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Research Paper

The improved heat integration of cement production under limited process conditions: A case study for Croatia

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ABSTRACT

Given that cement is the most widely used material for housing and modern infrastructure needs, this paper analyses the energy efficiency of the cement manufacturing processes for a particular cement plant. The cement industry is one of the largest consumers of carbon-containing primary energy sources and one of the primary polluters of the environment, emitting approximately 5% of global pollution. Energy consumption represents the largest part of the production cost for cement factories and has a significant influence on product prices. Given that it is realised in modern society that infrastructural projects lead to a higher level of economy and sustainability for countries, reducing the production cost in the cement industry is a very important problem. The authors analysed the energy consumption of a particular cement factory in Croatia to determine the minimum energy targets of production and proposed pathways to improve energy efficiency. The Process Integration approach was used in this study. Nevertheless, the features of the cement factory forced the research to update its methodological steps to propose real pathways for a retrofit project with the aim of achieving the optimal minimum temperature difference between process streams. There are various streams, including those that contain solid particles, gas and air streams, and streams, that should be cooled down rapidly; these facts become more complicated by the special construction of the process equipment, which causes heat transfer between some streams to be impossible. The main objective of this paper is to determine the potential of real energy savings and propose a solution for a new concept of heat exchanger network (HEN) that avoids the process traps and provides a feasible retrofit. The maximum heat recovery of that production of a particular type of cement was determined and improved when a HEN was built. The authors conclude that the energy consumption of the cement factory can be reduced by 30%, with an estimated recovery period of 3.4 months. The implementation of this retrofit project helps the plant's profitability and improves the environmental impact of the cement manufacturing process.

1. Introduction

The cement industry sector—as an energy-intensive industrial sector in which energy costs represent approximately 40% of the total production cost and one of the highest CO_2 emitting industrial sectors accounts for approximately 5% of global anthropogenic CO_2 emissions [1]. In 2011, the world cement production, according to the IEA, was 3635 Mt with a predicted increase to 4556 Mt in 2020, 4991 Mt in 2030 and 5549 Mt in 2050 for the high-demand scenario. According to the same scenario, by 2050, the cement producers will be required to reduce CO_2 emissions by 15%, representing a direct reduction of up to 913 $MtCO_2$ [2]. Therefore, the cement industry must adopt more energy-efficient technologies to reduce its environmental impact. However, owing to the large amount of CO_2 coming from the process itself, it will also be necessary to identify the potential for applications of renewables in the cement manufacturing process or even change from conventional production to a new, less CO_2-intensive production process.

Given the significance of the cement industry sector and increased environmental awareness [3], several studies in different parts of the world have demonstrated the energy efficiency of cement plants and CO_2 emission reduction. Much of that work studied the improvement of the cement production process and options for CO_2 emission reduction. Pardo et al. [4] demonstrated

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the potential for improvement in the energy efficiency of the EU's cement industry and CO_2 emission reduction by 2030. Liu et al. [5] reported the potential for the renovation and building of new cement plants in China. Chen [6] demonstrated the potential technical benefit of the cement clinkering process with compact internal burning of carbon inside a cement shaft kiln. The study showed that the proposed technique can compete with the existing precalciner kiln process. Hasanbeigi et al. [7] demonstrated the abatement CO_2 cost curve for the Thai cement industry. The possibilities and costs of CO_2 abatement were identified considering the costs and CO_2 abatement for different technologies. Worrell et al. [8] presented an in-depth analysis of the US cement industry, showing the possibilities for energy saving and CO_2 emission reduction based on a detailed national technology database. That work emphasized that the most energy-efficient pyro-processing cement manufacturing systems consist of preheaters, a calciner and a rotary kiln. Sheinbaum and Ozawa [9] reported the energy use and CO_2 emissions in the Mexican cement industry, concluding that the focus of the energy and CO_2 emissions reduction should be on the use of alternative fuels. This observation was also confirmed in the study by Mikulčić et al. [10]. Using real plant data and different types and amounts of alternative fuels, the study analysed the environmental impact of cement production. The study showed that the environmental impact of cement production can be reduced if a more energy-efficient process of cement production is utilised along with alternative fuels. Real plant data for the analysis of the parameters affecting the energy consumption of a rotary kiln were used in the study by Atmaca and Yumrutas [11]. The study showed that significant fuel savings can be achieved by minimising heat losses via effective insulation, reducing the temperature of gases at the outlet, and more effective heat transfer in the unit.

