Chapter 7

Heat Integration in a Cement Production

Stanislav Boldyryev

Additional information is available at the end of the chapter

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Abstract

The cement industry sector is an energy-intensive industrial sector; cement is the most widely used material for construction and modern infrastructure needs. The cement industry is one of the largest consumers of carbon-containing primary energy sources and one of the primary polluters of the environment. Energy consumption represents the largest part of the production cost for cement factories and has a significant influence on product prices. The potential of waste heat utilization of cement production was determined and a recovery potential accounting site wide in demand is defined by the process integration technique. The author has analyzed the energy consumption of a cement factory to obtain minimum energy needs of production and proposed the options to improve energy efficiency by the process integration approach. The authors conclude that the energy consumption of the cement factory can be reduced by 30%. The results help to the cement plant's profitability and reduce environmental impact of the cement industry as well as sustainability. Given that it is realized 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.

Keywords: process integration, pinch analysis, energy efficiency, cement production, energy targets, heat exchangers

1. Introduction

Nowadays, cement manufacturing is an energy-intensive industry. The energy costs of cement industry are about 40% of the product cost that indicates that this sector is one of the biggest CO_2 emitter. The global anthropogenic CO_2 emission of cement industry is approximately 5% [1].

The International Energy Agency reported in 2011 that the world cement production was 3635 Mt. with a forecast rising up to 4556 Mt. in 2020, 4991 Mt. in 2030 and 5549 Mt. in 2050 according to scenarios with high demands. In case of the same scenarios, by 2050, the cement manufacturers have to reduce the CO_2 emissions by 15%, with a direct decrease of up to 913 Mt. [2].

Hence, cement manufacturing has to implement more energy reduction to be more environmentally friendly. However, as there is a large amount of CO_2 coming from the existing technology, it is important to estimate a renewable energy potential use in the cement production industry or even switch from conventional fuel to a new one with low CO_2 emissions.

Due to great significance of the cement industrial sector and high environmental perception [3] last time, a lot of researches worldwide have shown the energy efficiency improvement of cement factories and pollution reduction. Most of the published researchers investigated the improvement of the cement technology and different varieties for CO_2 emission reduction. Pardo et al. [4] are trying to define the potential of energy efficiency improvement of the EU's cement sector and CO_2 gaseous emission reduction by 2030. Liu et al. [5] have presented the retrofit and building of new cement factories in China, accounting different technologies. Chen [6] had defined the advantages of the clinkering process by compact internal burning of carbon inside a cement shaft kiln. This research demonstrated the competitiveness of the proposed measure with the existing one that uses the precalciner kiln process. The work published by Hasanbeigi et al. [7] points out the CO_2 cost curves for the Thailand cement sector. An estimated potential and expenses of CO_2 abatement were investigated taking into account the expenses and CO_2 abatement for a variety of applications. As presented by Worrell et al. [8], an in-depth analysis of a US cement industry considering a potential for energy cost and CO_2 emission decreasing by the national technologies database was done. It was found that one of the most effective pyro-processing cement manufacturing systems composed of a calciner, several preheaters and the rotary kiln. The data of observed factory for the analysis of the parameters influencing the energy usage of a rotary kiln were utilized in the research by Atmaca and Yumrutas. Their work highlighted that high-energy savings may be obtained by reduction of heat losses with use of insulation, decreasing the outlet gas temperature and heat transfer enhancement. Sheinbaum and Ozawa [9] have presented the energy demands and CO_2 emissions of the cement sector of Mexico, summarizing, that the measures of a fossil fuel, CO_2 and other pollutants reduction have to be focused on the use of environmentally friendly energy sources. These assumptions were also concluded by Mikulčić et al. [10]. With the use of real industrial data and combination of kinds and flow rates of alternative energy sources, the work [11] estimated the ecological impact of cement manufacturing process. It is concluded that the environmental impact of the cement manufacturing process could be lowered if a more energy-saving process of cement manufacturing is utilized along with alternative fuels.

Stefanović et al. [12] estimated the potential of CO_2 emission reduction that may be lowered partly by use of cement with fly ash in the concrete. The research showed that the properties and quality of the new kind of concrete remain the same. Another work by Zervaki et al. [13] investigated the properties of the cement mortars manufactured by use of sludge water. It was examined that the sludge water, as well as a dry or wet sludge, may be employed in a mortar manufacturing process without remaining its physical properties. As presented by Wang et al. [14], the exergy approach combining with an organic Rankine cycle (ORC) and Kalina cycle were made to estimate of cogeneration opportunities of a cement factory as well as the calculation of optimal conditions and maximum efficiency. Process integration methods may be used as well to decrease energy use and emissions as were summarized in the work of Professor Seferlis et al. [15]. Presented approaches are based on thermodynamics laws and have different applications in different processing sectors; this issue was reported by Boldyryev and Varbanov [16]. In order to employ the industrial low potential heat and improve a heat utility system of different users and suppliers, a total site integration (TSI) may be employed as shown by Klemeš et al. [17]. Later, a similar approach was developed by different authors. As an example, Chew et al. [18] expanded the content of a pinch approach of individual process changes to improve a TSI and adapted the plus-minus principle for process modification options to improve process efficiency. Grip et al. [19] used the mixed-integer linear programming (MILP) approach, exergy analysis and pinch analysis (PA). Experience and results of a multiple approach were presented and considered in literature by many authors. For instance, Baniassadi et al. [20] represented a technique for an industrial energy system analysis with the use of modified R-curve approach. This methodology estimates the use of the most efficient fuel type for the industrial utility system. Mian et al. [21] employed the pinch analysis and the process integration approaches for energy optimization of cement manufacturing with primary energy demands of 3600 MJ/t. Authors calculated the thermodynamically and exergy available amount of heat that can be utilized and summarized that the potential of thermal energy reduction is 30%. However, the authors did not propose the retrofit project design nor was the definition of a feasible temperature approach provided. Summarizing the abovementioned, the recent works were rarely supplemented with proper industrial applications of the methodology, especially for the new heat exchanger network (HEN) design and retrofit of existing ones. The analysis and application of different methodologies are usually faced with process features of different industries. In addition, there is a lack of industrial applications of process integration techniques in the cement manufacturing processes owing to its specific process features and process limitations, such as solid particles of process streams, solid-gas and solid-air heat exchange and fast cooling of gaseous streams. Such approaches can be analyzed and subsequently used in appropriate case studies to achieve a real efficiency of the cement manufacturing processes. Thus, this chapter is dedicated to energy efficiency and pathways toward maximization of feasible heat recovery and the concept design of heat exchange system at the particular cement factory.

