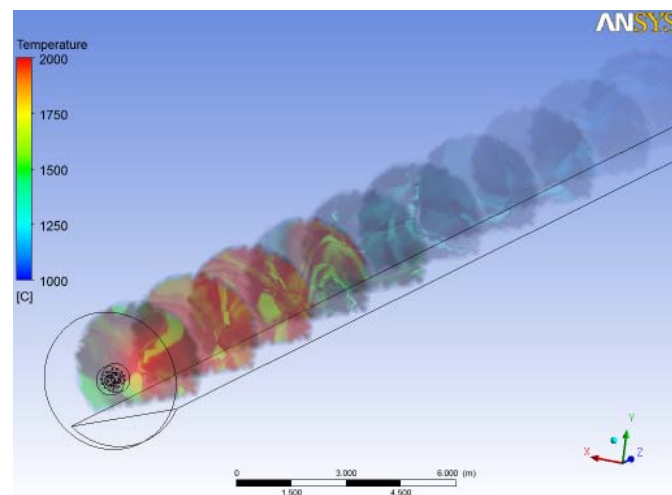


Fig. 8. Temperatures profile in transversal section

Figure 9 show the flame has an optimal length, about 20 meters and a lower temperature, between 1446 - 2000°C, contributing to the formation of the liquid phase of the clinker simultaneous with the diminished of NOx emissions.

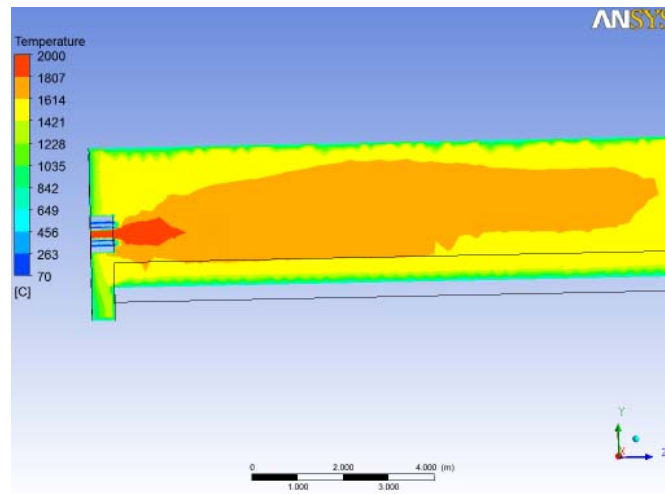


Fig. 9. Temperatures profile in the burner zone

Clinker rotary kiln is equipped with efficient burner providing low NO_x emissions and allowing simultaneous combustion of traditional and alternative fuels. Emissions of nitrogen oxides arise from firing process above 1300°C. These emissions can be minimized by the operation of a special multi-channel burner reducing the flame temperature by supplying rinsing air. The combustion air coming via burner into the kiln is called primary air. Primary air flow is divided into two streams: the swirl air and the axial air. The axial air flows almost parallel towards to the burner axis and the swirl air (spin air) has an axial and a tangential component. Both air streams acts to shape the flame and to assure the stability of the flame. In addition to the two air flows described, a third primary air stream, loaded with coal, circulating thru the burner. The third air stream is used as fuel transport vector. Due to the atomization the fuel by high pressure injection (6 bars), the flow rate of combustion air and the shape of the flame are optimized.

To final longer and stable shape of the flame a high contribution has the secondary air, injected from the cooler in the kiln within 8 fans. Secondary air has an optimal temperature, about 800°C - 900°C, in order to protect the refractory.

Results and Discussions – Simulation Analysis

The effects of substitution of traditional fuels are shown in temperature graphs (Table 3, Figures 10 and 11).

Table 3 Results validation

Kiln Length [m]	Temperature (simulated) [°C]	Temperature (measured) [°C]
0	1500	1250
10	1560	1450
20	1454	
30	1304	1300
40	1133	1000
50	1056	
60	997	
70	909	900
80	873	
97	814	800

