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Analysis of the parameters affecting energy consumption of a rotary kiln in cement industry

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HIGHLIGHTS

- We analyzed a rotary kiln and investigated the first law and second law efficiency values.
- Performance assessment of a kiln indicates that the burning process involves energy and exergy losses.
- The anzast layer affect the efficiency and production capacity of the kiln.
- The specific energy consumption for clinker production is determined.

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ABSTRACT

In this study, the effects of refractory bricks and formation of anzast layer on the specific energy consumption of a rotary kiln are investigated. Thermodynamic analysis of the kiln is performed to achieve effective and efficient energy management scheme. Actual data, which are taken from a cement plant located in Gaziantep, Turkey, are used in numerical calculations to obtain energy balance for the system. It is calculated that 12.5 MW of energy is lost from the surface of the kiln which accounts for the 11.3% of the total energy input to the unit. The specific energy consumption for clinker production is determined to be 3735.45 kJ/kg clinker. The formation of anzast layer and the use of high quality magnesia spinel and high alumina refractory bricks provide 7.27% reduction in energy consumption corresponding to a saving of 271.78 MJ per ton of clinker production. It is recognized that the anzast layer has an important role for durability of the refractory bricks and heat transfer out of the kiln. The applications prevent the emission of 1614.48 tons of CO_2 per year to the atmosphere.

1. Introduction

Cement industry is one of the most energy intensive industries in the world. It is essential to investigate the feasibility of reducing coal consumption and greenhouse gas emissions of the rotary kilns in the industry. In comparison to the other industrial sectors, cement industry has been consuming the highest proportion of energy. A typical well-equipped plant consumes about 4 GJ energy to produce one ton of cement. At the same time, this sector is one of the worst pollutant sector [1], which emits an increasing amount of greenhouse gases such as carbon dioxide, nitrogen oxide, chlorofluorocarbons and methane. For each ton of clinker produced, an equivalent amount of greenhouse gases are emitted [2,3]. Cement production in the world is about 3.6 billion ton per year [4]. About 2% of the electricity produced in the whole world is used during the grinding process of raw materials [5]. Total electrical energy consumption for cement production is about 110 kWh/t of cement, roughly two thirds of this energy is used for particle size reduction [6]. Because of high energy consumption rates and high environmental impact of the process, the manufacturing process has been considered by the investigators for many years. Schuer et al. [7] studied energy consumption data and focused on the energy saving methods for German cement industry considering electrical and thermal energy saving methods. Saxena et al. [8] investigated energy efficiency of a cement plant in India. Worell et al. [9] dealt with energy analysis in the U.S. cement industry for the years 1970 and 1997. Engin and Ari [10] analyzed a dry type rotary kiln system with a kiln capacity of 600 t clinker per day. They found that about 40% of the total input energy was lost through hot flue gas, cooler stack and kiln shell. The study indicates that for a dry type cement production process, the carbon dioxide emission intensity for kiln

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feed preparation process is about 5.4 kg CO_2 per ton cement produced. Camdali et al. [11] have calculated the enthalpies going into and leaving the rotary kiln in cement industry and the heat losses from the system by conduction, convection and radiation according to the first law of thermodynamics. Furthermore, exergy analysis of the system is made based on the second law of thermodynamics. Kabir et al. [12] analyzed a pyroprocessing unit of a typical dry process cement plant. In order to enhance the energy performance of the unit, they considered conservation of heat losses from the system. Application of waste heat recovery steam generator and secondary kiln shell were suggested. They showed that power and thermal energy savings of 42.88 MWh/y and 5.30 MW can be achieved respectively. Atmaca et al. [13–15] have employed energy and exergy analysis on a pyroprocessing unit in Turkey, the rate of heat loss is reduced from 22.7 MW to 17.3 MW by the application of insulation to the system. They determined that 1056.7 kW of electricity can be generated by using the waste heat, and annual emission rates have been reduced by 8.2%.

In this study, thermal performance of the rotary kiln presented in a cement plant is investigated using energy analysis based the first and second laws of thermodynamics. The data collected from a cement plant located in Gaziantep, Turkey, are used in numerical calculations to obtain realistic performance parameters. The effects of the anzast layer and thickness, type and composition of refractory bricks on the performance parameters of the kiln are examined. The literature survey indicates that studies on rotary kiln is limited in number and scope, and this paper can contribute to a better understanding of rotary kiln operation and parameters affecting its performance.

2. System description

Cement production is a long process which consumes large amounts of fossil fuels and electricity. The process includes five main stages: (a) mining and grinding of raw materials into fine powder, (b) blending the farine in homogenization silos prior to preheating in four staged cyclone preheaters, (c) increasing the temperature of farine (pre-calcination) in preheating tower with flue gases from the kiln, (d) burning the prepared mixture of farine in a rotary kiln (calcination) after the preheating tower and (e) grinding the clinker in a cement mill.