The energy efficiency potential of a cement factory is estimated. The total energy consumption of the particular cement manufacturing was compared with the benchmark value. Nowadays, considering a best available technology (BAT), the one with the lowest energy consumption of cement production is the rotary kiln use, many cyclone preheaters and the calciner. This technology has energy demands of a cement factory at about 2.93 GJ/t. The same amount is now used for benchmarking point [22]. Present technologies that use the kiln process have total energy consumption at about 3.65 GJ/t of cement. As mentioned, there are still opportunities to reduce the energy consumption of the particular cement factory.

The main goal of this chapter is to identify the potential of feasible energy recovery and to suggest pathways for a new concept design of heat exchange system avoiding the process traps and limitations. The maximum heat recovery of the particular cement manufacturing was obtained, and the updated heat exchange system was proposed. The author concluded that the energy consumption of the particular cement plant may be lowered by 30%. Thus, the features of the cement production process forced a methodology update to suggest feasible retrofit pathways with the objective of achieving the optimal temperature approach of the heat exchange system. There are different streams and processes that contain solid particles, gaseous phase and fast cooling down; these facts make a solution more complicated by the special construction of the process equipment, which causes impossible a heat transfer between some process streams.

2. Description of process flow diagram

Quarrying is the first step of the cement manufacturing (see **Figure 1**). Inside the quarry that is close to the cement factory, low- and high-grade marl and limestone are mined by blasting. Further, the raw material with granulation of up to 800 mm has to be 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 low-grade and high-grade marl and quartz (silica corrective material) are then stored separately. From the depository the raw materials are transferred to the vertical roller mill

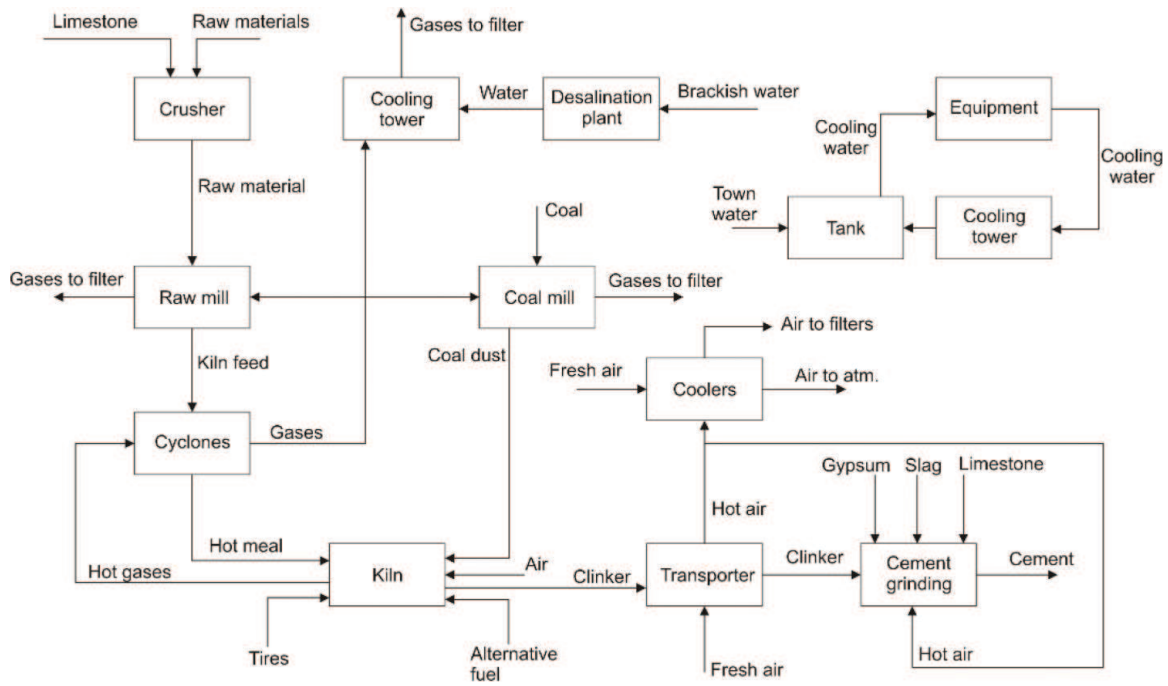

Figure 1. Principal flowsheet of the cement manufacturing process.

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with a capacity of 170 t/h and appropriate raw meal is produced. The storage of current raw meal has two silos with a capacity of 2200 t each.

The prepared raw meal from the silos is supplied to the kiln. The kiln has an operation capacity of 90 t/h and upper bound of 110 t/h. A total of 57 t/h of the clinker is produced inside the kiln. For the heating of the raw mill, kiln raw meal, and a coal mill, hot flue gases from the kiln are deployed. Gases exit from a preheating tower with a temperature at about 370°C. Flue gases have be cooled down at the cooling tower because the filter bags cannot operate at the temperature higher than 140°C. The flue gases at the cooling tower are cooled to a temperature of 175°C by 10.5 m^3 of cooling water. To further reduce the flue gas temperature from 175 to 105°C, fans are used to pump the ambient air. Flue gases go to the stack after filtration, and further, they are discharged into the environment.

At the kiln outlet side the temperature of the clinker is approximately 1450°C. At this stage, to preserve the clinker mineral structure, that is, its quality, the clinker has to be cooled very quickly to a temperature of approximately 150°C. A large amount of ambient air is introduced through seven clinker cooler fans to achieve the target temperature outlet. The ambient air is heated up to 290°C. After that, a small amount of this air is employed as an additional oxygen source in the kiln and a bigger part is supplied for cement mill heating if it is under operation. The operation mode with disabled cement mill envisages air cooling down before the filter bags. The gas has to be cooled to 105°C prior to the clinker cooler filter bags, after the gas is eliminated to the stack by four rows of four blowers.