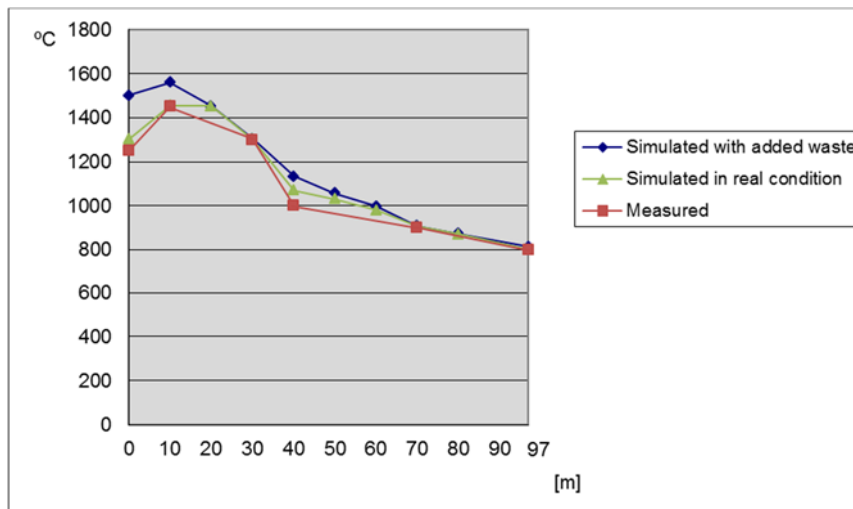
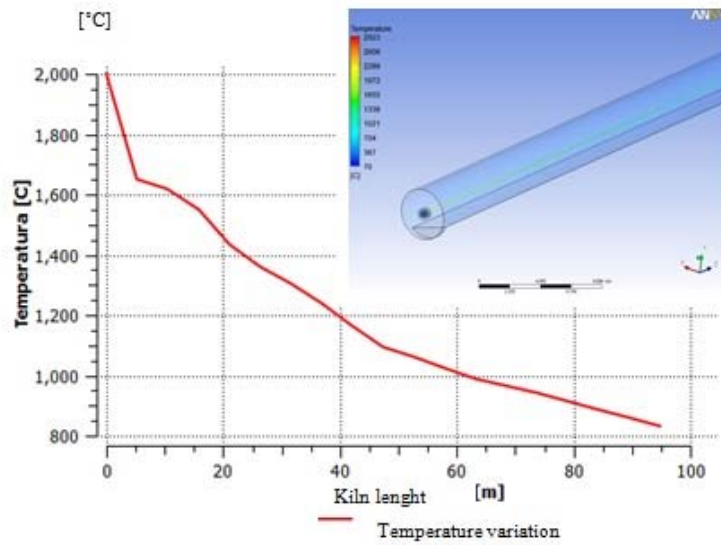


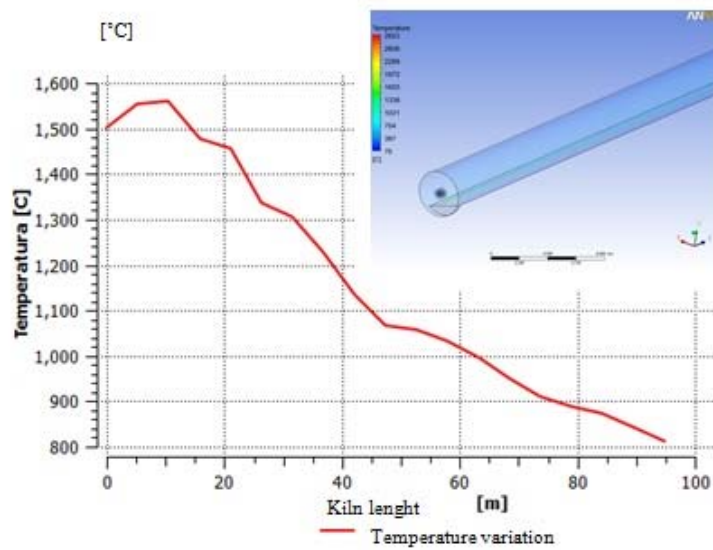
Fig.10. Results validation

Analysing the graphs of temperatures variation along the kiln (Figure 11a), is observed that the recommended temperatures were obtained in the four areas of clinker formation, validating measured

temperatures (Figure 10) in the main zones of the rotary kiln (as described in Chapter 2 hereof), also in terms of increasing the amount of waste used as alternative fuel (visualizing model output).



a)



b)

Fig.11 a), b) Temperature at the bed line and at the burner level along the kiln length

Comparing the temperatures obtained in the axial kiln direction (as shown in Figure 11 b) in the simulation model with the original system (Figure 10), we can conclude that the results of increasing the

quantities of waste used as alternative fuels, in addition with increasing oxygen amount by supplementing excess air, on the thermal processes of the rotary kiln, creating optimal conditions required for a high-quality clinker product.

