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THERMAL ENERGY OPTIMIZATION FOR CEMENT INDUSTRY USING PINCH POINT ANALYSIS, CASE STUDY OF ETHIO CEMENT PLC

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A Thesis submitted to the School of Chemical and Bio Engineering Addis Ababa Institute of Technology in Partial Fulfilment of the Requirements for the Degree of Master of science in Chemical Engineering under Process Engineering stream.

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This is to certify that the thesis prepared by Bedilu Belay, entitled: Thermal Energy Optimization for Cement Industry Using Pinch Point Analysis, Case Study of Ethio Cement PLC and submitted in partial fulfilment of the requirement for the degree of Master of Science (Chemical and Bio Engineering) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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DECLARATION

I declare that this thesis entitled "Thermal Energy Optimization for Cement Industry Using Pinch Analysis, Case Study of Ethio Cement PLC" has not been submitted in any form for another degree, diploma or an award at any university or other institution of the tertiary education. Whenever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature and discussions. Information taken from published and unpublished work of others has been acknowledged in the text and a list of references is given. The work was under the guidance of Dr. Lemma Dendena Tufa MIChemE (Associate Professor) instructor in Addis Ababa University, School of Chemical and Bio Engineering.

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ABSTRACT

Cement factory require large amounts of energy that needs a good attention to optimize its energy usage. This project analyses the thermal energy optimization of the cement manufacturing processes for a selected cement plant called Ethio Cement PLC (ECPLC) which is found to nearby Chancho city, Ethiopia. The cement industry is one of the biggest consumers of carbon-containing primary energy sources and one among the first polluters of the environment, emitting approximately 5% of world pollution. Energy consumption in ECPLC represents the most important part of the assembly cost for cement factories and contains a significant influence on product prices. Given that it's realized in modern society that infrastructural projects result in the next level of economy and sustainability for countries, reducing the assembly cost within the cement industry could be a vital problem. I analysed the energy consumption of ECPLC to see the minimum energy targets of production and proposed pathways to boost energy efficiency. Cement production is an energy user process that requires heat to be supplied at extreme temperature levels under the constraints of gas-solid heat exchange phenomena and also the kinetics of chemical reactions. In this project, the use of Pinch Analysis Technology techniques to optimize the thermal energy recovery of the cement production was explored. In addition to the energy recovery, heat exchanger network was designed for the targeted industry. Finally, from the investigation, ΔTmin = 10℃ was selected as minimum temperature difference between hot and cold streams. Hint software is use for the analysis. The targets for hot and cold utility were 1,481.6 kW and 17,330.5 kW respectively and the maximum heat recovery obtained was 43,208.5 kW. The minimum number of heat exchanger that required in this project was 17 and the type of heat exchanger used for design was Direct contact heat exchanger was selected. This is happen on a solid particle-fluid combination inside preheater, kiln and cooler. A retrofit of a heat exchanger network of Pinch technology in a cement factory (ECPLC) which works 24 Hours per day and 300 days per year can save approximately 243,052,454.3 $^{birr}/_{yr}$.Ethiopian Birr per year.

Key words: *Optimization, Pinch Analysis, Hint Software and Cement process.*

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LIST OF ACRONYM

CC	Composite Curve
ECPLC	Ethio Cement Private Limited Company
GCC	Grand Composite Curve
GHG	Green House Gases
HEN	Heat Exchanger Network
IEA	International Energy Agency
LEN	Latent Heat of Vaporization
MER	Minimum Energy Recovery
MPR	Mathematical Programming
ORC	Organic Rankin Cycle
PI	Process Integration
PPA	Pinch Point Analysis
PTA	Problem Table Algorithm
SSD	Steady State Device

1. INTRODUCTION

1.1. Background

Energy saving, warming and greenhouse emissions became major technological, societal, and political issues (1). Energy is that the burning issue of the twenty to begin with century. It encompasses associate degree awe-inspiring impact on the advancement and politics of a precise nation. The value of energy has exaggerated dramatically within the last years, and this trend is usually expected to continue. Additionally, there is a growing social concern concerning the property of current industrial development. Nowadays, production lines unit of measurement utilizing each renewable and non-renewable energy sources loosely, that's transfer irrecoverable hurt to the biological system and human kind. Cement producing plants unit measurement foremost vitality thorough business among the world. Cement could also be a finely ground, non-metallic, inorganic powder, and once mixed with water forms a paste that sets and hardens. This hydraulic hardening is primarily thanks to the formation of metallic element salt hydrates thanks to the reaction between combination water and therefore the constituents of the cement. Cement may be a basic material for building and engineering construction. Portland cement, the foremost widely used cement in concrete construction, was patented in 1824. Output from the cement industry is directly associated with the state of the development business generally and thus tracks the overall economic situation closely (2). Within the journey towards inclusive growth of a nation, the cement sector plays an important role in its economic advancement and stays one among leading focal points for the development sector and every one infrastructure projects (3).

Cement, second most consumed material on the world next to water, is necessary element of infrastructure development and most vital input for housing industry, significantly in infrastructure and housing programs, that area unit necessary for the socioeconomic growth and development. Energy and capital intensity nature of the business necessitate massive investments that need that need perspective on funding and returns. Besides, production and consumption of cement area unit primarily subject to economic and construction cycles, leading to volatility of operative prices and revenues (4).

The cement business sector as associate degree energy-intensive industrial sector within which energy prices represent about 40% of the full cost and one in all the best the best industrial sectors accounts for roughly 5% of worldwide of worldwide emissions. Cement process require large quantities of thermal heat.

In 2011, the globe cement production, in keeping with the International Environmental Agency (IEA), was 3635 Mt with a foreseen increase to 4556 Mt in 2020, 4991 Mt in 2030 and 5549 Mt in 2050 for the high-demand scenario. Consistent with an equivalent scenario, by 2050, the cement producers are going to be required to scale back CO_2 emissions by 15%, representing an immediate reduction of up to 913 MtCO_2. Therefore, the cement industry must adopt more energy-efficient technologies to scale back its environmental impact. However, due to the massive amount of CO_2 coming from the method itself, it will even be necessary to spot the potential for applications of renewables within the cement manufacturing process or maybe change from conventional production to a replacement, less CO_2-intensive production process. Given the significance of the cement industry sector and increased environmental awareness, 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 (5). Nevertheless, the worldwide cement production and consumption have continued to grow at a rapid pace, with emerging economies coming to the fore, in recent years. Consistent with Global Cement Review (GCR) and International Cement Research (ICR), cement consumption in 2013 is estimated at 3.9 Billion tons ('Bt' here after), which may be a 5.8% increase over 2012. A decade ago, global cement demand was largely influenced by the advanced economies, but, with growth, beginning to decelerate across these economies given sluggish economic recovery, demand for cement is on a long-term decline in these countries and therefore the global dynamics of cement consumption has drastically changed, with the centre of gravity moving steadily to the developing economies from the West. Thus, over the last few decades, increased demands are observed from emerging economies, with Asia mainly China and India accounting for quite half the world's consumption. Population and GDP growth still be the drivers for consumption in these regions with cement demand directly linked to increase because it spurs demand for housing and infrastructure.

This work emphasized that the foremost energy-efficient pyro-processing cement manufacturing systems contains preheaters, a calciner and a rotary kiln. The study showed that the environmental impact of cement production might be reduced if a more energy-efficient process of cement production is employed along side pinch analysis. Integration approaches could even be applied to scale back the fuel consumption and emission. Pinch analysis may be a technique that has been developed to spot the possible energy recovery by counter-current heat exchange between the recent streams to be cooled down and therefore the cold streams to be heated during a system. The pinch analysis is predicated on the definition of the minimum approach temperature (ΔTmin) that represents the energy capital trade-off between the energy savings obtained by heat exchange and the required heat exchangers investment (6).

Given the significance of the cement industry sector and increased environmental awareness, several studies in different parts of the world have demonstrated the energy efficiency of cement plants and CO2 emission reduction. Much of that work studied the improvement of the cement production process and options for CO2 emission reduction (7). In my work I exploited pinch point analysis and Hint software to determine the potential of real energy targeting for cement process and reducing energy consumption of cement process by calculating thermodynamically feasible energy. Pinch Point Analysis (PPA) is an extension of the second principle of Thermodynamics to the energy management of the whole plant. PPA deals with the optimal structure of the heat exchange between the process streams, and with the optimal use of utilities. Due to lack of energy audit practice in Ethiopia, it is difficult to make firm and detail industry level energy utilization comparison with global standards. Most importantly, the major opportunity for improving the competitiveness of cement firms mainly revolve around reducing energy cost through partly replacing imported coal with local, alternative energy source use, and application of energy enhancing technologies. Therefore, it is imperative to invest application of energy enhancing technologies in order to reduce cost of production and cement price.

1.2. Cement industry in Ethiopia

The Ethiopian cement industry has endured through three major milestones; the start of cement production and modernizations till 1984, construction boom in 2004 followed by acute shortage and aggressive expansion of the sector in 2012 onwards resulting in inflaming excess capacity. Ethiopia is well set up geographically for cement production and currently has more than 16 cement plants. The first cement factory, Dire Dawa Cement and Lime Factory, was established by the Italian occupying forces in 1938. The plant had an initial capacity of 120 tons of clinker (the intermediate product obtained by burning limestone) per day. In response to the increasing demand for cement, the Addis Ababa and Mestewa cement factories were established in 1964 and 1965 respectively, each with a capacity of 70,000 tons of clinker per year. In 1984, the State-owned Mugher Cement Factory was constructed and commissioned with a capacity of 300,000 tons per year, which created a large increase in capacity of the country's cement supply. Following Eritrea's independence in 1991, the Mestewa cement factory was no longer in Ethiopia and Mugher was the only manufacturer in the sector until Messebo Cement was established in 1996. Since 2012, Derba Midroc Cement emerged as the major market player in Ethiopia cement industry. As Derba Midroc and other small plants entered the market and a number of other cement investments with in the pipeline, the country government in March 2012 banned import of cement except special cement. Currently, the Ethiopian cement industry is experiencing excess production capacity (about 50% of total installed capacity is operational) consequently, most cement firms are struggling to survive and some small firms have even ceased operation (4).

1.3. Overview of Ethio-cement PLC

Ethio-Cement PLC is a joint venture The Company was established under the Ethiopian Commercial Code of 1960 by local and foreign promoter in January 2005. Ethio Cement PLC, has been incorporated as a personnel limited company registered at Addis Ababa, Ethiopia, for the fixing of integrated cement plant with a capacity of the clinker production plant 540,000 tons once a year of clinker, main raw material for creating or making of clinker of 771,429 tons per annum of Cement . The plant is located near Addis Ababa, capital of Ethiopia, in North Shewa, Oromia region, Sululta woreda, Chancho City. Sululta is one among the woredas with in the Oromia Region of Ethiopia. It was part of former Mulona Sululta woreda, which was separated for Mulo and Sululta woredas. Part of the Oromia Special Zone Surrounding Finfinne, Sululta is bordered on the south by the city of Addis Ababa, on the west by the Mulo and Mirab Shewa Zone, on the north by Semien Shewa Zone, and on the east by Bereh. Towns in Sululta include Chancho, Durba, Muger Sheleko, Rob Gebeya, Sululta and Segno Gebeya. The 75% of cement is consumed in the country. Due to huge investment cost of the project, the company has inducted an experienced industrialist. The major raw material inputs are lime stone and clay with additive gypsum, and pumice. Lime stone deposit is identified in two sites with a total reserve of 93,728,250 tons, which is sufficient for 80 years. Similarly, the amount of reserve for clay is 13,852,800 tones for 28 respectively. The plant produces ordinary Portland cement (OPC) and

Portland Pozzolana cement (PPC). PPC is produced by grinding gypsum, pumice and clinker in varying proportions. PPC Acquires slower than OPC but will acquires equal strength a later stage used for construction like floors, Houses, dams (where there is sulphate) and other construction which does not requires fast early strength. OPC is produced by grinding gypsum and clinker without other additives. It has relatively higher early strength and higher heat of hydration. It is used for construction such as bridge, dams and other that requires higher early strengths.

Cements are different by their ingredient, different by the company's goal and procedures to fabricate cement type composition application and quality of cement is different from factory to factory. Ethio-cement product is relatively good and its product is served for different infrastructure. The most customers' are the nearer community in Addis Ababa, Oromia and neighbouring countries.

The main local customers of the company are

- Different governmental organization and Private sectors.
- Educational bureau
- Construction sector
- Civil associations and Ethiopian Road Authority

1.4. Statement of the Problem

Ethio cement PLC is one in every of the foremost cement producers in Ethiopia. They need detail energy analysis. In ECPLC I have seen two main problems which is lack of process integration and equipment arrangement problem. Cement manufacture is an energy-intensive industry during which energy is particularly consumed within the pyro-process of the kiln plant for producing cement clinker. For land-locked countries like Ethiopia, imported fossil fuels like furnace oil, coal, and petcock provide most of the energy needs of cement industries. Energy consumption represents the foremost important part of the assembly cost in Ethio Cement factories and features a major influence on product prices. As long as it's realized in modern society that infrastructural projects cause a more robust level of economy and sustainability for countries, reducing the assembly cost within the cement industry is also a significant problem. Within the current energy crisis scenario everywhere the world, the target of any process designer is to maximise the process-to- process heat recovery and to attenuate the utility (energy) requirements. In Ethio Cement PLC the energy management system way wasn't consider into own problem and that they don't have detail energy audit strategy. To satisfy the goal of maximize energy recovery or minimum energy requirement (MER) an appropriate device network (HEN) is required in Ethio Cement PLC. Energy conservation has become one among the foremost current concerns thanks to continuous increase in energy prices. Among process integration methodologies, pinch analysis is that the most generally used. This can be often due to the simplicity of its underlying concepts and particularly to the spectacular results; it's obtained in numerous projects worldwide. Before the arrival of pinch analysis, industrial equipment was designed and operated separately in terms of external utilities, with pinch analysis those process equipment are often incorporated so as to attenuate the utilization of external utilities like energy, hydrogen and water. Then for that, reason it must analysed the energy consumption methods of cement factory to work out the minimum energy targets of production and proposed pathways to enhance energy efficiency by using Pinch point Analysis. Therefore, this study will give the potential of real energy targeting for cement processing industry and reducing energy consumption of cement process by calculating thermodynamically feasible energy using Pinch Technology and Hint software.

1.5. Objective

1.5.1. General Objective

The main objective of this project is to use pinch point analysis to optimize Thermal energy use in Cement production plant with a special focus on Ethio-Cement PLC, Chancho, Ethiopia.

1.5.2. Specific Objective

- To extract data from cement process diagram.
- To determine minimum temperature difference.
- To construct temperature interval, cascade and composite curve diagrams.
- To determine hot utility requirement, cold utility requirement and pinch point.
- To identify pinch rules violations if any in the existing process energy system.
- To modify the heat exchanger network for maximum heat recovery and minimum utility consumption.

1.6. Significance of the Research

This research provides a safe and sound solution for Ethiopian cement industries and most importantly, to the energy targeting. My research work is very crucial for the energy management of cement factory, as it will make energy management to device means of cutting down cost on energy wastage activities in order to make reasonable profits by ensuring energy wastage minimization. Energy audits are commonly used to improve energy efficiency. However, the audits do not usually involve in-depth analysis of design features for optimum energy use. Pinch technology analysis, which involves heat exchanger design and retrofits, is increasingly being used to optimize energy utilization especially in cement industries. Various pinch analysis studies have been conducted in different manufacturing and processing plants. However, there is no published literature about pinch analysis studies in the cement process in Ethiopia. Finally, it will serve as a blue print of action guide to infant companies found in the country and as a compendium of knowledge for further research work in pinch analysis for cement, for various indigenous cement and other companies found in the country.

1.7. Scope of the study

The identification of heat requirements related to chemical reactions and heat transfer phenomena occurring between mixed solid and gaseous streams is one of the major key points of this study since the majority of process units (preheating tower, calciner, rotary kiln and clinker cooler) are characterized by direct heat exchange.

2. LITRATURE REVIEW

The literature review included during this chapter contains available information (studies) associated with Energy Optimization for Cement Process Using Pinch Analysis. Both theoretical and empirical literature is goes to be reviewed throughout this chapter. In the theoretical aspect, sufficient and relevant theories on the topic under investigation are reviewed. Again, a relevant and sufficient empirical works also will be investigated. Most materials contain energy, energy management, energy Auditing, Energy requirement and CO_2 emission for cement production should be meet the need of the thermal energy. Small researches and case studies reviewed and analysed Energy Optimization for Cement process using Pinch Analysis. Particularly, studies associated with the environmental, health, social and economic costs and benefits of the cement process compared to the other chemical process industries.

2.1. Over view of Researches and developments on energy optimization in cement factory

Many researches and modification are created to scale back the particular energy consumption. Specific energy consumption in cement production varies from technology to technology. The dry method uses a lot of electrical however a lot of less thermal energy than the wet method.

The energy prices of cement industry are about 40% of the product cost that indicates that this sector is one of the biggest CO_2 emitter. The cement industry is an energy-intensive industry where the thermal energy consumption accounts for around 80% of the primary energy; the remaining 20% is with in the style of electrical energy (8). Previous studies have known several advantages for cement industries particularly on energy saving and CO_2 emission management techniques. These advantages include scale back CO_2 emission, energy management, energy potency improvement, energy prices and energy sources. A sizeable quantity of energy is employed in producing cement. Thus focus ought to tend on the reduction of energy and energy connected environmental emissions locally and globally.