The hot gases are needed for the cement grinding process. The hot air is taken to the separator where materials (clinker, limestone/slag and gypsum), pre-grinded on the roller press, are heated to extract moisture and prepare the resulting material for filter bags. They can be delivered from the clinker cooler or, in the case when the kiln does not operate, generated by a hot gas generator (HGG) with use of light oil as a fuel. It is the expensive option but it is used only in several weeks when the kiln overhauls. The consumption of the light oil is about 200 l/h.

A material mixture is kept in a bin with a capacity of 70 t that is supplied by a cement ball mill. Dust and fly ash are supplemented after the ball mill depending on the required kind of cement. The cement is then transferred through a bucket elevator to the next separator. Particles comprise the final product that is supplied to the cement silo.

3. Process integration in cement production

The methodology is grounded on the thermodynamic analysis of the heat energy system by composite curves of process streams. The general issues are based on process integration aspects. The pinch analysis (PA) for optimal process structure synthesis is well illustrated by Klemeš et al. [23]. It provides a solution that is very close to the global optimum in a simply and understandable way. The methodology produces the result of potential savings, capital cost and payback period prior to the flow-sheet design. Often, a super targeting procedure is employed to obtain the optimal temperature approach (ΔT_{min}) of the heat exchanger network, but in this case, it is difficult due to manufacturing issues. The existing process design presumes a hot meal heating inside the kiln by flue gases that cannot be executed by another stream owing to the technology. Another problem is a hot clinker, which is from the kiln. The clinker must be cooled down rapidly, and that is done by fresh ambient air. The level of technology that is used now has several restrictions for process changes. They have to be taken into account when the retrofit of HEN is made. The methodology stages were updated and are presented later to obtain the more feasible solution of an efficient heat exchanger network design.

3.1. Data extraction by energy expertise execution

An audit expertise of a particular cement factory was conducted to verify energy and mass balances. A measurement of temperatures, flow rates and fuel burning efficiency is accomplished. The composite curves approach and balanced grand composite are employed for the estimation of energy targets, heat recovery and the operation condition of heat transfer equipment, taking into account the cross-pinch heat exchange. Inefficient heat transfer is identified, and process restrictions and forbidden matches between heat transfer equipment are determined.

3.2. Targeting

Considering the next step, the composite curves of cement production are constructed to obtain the energy target and pinch point position of the existing and improved process. At this step, process restrictions are not considered, and only thermodynamically available heat recovery is obtained.

3.3. New concept of heat exchanger network

Based on the previous stages, the heat exchanger network is built taking into account the process restrictions. It is shown that the cross-pinch heat transfer still exists and it cannot be avoided in this production process due to features. Process streams with limitations are not excluded from the considerations to show the actual heat recovery and the real energy efficiency potential of cement manufacturing. The heat exchanger network was built for the range of ΔT_{min} from 1 to 300°C with step 1°.

3.4. Heat recovery improvement

Based on the previous step, energy targets and pinch point location are defined for different $\Delta T_{min,}$ and maximum heat recovery was found. This procedure determines the heat exchanger network temperature approach, cross-pinch heat transfer and topology heat matches in the heat network.

3.5. Economic analysis

All topologies of heat exchanger network are compared with the base case taking into account operation cost, investment for new networks, operation time, tax rate and other economic prerequisites. Economic results of retrofit execution are defined based on the determination

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of the reduced total cost of the new design with the use of reduced operating and investment cost [23].

3.6. Utilization of waste heat in cement production

The next step is performed by the analysis of the waste heat potential in the retrofitted cement production. As was identified by grand composite, there is waste heat utilization potential, and its possibility should be analyzed additionally. The appropriate integration and efficient placement of heat engines is used by grand composite, which shows the available energy, the supply and demand temperatures of heat engines and a heat source. The waste heat utilization that is discarded by cooling capacity, along with attempts to derive energy from low-potential heat sources, has motivated the use of heat engines, for example, by the organic Rankine cycle (ORC) [24] or utilization of wide site cooling and heating demands [16].

An additional intermediate stream may utilize the heat from process streams to site heating capacities. This may be steam of different pressure, hot water, thermal oil and so on. The selection of the intermediate utility stream is mainly dependent from its start and target temperatures. The T-H diagram represents a total site sink and source profiles by employing individual ΔT_{min} specifications of heat transfer between process streams to show the real stream temperatures [25]. Total site targets of heating and cooling, heat engine capacity and produced emissions are considered by Sun et al. [26]. The use of multiple intermediate utilities of heat recovery and modified total site targets is represented by Boldyryev [27] and methodology advances are discussed. All computations were performed by the HILECT software [28] applying integrated process design with technological restrictions mentioned earlier.

4. Representative case study

4.1. Data collection and reconciliation

This case study was previously introduced by Boldyryev et al. [29, 30]. The energy expertise of the cement factory was conducted during the summer operation mode. The steady-state devices and portable equipment were used. The historical data of process monitoring were collected and analyzed. There are two operation modes of the particular cement factory. The first one is when the raw mill is under operation and, in this case, the cooling water flowrate at the cooling tower is 3 t/h. A hot gas from the kiln is fed into the raw mill and a raw material is heated. The second operation mode presumes that the raw mill is out of operation. In this case, the cooling water flowrate greatly increases and it is 11 t/h. At the same time, the waste heat with hot gases from the kiln is also increased. There are 18 process streams, which may be included to the heat integration of a particular cement factory. There is a heat recovery of an inspected cement plant and a necessary process heat is provided by the fuel combustion while a cooling capacity is delivered by ambient air that is pumped by air fans. **Table 1** has all necessary thermophysical parameters of process streams under analysis.