Replacing traditional fuels with specific waste types, with high calorific value, can be successfully done, bringing also economic and environmental benefits. The use of alternative fuels affects slightly the temperatures inside the rotary kiln and therefore the optimal conditions for clinkerization can be offset by increased excess air.

Besides reducing consumption of traditional fuels (non-renewable), using waste as a fuel has the effect of reducing NO_x emissions. As seen in Figure 12, emission levels is below the limit values set up by legislation, thereby contributing to reduce air pollution and reduce greenhouse gas emissions.

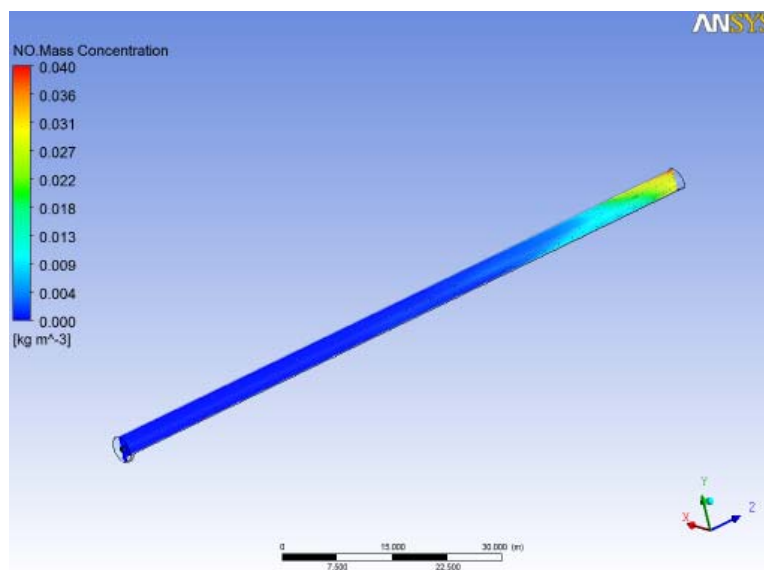


Fig.12. Simulation of NO_x emissions

Without the replacement of traditional fuels with waste fuel NO_x emissions varies according the measurements records between 0.05 kg/m³ and 0.6 kg/m³. Analysing simulation results we can conclude

the replacement of traditional fuels with waste diminish NO_x emissions to 0.04 kg/m^3 (shown in Fig. 12), below actual emission level from traditional fuels combustion.

Conclusions

Mathematic simulation of heat transfer in rotary kiln is very useful for the assumption of necessary operational parameters for safe incineration of hazardous wastes (used oils, wastes from petroleum refining), and for improving the combustion by optimization of air flow in existing installation presented in the paper.

By using CFD software from ANSYS, we successfully analysed the effects of replacing 25 % of the traditional fuels used in an existing cement factory with fuels obtain by a mixture o wastes. By running CFD simulations, we determined a number of subtle process changes (ex. additional excess air supplying) and adjustments required by the new fuels, ultimately discovering the optimal set of conditions under which green fuels can be used to support a high-quality cement product.

Based on the simulations we proved that the cement producers can successfully replace the traditional fossil fuels with alternative secondary fuels having result economic and environmental benefits.

References

1. UN Conference, (1992): Rio Declaration on Environment and Development, Having met at Rio de Janeiro from 3 to 14 June 1992, United Nations publication, Sales No. E.73.II.A.14 and corrigendum, chap. I.
2. COM, (2005): COM(2005) 666 final, Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the

