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Exergy analyses in cement production applying waste fuel and mineralizer

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ABSTRACT

The cement industry is an energy-intensive industry and emits large quantities of carbon dioxide, so waste fuels could usefully substitute part of the fossil fuels. They can also help resolve air pollution problems associated with the use of fossil fuels. Other wastes have properties of reducing the thermal energy consumption of clinker production. They are named mineralizers. Then the application of both in the cement industry contributes to the reduction of environmental liabilities and provides lower cost of acquisition of fossil fuels. The aim of the present study is confirm the advantages of the application of waste SPL (spent pot lining) as a mineralizer in clinker production from an exergetic viewpoint.

1. Introduction

Industrial growth is accompanied by a growth in waste production. This is a challenge to overcome and has been an environmental problem in recent years, mainly for the industries that generate hazardous residues. According to the Brazilian Association of Waste Treatment Companies [1], 2.9 million tons of hazardous industrial wastes are generated annually in Brazil. Only 600 thousand tons (about 22%) receive appropriate treatment. The remaining 78% are deposited in landfill without treatment [1].

Brazil, for example, in 2010 produced 67.3 million units of tyres [2] that are incorrectly classified as useless and cause negative impacts on the environment and serious problems for public health. One alternative for waste tyres is to burn them in the rotary kilns of the cement industry, in this way recovering the energy from the tyres and simultaneously promoting a thermal treatment of the waste. In 2008, 32 million waste tyres were burned in cement plants [3].

The cement industry has characteristics that make the burning of wastes viable, since it is characterized by high energy thermal consumption due mainly to the high temperatures necessary to produce the clinker which is the main component of the cement, and it is responsible for its hydraulic properties. The clinker is obtained from the grinding, homogenization and burning (high temperatures – 1450 °C) inside rotary kilns of raw materials (limestone, clay, sand, iron ore). The next steps are the cooling of the clinker, grinding the clinker with gypsum and other additives to produce cement and finally storing, packaging and transporting the cement to the end user [4,5]. The use of wastes in the cement industry has another important advantage, which is the property of mineralizing some wastes. Their incorporation in small proportions improves the clinkering conditions as well as decreasing the maximum clinkering temperature, or improves the phase formation in the clinker without altering the final properties of the product [6].

One waste applied as mineralizer is the SPL (spent pot lining) originating from the aluminum industry, whose properties allow the clinkering temperature to be reduced by up to 80 °C [7]. With this advantage this work selected this mineralizer, and an exergy analysis of clinker production was computed based on the second law of thermodynamics. This analysis identified the exergy losses and irreversibility, producing suggestions on how the process could be improved [8]. At the end of the present study, the exergy efficiencies of each stage of clinker production are compared.

1.1. Exergy analysis in cement industry

In the literature, there are many works that have applied exergy analysis for the cement industry. For example, the work [9] reviewed exergy analysis, exergy balance and exergetic efficiencies for the cement industry. The results showed that exergy efficiency remains lower than 26% and the main source of irreversibility in the cement industry is the rotary kiln where the pyro-process

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occurs. Pyro-processing also accounts for the major share of the total energy use (93–99% in some cases). Thus the use of alternative fuels or waste heat recovery could be important for future research and development [10].

The work [11] examined heat recovery from the rotary kiln at a cement plant in Turkey. First, an exergy analysis was carried out based on the operational data of the plant. The results indicated the presence of 217.31 GJ of waste heat, which is 51% of the overall heat of the process. Then a mathematical model was developed for a new heat recovery exchanger for the plant. It was determined that 5% of the waste heat can be utilized with the heat recovery exchanger. This system is expected to reduce domestic coal and natural gas consumption by 51.55% and 62.62% respectively. CO_2 emissions may also be reduced by 5901.94 kg/h and 1816.90 kg/h when waste heat is used instead of coal and natural gas.

The work [12] performed energy and exergy analyses of a coal-preparation unit in a cement plant and investigated the effect of varying dead state (ambient) temperatures on exergy efficiency. The mean values of energy and exergy efficiencies of the unit were found to be 74.03% and 21.36% respectively, while the average potential improvement of the unit was calculated as 78.24%. The analyses also demonstrated that the exergy destruction ratio affected the CO_2 emission rate of the unit. The technique can therefore be a tool used for the purpose of developing energy policies and providing energy conservation measures, especially concerning similar types of industrial processes.