The International Energy Agency rumoured in 2011 that the planet 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. Just in case of a similar scenarios, by 2050, the cement manufacturers have to reduce the CO_2 emissions by 15%, with a right away decrease of up to 913 Mt.(9) 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 vital to estimate a renewable energy potential use within the cement production industry or perhaps switch from conventional fuel to a replacement one with low CO_2 emissions. Because of nice significance of the cement industrial sector and high environmental perception (10) last time, loads researches worldwide have shown the energy efficiency improvement of cement factories and pollution reduction. Most of the published researchers investigated the advance of the cement technology and different varieties for CO_2 emission reduction. Within the previous couple of decade's energy intensive areas are identified and various significant modifications (processes and equipment's) are made. In order to reduce both electrical and thermal energy consumption different saving actions developed supported the performed energy assessment. To realize these, kiln rotational speed, improper fitness between some fittings and several other parts in preheater and kiln, cooperation between laboratory, mine and production units, electricity consumptions and crusher was the main concern action(11). Hidalgo et al. (12)has presented a recursive simulation model of the cement industry, the CEMSIM model. The model has been used to study the foremost important trends within the world cement market concerning production, technology development, energy consumption and carbon emissions within the 2000–2030 periods. The article also analyses the potential impact on the cement sector derived from the implementation of recent market mechanisms aimed to fulfil the carbon reduction targets founded by the Kyoto Protocol on global climate change. Specifically, the advantages of three potential international emission trading markets are calculated. Pardo et al. (8) are try to define the potential of energy efficiency improvement of the EU's cement sector and CO gaseous emission reduction by 2030. Liu et al. (13) have presented the retrofit and building of recent cement factories in China, accounting different technologies. Chen (14) had defined the benefits 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 prevailing one that uses the precalciner kiln process. The work published by Hasanbeigi et al. (15) points out the CO_2 value curves for the Thailand cement sector. An estimated potential and expenses of CO_2 abatement were investigated taking under consideration the expenses and CO_2 abatement for a spread of applications. The work published by Hrvoje et al. (16) indicates the Croatian cement industry CO_2 emission idea. The paper analyses the potential for achieving CO_2 emission reduction within the Croatian cement industry. In the Croatian cement industry, there are three economically viable measures for reducing CO_2 emissions. The reduction of clinker to cement ratio by adding different additives, the replacement of fossil fuels with alternative and biomass fuels, and an additional improvement within the energy efficiency of the present kiln processes, are the economically viable measures which may decrease CO_2 emissions of the cement industry in Croatia. As presented by Worrell et al. (17), an in-depth analysis of a US cement industry considering a possible for energy cost and CO_2 emission decreasing by the national technologies database was done. It absolutely was found that one amongst the foremost effective pyro-processing cement manufacturing systems composed of a calciner, several preheaters and also the rotary kiln. They also analysed historic trends for energy efficiency within the US cement industry, yet as well as identified cost-effective energy and CO_2 savings that may be achieved in the near future. The first and second law analysis of a raw mill is performed and certain measures are implemented in an existing raw mill in a cement factory in order to reduce the amount of energy consumption in grinding process and efficiency of the raw mill is determined by Atmaca and Kanoglu (18). Their work highlighted that high-energy savings could also be obtained by reduction of heat losses with use of insulation, decreasing the outlet gas temperature and heat transfer enhancement. Sheinbaum and Ozawa (19) have presented the energy demands and CO emissions of the cement sector of Mexico, summarizing, that the measures of a fossil fuel, CO 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. (20). With the use of real industrial data and combination of kinds and flow rates of alternative energy sources, the work (21) 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. Hasanbeigi et al.(15) Estimated the CO_2 abatement cost curve for the Thailand cement industry. This study attempts to grasp the potential for CO_2 emissions reduction in this sector and its costs. The bottom-up CO_2 abatement cost curve (ACC) constructed in this study for the Thai cement industry to see the potentials and costs of CO_2 abatement by taking into consideration the prices and CO_2 abatement of various technologies. They also conducted a sensitivity analysis for discount rate parameter. Another work by Claudia Sheinbaum and Leticia Ozawa (19) investigated the Two important factors that contributed to increased CO_2 emissions were the substitution of NG by oil and also the increase of the electricity emission coefficient. In spite of technological progress and modernization, the activity effect drove clinker fuel use and CO_2 emissions up, illustrating the dilemma which developing countries face between the necessities to scale back CO_2 emissions and promoting of economic process.

As presented by Wang et al. (22), the cogeneration power plants in cement plant can recover the waste heat available from the preheater exhaust and clinker cooler exhaust gases and generates electricity on endless basis without interfering with the core, clinker production process. The exergy approach combining with an Organic Rankine Cycle (ORC) and Kalina cycle were made to estimate of cogeneration opportunities of a cement factory additionally because the calculation of optimal conditions and maximum efficiency. M.Ziya (23), examined exergetic efficiency of Turkish cement production and CO2 emissions caused by the sector due to exergetic losses and environmental effects. Elita et al.(24) Propose a fuzzy multi criteria approach for evaluating sustainable manufacturing in cement industry which integrated the Interpretive Structural Modelling (ISM) and also the Fuzzy Analytic Network Process (FANP) methodology. The network relationship model is made using ISM methodology. Importance weights of indicators are assigned by pairwise comparisons and calculated using fuzzy ANP methodology. But it is not concern on energy saving or energy optimization idea. Mirzakhani et al.(25) Have studied the clinker production process (pyro-process unit) has been investigated by Pinch Analysis to systematically modify the method and improve thermal energy consumption. This new design proposes another method for recovering some heat from the clinker and preheats the materials within the preheater tower. Process integration methods could also be used additionally to decrease energy use and emissions as were summarized within the work of Professor Seferlis et al. (26) Presented approaches are supported thermodynamics laws and have different applications in numerous processing sectors; this issue was reported by Boldyryev and Varbanov (27). In order to use the economic low potential heat and improve a heat utility system of various users and suppliers, a complete site integration or total site integration (TSI) is also employed as shown by Klemeš et al. (28). Similar work by Nemet et al.(29) deals with the evaluation of the opportunity cost for the generation and use of site utilities (e.g. steam, hot water, cooling water), which enables the evaluation of the trade-off between heat recovery and opportunity cost targets for Total Sites, thus allowing to line optimal ΔTmin values for the assorted processes. Later, an analogous approach was developed by different authors. As an example, Ravipati et al.(30) Highlighted the importance of Pinch Technology in improving the performance of cement manufacturing process. They paper's provides results that show a device network or Heat Exchanger Network with maximum heat recovery among process streams, thereby reducing the external utility consumption. In their own study, researchers considered one kind of hot and cold utility to style HEN. The choice of optimum amount heat to be recovered during Total Site integration and utility targets for external heating, cooling, refrigerating etc. should be used as was reported by Boldyryev et al.(31) The methodology provides the calculation of minimum capital investment during heat integration of business site. It uses heat transfer area targets, utility distribution with overall cost of retrofit. Hong et al. (32) expanded the content of a pinch approach of individual process changes to boost a TSI and adapted the plus-minus principle for process modification options to boost process efficiency. Grip et al. (33) used the mixed-integer linear programming (MILP) or applied maths approach, exergy analysis and pinch analysis (PA). Experience and results of a multiple approach were presented and thought of in literature by many authors. As an example, Baniassadi et al. (34) represented a way for an industrial energy system analysis with the utilization of modified R-curve approach. This technique estimates the utilization of the foremost efficient fuel type for the economic utility system. Mian et al.(35) employed the pinch analysis and therefore 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 which will be utilized and summarized that the potential of thermal energy reduction is 30%. However, the authors did not think 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 various methodologies are usually faced with process features of various industries. Additionally, there is an absence of industrial applications of process integration techniques within the cement manufacturing processes because of its specific process features and process limitations, like solid particles of process streams, solid-gas and solid-air heat exchange and fast cooling of gaseous streams. Such approaches may be analysed and subsequently utilized in appropriate case studies to realize a true efficiency of the cement manufacturing processes. Thus, this project is devoted to energy efficiency and pathways toward maximization of feasible heat recovery and therefore the concept design of heat exchange system at the Ethio-Cement factory. The energy efficiency potential of a cement factory is estimated. The whole energy consumption of the Ethio cement manufacturing was compared with the benchmark value. Nowadays, considering a best available technology (BAT), the one with all-time low energy consumption of cement production is that the rotary kiln use, many cyclone preheaters and therefore calciner. This technology has energy demands of a cement factory at about 2.93 GJ/t. The identical amount is now used for benchmarking point (16) 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 cut back the energy consumption of the actual cement factory. I concluded that the energy consumption of the Ethio cement plant is also lowered by some per cent. Thus, the features of the cement production process forced a strategy update to suggest feasible retrofit pathways with the target 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 an answer more complicated by the special construction of the method equipment, which causes impossible a heat transfer between some process streams.

The main gap that occur in the different literature they have no detail energy analysis, lack of process integration and equipment arrangement problem.

2.2. Description of the cement production process

Raw materials should be mixed precisely to manufacture hydraulic cement. The cement clinker requires appropriate amount of compositions of the weather calcium, silicon, aluminium and iron. Of these raw materials together along with the fuel ash must be combined to make the standard clinker composition a dry cement manufacturing process, which operates with a virtually dry raw mix containing but 20% moisture by mass. However, during a wet process water is added to the raw mix to make slurry and then is transported to the kiln. Raw meals are grounded, blended, pre-calcined, and burned in manufacturing cement. During a cement manufacturing process, lime- stone and calcium, silicon, aluminium and iron oxides are crushed so milled into a raw meal. This raw meal is mixed in blending silos and is then heated within the pre-heating system. This can dissociate carbonate to calcium oxide and carbon dioxide both are greenhouse gas. A secondary fuel is supplied to the preheating system so temperature is sufficiently high. The meal then passed through the kiln for heating. Then a reaction takes place between quicklime and other elements. This reaction will produce calcium silicates and aluminates at about 1500℃. Primary fuel is employed to stay the temperature high enough within the burning zone for the chemical reactions to require place. A nodular product named clinker is produced and then allowed to leave the kiln. The clinker will be inter-ground with gypsum, limestone and/or ashes to a finer product called cement (36). Cement is a good example of developments in manufacturing processes used to make a product, which by itself has not changed much. Developments in processes of manufacture of cement are reflections of the needs of the periods such as scale of production, product quality and specific consumption of thermal and electrical energy to produce it (37). Cement is an inorganic, non-metallic substance with hydraulic binding properties, and is used as a bonding agent in building materials. It is a fine powder, usually gray in colour that consists of a mix of the Portland cement minerals to which one or more sorts of calcium sulphate are added. Mixed with water it forms a paste, which hardens thanks to formation of cement mineral hydrates. Cement is that the binding agent in concrete, which may be a combination of cement, mineral aggregates and water. Concrete may be a key artifact for a spread of applications. Most industry is made up of either Portland cement plants that produce clinker and grind it to make finished cement, or clinker-grinding plants that inter grind clinker obtained elsewhere, with various additives.

Clinker is produced through a controlled high-temperature burn during a kiln of a measured blend of calcareous rocks (usually limestone) and lesser quantities of siliceous, aluminous, and ferrous materials. The kiln feed blend (also called raw meal or raw mix) is adjusted counting on the chemical composition of the raw materials and therefore the sort of cement desired. Cement plants are typically constructed in areas with substantial raw materials deposits (e.g. 50 years or longer).

2.2.1 Mining and Quarrying

The manufacturing process of cement is beginning with extraction and preparation of raw the material .The process covering the stage from raw material quarrying to feeding the raw meal in to preheater. Raw material needed for the cement production process is quarried by blasting hydraulic excavator or ripping. The most common raw materials used for cement production are limestone and clay with additive such as basalt, rhyolite, pumice and gypsum.

Quarrying is the first step in the cement production process (7). the most common raw materials used for cement production are limestone and clay with additive such as basalt, rhyolite, pumice and gypsum. Ethio Cement factory mining area is located within the Aanda Weizero Peasant Association in Sululta Wereda, Shoa Zone of Oromiya Regional State and is about 7 km (crow fly distance) from the Derba city. The major component of the raw materials, the limestone or chalk, is usually extracted from a quarry adjacent to or very close to the` plant. Limestone provides the specified quicklime and a few of the opposite oxides, while clay, shale and other materials provide most of the silicon, aluminium and iron oxides required for the manufacture of Portland cement. In most cement factory, the limestone is extracted from open-face quarries. The raw materials are selected, crushed, ground, and proportioned in order that the resulting mixture has the specified fineness and chemical composition for delivery to the pyro processing systems. It is often necessary to boost the content of silicon oxides or iron oxides by adding quartz sand and ore , respectively. The quarried material is reduced in size by processing through a series of crushers. Normally primary size reduction is accomplished by a jaw or gyratory crusher, and followed by secondary size reduction with a roller or hammer mill. The crushed material is screened and stones are returned. More than 1.5 plenty of raw materials are required to supply one ton of hydraulic cement.

2.2.2 Raw Material Preparation

Process flow of raw material preparation is divided into following 6 items: limestone, clay crushing and conveying Limestone, claying pre-blending and conveying Gypsum crushing and conveying, pumice conveying, raw coal crushing and conveying united pre-blending and conveying to raw meal preparation.

After primary and secondary size reduction, the raw materials are further reduced in size by grinding. The grinding differs with the pyro processing process used. In dry processing, the materials are ground into a flow able powder in horizontal ball mills or in vertical roller mills. In a ball (or tube) mill, steel-alloy balls (or tubes) are responsible for decreasing the size of the raw material pieces in a rotating cylinder, referred to as a rotary mill. Rollers on a round table fulfil this task of commination in a roller mill. Utilizing waste heat from the kiln exhaust, clinker cooler hood, or auxiliary heat from a stand-alone air heater before pyro processing may further dry the raw materials. The moisture content in the kiln feed of the dry kiln is typically around 0.5% (0 - 0.7%).When raw materials are very humid, as found in some countries and regions, wet processing are often preferable. In the wet process, raw materials are ground with the addition of water in a ball or tube mill to produce slurry typically containing 36% water (range of 24-48%). Various degrees of wet processing exist, e.g. semi-wet (moisture content of 17-22%) to scale back the fuels consumption within the kiln.

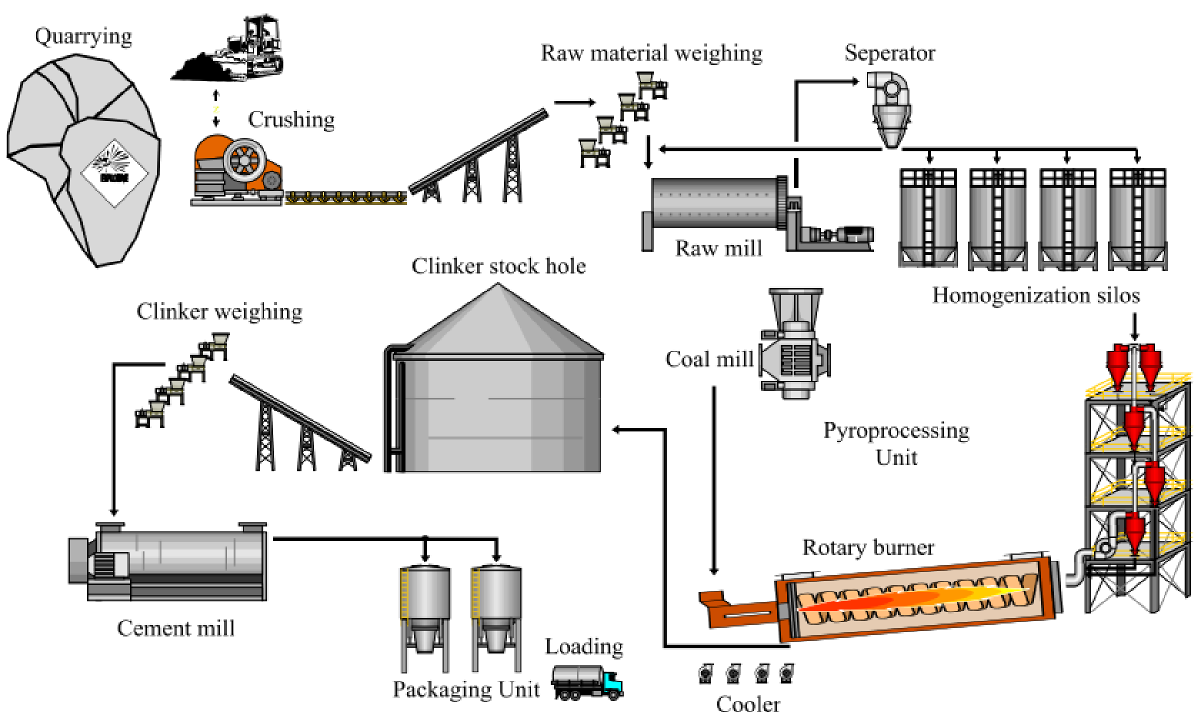


Figure 2.1. Raw material flows in cement plant (38)

2.2.3 Clinker Production (Pyro-Processing)

Clinker is produced by pyro processing in large kilns. These kiln systems evaporate the inherent water in the raw meal, calcine the carbonate constituents (calcination), and form cement minerals (clinkerization).(39)

The main pyro processing kiln type used in the Ethio cement company is the rotary kiln. In these rotary kilns, a tube with a diameter up to 3.2 m is installed at a 3-4-degree angle that rotates 1-3 times per minute. The ground staple, fed into the highest of the kiln, moves down the tube counter current to the flow of gases and toward the flame-end of the rotary kiln, where the raw meal is dried, calcined, and enters into the sintering zone. In the sintering (or clinkering) zone, the combustion gas reaches a temperature of 1400^0C – 1500^0C.

In a dry rotary kiln, feed material with much lower moisture content (0.5%) is used, thereby reducing the need for evaporation and reducing kiln length Once the clinker is made within the rotary kiln, it's cooled rapidly to attenuate the formation of a glass phase and make sure the maximum yield of alite (tricalcium silicate) formation, a crucial component for the hardening properties of cement. The main cooling technologies are either the grate cooler or the tube or planetary cooler. In the grate cooler, the clinker is transported over a reciprocating grate through which air flows perpendicular to the flow of clinker. The cooling air is used as secondary combustion air for the kiln. In Ethio cement share company uses grate cooler type grate cooler is cross flow heat exchange through clinker bed with cold air. Each alternative row consisting of movable (reciprocating) steel plates, grates can be horizontal. Alternative forms with two stage cooling and air recirculation are possible.