№	Name of the stream	Type	Supply temperature (°C)	Target temperature (°C)	Heat capacity flowrate (kW/K)	Heat load (kW)
1	Gases to raw mill	Hot	370	105	13.35	3537.42
2	Gases from the kiln	Hot	860	380	40.97	19,663.31
3	Hot gases to cooling	Hot	370	175	11.68	2276.67
4	Gases to coal mill	Hot	370	90	0.73	204.75
5	Clinker from the kiln	Hot	1450	60	15.00	20,850.00
6	Air after clinker cooling	Hot	290	100	70.28	13,352.75
7	Air to cement grinding	Hot	270	105	8.86	1461.60
8	Raw material in a raw mill	Cold	25	110	41.62	−3537.42
9	Kiln raw material	Cold	105	810	21.44	−15,114.42
10	Hot meal	Cold	810	1450	21.19	−13,559.47
11	Coal/petcoke to coal mill	Cold	25	90	3.15	−204.75
12	Coal dust to kiln	Cold	55	170	1.75	−201.25
13	Air to the kiln	Cold	25	170	38.13	−5528.29
14	Tires to the kiln	Cold	25	170	0.14	−20.30
15	Used oil to kiln	Cold	25	170	0.28	−40.48
16	Ambient air for clinker cooling	Cold	25	290	78.68	−20,850.00
17	Clinker to cement grinding	Cold	25	105	15.00	−1200.00
18	Mineral components grinding	Cold	25	105	3.27	−261.60

Table 1. Extracted data of inspected cement factory: raw meal under operation.

Economic data of utilities were also extracted to be able to execute the economic calculation of the retrofit solution. There are two types of fuel supplied to the kiln: coal and petcoke. Cooling water cools down the exhaust gases before the filter bags; the water is fed by the desalination plant. Another cold utility is electricity, and it is used by the hot air coolers, which emerges from the clinker cooling. Cleaned and cooled air from air filter bags is ejected to the environment. A total of 15.6 MW of low-grade heat is ejected to the atmosphere during raw mill operation; this amount is increased up to 19.4 MW if the raw mill is turned off. All fans and pumps of the cooling tower use the electricity.

The primary fuel that is used for this particular cement factory is coal and petcoke. The coal/petcoke ratio is 40/60%, and the caloric values of the fuel are 25.5 and 33 GJ/t, respectively, for coal and petcoke. The average power supply of the cement plant is 5.8 MW, whereas the minimum power consumption is 1.1 MW and the peak load reaches 10 MW. The reduced price of the hot utility is 75.9 EUR/kWy, and the cold utility is 82.0 EUR/kWy.

4.2. Results and discussion

4.2.1. Existing process analysis

Based on the energy expertise, heat balances and stream table data, the composites of the existing cement factory were constructed considering different operation modes of the raw mill. The composite curves of the existing process are presented in **Figure 2**.

The composite curves in **Figure 2** present the energy requirements of the existing cement factory. The operation mode with the raw mill has a heat recovery of 41,125 kW, whereas the process requires extra heating of 19,397 kW and extra cooling of 20,225 kW. For the operation regime without raw mill it is necessary to have larger utility load as presented in **Figure 2**. The energy demands increase to 22,923 kW and 24,006 kW for heating and cooling, respectively. At the same time, the heat recovery decreases to 37,599 kW during raw mill operation mode. The minimum temperature approach of the heat exchanger network of the existing process with the raw mill operation is 247°C; without the raw mill operation, it goes up to 308°C. Both these temperature differences are calculated by energy expertise, mass and heat balances and data reconciliation. It should be noted that the minimum temperature approach of the particular process is 1°C due to direct heat transfer in a raw mill or at cement grinding. The raw mill operation mode is under further consideration to get low bound of energy-saving potential. It has to be extended in future by development of the factory operation modes taking into account fluctuations of process parameters and to develop a tool for operators. The significant difference between the thermodynamically grounded (see **Figure 2**) and real minimum temperature approaches may be additionally explained by cross-pinch heat transfer in the existing heat exchanger network. This is well presented in **Figure 3** by composite curves. Arrows show that the heat transfer from hot to cold streams and cross-pinch lines is absent as well as cold utilities are used above the pinch in E-108 (**Figure 4**).

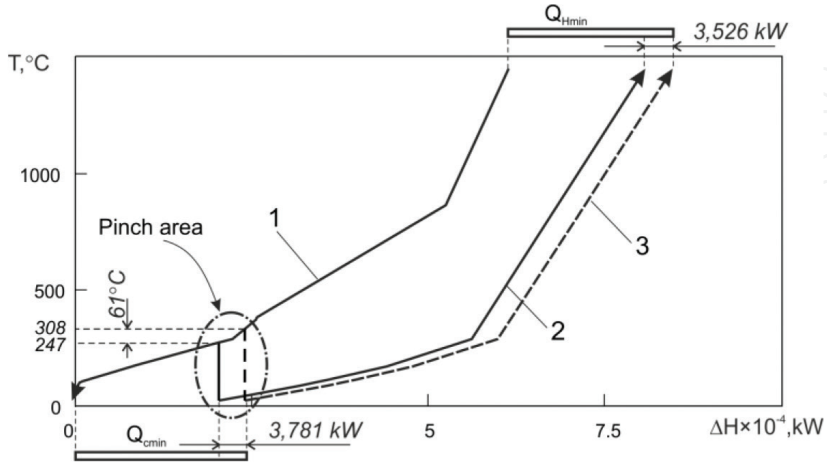

Figure 2. Temperature profiles of a particular cement factory. 1—Hot composite; 2—cold composite raw mill operation mode; 3—cold composite no raw mill operation; Q_{Cmin} = 24,006 kW—cold utility demands (cooling water, air); Q_{Hmin} = 22,923 kW—hot utility demands (fuel) (developed after [30]).