The raw mill in a cement production plant has also been investigated in relation to exergy analysis. The work [13] performed an energy and exergy analysis of a raw mill and raw materials preparation. The results obtained for the energy and exergy efficiency of the raw mill were 84.3% and 25.2% respectively. The results identified heat losses by conduction; convection and radiation from the surface of the raw mill were about 14,300 MJ/h, which indicates an energy recovery of 15.70% of the total input energy into the raw mill. The work [14] also studied the raw mill, especially the effects of ambient air temperature and the moisture content of raw materials on the performance of the raw mill. The results showed that an external hot gas supply provides a 6.7% reduction in energy consumption, corresponding to a saving of 1.66 kW h per ton of farine production.

1.2. Co-processing (waste fuel)

The cement industry has one of the most intensive energy consumptions. For example, to produce one ton of cement, it is necessary to use 60–130 kg of fuel and 110 kW of electricity [15]. Due to the large consumption of energy, which represents over 30% of the total production cost for the cement industry, the reduction in spending on energy inputs is a motivation for technological advances in the production process.

In this context, the burning of waste materials in cement kilns represents a "win–win" situation. The cement manufacturer wins because kiln fuel costs are dramatically reduced by replacing primary fuel from the kiln with waste material and potentially earning disposal fees from waste generators for treating the waste in the kiln. In the co-processing, hazardous waste is not only destroyed at a higher temperature (around 1450 °C), with a long residence time (retention time up to 8 s), alkali combustion material, and an oxidizing atmosphere [16], but its inorganic content is fixed with the clinker, quite apart from using the energy of the waste.

The decision on what type of substance to use is based on the clinker production processes, the raw material and fuel compositions, the feeding points, the air pollution control devices and the waste management problems involved. Certain kinds of waste must be dried and pulverized. In addition, the calorific value from the organic part of the waste and the material value from the mineral part of the waste are also important [17].

Another aspect is the influence of the use of alternative fuels on the clinker properties. The burning behavior of most alternative fuels differs significantly from the behavior of fossil fuels due to higher particle sizes and different material densities and transport characteristics. This can change the temperature profile of the kiln, including the sintering temperature, the length of the sintering zone and the cooling conditions. All of these changes can affect different clinker characteristics like the burning grade of the clinker, the porosity of the granules, the crystal size of the clinker phases or their reactivity [18].

The work [19] found that the addition of different types of waste fuels requires an excellent control of the temperature in the clinkering zone, because even slightly exceeding the required temperature would excessively fluidize the clinker and might cause damage to the refractory lining of the furnace.

Currently, a wide range of hazardous waste materials may be co-processed, such as rubber residues, pulp sludge, used tyres, plastic residues, wood waste and more. There are also hazardous liquid wastes such as tar, chemical wastes, distillation residues, waste solvents, used oils, wax suspension, and oil sludge [20].

Examples of waste which is not suitable for co-processing in the cement industry include nuclear waste, infectious medical waste, entire batteries and untreated mixed municipal waste. Thus, the co-processing needs an adequate quality control system for all materials used. This ensures that they are co-processed in an environmentally safe and sound manner, safeguarding the [21]:

1. Health and safety of the workers in the plant and the people living in the neighborhoods.
2. Environmental impact of the production process.
3. High quality of the final product.
4. Correct and undisturbed functioning of the production process.

Due to the danger inherent in some wastes, in Brazil there is a system of federal agencies designed to ensure the efficacy of environmental legislation. The main Federal Standards controlling emissions from cement kilns are Resolution CONAMA 264/1999, which provides the procedures and the specific criteria of co-incineration, and Resolution CONAMA 316/2002, which sets out the procedures and criteria for the operation of waste treatment systems [22].

In Brazil, the waste fuels are exploited by the cement industry using a co-processing technique that has been used in Brazil since the 1990s. The co-processing has the following characteristics during the production process [23]:

- The alkaline conditions and the intensive mixing favor the absorption of volatile components from the gas phase. This internal gas cleaning results in low emissions of components such as SO_2 and HCl.
- The clinker reactions at 1450 °C allow incorporation of ashes and chemical binding of metals to the clinker.

In 2008, approximately one million tons of industrial wastes were co-processed in cement kilns. 44% of the wastes were employed as substitutes for raw materials, 39.4% were applied as fuels in the kiln, and 16.6% were tyres. In the period 2001–2006, 40 million tyres were sent for use by the cement industry [24].

1.3. Mineralizer and spent pot lining (SPL)

Mineralizers have been applied in the cement industry for years, with the purpose of reducing thermal energy consumption