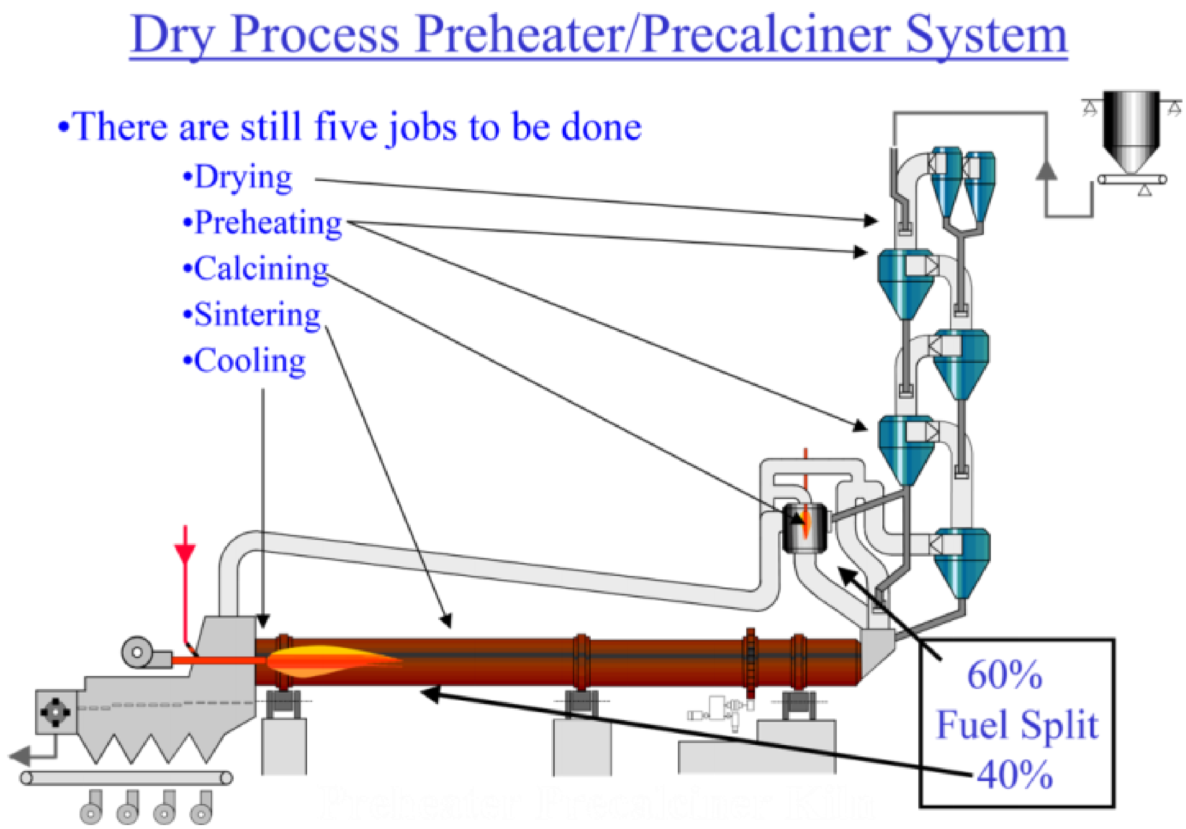


Figure 2.2. Dry processes preheater (source from company Document)

2.2.4 Finish Grinding

The finish grinding process is one of the basic technical operations of cement production. The manner in which this operation is conducted, determines the quality of the cement. It is useless to grind cement to a large specific surface, but the ground product must obey certain laws relative to particle size distribution in order to favour the ensuing hardening process. After cooling, the clinker can be stored in the clinker dome, silos, bins, or outside The material handling equipment used to transport clinker from the clinker coolers to storage and then to the finish mill is analogous thereto wont to transport raw materials (e.g. belt conveyors, deep bucket conveyors, and bucket elevators). To produce powdered cement, the nodules of cement clinker are ground to the consistency of powder. Grinding of cement clinker, along side additions (3-5% gypsum to regulate the setting properties of the cement) are often wiped out ball mills, ball mills together with roller presses, roller mills, or roller presses. While vertical roller mills are feasible, they have not found wide acceptance in the cement company. Coarse material is separated during a classifier that's re-circulated and returned to the mill for extra grinding to make sure a consistent area of the ultimate product. In our company the grinded cement is stored in 4 cement silos(1#, 2#, 3# and 4#).we dispose 2 roots blowers at the bottom of each silo(one for use, one for spare), used for blending and discharging inside cement silo. Each aeration system equips a control system to ball valve, used to control the number of aerating point and interval.

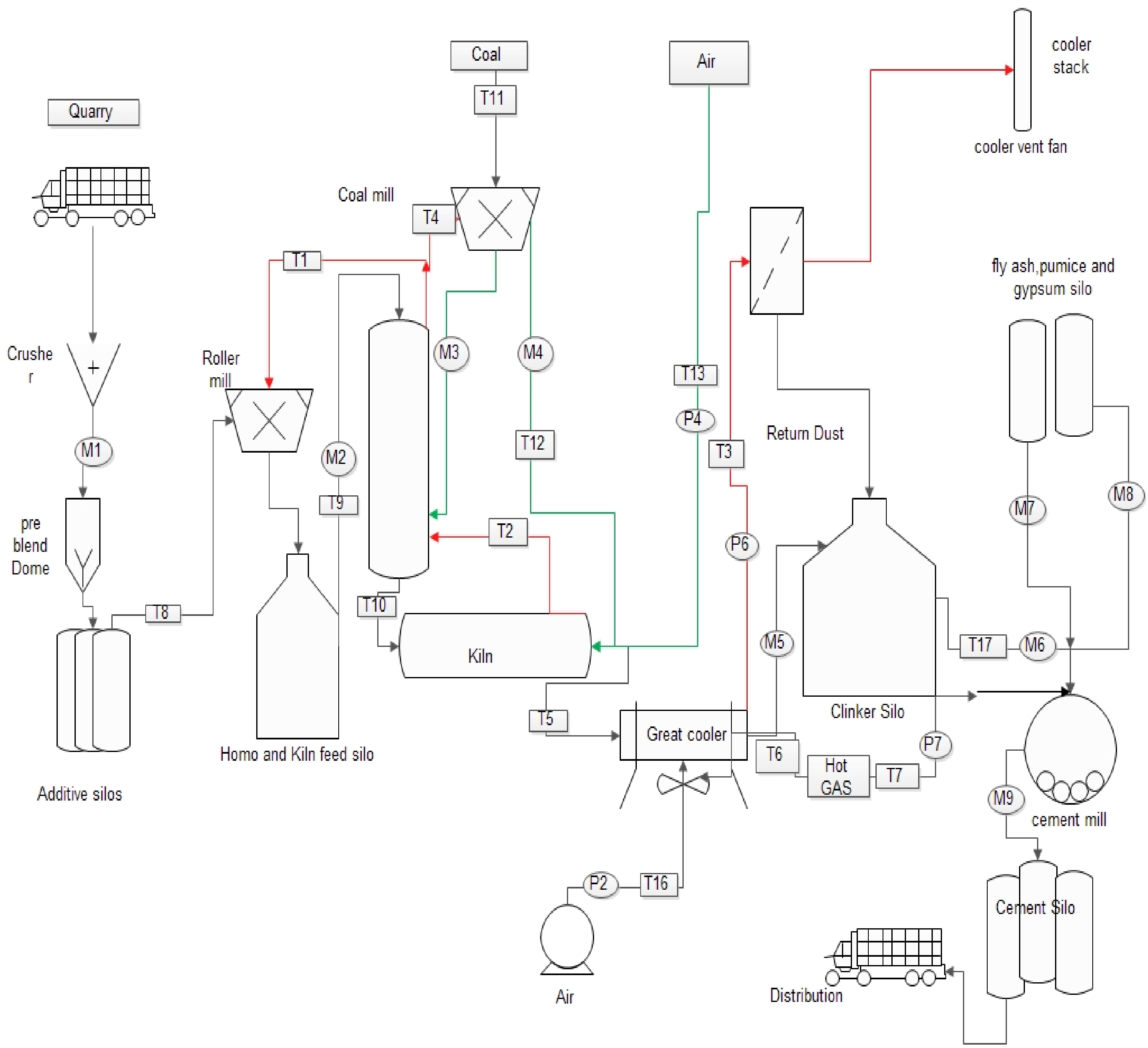


Figure 2.3. Principal flow sheet of cement production

2.3. Energy

Energy is exists in nature in various forms. The different forms of energy used by peoples and industries for different purposes consist of lighting, heating, running machinery, transportation and for other applications. In short, energy has therefore applications in different spheres of activities such as domestic, Industrial, Agricultural, Commercial & transportation. Energy should be efficiently utilized in order to ensure that for a given amount of energy maximum activities, productive work and profitability is achieved. It is thus slightly different from the word 'saving' which may in strict sense, mean avoiding spending or consumption or suppression of demand. While the word conservation appropriately denotes efficient, financial and careful use of energy (40). The increasing cost of energy and environmental concerns have led the cement industry to search for techniques of reducing energy consumption in cement operations. The concerns on energy sustainability and security coupled with increasingly stringent environmental regulations have pooled to elevate the challenge of energy efficiency particularly for energy intensive industries, to a high-priority subject (41).

Energy is without a doubt one of the significant items for surveying the warm execution of any cement industry .The cement is an energy serious industry with energy ordinarily representing 30– 40 per cent of the generation costs. The high-energy utilization puts the division to an essential position from financial perspective. Energy proficiency change in cement industry is in this way an essential territory of research. A proper strategy for warm execution examination must be embraced to accomplish the main targets, for example, expanding the plant efficiency; limiting the crude material; limiting the energy utilization, and enhancing the execution at fractional load, of any cement industry (42). The energy sector in Ethiopia can indeed be looked upon as an asset rather than a liability to development. Several sectors can take advantage of the energy resources and, in fact, hinge their development on the availability of a wide range of energy forms to meet their needs at low costs. There are constraints in the development of the energy resources, but these constraints are expected to diminish with growth in the other sectors. Economic growth in the other sectors will generate increased demand for energy. The increased energy demand will mean economies of scale for energy projects and the resulting increases in energy sales will mean greater capability for investment in the energy sector.(43)

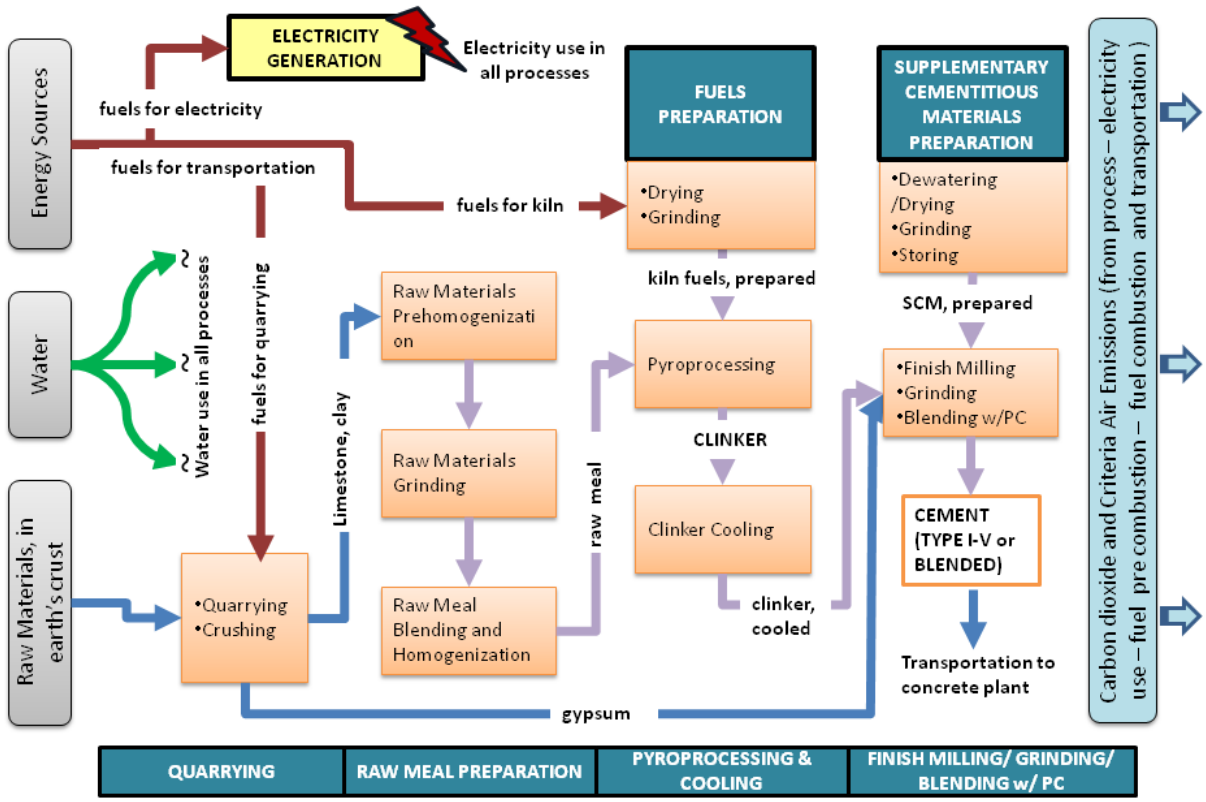


Figure 2.4. Cement production process and energy used (source from company document)

2.4. Energy source for cement production

In the Chemical and Petrochemical Industry, energy conservation has become one of the most relevant current concerns. Continuous increase of energy prices, decreasing fuel availability and environmental restrictions to pollutant emission justify investments in industrial projects to minimize energy consumption. Besides, large energy optimization opportunities reside on old industrial plants, since energy concerns in past decades were not as strong as today and appropriate tools were not available to take care of these aspects.(44) In cement production energy consumption takes the largest bulk of production cost. Due to this impact, the cement manufacturers are always concerned about using alternative fuel mixture with low cost without losing the standard of the ultimate product and fewer environmental impact to the society.(45) Cement industry uses coal, natural gas and petroleum products to generate thermal energy for clinker production. The capacity utilization has a significant impact on the productivity and efficiency of any industry and cement industry is not an exception.(46)

During Primary, fuels used in cement industry are mineral coal, petroleum coal, gas oil and natural gas. These provide most of the energy needs of the World today. Coal and gas are utilized in their natural forms, but petroleum and other fossil fuels like shale and bituminous sands require distillation and refinement to supply consumable fuels. These fuels exist in the following forms: Gaseous, liquid, and solid. The high cost of fossil fuels and most significantly, their damaging effect on the environment underscore the necessity to develop alternative fuel mixture for several industrial systems that rely on fossil fuels. Fuel costs are the only largest variable cost at cement plants. Variable costs are typically about 50% of overall operating costs, so energy is usually the only largest cost, besides raw materials. Labour is relatively small at a cement plant.(39) While coal is the primary fuel used, significant amounts of electricity and natural gas are also consumed.

Energy use associated with mining and quarrying raw materials for cement production are not typically included in the cement sector, but rather are accounted for in the mining sector. As such, the cement sector energy consumption is comprised of energy used for raw material preparation, clinker production, and finish grinding. Staple preparation is an electricity intensive production step requiring generally about 23- 32 kWh/short ton although it could require as little as 10 kWh/short ton. The production of clinker is that the most energy-intensive step. It requires the calcination in a high-temperature kiln (1450 °C) of raw materials (clay, limestone, etc.) previously prepared in paste or powder form depending on the production process (wet or dry).(47) The actual specific fuel demand of clinker production for different kiln types is given in Table 2. Electricity is mainly required for raw and finish grinding and the exhaust fans. Total specific electricity production is in the order of 90-130 kWh/tonne cement (0.3-0.5 GJ/tonne).

Clinker production is the most energy-intensive stage in cement production, accounting for over 90% of total industry energy use, and virtually all of the fuel use. Fuel use for clinker production in a wet kiln can vary between 4.6 and 6.1 MBtu/short ton clinker. Typical fuel consumption of a dry kiln with 4 or 5-stage preheating can vary between 2.7 and 3.0 MBtu/short ton clinker, electricity use increases slightly due to the increased pressure drop across the system.

Table 2.1. Actual fuel demand for cement kilns [BREF- Cement, 2000].

Kiln Type	Specific Fuel use (GJ/tonne clinker)
Dry process, multi-stage cyclone preheater and precalciner kiln	About 3.0
Dry rotary kiln equipped with cyclone preheater	3.1-4.2
Semi-dry/semi-wet process (Lepol-klin)	3.3-4.5
Dry process long kiln	up to 5.0
Wet process long kiln	5.0-6.0
(Shaft kiln)	(3.1-4.2)

A six stage preheater kiln can theoretically use as low as 2.5-2.6 MBtu/short ton clinker. The most efficient pre-heater, pre-calciner kilns use approximately 2.5 MBtu/short ton clinker. Alkali or kiln dust (KD) bypass systems could also be required in kilns to get rid of alkalis, sulfates, and/or chlorides. Such systems cause additional energy losses since sensible heat is removed with the bypass gas and mud. Power consumption for grinding depends on the area required for the ultimate product and therefore the additives used. Electricity use for raw meal and finish grinding depends strongly on the hardness of the fabric (limestone, clinker, pozzolana extenders) and therefore the desired fineness of the cement also as the amount of additives. Blast furnace slags are harder to grind and hence use more grinding power, between 45 and 64 kWh/short ton for a 3,500 Blaine2 (expressed in cm2/g). Modern ball mills may use between 29 and 34 kWh/short ton for cements with a Blaine of 3,500.

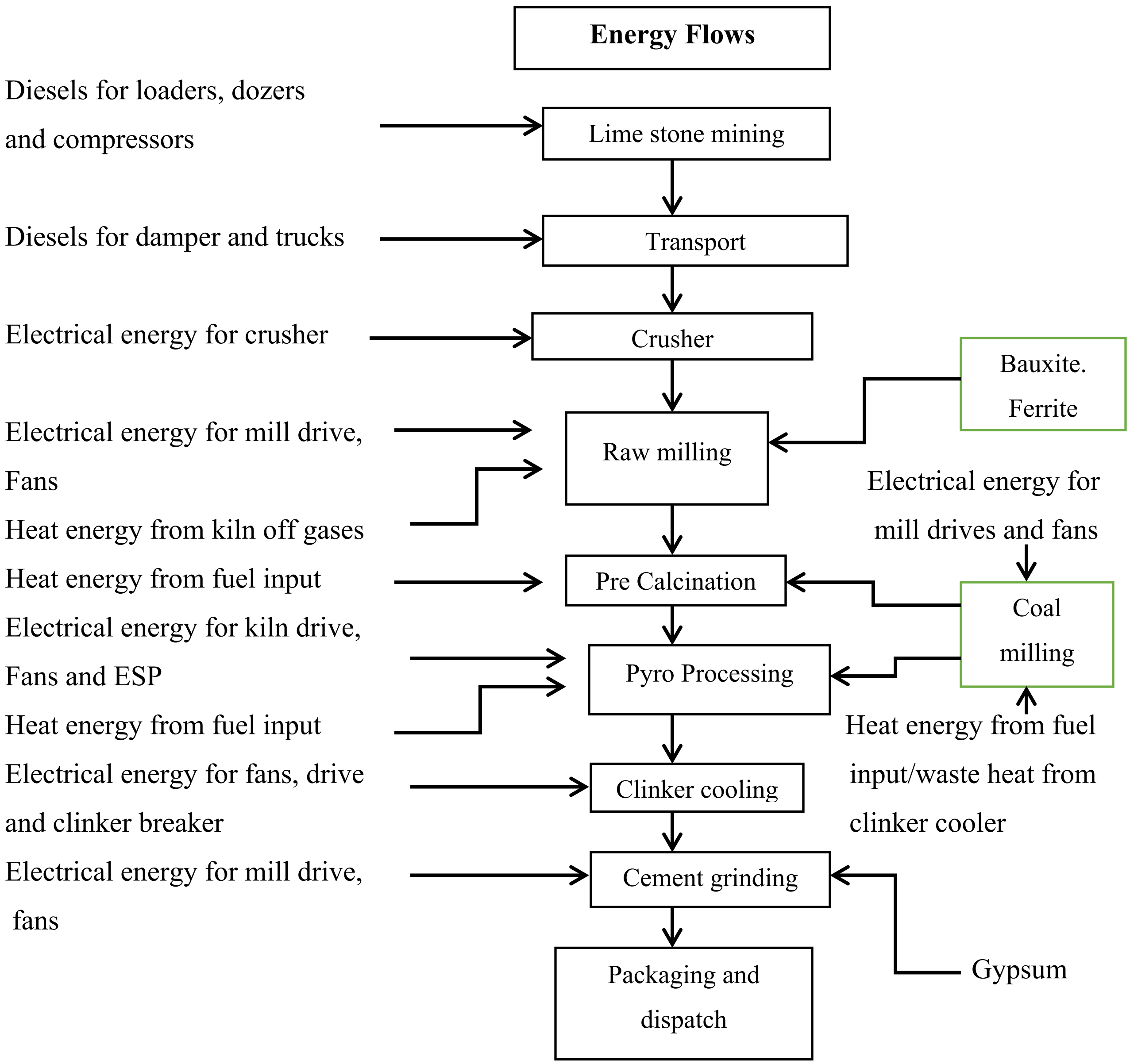


Figure 2.5. Energy flows in cement production process (36)

2.5. Energy Efficiency Technologies and Measures for Cement Industry

Opportunities exist within cement plants to improve energy efficiency while maintaining or enhancing productivity. Improving energy efficiency at a cement plant should be approached from several directions. First, plants use energy for equipment such as motors, pumps, and compressors. These important components require regular maintenance, good operation and replacement, when necessary. Thus, a critical element of plant energy management involves the efficient control of cross cutting equipment that powers the assembly process of a plant. A second and equally important area is the proper and efficient operation of the process. Process optimization and ensuring the most efficient technology is in place is a key to realizing energy savings in a plant's operation. Finally, throughout a plant, there are many processes simultaneously. Fine-tuning their efficiency is important to make ensure energy savings are realized.