Clinker production in rotary kiln system is the most energy intensive stage in cement production, accounting for about 90% of total thermal energy use [8].

In the present study, Gaziantep cement plant located in the South-east of Turkey is considered as a case study for the thermal energy analysis. Annual cement production capacity of the plant is 1.5 million tons. The cement plant operates on a dry cement process line. The rotary burner is a refractory lined tube type kiln with a diameter of 4.2 m and 59 m length. It is inclined at an angle of 3.5°, and its rotational speed is 1–2 rpm. The average clinker production capacity of the rotary kiln is 65 t/h. Four stage cyclone type pre-heater is used to pre-calcinate the raw material before it enters the kiln. In a typical dry rotary kiln system, pre-calcination gets started in the pre-heaters, and approximately one third of the raw material would be pre-calcined at the end of pre-heating. The temperature of the pre-heated material is about 1000 °C. The raw material passes through the rotary kiln towards the flame. In the calcination zone, calcination process, combination of alumina, silica and ferric oxide with lime take place at about 1500 °C. Pulverized coal is burnt in the rotary kiln to reach the required reaction temperature. After the combustion and the reactions inside the kiln, clinker, the semi product of cement is produced. Clinker is rapidly cooled in cooling unit after the rotary kiln. Fast cooling of the clinker enables heat recovery from clinker, and improves the product quality [9]. The clinker is ground together with gypsum and other pozzolans materials and finally cement is produced. The flow diagram of the rotary kiln is shown in Fig. 1.

3. Thermodynamic analysis of the rotary kiln

The rotary kiln is heart and the most energy consuming part of a conventional cement plant. Thermodynamic analysis of the kiln system is performed in this section to achieve effective and energy efficient management scheme. Energy and exergy analyses for the kiln unit of the cement factory are performed by using the first and second laws of thermodynamics. Specific heat capacity, input and output mass of each item, temperature, pressure values and constant specific heat of the input and output materials are determined for the operating rotary kiln. Cement production is a continuous process. Stopping the production process in order to change the refractories is a long, costly and undesirable process. The refractory bricks of the rotary kiln are changed when they lose their thermal properties. In order to enter into the rotary kiln and measure the thickness of the anzast layer, we waited for the appropriate time. Many measurements have been taken for about 3 years and average values are used. During the analysis, the following assumptions are made: (1) the system is assumed to be steady state, steady flow process, (2) kinetic and potential energy chances of input and output materials are negligible, (3) the gases inside the kiln are assumed to be ideal gases, (4) electrical energy produces the shaft work in the system, (5) the ambient and kiln average surface temperatures are constant throughout the period of the study.

In order to find heat and work interactions, energy and exergy efficiencies, and the rate of irreversibility in a steady state flow process, the following balance equations are applied. The mass balance for an open system operating under steady state conditions is expressed as:

$$\sum \dot{m}_{\text{in}} = \sum \dot{m}_{\text{out}} \tag{1}$$

where $\dot{m}$ is the mass flow rate of the kiln, subscripts "in" and "out" in all expressions stand for input and output values of each parameter.

The general energy balance can be expressed as:

$$\sum \dot{E}_{\text{in}} = \sum \dot{E}_{\text{out}} \tag{2}$$

$$\dot{Q}_{\text{net,in}} - \dot{W}_{\text{net,out}} = \sum \dot{m}_{\text{out}} h_{\text{out}} - \sum \dot{m}_{\text{in}} h_{\text{in}} \tag{3}$$

where $\dot{Q}$ is the rate of heat transfer, $\dot{W}$ is the rate of work, $\dot{m}$ is mass flow rate, and h is enthalpy. The first law (energy or energetic)

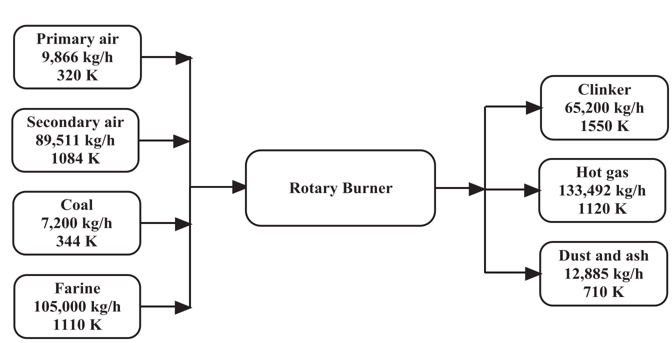

Fig. 1. Rotary kiln flow diagram.