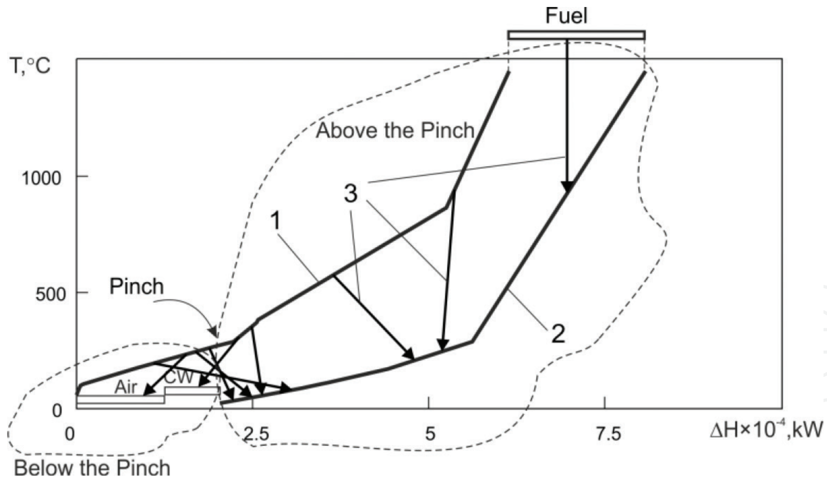

Figure 3. Heat transfer in cement production with raw mill considering the minimum temperature difference. 1—Hot composite curve; 2—cold composite curve, 3—heat exchangers (developed after [30]).

Grid diagram shown in **Figure 4** illustrates the initial heat exchanger network representing the heat transfer between the hot and cold process streams and utilities. The grid diagram illustrates cross-pinch heat transfer; it is a reason of increased utility consumption and lowered efficiency. It is a result of concept design, which was done without the use of optimal heat exchanger network methods and mostly oriented proper product quality.

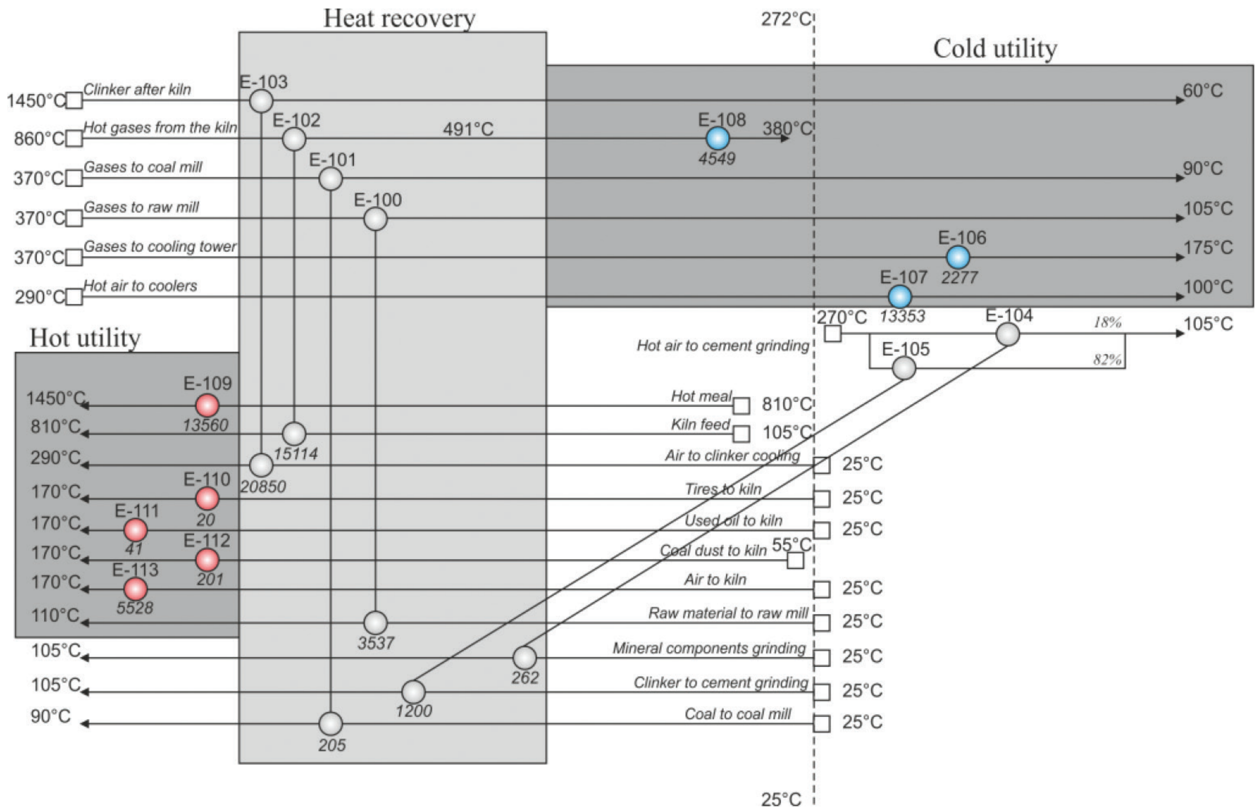

Figure 4. Grid diagram of existing cement production (developed after [30]).

Heat exchanger label	Cross-Pinch heat transfer (kW)
E-100	2229.0
E-101	133.1
E-102	0.0
E-103	3180.0
E-104	261.6
E-105	1200.0
E-106	1132.0
E-107	12,088.5
E-108–E-113	0.0
Network cross-pinch load	20,224.2

Table 2. Analysis result of heat exchanger placement.

The process design, which was oriented to obtain a product rather than energy efficiency, reduces opportunities for overall efficiency of plant operation as highlighted in [31]. The overview of heat exchangers placement of the initial plant design is shown in **Table 2**. The initial cross-pinch transfer is now greater than 20 MW that confirms the low efficiency of the initial design of the heat exchanger network.

4.2.2. Maximization of heat recovery considering process limitations

By providing pinch analysis, it is possible to get thermodynamically available energy targets for particular cement production that shows a large energy-saving potential. Eliminating the cross-pinch heat transfer and cold utility use above the pinch, it is possible to decrease energy consumption and heat recovery improvement. Additionally, the minimum temperature approach may be lowered to minimize the energy targets. This is well illustrated in **Figure 5** by composite curves position for ΔT_{min} = 20°C. Energy targets for hot and cold utilities are 4076 and 4904 kW, respectively; the heat recovery is enlarged up to 56,446 kW; the heat recovery improvement in case of maximum saving is 15,321 kW.