Stefanović et al. [12] evaluated the CO_2 emission reduction potential that can be achieved by partial substitution of cement with fly ash in the concrete. The study further concluded that the quality of the concrete will remain the same. Zervaki et al. [13] studied the physical properties of the cement mortars produced with the use of sludge water. It was proved that sludge water, as well as sludge in a wet or dry form, could be used in the production of mortar without degrading any of its properties. Wang et al. [14] conducted an exergy analysis with use of the organic Rankine cycle and Kalina cycle for cogeneration in a cement plant and found optimal parameters to maximise exergy efficiency. Integration approaches could also be applied to reduce the fuel consumption and emission as reported by Seferlis et al. [15]. These methods are grounded on the thermodynamic approach and have very wide applications in reprocessing industries, as explained by Boldyryev and Varbanov [16]. To utilise waste industrial heat and optimize the site utility system of some energy consumers and producers, Total Site Analysis (TSA) can be used as presented by Klemeš et al. [17]. This methodology was later extended by many researchers. Chew et al. [18] extended the scope of Pinch Analysis for process modifications of individual processes to Total Site Heat Integration and applied the plus–minus principle to enable beneficial process modification options to maximise energy savings. Grip et al. [19] analysed Mathematical Programming using an MILP method, exergy analysis and Pinch Analysis. Experiences and examples of results with the different methods have been given and discussed by different authors. Baniassadi et al. [20] presented applied methodology for the analysis of an industrial energy system based on the modifications of the R-curve concept. This method calculates and most efficient fuel for the utility system. Mian et al. [21] use Pinch Analysis and Process Integration techniques to optimize the energy efficiency of cement production with primary energy consumption of 3600 MJ/t. They estimated the thermodynamic and exergy-available heat that can be recovered and concluded that heat energy could be reduced by 30%. Nevertheless, the authors did not provide the solution of a retrofit project, nor did they provide the definition of a feasible temperature approach. The previous developments mentioned above were rarely supplemented with proper applications of the methodology, especially for HEN generation. The analysis and application of different methodologies are usually faced with process features of different industrial clusters. In addition, there is a lack of applications of Process Integration approaches in the cement industry owing to its specific process condition and some limitations, including different streams with solid particles, solid–gas and solid–air heat transfer, and streams that should be cooled down rapidly. In appropriate case studies, this approach can be analysed and subsequently used to achieve real savings in the cement industry. Therefore, in this paper, the possibility of and pathways toward maximisation of heat recovery and the concept design of HEN are analysed and developed.

The energy efficiency of a particular cement plant is evaluated such that the total energy consumption of that particular cement plant is compared with the total energy consumption of a benchmark. Currently, the best available technology, the one with the lowest energy consumption, for cement manufacturing is the use of a rotary kiln along with a multistage cyclone preheater system and a calciner. The total energy consumption of such a plant is 2.93 GJ/t, and this value is currently considered as the benchmark [22]. The total energy consumption is also used to evaluate the improvements in the energy efficiency of the cement production process. The current total energy consumption of a kiln process in the Koromačno cement plant, the plant analysed in this study, is 3.65 GJ/t of cement. As seen, there is still space for certain improvement in the energy efficiency of this particular cement plant.

2. Process description

Quarrying is the first step in the cement production process (see Fig. 1). Inside the quarry that is near the cement plant under study, which is under Holcim's concession for the next 30 years, low- and high-grade marl and limestone are gathered by blasting. After that, the material with granulation of up to 800 mm is transported via dump trucks to the hammer crusher, where it is crushed to the granulation of 0–80 mm for marl and 0–50 mm for limestone.

The high-grade and low-grade marl and quartz (silica corrective material) are then stored separately.

From the storage, the raw materials are transported to the vertical roller mill position No. 361 in Fig. 1 (pos. 361), which has a capacity of 170 t/h, and very fine raw meal is produced. The storage of this raw meal consists of 2 silos (pos. 391, 381) with a capacity of 2200 t each.

The fine raw meal from the silos is then fed to the kiln (pos. 461) with a standard capacity of 90 t/h and maximum capacity of 110 t/h. Inside the kiln, approximately 57 t/h of clinker, the main ingredient of cement, is produced. The hot flue gases from the kiln are used to heat the raw mill system, coal mill system, and raw meal in the kiln. The gasses exit the preheating tower with a temperature of 370 °C. Because the filter bags (pos. 421) cannot withstand temperatures higher than 140 °C, the flue gasses must be cooled at the cooling tower. The flue gasses at the cooling tower are cooled to a temperature of 175 °C and to achieve this, approximately 10.5 m^3 of cooling water is used. Afterwards, a fan is used to further reduce the flue gas temperature from 175 °C to 105 °C. After the flue gasses are filtered, they go to the stack, from which they are discharged into the atmosphere.

On the kiln outlet side, where the clinker is exiting, the temperature of the clinker is approximately 1450 °C. At this