Environmental impact assessment of combustible wastes utilization in rotary cement kilns

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***Abstract* – This study focuses on the environmental impact assessment of the coal combustion and its substitution by alternative fuels from combustible wastes during Portland cement clinker sinterization in rotary cement kiln. Environmental impact assessment was carried out based on the fuels chemical composition and operating parameters of a rotary cement kiln in accordance with EURITS and IMPACT 2002+ methods.**

Keywords – Environmental impact assessment, midpoint level, damage level, rotary cement kiln, alternative fuel, used tires, shredded solid alternative fuel, coal, combustion, pollutant.

I. Introduction

Cement production life cycle includes high energy-consuming process of sintering raw materials in a rotary kiln. The formation of Portland cement clinker requires a temperature of about 1450 °C with a continuous stirring and a long residence time in a rotary kiln. Such conditions are also optimal for a comprehensive utilization of a wide range of combustible wastes as alternative fuels. This practice of waste co-processing in cement kilns has been successfully applied in the EU countries, USA, Japan etc. Most cement plants in Ukraine plan to reduce fuel costs and to substitute 40 % of fossil fuels (natural gas, coal) by alternative fuels. Today only a small percentage of coal is substituted with used tires, however. According to the statistical information, about 18 million tonnes of combustible wastes in Ukraine are unused every year. Thus, it would be reasonable to process them into alternative fuels and apply in cement industry.

In the cement industry, a multi-stage emission cleaning is widely applied. During the sintering process, heavy metals (except for mercury, cadmium and thallium) are almost completely immobilized in clinker minerals structure, while their leaching-out from the hardened concrete was not observed [1]. However, rotary cement kilns significantly contribute to air pollution. A typical 4x150 m wet process rotary kiln with the capacity of 34 t/h of Portland cement clinker emits approximately 350,000 m^3/h or 10,294 m^3/t of flue gases.

II. Estimation of flue gas amount

Portland cement clinker kiln production consists of two parallel processes – fuels combustion and raw materials sintering. To calculate the amount of pollutants from the fuels combustion (coal, used tires, shredded solid alternative fuel) in the rotary kiln were used EURITS methods [2]. A shredded solid alternative fuel was prepared by mixing wastepaper processing waste (80 %), PET-bottles waste (10 %) and sawdust (10 %) followed by shredding it to a size of ≤10 mm [3]. Flue gas amount from different fuels combustion in rotary kiln was calculated using Eq. 1 [2]:

$$C_xH_yO_zN_uCl_vS_w + \left(x + \frac{y-v}{4} - \frac{z}{2} + w\right)\cdot O_2 \rightarrow \\ \rightarrow x\cdot CO_2 + \left(\frac{y-v}{2}\right)\cdot H_2O + \left(\frac{u}{2}\right)\cdot N_2 + \\ + v\cdot HCl + w\cdot SO_2 \qquad (1)$$

where C + H + O + N + Cl + S = 100 wt%

A specific emission A_{ij} of j-th pollutant from combustion of the i-th fuel (kg/t_{fuel}) was calculated by the Eq. 2:

$$A_{ij} = \frac{(V_m \cdot v_{ij} \cdot \rho_j \cdot TK_j)}{100\%} \qquad (2)$$

where V_m – molar volume of the pollutant (m^3/mol), v_{ij} – amount of substance (mol/kg_{fuel}), ρ_j –density of the pollutant (kg/m^3), TK_j – transfer coefficient of the pollutant (%) [4].

Specific emission B_{ij} of j-th pollutant from combustion of the i-th fuel during clinker production (kg/$t_{clinker}$) was calculated by the Eq. 3:

$$B_{ij} = \frac{A_{ij} \cdot Q_{кл}}{Q_i} \qquad (3)$$

where A_{ij} – specific emission of pollutant from combustion of the fuel (kg/t_{fuel}), Q_i – fuel net calorific value (GJ/t_{fuel}), $Q_{clinker}$ – specific heat for clinker sintering (GJ/$t_{clinker}$).

III. Environmental impact assessment

A potential environmental impact of coal usage and alternative fuels from combustible wastes co-processing was evaluated in accordance with the life cycle impact assessment methodology IMPACT 2002+ (ver. 2.1) [5].

Algorithm of environmental impact assessment is derived by multiplying the amount of consumed/emitted compounds from different elementary flows with respective characterization factors, corresponding to impact categories (Fig 1). A “point” represents the average impact in a specific category “caused” by a person during one year in Europe.

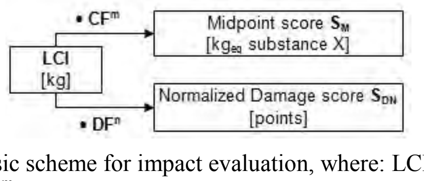


Fig.1 Basic scheme for impact evaluation, where: LCI – flows (kg); CF^m – midpoint characterization factor (kg_{eq}-substance X/$kg_{emitted}$); DF^n – normalized damage factor (points/$kg_{emitted}$).