However, the cement manufacturing process has different features previously mentioned in Part 3 of this chapter, such as process streams with a mixture of solid-gas and others. These issues make the feasibility of the heat exchanger network retrofit with maximum heat recovery as impossible. Based on this, the heat exchanger network of the cement factory has huge energy efficiency potential, but it is not easy to achieve a profitable solution owing to the process limitation connected to heating and cooling process streams No 5 and No 10.

It is impossible to avoid process restrictions when implementing an integrated solution. There are some process streams that have such technological limits. First one is a hot meal that has to be heated from 810 to 1450°C inside the kiln. It is not possible to heat it in another with particular technology. Another issue that should be analyzed additionally is clinker from the

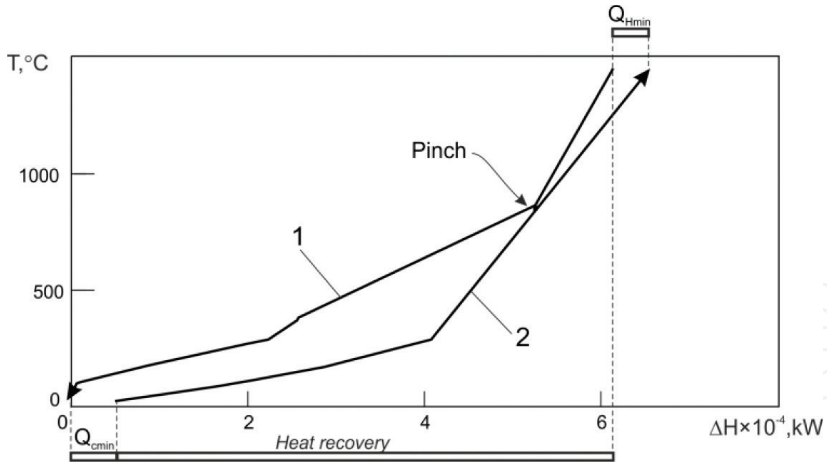

Figure 5. Composite curves of cement production with maximum heat integration. 1—Hot composite curve; 2—cold composite curve with raw mill operation; Q_{Hmin} = 4076 kW—hot utility demands; Q_{Cmin} = 4904 kW—cold utility demands (developed after [30]).

kiln; it has to be cooled down rapidly to 60°C. This is done in the existing process by big fan coolers, and the heat of air is ejected to the environment.

The maximum possible heat recovery of the cement factory taking into account the process restrictions was previously discussed in this chapter. There is an energy target (see right Y-axis, **Figure 6**) and pinch temperatures (left Y-axis, **Figure 6**); these indexes depend from the minimum temperature approach of the heat exchanger network. **Figure 6** shows energy targets (lines 1 and 2 in **Figure 6**, right axis Y) of the cement factory, which may be lowered to a process limit that is 50°C. The reduction of ΔT_{min} below 50°C is useless, as shown in **Figure 6**, due to its increases in the cross-pinch heat transfer and heat transfer area while the energy consumption remains unchanged. This issue also influences the heat exchanger network topology and reduces the cross-pinch heat transfer. The traditional super targeting

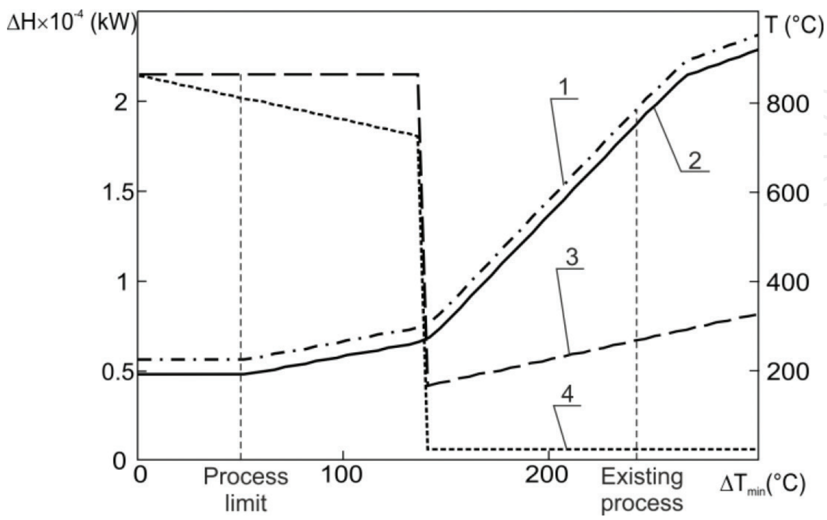

Figure 6. The definition of maximum heat recovery taking into account process restrictions. 1—Cold utility target; 2—hot utility target; 3—hot pinch temperature; 4—cold pinch temperature (developed after [30]).

procedure [23] does not take into account the technological restrictions, for example, as for particular cement manufacturing, and does not have a feasible solution. In our case, the minimum of total reduced cost corresponds to ΔT_{min} = 29°C (see **Figure 7**). Nonetheless, the design of the retrofit for ΔT_{min} = 29°C has the same energy targets as one with ΔT_{min} = 50°C but the heat transfer area is much higher (see **Figure 6**).

4.2.3. New concept of retrofit design

Based on results presented in **Figure 6**, the targets of the retrofit design of cement production are taken, including the minimum temperature approach, energy requirements and pinch point position.

The grid diagram shown in **Figure 8** is the base concept of a new heat exchanger network of a cement factory with minimized energy consumption. It has additionally installed four heat exchangers with an estimated heat transfer area of 1555.1 m^2 and total recovered heat energy of 5790.08 kW. The basic parameters of the new heat exchangers are illustrated in **Table 3**. The new heat exchanger network is presented in **Figure 8**, and it is shown that there is still a large cross-pinch transfer of 8850 kW. This issue may be additionally investigated in the future research of new efficient technologies of cement manufacturing. The cross-pinch heat transfer of the proposed heat exchanger network is illustrated in **Table 4**; there is only one cross-pinch heat exchanger.