- Regions, Taking sustainable use of resources forward: A Thematic Strategy on the prevention and recycling of waste, {SEC(2005) 1681} {SEC(2005) 1682}– Not published in the Official Journal
3. EC Directive, (1009): Directive 2009/28/EC on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, Annex V, Official Journal of the European Communities, L 140, 5.6.2009, p. 16–62, Brussels.
 4. Law, (2008): Legea nr. 220/2008 pentru stabilirea sistemului de promovare a producerii energiei din surse regenerabile de energie - Republicată în temeiul art. II din Legea nr.139/2010 privind modificarea și completarea Legii nr. 220/2008 pentru stabilirea sistemului de promovare a producerii energiei din surse regenerabile de energie (Law no. 220/2008 to establish the system for promoting energy production from renewable energy sources, Republished in Romanian Official Monitor, part I, no. 577 from 13th of August 2010).
 5. GD, (2004): Hotărârea Guvernului nr. 1470/2004 privind aprobarea Strategiei naționale de gestionare a deșeurilor și a Planului național de gestionare a deșeurilor, publicată în Monitorul Oficial al României, Partea I, nr. 954 bis din 18 oct. 2004 (Governmental Decision No. 1470/2004 for the approval of National Waste Management Strategy, published in Romanian Official Monitor, part I, no. 954 bis from 18th of October, 2004).
 6. GD, (2004): Hotărârea Guvernului nr. 163/2004 privind aprobarea Strategiei naționale în domeniul eficienței energetice, publicată în Monitorul Oficial al României, Partea I, nr. 160 bis din data de 24 februarie 2004 (Governmental Decision No. 163/2004 for the approval of National Strategy for Energy Efficiency, published in Romanian Official Monitor, part I, no. 160 bis from 24th of February, 2004).
 7. UN Convention 1998: Kyoto Protocol to the United Nations Framework Convention on Climate Change, United Nations, 1998.

8. UBA (Federal Environmental Agency of Germany), (2008): Status report on CO₂ emission saving through improved energy use in MSWI plants, 2008
9. Kees Wielenga, (2008): Waste-to-Energy and the revision of Waste Framework Directive 's contribution to climate protection. Waste-to-Energy's contribution to climate protection, study made by FFact for CEWEP, FF/KW/2008.02-01, Braine l'Alleud, February 2008.
10. UBA (Federal Environmental Agency of Germany), (2005): Status report on the waste sectors contribution towards climate protection and possible potential, August 2005,
11. Profu Study, (2004): Evaluating Waste incineration as treatment and Energy recovery method from the environmental point of view, conducted on behalf CEWEP (Confederation of European Waste to Energy Plants) during the spring 2004
12. Thomanetz Erwin, (2014): Solid recovered fuels in the cement industry with special respect to hazardous waste, Waste Management & Research, March 2014; 32 (3)
13. Francesco Lombardi, Emanuele Lategano, Stefano Cordiner, and Vincenzo Torretta, (2013): Waste incineration in rotary kilns: a new simulation combustion tool to support design and technical change, Waste Manag Res July 2013 31: 739-750, first published on April 30, 2013 doi:10.1177/0734242X13484187
14. EC Directive, (2008): Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives, published in the Official Journal of the European Communities, L 312, 22.11.2008, p. 3–30, Brussels
15. APMBC, (2005): Autorizație integrată de mediu nr. 9 / 20.10.2005, revizuită 2009 Ministerul Mediului și Gospodăririi Apelor, Agenția Națională de Protecție a Mediului, Agenția Regională pentru Protecție a Mediului Bacău Pentru Regiunea Nord-Est (Integrated Environment Permit no. 1 from 14.12.2005, Ministry of Environment and Water Management, National Environmental

Protection Agency, Regional Environmental Protection Agency Bacău for Region Northeast, 2009),

On line at: http://apmbc.anpm.ro/upload/94576_CARPATCEMENT.doc

16. BREF, (2010): Reference Document on Best Available Techniques in the Cement, Lime and Magnesium Oxide Manufacturing Industries, European Commission, May 2010.
17. Alexei Atudorei, (2007): Study on the advantages and disadvantages of using heat treatments for disposal / recovery of municipal waste from economic and environmental point of view, in the implementation of energy efficiency concept, SC ROSAL GRUP SRL Bucharest, Directorate Programs Strategies, Research & Development department, contract no. 3194/26.07.2007, beneficiary: Ministry of Environment and Sustainable Development, December 2007.
18. Boateng Akwasi A., (2008): Rotary Kilns Transport Phenomena and Transport Processes, Published by Elsevier (2008-02-06), ISBN 10: 0750678771 / ISBN 13: 9780750678773 , Burlington, USA, 152-154 (2008)
19. Wang Zhuo, Wang Tian-ran, (2008): Dynamic Model for Simulation and Control of a Cement Rotary Kilns, In Journal of System Simulation, vol. 20, 19., 2008.
20. ANSYS, (2006): CFX-Solver Theory Guide, ANSYS CFX Release 11.0, December 2006.