If a corporation owns more than one plant, energy management can be more complex than just considering the needs of a single one. A corporate energy management program helps to ensure energy efficiency is achieved across the company's plants. Whether for a one plant or for a whole corporation, establishing a robust organizational energy management framework is vital to implement energy efficiency measures effectively. Several technologies and measures exist which will reduce the energy intensity (i.e. the electricity or fuel consumption per unit of output) of the varied process stages of cement production.

Energy audits assist industrial companies or facilities in understanding how they use energy and help to spot the areas where waste occurs and where opportunities for improvement exist.(48) An energy audit may be a key to assessing the energy performance of an industrial plant and for developing an energy management program. The typical steps of an energy audit are:

- Preparation and planning
- Data collection and review
- Plant surveys and system measurements
- Observation and review of operating practices
- Data documentation and analysis
- Reporting of the results and recommendations

There are several relatively similar definitions of an energy audit. In CIPEC (2002) defines energy auditing as: A scientific, documented verification process of objectively obtaining and evaluating energy audit evidence, in conformance with energy audit criteria and followed by communication of results to the client.

In the Indian Energy Conservation Act of 2001 (BEE 2008), an energy audit is defined as: "The verification, monitoring and analysis of the utilization of energy and submission of technical report containing recommendations for improving energy efficiency with cost-benefit analysis and an action decide to reduce energy consumption." It should be noted that the term "energy assessment" is usually used interchangeably with "energy audit" in some countries like the U.S.(48)

Due to lack of energy audit practice in Ethiopia, it is difficult to make firm and detail industry level energy utilization comparison with global standards. The establishment of Ethiopia Energy Authority as autonomous institution and proclamation of 2014 energy audit requirement may lay down the foundation for the near future to make periodic energy audit and enforcement of compulsory energy audit practice. Nonetheless, it is reasonable to assume that the current energy efficiency status of the cement industry to be very low as compared to international standards. Furthermore, results from interview disclosed that energy cost accounts for nearly around 50 to 60% of the total cost structure of cement firms compared to 30 to 40% of global standards. Most importantly, the major opportunity for improving the competitiveness of cement firms mainly revolve around reducing energy cost through partly replacing imported coal with local, alternative energy source use, and application of energy enhancing technologies. Therefore, it is imperative to invest application of energy enhancing technologies in order to reduce cost of production and cement price.

Energy efficiency is a crucial component of a company's environmental strategy. End- of-pipe solutions are often expensive and inefficient while energy efficiency are often a cheap opportunity to scale up criteria and other pollutant emissions. Energy efficiency are often an effective strategy to figure towards the so-called "triple bottom line" that focuses on the social, economic, and environmental aspects of a business.1 In short, energy efficiency investment is sound business strategy in today's manufacturing environment.(49) The concerns on energy sustainability and security coupled with increasingly stringent environmental regulations have pooled to elevate the challenge of energy efficiency particularly for energy intensive industries, to a high-priority subject.(41) Energy consumption is increased by such factors as population increment, urbanization, industrialization, and technological development.(50)

2.6. Energy Management Systems and Programs

Improving energy efficiency should be approached from several directions. A strong, corporate wide energy management program is important. Cross cutting equipment and technologies such as compressed air and motors, common to most plants and manufacturing industries, including cement, present well-documented opportunities for improvement. Equally important, the assembly processes are often fine-tuned to supply even greater savings. Although technological changes in equipment conserve energy, changes in staff behaviour and attitude can also have a great impact. Energy efficiency training programs can help a company's staff incorporate energy efficiency practices into their day-to-day work routines. Personnel at all levels should be aware of energy use and company objectives for energy efficiency improvement.

Energy management programs;- Changing how energy is managed by implementing an organization-wide energy management program is one among the foremost successful and cost-effective ways to cause about energy efficiency improvements. Energy efficiency does not happen on its own. A strong energy management program creates a foundation for positive change and provides guidance for managing energy throughout a corporation. Energy management programs also help to ensure that energy efficiency improvements do not just happen on a one-time basis, but rather are continuously identified and implemented in an on-going process of continuous improvement. Furthermore, without the backing of a sound energy management program, energy efficiency improvements might not reach their full potential thanks to lack of a systems perspective and/or the support of proper maintenance and follow-up.

2.7. Pinch analysis

Process Integration (PI) is a family of methodologies for combining several processes to reduce consumption of resources or harmful emissions to the environment. It started as mainly heat integration stimulated by the energy crisis in the 1970's.(51) It became a popular method to improve energy efficiency in industrial processes, especially during the times of oil price surge in the late 1970s and early 1980s. Pinch analysis when initially introduced for optimizing heat recovery was based on the principle of identifying system bottlenecks where temperature differences between streams reached a minimum threshold value for effective heat transfer between process streams.(52) Energy integration is a subdivision of a wider field of process integration, which is an efficient approach that allows industries to increase their profitability through reduction in energy, water and raw materials consumption, reduction in greenhouse gas (GHG) emissions and waste generation. Process integration causes industry to moderate energy and material. Thoughtfully Process integration is a term in compound building, which implies an all-encompassing way to deal with process outline, which considers the collaborations between various unit operations from the beginning, as opposed to upgrading them independently.

Process integration is an all-encompassing way to deal with process configuration, retrofitting, and operation of production plants, with applications concentrated on asset protection, contamination avoidance and energy administration. Process integration has just profoundly affected the substance process enterprises, as Pinch analysis and heat-exchanger-network advancement.(42)

Pinch Analysis and Exergy analysis are the basic approaches that can be utilize for improving the energy efficiency of industrial processes. Pinch Technology provides an organised approach for energy saving in processes and whole sites. The technique depends on thermodynamic standards. This Energy pinch analysis principally matches cold and hot process streams with a network of exchangers so that demands for externally supplied utilities are minimized.(53) "Pinch Analysis" is often used to denote the application of the tools, algorithms and heuristics that are embedded in pinch technology. The laws of thermodynamics provide the basis for determining the enthalpy changes and direction of heat flow and as such pinch analysis can be used to identify energy targets and heat exchanger network (HEN) cost of capital targets for a process by recognizing the pinch point, the temperature at which the driving force for heat transfer is zero, and designing exchange networks based on the location of this point. The process streams that affect energy consumption are identified, quantified in terms of heat and mass flow and categorized in respect to their utility requirements as heating or cooling then combined in form of two composite curves on a temperature-enthalpy diagram wherein the region for possible heat recovery and utility requirements can easily be identified. Grand composite curve analysis helps towards identifying opportunities for energy-efficient utility integration to satisfy the energy requirements.(41) Pinch technology presents a simple energy analysis and systematic methodology for industrial processes and the surrounding utility systems.(41) Pinch analysis is a methodology for minimizing energy consumption of a process plant by maximizing the utilization of hot and cold utilities available within the process, thereby reducing the use of external utilities. It is also known as process integration, heat integration, energy integration or pinch technology. Energy conservation has become one of the most current concerns due to continuous increase in energy prices. Among process integration methodologies, pinch analysis is the most widely used. This is due to the simplicity of its underlying concepts and especially to the spectacular results; it has obtained in numerous projects worldwide. Before the advent of pinch, analysis, industrial equipment were designed and operated separately in terms of external utilities, with pinch analysis those process equipment can be incorporated in order to minimize the use of external utilities such as energy, hydrogen and water.(53) The Pinch technology has been developed as an instrument for the thermodynamic analysis of industrial processes by calculation of minimum heat loads (process hot and cold utility demand) through the process streams and minimum temperature difference (MTD) through the heat exchanger networks (HEN).(50) A Pinch Analysis starts with the heat and material balance for the process. After the heat and material balance is established, targets for energy saving can be set prior to the design of the heat exchanger network. The Pinch Design Method ensures that these targets are achieved during the network design. Targets can also be set for the utility loads at various levels (e.g. steam and refrigeration levels). The utility levels supplied to the process may be a part of a centralised site-wide utility system (e.g. site steam system). Pinch Technology extends to the site level, wherein appropriate loads on the various steam mains can be identified in order to minimise the site wide energy consumption. Pinch Technology therefore provides a consistent methodology for energy saving, from the basic heat and material balance to the total site utility system.(54)

The Pinch Point Analysis (PPA) is an extension of the second principle of Thermodynamics to the energy management of the whole plant. PPA deals with the optimal structure of the heat exchange between the process streams, and with the optimal use of utilities. Among benefits, I mention:

- Assess the reference basis of anCa_3SiO_5 energy-saving project, namely: – Minimum Energy Requirements (MER), such as heating and cooling loads for utility system, for a minimum temperature approach ΔT min assumed at Pinch; – Maximum energy saving by process/process heat exchange; – Capital and operation costs needed by MER.
- Set optimal targets before the detailed design of the Heat Exchanger Network (HEN): – Design targets for the HEN, such as the total heat exchange area and the number of units for achieving MER; – Nature and amount of utilities needed for satisfying the optimal loads; – Integration of heat saving with power generation.
- Suggest modifications in process design with significant impact on saving energy, as: – Optimization of the operating parameters of reactors and separators; – Heat integration of distillation columns; – Optimal placement of heat engines and heat pumps, etc.

PPA makes intensive use of conceptual graphical tools. The concept of Pinch has proved a generic value, being extended to the management of other valuable resources, such as water, solvents and hydrogen. In parallel with PPA, a different approach was developed, based on Mathematical Programming (MPR). At present, the two approaches are largely complementary, PPA as a conceptual tool, while MPR as an automatic design tool.

2.7.1. Basic Concepts

2.7.1.1. Composite and Grand Composite Curves

The most fundamental concepts in Pinch Analysis are Composite and Grand Composite Curves. Composite Curves (Figure 2.6.1) visualize the flow of heat between the hot and cold process streams selected for heat integration. A composite curve (CC) is obtained by plotting the cumulative enthalpy of streams, cold or hot, against temperature. The relative position of the CCs depends on the minimum temperature difference ΔT_{min} between cold and hot streams. This sets the Pinch position as the place where the heat transfer between the hot and cold streams is the most constrained. The CCs allow determining the MER from stream data without ever designing the heat exchangers. These MER are the minimum hot utility (Qh) and the minimum cold utility (Qc) required for driving the HEN, with a minimum driving force of ΔT_{min} at Pinch. The Pinch principle states that any design where heat is transferred across the Pinch will require more energy than minimum requirements. Consequently, the heat recovery problem is divided into two sub-systems, above and below pinch point.

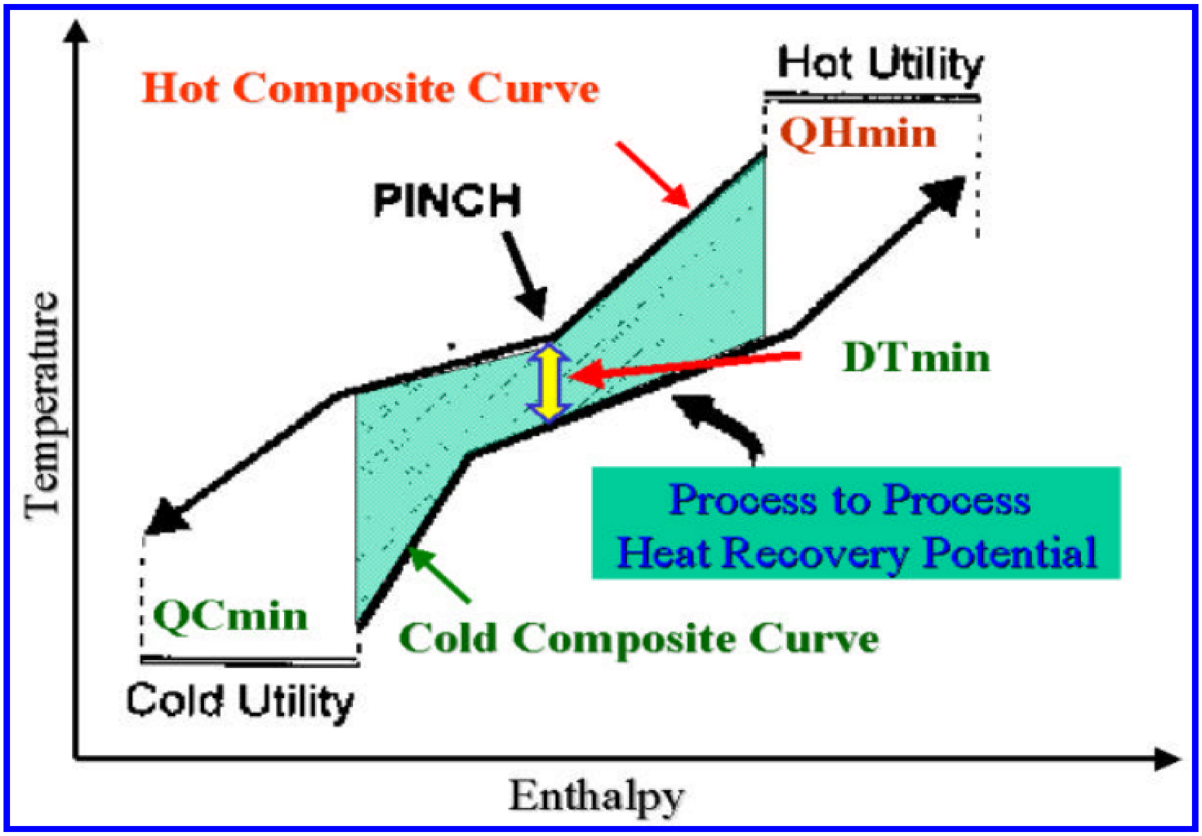


Figure 2.6. Composite Curve, Pinch Point and Minimum Energy Requirement(55)

The same information can be used for drawing the diagram Grand Composite Curve (GCC) (Figure 2.7) is the difference between the enthalpy of the hot and cold streams is plotted against a conventional shifted temperature scale. This representation identifies the possibilities of heat recovery by internal process/process exchange, as well as the optimal selection and placement of utilities.

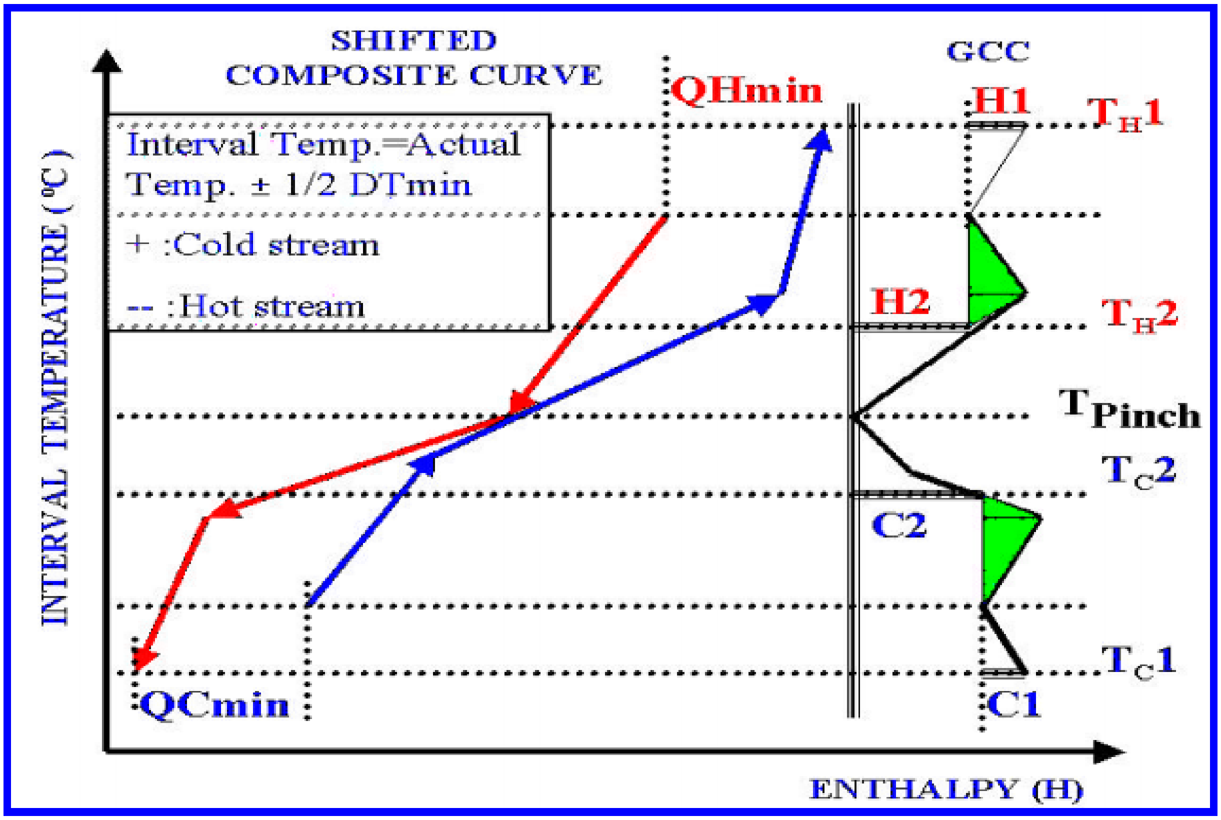


Figure 2.7. Grand Composite Curve, Pinch and MER(55)

2.7.1.2. Super targeting

Energy costs increase roughly proportional to ΔT min, while capital costs (heat exchangers) decrease- sharply with ΔTmin. Super targeting consists of setting design targets for the whole process by an overall optimization procedure without the need of the detailed sizing of heat exchangers.