The estimated total investment for new heat exchanger network implementation is 256,079 EUR, accounting the installation cost of E-114 and E-115 as 5000 and 10,000 EUR and 30,000 EUR for E-116 and E-117, respectively. The price of the heat transfer area is 800 EUR per 1 m^2, and the nonlinearity price coefficient is 0.87. A new concept design allows reduction of operation cost of 914,401 EUR/year assuming 8200 operation hours per annum. The simple payback period of investments is 3.4 months. By applying the process integration approach, the energy consumption is lowered by 2.56 GJ/t of produced cement, which is 14% less than the existing

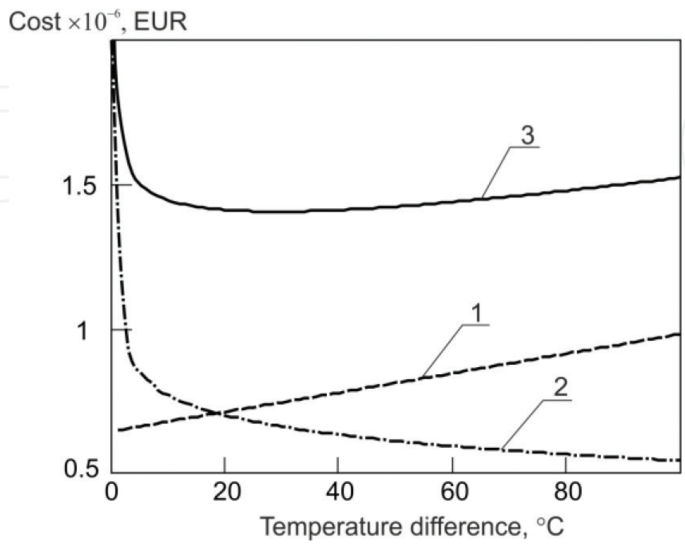

Figure 7. Super targets of cement production. 1—Operation cost; 2—investments; 3—total cost (developed after [30]).

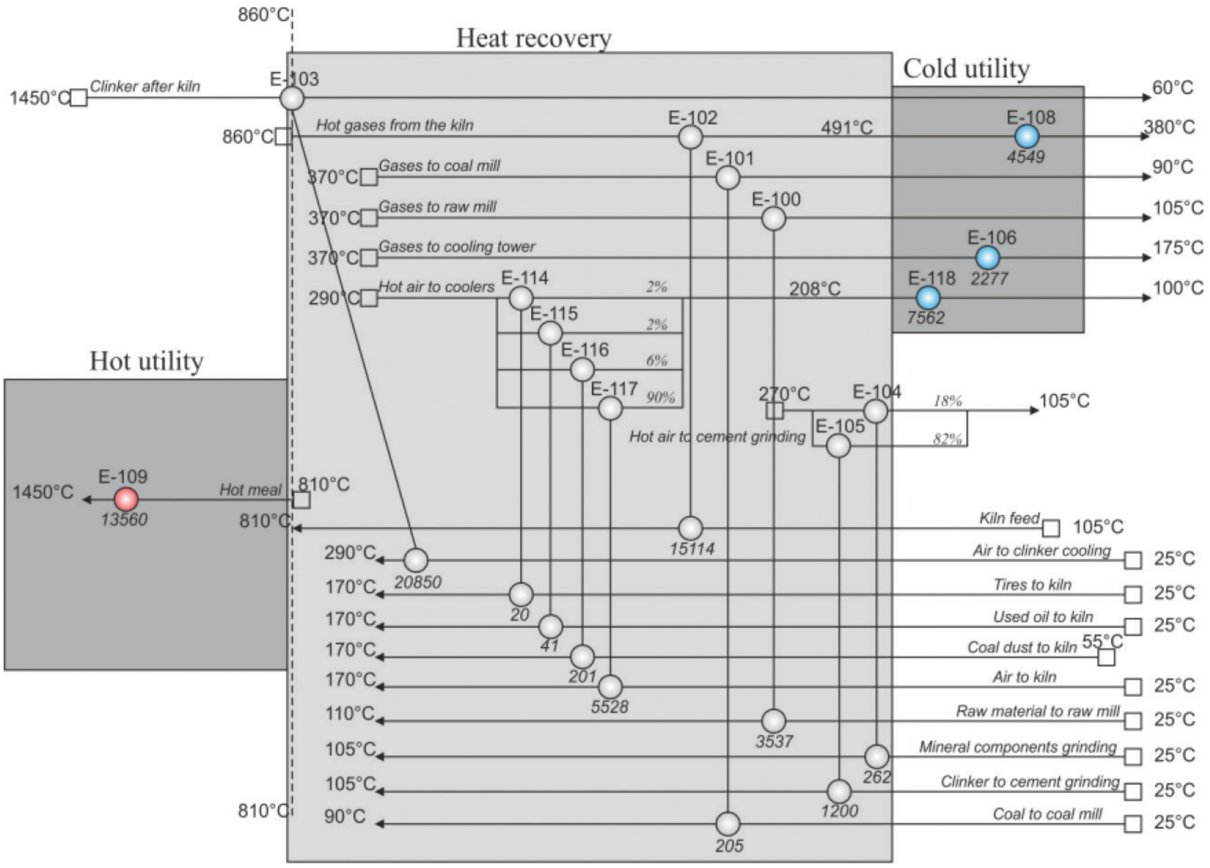

Figure 8. A grid diagram of a retrofit concept design of cement factory (developed after [30]).

Heat exchanger	Cold stream			Hot stream			Load (kW)	Area (m²)
	Name	T_{in} (°C)	T_{out} (°C)	Name	T_{in} (°C)	T_{out} (°C)		
E-114	Tires to the kiln	25	170	Hot air to coolers	290	275.6	20.30	3.4
E-115	Used oil to the kiln	25	170	Hot air to coolers	290	261.2	40.48	6.7
E-116	Coal dust to the kiln	55	170	Hot air to coolers	290	242.3	201.30	39.9
E-117	Air to the kiln	25	170	Hot air to coolers	290	202.6	5528.00	1505.1
Total							5790.08	1555.1

Table 3. Calculated parameters of new additional heat exchangers of cement factory.

benchmark level. The developed new concept design of energy-efficient cement manufacturing demonstrates the feasible and profitable solution that could be potentially used for retrofit as well as new factory design.

Heat exchanger	Cross-pinch heat transfer (kW)
E-100–E-102	0.0
E-103	8850.0
E-104–E-118	0.0
Network cross-pinch load	8850.0

Table 4. Cross-pinch heat load of retrofitted heat exchanger network.