In most cases, pollutants from fuel combustion had a simultaneous negative effect on several environmental categories (Fig. 2). An arrow shows a quantitatively modelled impact pathway. The impact pathways between midpoint and damage categories, presented by dotted arrows, presumably exist, however, due to the missing data they were not quantitatively modelled [5].

The impact in relative units (%) for wet process kilns is the same as for dry process kilns.

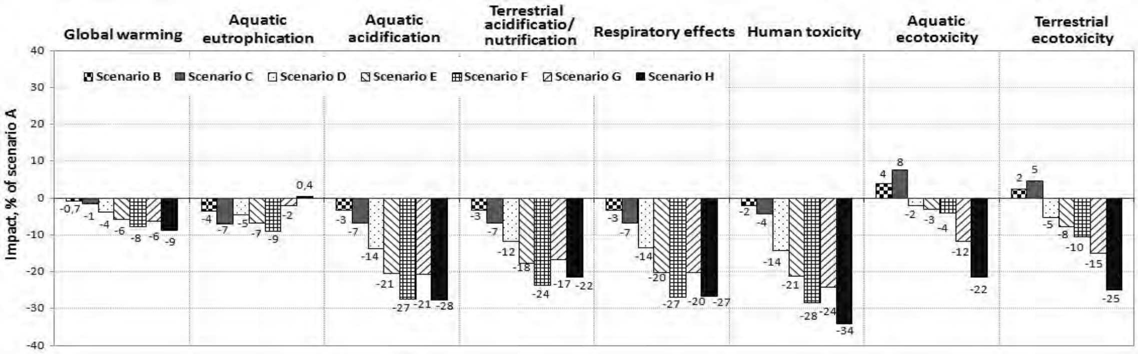


Fig. 4 .The scheme of midpoint categories used for the environmental impact assessment of fuel combustion in rotary cement kiln

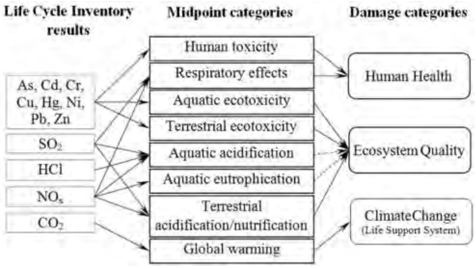


Fig.2 The scheme demonstrates environmental impacts of fuel combustion in rotary kiln based on the IMPACT 2002+ methodology and links life cycle inventory results, midpoint categories and damage categories

Presented results of the environmental impact assessment was calculated for different scenarios (Fig. 3).

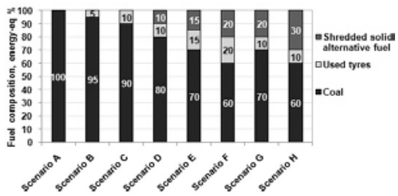
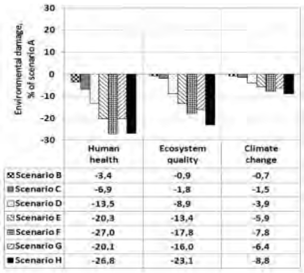


Fig.3 Different scenarios of the fuel mixture composition

An impact assessment results at the midpoint level of fuels combustion by the scenarios shown in Fig. 4.

In consequence, a further step allocated all nine midpoint categories, without aquatic acidification and aquatic eutrophication taken into account, to one or more damage categories (Fig. 5).

The higher the value, the greater impact on the environment, negative values (below zero) reflect the best environmental outcomes compared to the baseline scenario. In the midpoint level (Fig. 4) coal substitution by shredded solid alternative fuel in equal proportions with used tires (Scenarios D, E, F) reduces the impact of fuel combustion in cement kiln on the environment compared to the baseline scenario and in case of the usage of coal alone and used tires (Scenarios B, C). Coal substitution by alternative fuels in all proposed scenarios caused less damage to human health, ecosystem quality and climate change compared to the baseline scenario (Fig. 5). Increase of the part of alternative fuels in the fuel mixture led to decreased environmental damage.



	Human health	Ecosystem quality	Climate change
Scenario B	-3,4	-0,9	-0,7
Scenario C	-6,9	-1,8	-1,5
Scenario D	-13,5	-8,9	-3,9
Scenario E	-20,3	-13,4	-5,9
Scenario F	-27,0	-17,8	-7,8
Scenario G	-20,1	-16,0	-6,4
Scenario H	-26,8	-23,1	-8,8

Fig.5 The scheme of damage categories used for the environmental impact assessment of fuel combustion in rotary cement kiln

Conclusion

It was revealed that partial coal substitution by alternative fuels causes less negative impact on the environment than coal combustion. The results of environmental impact assessment allows us to optimally decrease the usage of non-renewable natural fuels in cement industry.

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