2.7.1.3. Grid Diagram

Grid diagram designates a working frame for developing the HEN. The development of HEN is based on feasibility rules belonging to the Pinch Design method. HEN developed for MER is optimal when both energy and capital costs are considered Additional reduction in capital costs may be obtained by removing small units. This operation might transfer heat across the Pinch, and as a result increase the total consumption of utilities.

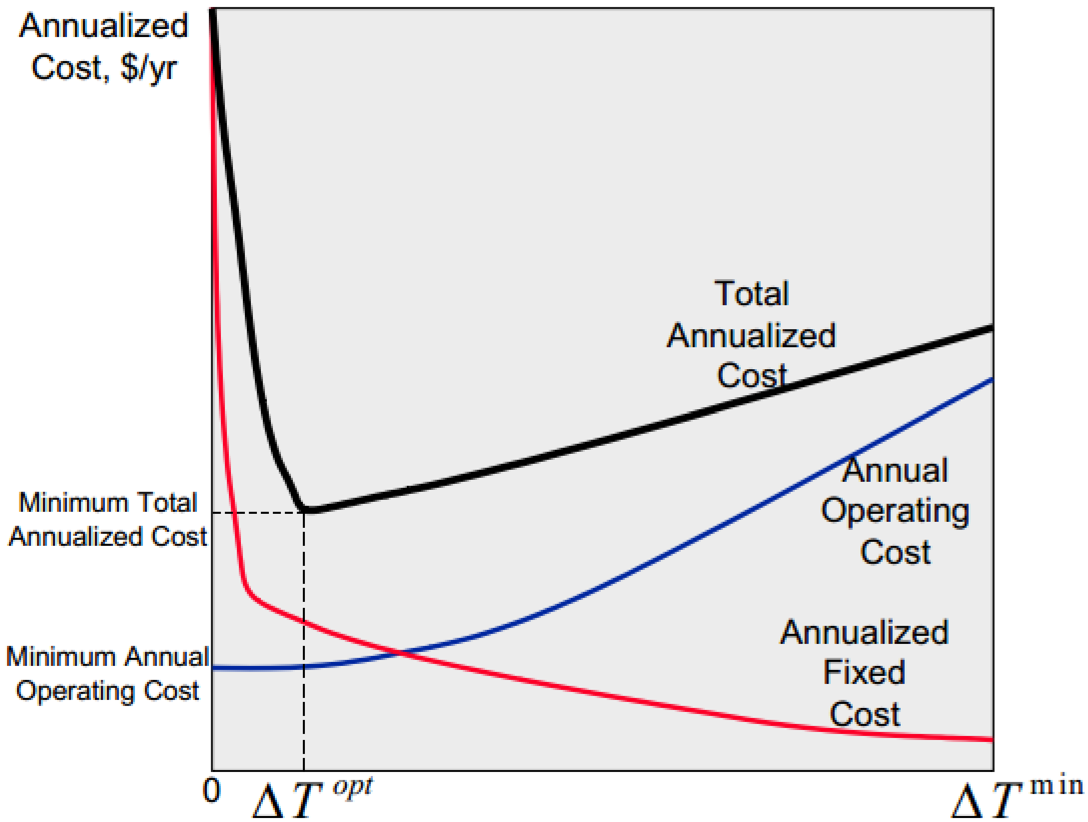


Figure 2.8. Targeting of Energy and Capital Cost before HEN Design (56)

2.7.1.4. Appropriate Placements

To guarantee energy saving, the position of unit operations with respect to Pinch must respect the rules of the Appropriate Placement. For example, a heat engine has to be placed either above or below the Pinch, but not across it. Distillation columns should not be placed across the Pinch. Contrarily, a heat pump is optimally placed across the Pinch.

2.7.1.5. Balanced CCs and Grid Diagram

Balanced CCs are similar with those discussed above, with the difference that now the utilities are considered as streams. Since the utilities cover any imbalance between the streams selected for integration, the enthalpy balance is closed. Moreover, the design of the heat exchangers is done in the balanced grid diagram.

2.7.2 .Targets For Energy Recovery

2.7.2.1 Stream data: - It presents the stream data chosen to illustrate the construction of the CCs. The following minimum elements are necessary:

- Stream or segment temperatures: supply Ts and target Tt.
- Heat capacity of each stream or segment, defined as CP=ΔH/ΔT, where ΔH is the enthalpy variation over the temperature interval ΔT. Conversely, the enthalpy change of a stream segment is as follows:
  ΔH=CP (T t – T s)

The hypothesis of constant CP is fundamental in PPA. If the enthalpy–temperature relation is not linear, then the stream must be "segmented".

2.7.2.2 .Composite Curves

The CC displays the cumulated enthalpy of all streams, hot or cold, available in a temperature interval between the extreme supply and targets temperatures. In this way, the graphical representation has identified two fundamental elements of a heat integration problem:

1. Minimum temperature approach at Pinch, ΔT min.
2. MER as utility targets for heat recovery.

2.7.2.3. Problem Table algorithms

When investigating the heat integration between hot and cold streams available in a temperature interval, we must ensure that the driving force is at least equal with ΔT min. First, the temperature scale is modified to accommodate a minimum driving force ΔT min. Hot streams are represented on the left scale. Cold streams are plotted on the right scale, where the temperature is shifted by ΔT min. Both hot and cold streams can be referred to shifted temperature scale, where the hot stream temperatures are moved down by ΔT min/ 2, and the cold stream temperatures are shifted up by ΔT min/2(by subtracting ΔT min/2 from the hot stream and adding ΔT min/2 to the cold stream).

Seconds In each shifted temperature intervals calculates energy balance from

$\Delta Hi = [\sum Cp\ cold - \sum Cp\ hot] * \Delta Ti$

Where ΔHi = the heat balance for shifted temperature interval i

ΔTi = the temperature difference for shifted temperature interval i

2.7.2.4 .Grand Composite Curves

With the information issued from the Problem Table, we can draw the GCC. A GCC is obtained by plotting the heat content of each temperature interval (x-axis) against the shifted temperature scale (y-axis). As mentioned, the shifted temperature scale takes into account a difference of ΔT min between hot and cold streams. The following observations are of interest:

- The Pinch Point divides the diagram in two regions, above and below the Pinch, in which the heat recovery problem can be analyzed separately.
- Above the Pinch, there is a need only for hot utilities. Below the Pinch, only cold utilities must be used.
- The "pockets" of the GCC designate possible heat recovery by process–process exchange.

2.7.3. Pinch Point Principle

The rules of pinch analysis include several principles that offer guidance in constructing a feasible and optimal heat exchanger network. The pinch rules are:

1. Heat should not be transferred across the pinch point.
2. No hot utility should be used below the pinch point.
3. No cold utility should be used above the pinch point.
4. No process-to-process heat exchanger should have an approach temperature less than the specified ΔTmin (minimum temperature difference in the exchanger).

When matching steams for heat transfer between the streams, some conditions have to be considered which are

1. above pinch $C_{Ph} \leq C_{Pc}$
2. below pinch $C_{Ph} \geq C_{Pc}$

C_{Ph} stands for specific heat capacity of hot stream, while C_{Pc} is for cold stream.(53)

If there is a heat flow across the Pinch, then the energy consumption is higher than the minimum necessary. Both hot and cold utility consumption will increase by the same amount XP above the minimum targets. The Pinch equation is as follows:

Actual energy (A) = target (T) + cross-pinch energy flow (XP)

Thus, transferring heat across the Pinch is a double loss in energy. However, during the effective design of the HEN, the initial targets must be revised to accommodate constraints, as, for example, a smaller number of units, or some imposed loads. The actual energy consumption could increase above the minimum targets, but the designer should try to keep the Pinch violation as small as possible. The temperature approach ΔT min is a key variable in PPA.

3. MATERIAL AND METHODS

3.1. Methodology

The methodology used in this work is based on principal of Pinch Analysis and Hint software was used to analyse the collected data for the pinch study as it performs energy target calculations. Pinch Analysis for synthesis of optimal flow sheets, are simply and understandably enables discovery of a solution that is very close to the global optimum. This method is based on thermodynamic analysis of Composite Curves of process streams. As results of possible savings, capital investments and simple payback time can be calculated. Usually, super-targeting is used to obtain the optimal ΔT min, but in my case, this is difficult for processing reasons. Hot meal is heated inside the kiln by flue gases in the existing process design, which cannot be heated by other process streams owing to the process design. From the other side, we have the hot clinker after the kiln that has to be cooled down rapidly, which can be accomplished by fresh air. For the present level of process equipment design, I have two limitations of the existing flow sheet that must be considered in the overall HEN design of the retrofit project. To obtain the maximum feasible heat recovery for the production process, the methodological steps were transformed as shown below.

3.1.1. The energy audits

Step1. An energy audit of the existing cement production was performed to ensure mass and energy balance. Composite Curves are used for the estimation of energy consumption, recovery and efficiency of heat exchangers considering the Cross-Pinch heat transfer. Inefficient heat exchangers are identified, and process limitations and forbidden matches between heat exchangers are defined. For energy and mass balance I used different instruments like infrared thermometer and pressure gauges to collect data.

3.1.2. Setting ΔT min value and obtaining energy targets

Step2. In order to generate the Composite and Grand Composite Curves used for Pinch Analysis, it is first necessary to set ΔT min values for the problem. ΔT min, or minimum temperature approach, is the smallest temperature difference to be allowed in any heat exchange match between hot and cold streams. This parameter reflects the trade-off between energy consumption (which decreases as the ΔT min value gets smaller) and the required capital investment for heat recovery equipment (which increases as the ΔT min value gets smaller).

It is possible to explore this trade-off quantitatively (for example, by using Pinch area targeting and capital cost targeting tools as presented in the Pinch Analysis for the Efficient Use of Energy), but in practice this is rarely done. Rather, there are typical ranges of ΔT min values that have been found to represent a reasonable trade-off between capital and energy that generally can be applied with a high level of confidence.

In this step, Composite Curves are built to obtain the energy target and Pinch point localization. Here, process limitations are not considered, and thermodynamically available recovery is targeted.

3.1.3. Obtaining new HEN topology

Step3. Based on the previous steps, the HEN is built considering the process limitations mentioned above. There is still Cross-Pinch heat transfer, which cannot be eliminated. Process streams with limitations are not excluded from the analysis to show the real picture of heat recovery and the future potential of energy efficiency. Steps 2 and 3 are repeated for the full range of ΔT min.

3.1.4. Definition of point with maximum heat recovery

Step4. Dependences of heating and cooling demands and Pinch point localization from ΔT min are defined to find the maximum heat recovery. It is achieved by the reduction of ΔT min while the hot and cold utilities are changed. The procedure defines the network temperature approach, Cross-Pinch transfer and topology concept design of the heat exchanger network.

3.1.5. Economic indicators

Economic indicators of retrofit realization are determined based on the calculation of the reduced total cost of the design with the use of reduced operating and investment cost.

3.1.6. Utilization of waste heat

This step is connected with the analysis of the potential of waste heat in the improved process. There is still a capacity for heat utilization, and its potential should be analysed and developed. The utilization of waste heat, which is now covered by cold utility, along with attempts to derive energy from low-potential heat sources have motivated the use of heat engines for example, by the organic Rankine cycle (ORC) or utilization of site heating demands. The basics of heat integration are used for appropriate and efficient placement of heat engines. Composite Curves show the energy targets, the source and sink temperatures of heat engines and the process streams available as sources. An intermediate utility can utilize the heat from process streams for site heating demands. This can be steam with different pressure levels, hot water, thermal oil, refrigerants, etc. The selection of the intermediate utility depends on the temperature level on which it is used. The Total Site Sink and Source Profiles should be plotted together on the T–H diagram by applying individual ΔT min specifications for heat exchange between process streams to present the streams with their real temperatures. In the Total Site targets for fuel, turbine loads, emissions and cooling are presented. The modified Total Site targets with the use of multiple intermediate utilities for heat recovery are shown in. The calculation was executed by Achilles software, which was developed for industrial implementations of Process Integration solutions.

3.2. Running of Hint software

After installing the Hint Software in a computer we get the icon of Hint software. The Hint software was ran by first starting up the menu. This was done by double clicking on the Hint software to display the start up menu, file from the tool bar was clicked, a new command was selected and appropriate units were chosen. The Hint Software display can be divided into three parts which was:

i. Bottom part:- this section introduce thermal properties
ii. Central part:-this section used to display different diagrams such as composite curve, grand composite curve, grid diagram …etc.
iii. Top part: - these parts contain all necessary information like setting and file.

Hot streams data page was displayed; the hot streams data were computed then followed by the selection of cold streams from the tool bar. The cold streams data page was displayed, the cold streams data were computed and return to main menu was clicked. System from the tool bar was selected and ΔTmin was computed. Worksheet from the tool bar was clicked to select summary of table which displayed the summary of the data provided.

Cascade diagram which displayed the cascade diagram, from which the pattern of heat transfer from heat surplus to heat deficit intervals and the requirement of external utilities were obtained. T-H Diagram which displayed the T-H (temperature- enthalpy) diagram, from which the pinch point, hot utility requirement, cold utility requirement and the possible heat recovery area were obtained. Work sheet from the tool bar was clicked to select design above the pinch, from which the appropriate streams matching and network modification were performed. Also work sheet was clichéd again to select design below the pinch and appropriate stream matching and network modification were performed.

For Hint software the procedure involved:

- Identification of hot process, cold process and utility (hot and cold) streams of a particular Cement plant.
- Data extraction of relevant plant process utility and streams (supply and target temperatures, heat capacity and enthalpy) that could be used in calculations for the heat exchanger network.
- Selection of a "suitable" ΔTmin value, in determined range, that serves as the design parameter.
- The collected data was fed to Hint. The information required for this calculation are the thermal properties of the streams (supply/target temperatures) and enthalpy (H) or heat capacity flow rate (mCp) obtained at ΔTmin.
- Generation of composite and grand composite curves using the extracted data to evaluate the type of utility required and the amount of heating and cooling required in the HEN.

The flowchart in Figure 3 summarizes the procedure undertaken to establish the energy targets in this work.

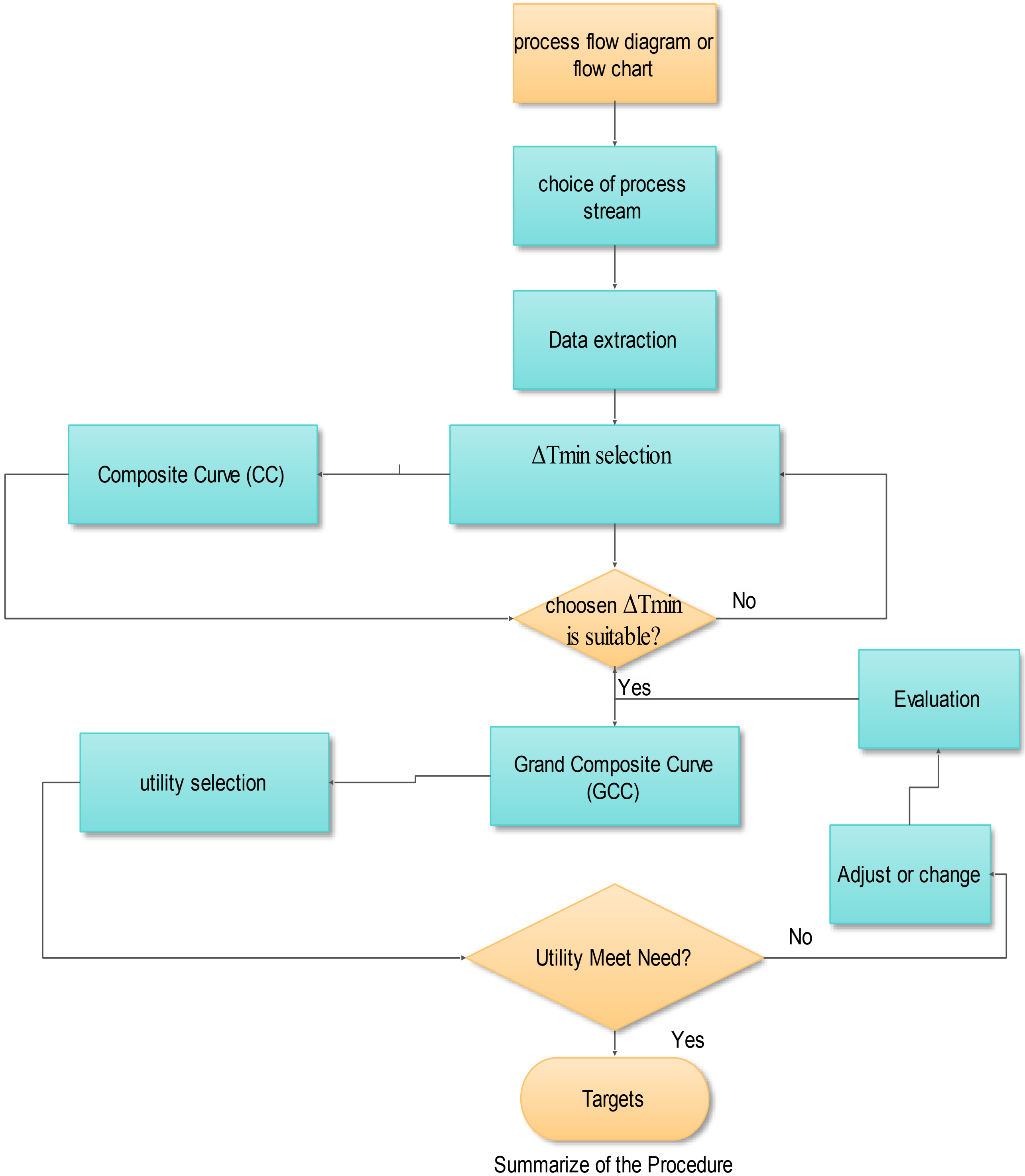


Figure 3.1. Summarize of the procedure

3.3. Data Collection Procedures

After developing the drafts of the questionnaire and interview questions, for the convenience of this study questions which are written in English are used to gather information from factory production and quality heads, shift engineer, and Amharic language is used to collect information from the operators. I orally had well informed the factory worker about the purpose of the questionnaire and procedure to be followed to administer. I had distributed the questionnaires to all operators in each section of the process. The interview questions are set consisted of a series of questions that focused on encouraging them to explain the issue under study on energy integration and utilization.