Making an additional analysis with taking into account site-heating needs and power demands of a cement factory other solutions were also proposed in this chapter. The waste heat potential may be used, for example, for electricity generation with use of Organic Rankine Cycle, which is shown in **Figure 9a**. The heat sources, in this particular case, are process streams 3 and 6 (for more details see **Table 1**), and the calculated power generation is 2482 kW.

The estimated investment cost of power generation design is about 3.4 million EUR. The analysis of site demands in winter operation mode identified the other option of waste heat utilization, which is a district heating system. The low-grade heat potential of existing cement factory is given in **Figure 9b** (see curve 3) and due to this measure it is possible eliminating cold utility while the hot utility remains. In a particular case, the primary cold utility is power for air fans (680 kW), and from the other side, 20,225 kW of site heating demands may be covered by low-grade waste heat. The implementation of winter mode retrofit measures requires an estimated investment cost of 20.3 million EUR. The total saving of both retrofit designs during winter and summer operation modes is 7.648 million EUR. The payback time of combined retrofit for winter and summer operation modes is 3.01 per year assuming the total investment cost of 23.7 million EUR.

4.2.4. Impact and future work

An additional analysis of the energy-saving heat exchange system for cement factory presents a room for improvement in terms of efficient energy use. The grid diagram of the proposed

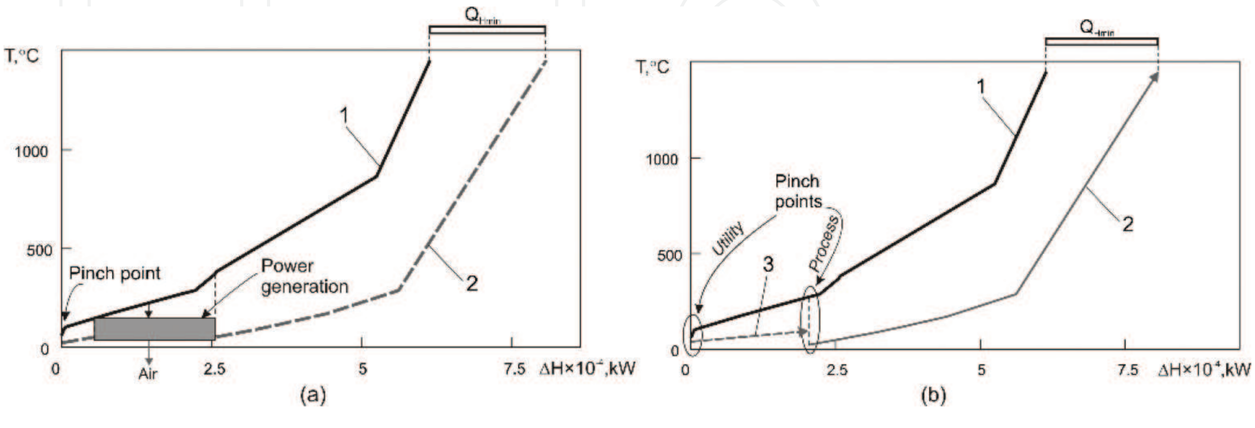

Figure 9. Composite curves of cement manufacturing for low-potential heat utilization; a—summer operation mode; b—winter operation mode; 1—hot composite curve; 2—cold composite curve with raw mill operation; 3—site heating demands; Q_{Hmin}—hot utility demands (developed after [29]).

heat exchanger network of the cement plant (**Figure 8**) has illustrated the ways to use waste heat. The potential of waste heat may be used for power generation by heat engines' application as demonstrated by Quoilin and Lemort [32]. The heat duty of waste gas is 14,338 kW and the temperature is 200°C or higher (see **Figure 8**). However, if the plant is operated in the mode without a raw mill, the power generation increases as well. Important points that have to be additionally discussed are the fluctuations of plant operation parameters, solid–gas source streams and installation features of power generator.

Another option of waste heat utilization from integrated cement production is the covering of site heating demands. The district heating system may be potentially supplied by waste heat to fulfill energy demands. The maximum capacity of waste heat that may be used is 14,338 kW as illustrated earlier. However, the technical implementation, including the heat losses and pressure drops, has to be additionally analyzed in details along with the economic issues of the retrofit design as well as energy planning. The results presented in this chapter have a cross-disciplinary impact and additional potential for future development of new cement manufacturing processes. A new design of a heat exchanger network could be a part of an energy-efficient environmentally friendly cement manufacturing process. It reduces fossil fuel consumption, CO_2 emission and operation cost of cement factories.

The utilization of low-grade heat for district heating systems could help for planning energy systems. The cement manufacturing process may be also considered as an energy source of district heating systems, additional power generation and so on. Nevertheless, the locations of cement factories have to be additionally analyzed with use of other systematic techniques, for example, based on total site analysis [33] to find a solution really close to the optimum.

5. Conclusion

This chapter provides results of research, which identified large energy-saving potential in the cement manufacturing process. Main results may be achieved by improvement of heat recovery, and potential of utility reduction is 30% and 29% for heating and cooling capacity, respectively, which translates to lower primary energy sources. These results were achieved by an updated process integration technique and update of a heat exchanger network. The case study of a particular cement factory was considered and feasible solutions were described that require an investment cost of 256,079 EUR with a payback period of 3.4 months. Besides, the improvement of energy efficiency may be additionally reached by improving the existing process of heat transfer equipment. Low-potential heat utilization covering 43% of power demands of the factory during summer operation mode and utilization of 20,225 kW of waste heat to site-district heating during winter operation are determined.

The use of excess heat may provide a way to reduce the primary energy sources and contribute to global CO_2 mitigation. This chapter shows a pathway for energy efficiency, main process restrictions and most feasible solutions for a new concept design of the cement industry. Nevertheless, the technical issues have to be additionally discussed for successful implementation.

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Author details

Stanislav Boldyryev

Address all correspondence to: stas.boldyryev@fsb.hr

The Centre for Sustainable Development of Energy, Water and Environment Systems (SDEWES Centre), Zagreb, Croatia

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