Primary Data Collection

The primary data is used to obtain the amount of temperature which gives an estimate to the targeting temperature that we will work later.

Secondary Data Collection

Data from other sources as well as relevant documents and other related materials are collected to estimate the amount of temperature at each section of the process.

A survey of the processes in Ethio Cement plant was carried out. The survey lasted one month. A sketch of the processes was drawn. The sketch assisted in identification of the areas where data was to be collected. During data extraction, 15 process streams were selected for process analysis; there are 7 hot streams and 8 cold streams. Some of the cold streams are heated by the hot stream, and this stream population forms the heat recovery component. The external heating and cooling are provided by the utility system. Cold water and ambient air are used for cooling, and heat from the fuel combustion is used as hot utility. All process streams that can be included to the process analysis are collected in Table 3.1. Utility data of cement production are also provided to perform an economic analysis. The hot utility consists of different types of fuel that are fed to the kiln, the main fuels used for current cement production are coal, cooling water provided by the desalination plant cools the exhaust gases before the gas filters. Ambient air is also used as cold utility for the hot air cooling, which emerges from the clinker cooling stage. The hot air passes through the coolers and air filter before being discharged to the atmosphere.

Data was collected for tow months. Every day, data collected five times, on an hourly basis. The values were averaged.

Table 3.1 Stream data of cement production with raw meal operation

No	Stream name	Type	T_s(℃)	T_t(℃)	C_p(kw/k)	$\Delta H(kw)$
1	Clinker after kiln	Hot	1450	60		
2	Hot gases from kiln	Hot	900	420		
3	Gases to cooling tower	Hot	370	175		
4	Gases to coal meal	Hot	216	90		
5	Gas to raw meal	Hot	267	105		
6	Hot air to coolers	Hot	270	105		
7	Hot air to cement grinding	Hot	270	105		
8	Raw material to raw meal	Cold	25	110		
9	Kiln feed	Cold	145	850		
10	Hot meal	Cold	800	1450		
11	Coal to coal mill	Cold	25	90		
12	Coal dust to kiln	Cold	55	170		
13	Air to kiln	Cold	25	170		
14	Air for clinker cooling	Cold	25	290		
15	Clinker to cement grinding	Cold	25	100		

4. RESULTS AND DISCUSSION

4.1. Identification of Hot, Cold and Utilities Streams in the process

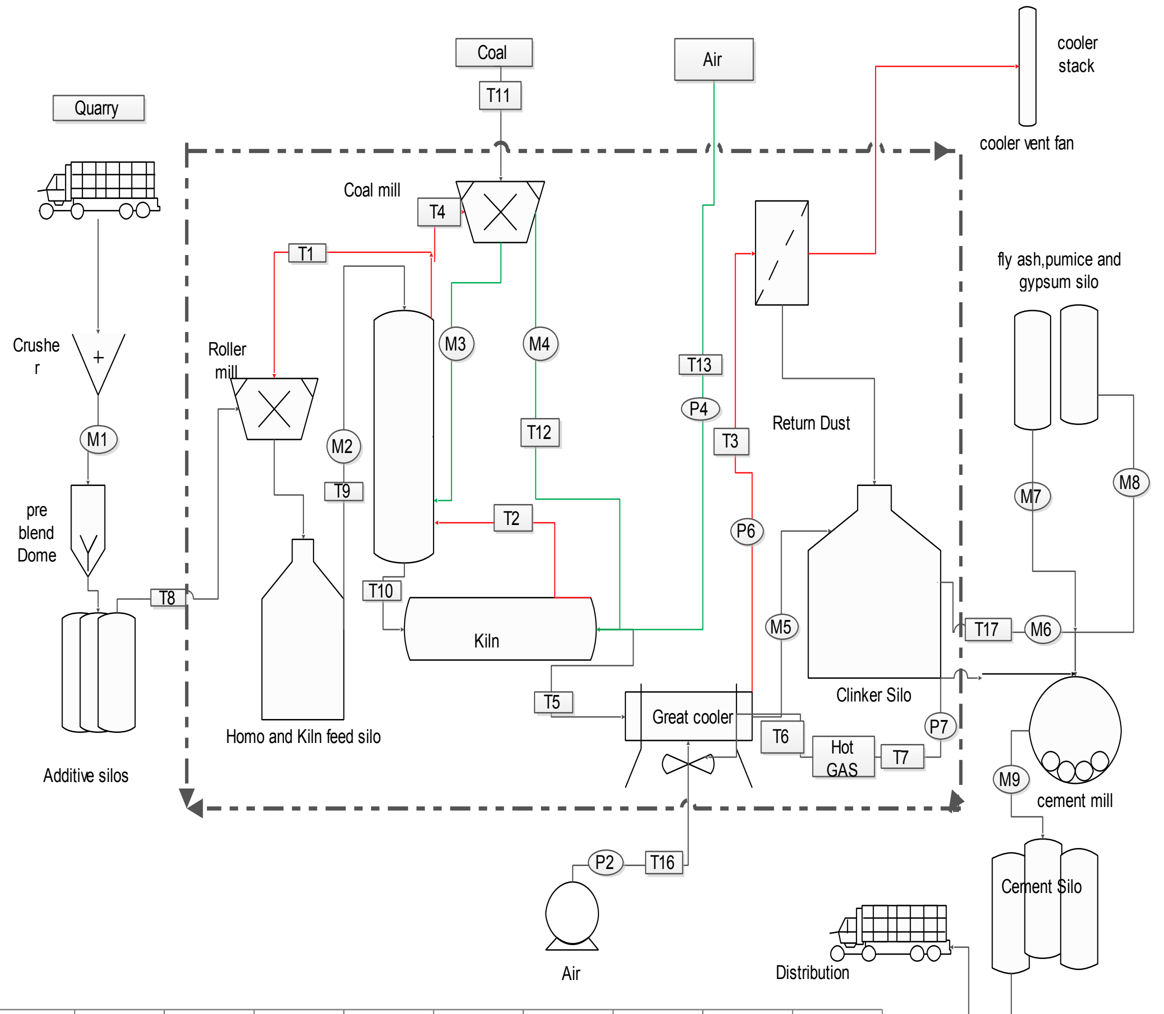
The identification of streams was the crucial part of my research paper because of without streams we have no any information about energy optimization and heat exchanger networks.
This is discus above the stream table in Table 3.1 the data collection part. From stream number 1 up to stream number 7 I have hot stream and from stream number 8 up to 15 I have cold stream type.

Hot streams: - which required being cool

Cold streams: - which required being hot

4.2. Thermal Data Extraction for process and utility streams

Data was extracted from the flow sheet by using control volume and around the control volume I can calculate material and energy balance for each stream. Data extraction relates to the extraction of information required for Pinch Analysis from a given process heat and material balance. Material and energy balances are very important in an industry. Material balances are essential to the control of handling, especially within the control of yields of the items. The first material balances are determined in the exploratory stages of a new process, improved during pilot plant experiments when the process is being planned and tested, checked out when the plant is commissioned and after that refined and kept up as a control instrument as production continues. The value discuss below in Table 4.1. and Table 4.2.
The control volume and Temperature value also shown in below figure.



measure	value	measure	value	measure	value	measure	value	measure	value
T1	370oC	T8	25oC	T15	25oC	M4	___ton/h	P2	___pa
T2	860oC	T9	105oC	T16	25oC	M5	___ton/h	P3	___pa
T3	370oC	T10	810oC	T17	25oC	M6	___ton/h	P4	___pa
T4	370oC	T11	25oC	T18	25oC	M7	___ton/h	P5	___pa
T5	1450oC	T12	55oC	M1	___ton/h	M8	___ton/h	P6	___pa
T6	290oC	T13	25oC	M2	___ton/h	M9	___ton/h	P7	___pa
T7	270oC	T14	25oC	M3	___ton/h	P1	___pa		

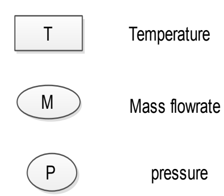


Figure 4.1. The process flow diagram with boundary

Table 4.1. Mass Balance Value for Each stream

No	Name of the streams	Amount of mass per clinker (Kg/ Kg clinker)
1	Raw material to raw mill	1.65
2	Air consumption of cooler	2.45
3	Coal to calciner and kiln	0.104
4	Primary air consumption	0.0223
5	Preheater exhaust gas	1.083
6	Cooler ESP exhaust gas	0.5172
7	Clinker	1
8	Dust	0.165
9	Coal conveying air	0.063
10	Kiln feed moisture	0.02
11	Excess hot air with clinker	1.02
12	Hot gas to clinker	3.343
13	Uncounted loss	0.3981

Table 4.2 Heat Balance for Each stream

No	Heat Input	Value (Kcal/kg clinker)	Heat output	Value (Kcal/kg clinker)
1	Heat of Combustion	780	Heat of clinker reaction	411.2
2	Sensible Heat from coal	0.287	Heat loss from clinker at cooler outlet	23.28
3	Sensible Heat of Raw Material to raw mill	25.78	Heat loss through dust in the exhaust gas	13.863
4	Sensible heat from cooler air	1.764	Heat loss through evaporation moisture	8.3268
5	Sensible heat from primary air	0.0163	Heat loss from exhaust gases from preheater	77.356
6	Sensible heat from coal conveying air	0.779	Heat loss from exhaust gases from cooler	41.97
7	feed moisture	5.84	Uncounted losses	238.47

4.3. Selection of Minimum Initial Temperature Difference

The selection of ΔTmin depends based on the factory processes. It is therefore recommended that the use of experience based ΔTmin is treated with caution and that as much as possible the choice is backed up by quantitative information (such as ΔTmin versus energy plot etc.). Typical ΔTmin values based on experience are available in different literature for reference. Linnoff March discuses more about typical ΔTmin for various industrial sectors. The following tables detail Linnhoff March's experience ΔTmin values.

Table 4.3 Typical ΔTmin values

No	Industrial sector	Experience ΔTmin
1	Oil refining	20-40℃
2	Petrochemical	10-20℃
3	Chemical	10-20℃
4	Low temperature process	3-5℃

According to the values based on Linnhoff March's application experience, the value of ΔTmin for chemical industries is between 10 - 20 °C. Cement factory is one of the chemical industrial sectors.

The optimum value of ΔTmin was automatically obtained by using the range-targeting feature in Aspen Energy Analyser. The software tool simulates the capital and operating cost at the various values of ΔTmin and generates a graph of total cost vs ΔTmin. That graph gives the knowledge comparable to the optimization of the minimum approach temperature, which is calculated by minimising the total annual cost. It means finding the best compromise between utility requirements, heat exchange area and unit shell number.(30) but in my work I am taking according the reference value of chemical sectors minimum temperature difference value.

- **Variation of Pinch Temperature with** ΔTmin

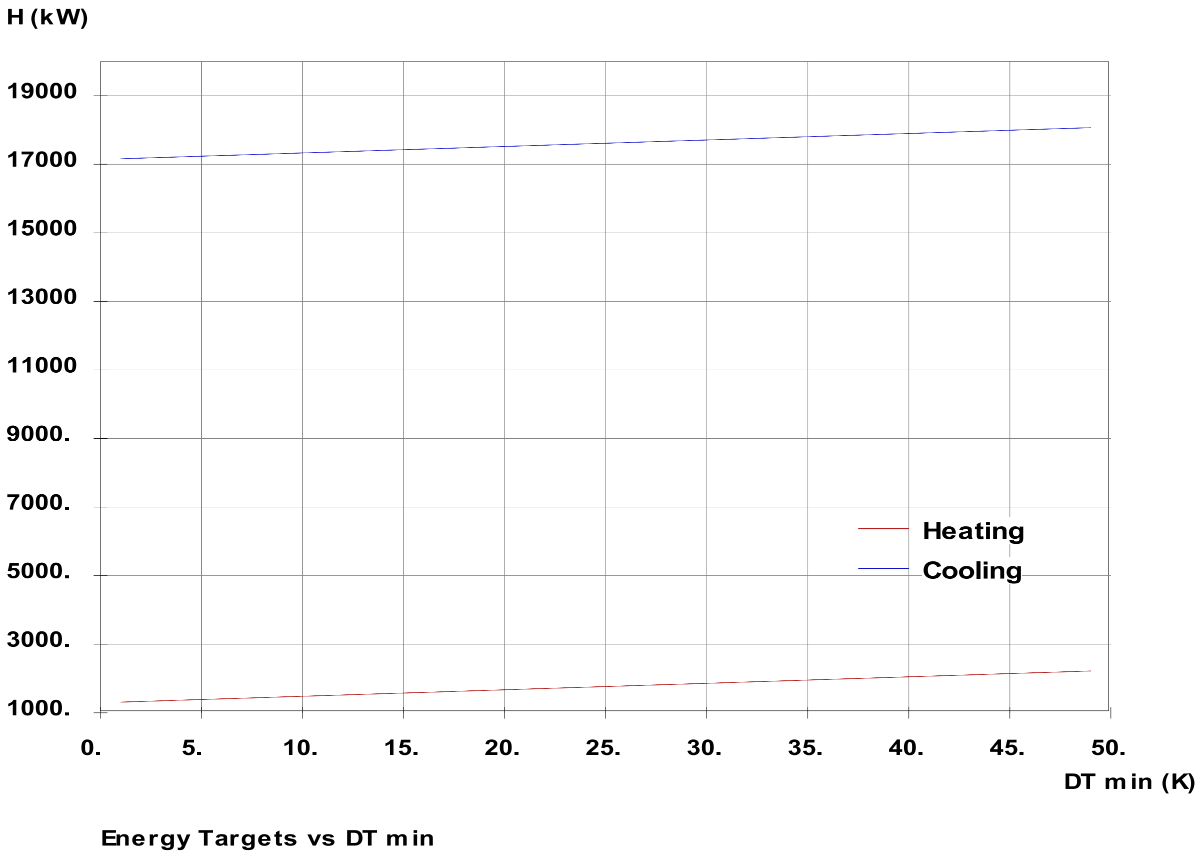


Figure 4.2 Energy Targets vs. DT min

The above graph shows the relationship between minimum temperature difference requirement for the given process and energy target.

Based on the above figure large amount of minimum Temperature difference shows high amount of energy targets (heating and cooling utility) and figure 4.3 show low amounts of Area Targets. Which shows high amount of minimum temperature difference required high amount of energy cost and low amount of capital cost according to the literature review and the above discussion I am selecting 10℃ as minimum temperature difference for my new cement process.

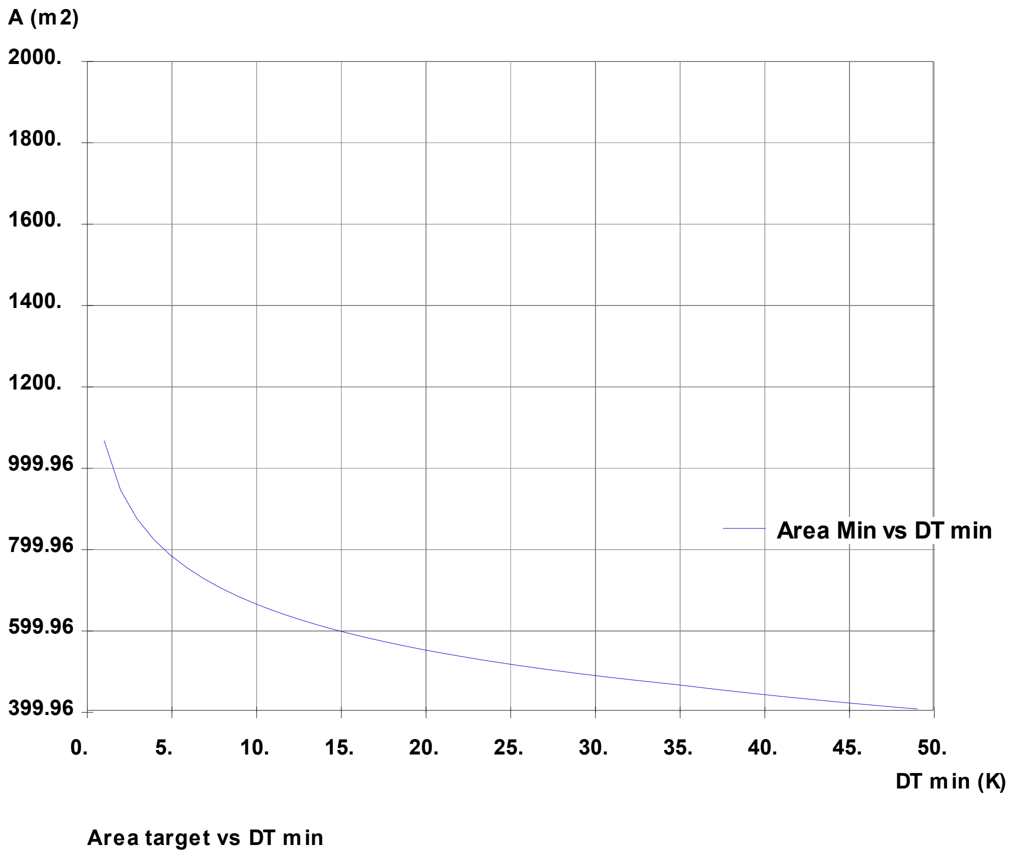


Figure 4.3 Area target vs. DT min

4.4. Analysis of existing process

Based on the process energy audit, heat balances and stream table data, the Composite Curves of existing cement production were built considering raw mill operation mode exist. It means in Ethio Cement PLC we have horizontal raw mill which used for preparation of raw meal. In addition to that raw mill required less amount of energy than pyro processing. For stream table assuming, all unites are converted to international accepted value and the following calculation can be valid. Enthalpy change (ΔH) associated with a stream passing through the exchanger is given by the first law of thermodynamics:

First law energy equation: $H = Q \pm W$

In a heat exchanger, no mechanical work is being performed:

$$W = 0$$

The above equation simplifies to: $H = Q$ where Q represents the heat supply or demand associated with the stream, it is given by the relationship $Q = (T_s - T_t)C_P$

$$\Delta H = (T_s - T_t)C_P$$

$$C_P = \dot{m} \times c_p$$

Where:- $C_P = Heat\ Capacity\ Flow\ Rate$

$\dot{m} = Mass\ Flow\ Rate$

$c_p = Specific\ Heat\ Capacity$ Where the value of 1cal equal to 4.184 J

By constructing the composite curve we loose information on the vertical arrangement of heat transfer between streams. My composite curve used to predict targets for minimum energy (both hot and cold utility) required. Table 5.1 shows stream data of cement production with raw meal operation. The table has more information that used for existing cement factory and for constructing new heat exchanger network for retrofit cement factory.

Table 4.4 Stream data of cement production with raw meal operation

No	Stream name	Type	T_s(℃)	T_t(℃)	$\dot{m}$(kg/s)	c_p (kcal/kgk)	C_p(kw/k)	$\Delta H(kw)$
1	Clinker after kiln	Hot	1450	60	20.83	0.19	16.56	23,018.4
2	Hot gases from kiln	Hot	900	420	21.25	0.461	40.97	19,665.6
3	Gases to cooling tower	Hot	370	175	10.78	0.252	11.36	2,215.2
4	Gases to coal meal	Hot	216	90	10.56	0.2551	10.73	1,351.98
5	Gas to raw meal	Hot	267	105	12.51	0.2551	13.35	2,162.7
6	Hot air to coolers	Hot	270	105	69.65	0.241	70.23	11,587.9
7	Hot air to cement grinding	Hot	270	105	8.79	0.241	8.86	1,461.9
8	Raw material to raw meal	Cold	25	110	34.38	0.217	31.21	-2,652.8
9	Kiln feed	Cold	145	850	24.38	0.217	22.14	-15,608.7
10	Hot meal	Cold	800	1450	20.83	0.217	18.91	-12,291.5
11	Coal to coal mill	Cold	25	90	2.17	0.276	2.50	-162.5
12	Coal dust to kiln	Cold	55	170	1.52	0.276	1.76	-202.4
13	Air to kiln	Cold	25	170	0.465	0.2236	0.43	-49.45
14	Air for clinker cooling	Cold	25	290	50.99	0.24	51.20	-13,568
15	Clinker to cement grinding	Cold	25	100	12.86	0.2643	14.22	-1,066.5

The Composite Curves in Fig. 5.1 show the energy targets of the existing cement production. The operation mode with the raw mill features heat recovery of 37,889.6 kW, whereas the process requires external heating of 7,611.5 kW and cooling of 23,460.4 kW. The operation mode with raw mill requires lower utility demands than the operation mode without raw mill. The minimum temperature approach in the heat exchanger network of the existing process with the raw mill is 250 °C. These values are found from existing energy targets based on audit data and heat balances. However, the real temperature approach of some heat exchangers is 1 °C because the equipment uses direct heating for example, raw mill or cement grinding.

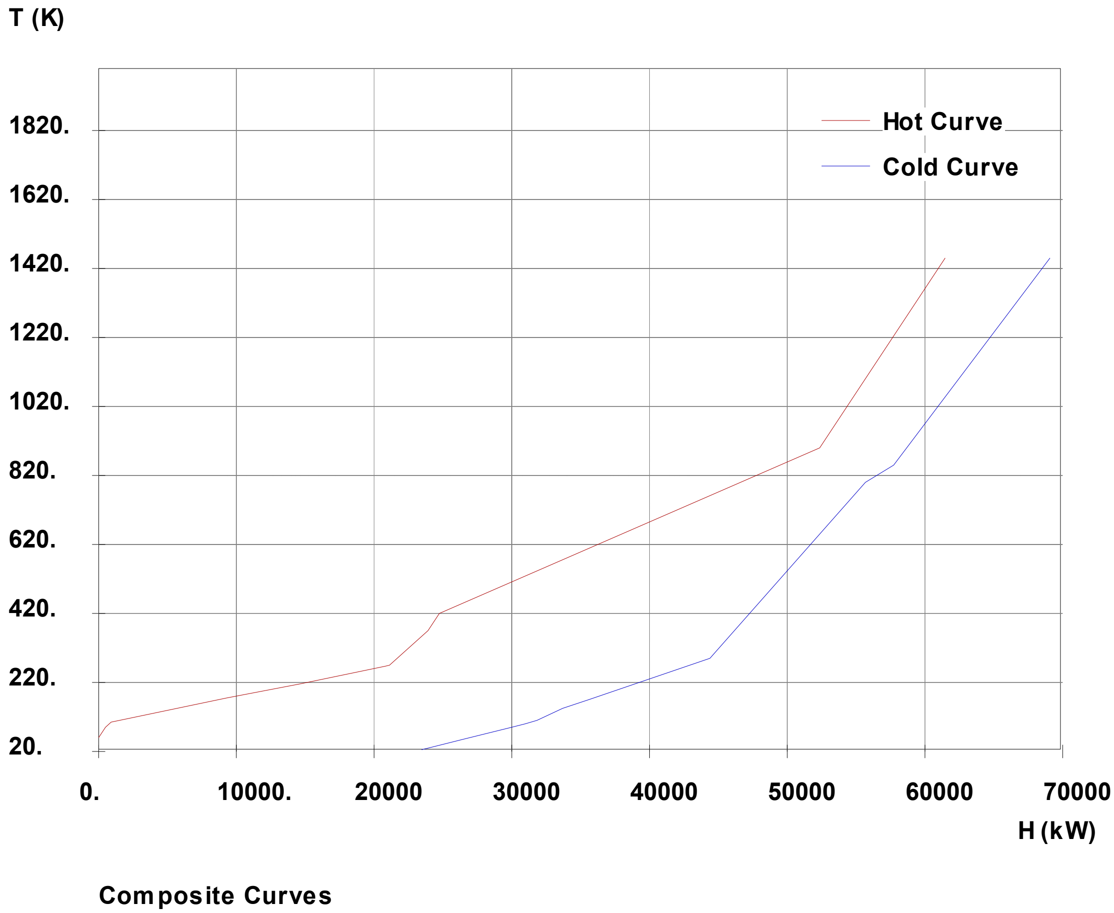


Figure 4.4 Composite curve for existing plant using Hint Software

From the figure above, the overlap area in between the hot and cold composite curves represent the potential of maximum amount of heat recovery possible in the process. The overshoot of the cold composite curve, is the amount of external heat required from the utilities which is Q_{Hmin} in the figure above. On the other hand, the overshoot of the hot composite curve is the amount of external cooling required from the utilities, which isQ_{Cmin}. The pinch temperature is the closest point of two curves. A minimum temperature difference, ΔTmin is the minimum temperature for heat exchange, to target the external heating and cooling utilities.

Heat composite curve is then constructed to target the potential recoverable energy and minimum hot and cold utilities required in the system.

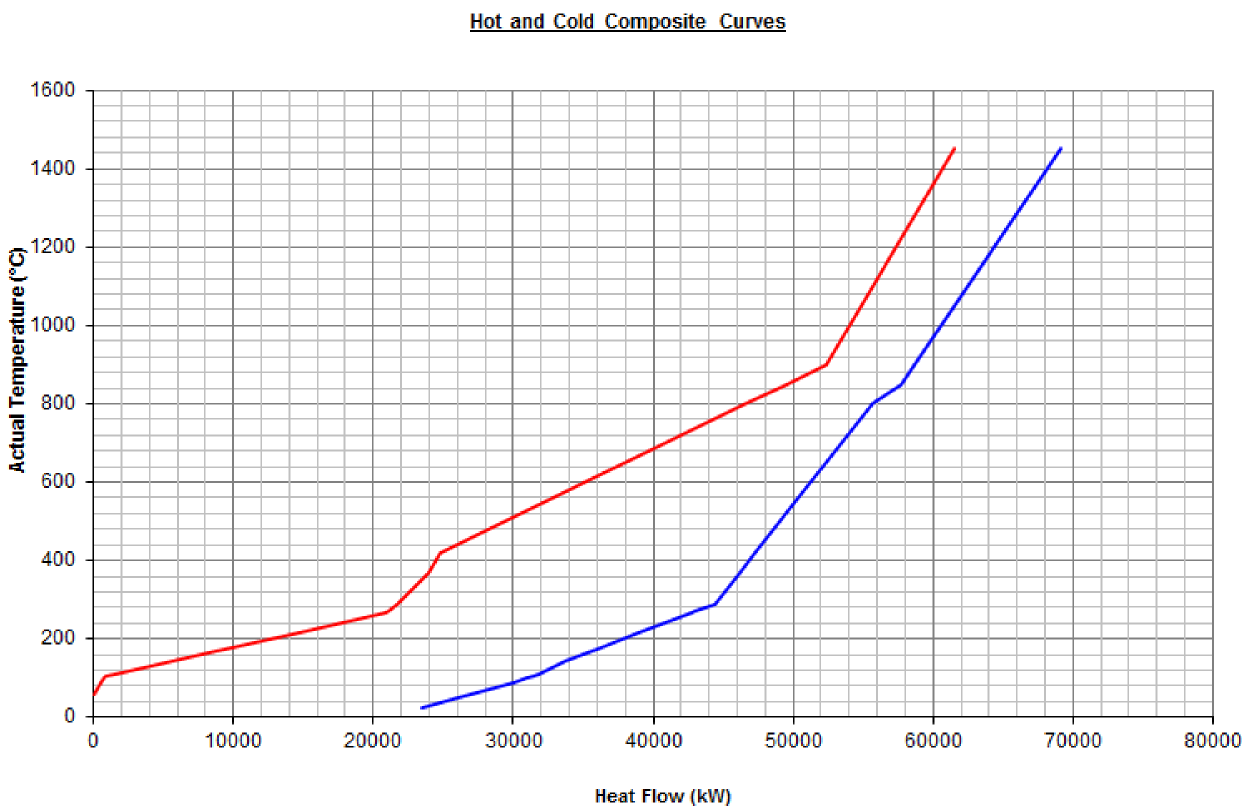


Figure 4.5. Composite curve for existing cement factory using pinch analysis spread sheet

The existing heat exchanger network is represented by a Grid Diagram below, showing the heat transfer between the process streams, but some equipment are not classical heat exchangers for example, cement grinding or raw mill. The matching and splitting of the streams were carried out on the grid through the different procedures: the matching was carried out using feasible criteria. There are some heat exchangers that cross the Pinch, which increases the utility consumption and reduces the efficiency of energy usage. From the other side, this practice is a result of a design concept, which was oriented mostly on obtaining product rather than energy efficiency. This reduces the opportunities for energy efficiency at the plant operation stage. The overview of the appropriateness of the heat transfer of the existing cement factory is presented in figure below. It is shown that the total Cross-Pinch heat transfer is more than 43,438.9 KW its equal to 43.4389 MW, which proves the inefficiency of the existing heat system.

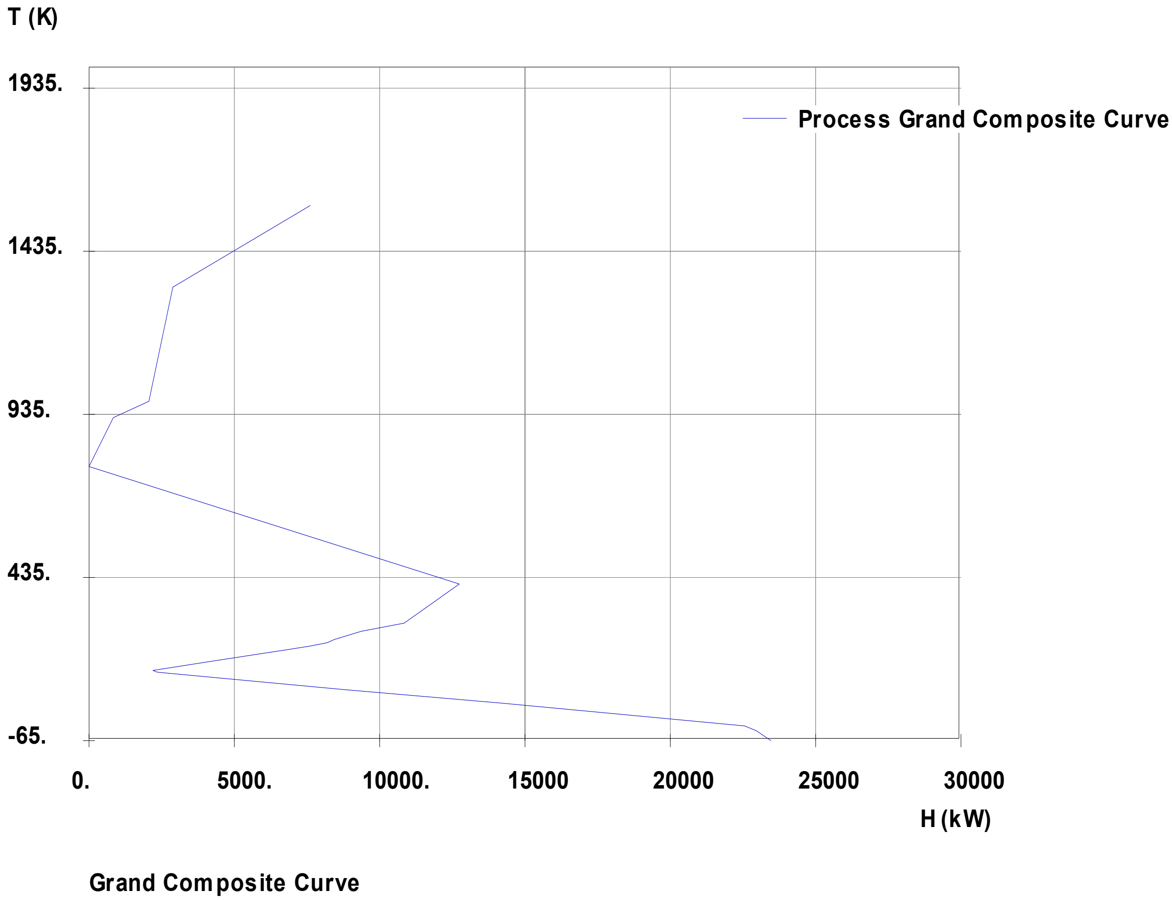


Figure 4.6 Grand composite curve for existing cement factory

Another way to represent the heating and cooling demand is to merge the hot and cold composite curves into one, the grand composite curve (GCC). In this curve the temperatures are adjusted into shifted temperatures, which mean that hot streams are lowered with ΔTmin/2 and cold streams lifted with ΔTmin/2. An advantage with the GCC is that it shows at what temperature the heating and cooling demands occur. This means that it is easier to find possibilities for heat integration and use of waste heat. In Figure 5.3 an existing cement factory of a GCC is shown.

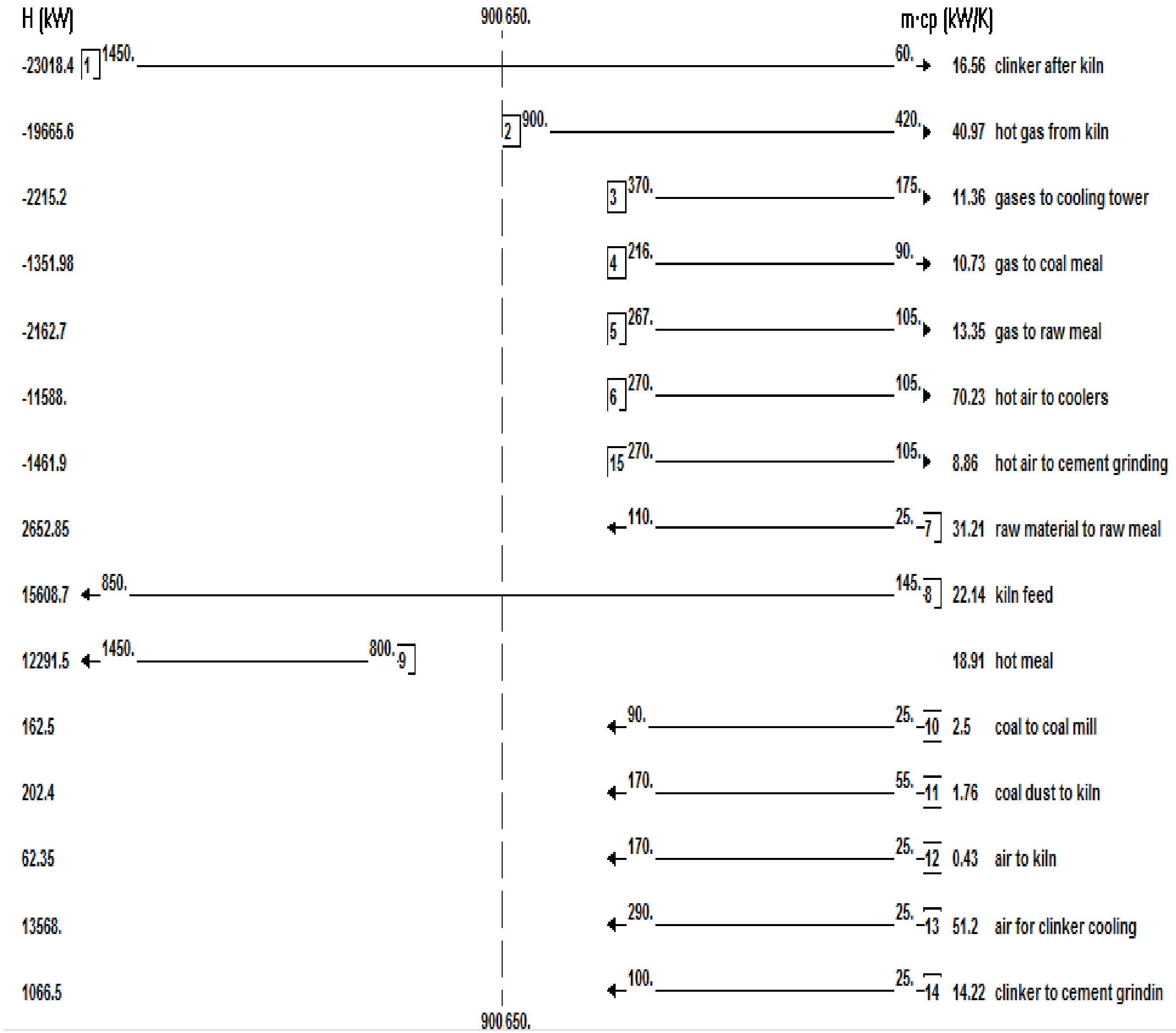


Figure 4.7 Grid diagram for existing cement factory

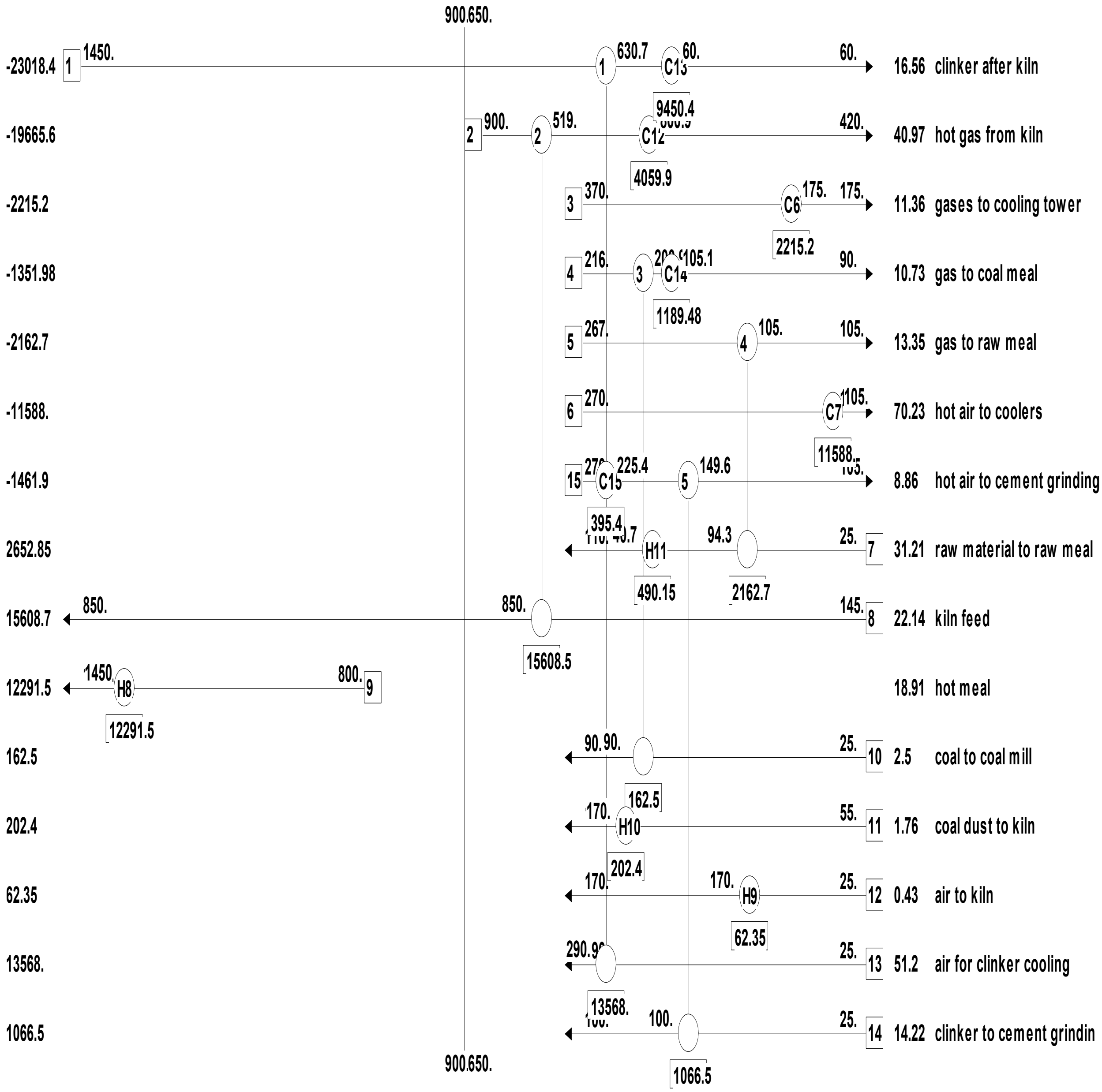


Figure 4.8 Heat exchanger network for existing cement factory

➢ Pinch violations

In the existing heat exchanger network the heating and cooling demand is larger than what the process requires as a minimum. The difference between the present fuel demand and the minimum demand for hot utility is due to pinch violations i.e. non optimal heat exchange. Figure 4.9 shows the result of pinch violations for the plant.

Heat exchanger No.2 breaks the minimum Temperature difference

Heat exchanger No.3 breaks the minimum Temperature difference

Heat exchanger No.4 breaks the minimum Temperature difference

Heat exchanger No.5 breaks the minimum Temperature difference

Heat exchanger No.2 transmits heat across the pinch

Heat exchanger No.9 transmits heat across the pinch

Heat exchanger No.10 transmits heat across the pinch

Heat exchanger No.11 transmits heat across the pinch

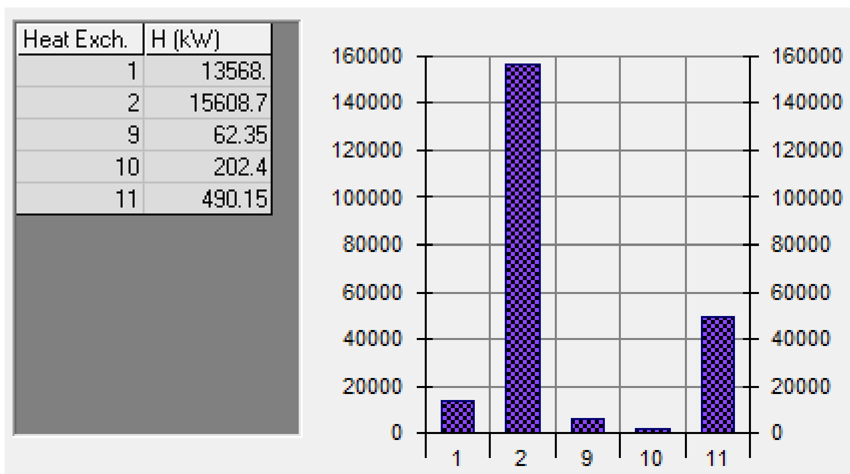


Figure 4.9 Heat transferred across the pinch for existing cement factory

The total amount of heat transferred across the pinch for existing cement factory was 29931.6 KW.

4.5. Maximization of Heat Recovery for New Cement Processing

By providing a Composite Curves analysis, it is possible to obtain thermodynamically available energy targets for integrated cement production that show large potential for energy savings. Eliminating the Cross-Pinch heat transfer and cold utility above the Pinch point enables decreased utility consumption and increased heat recovery. Additionally, the minimum temperature approach can be reduced to minimize the energy targets. This situation is well illustrated in Fig 5.7 by Composite Curves for ΔTmin = 10°C. The targets for hot and cold utility are 1481.6 kW and 17,330.53 kW, the heat recovery is increased to 43,208.5 kW. The heat recovery could be improved by 5,318.9 kW. However, the cement production mostly has the process streams with solid and gas phases and other process and the feasibility of the retrofit project according to the energy targets. On this basis, the heat system of cement production has significant potential for energy efficiency, but it is not easy to achieve a profitable solution owing to the process limitation connected to heating and cooling process streams. There are some process streams that have such technological features, and it is impossible to avoid it when implementing an integrated solution. Hot meal is heated from 850 °C to 1,450 °C in the kiln, and it cannot be changed using the present level of technology. The second limitation is the cooling of the clinker after the kiln to 60 °C, which must be performed quickly and is currently conducted via fans.

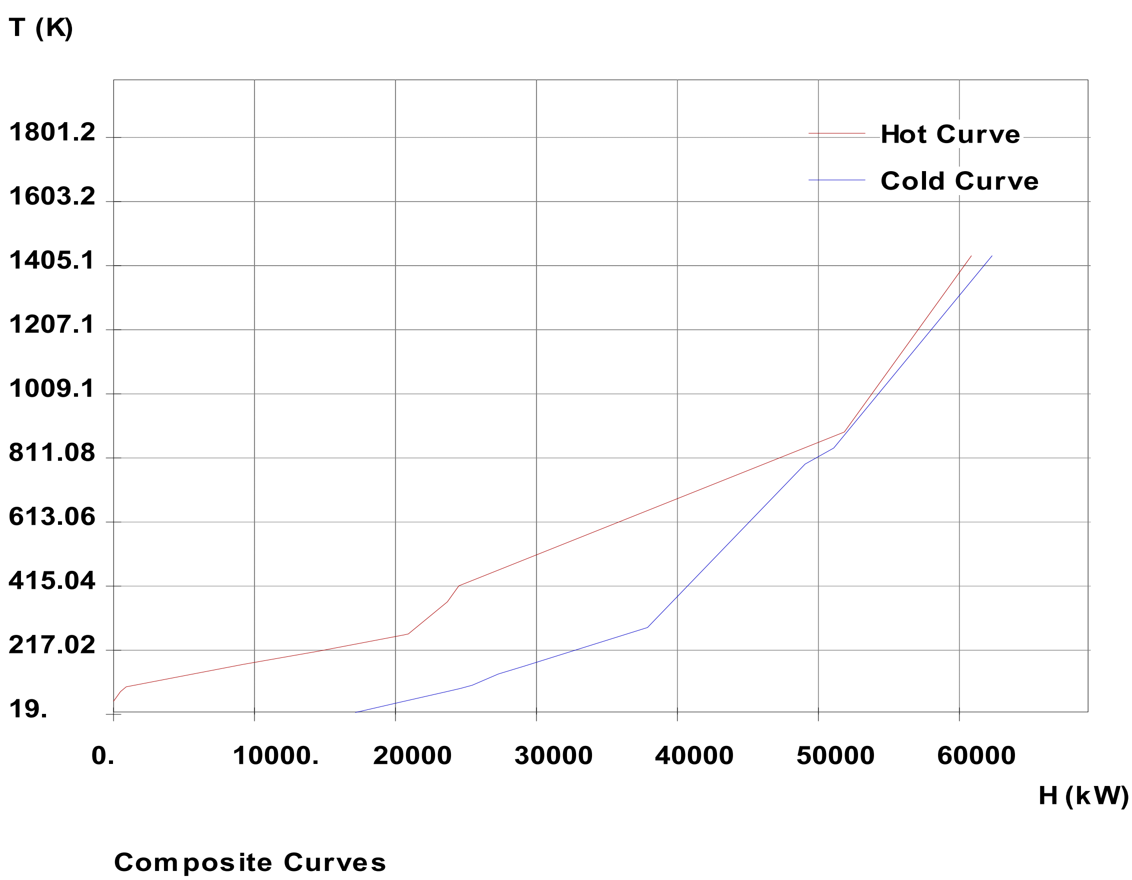


Figure 4.10 Composite curve of cement production with improved heat integration

The composite curves provide overall energy targets but do not clearly indicate how much energy must be supplied by different utility levels. The utility mix is determined by the Grand Composite Curve.

Prior to HEN design, a composite curve of temperature-enthalpy of hot and cold steams illustrated in Fig 5.7. It gives information about maximum and minimum utility requirement of hot and cold streams. The pinch point is the closest temperature difference between the hot and cold utility curves (Δ*T*min).

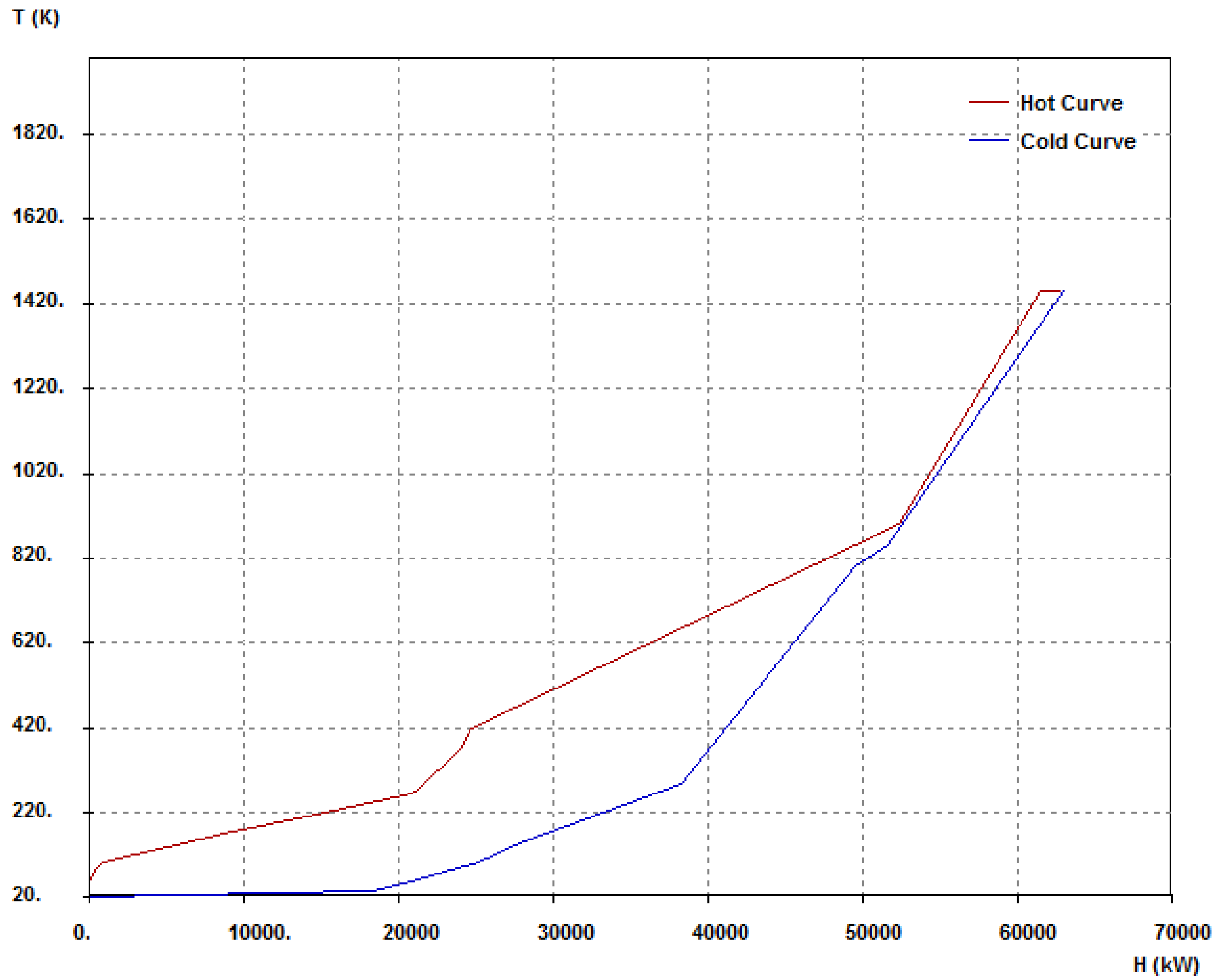


Figure 4.11 Composite curve with utilities

Another diagram that might be useful is the grand composite curve. Grand composite curve is obtained by plotting the heat content of each temperature interval (x-axis) against the shifted temperature scale (y-axis). As mentioned, the shifted temperature scale takes into account a difference of ΔT min between hot and cold streams. To prepare this curve, begin with the pinch temperature, assigning a zero value to it. For the case study, the pinch temperature is 890. Then for the next higher temperature interval, again define the average temperature and calculate the total heat flow.

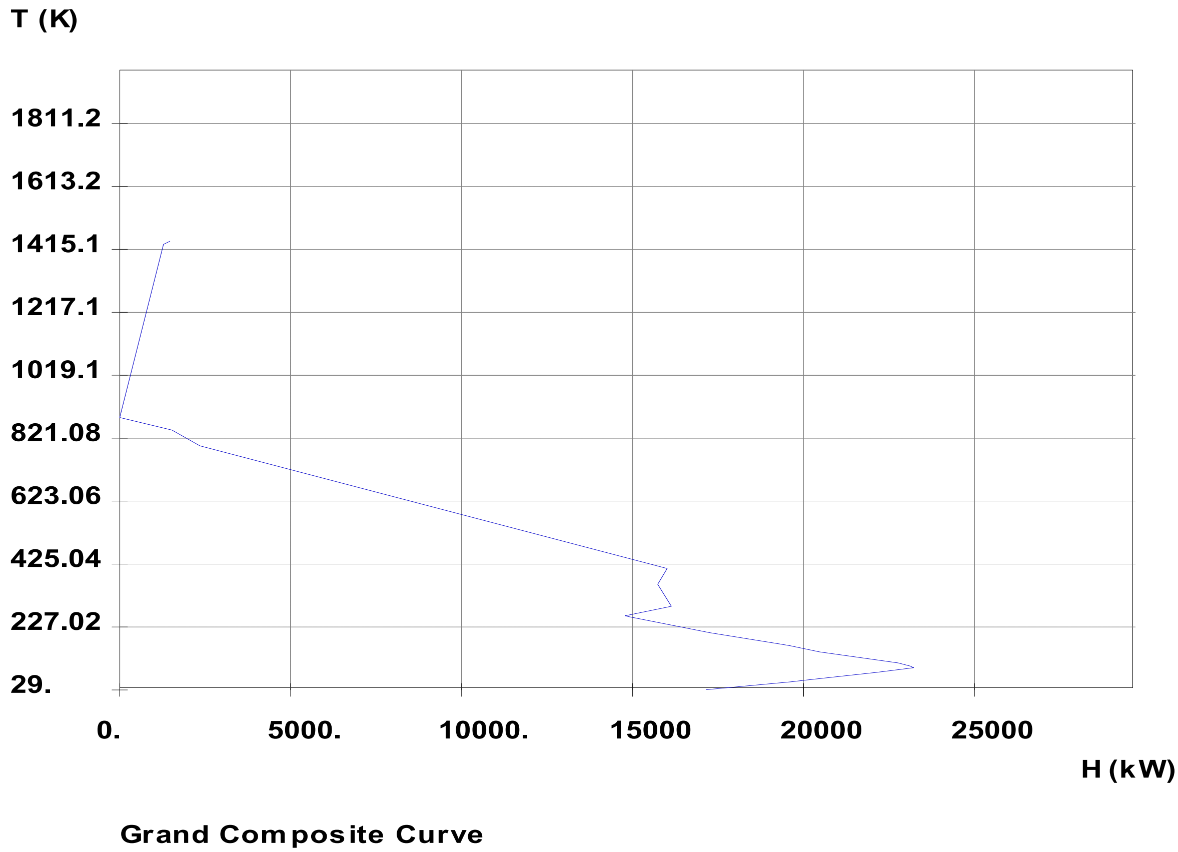


Figure 4.12 Grand Composite Curve for improved one

The pinch temperature and the minimum requirement of heating and cooling utilities are characterized by the pinch technique. A grand composite curve shown in Fig above was generated to provide the excess internal heat available within each temperature interval for selecting utilities by minimizing the use of expensive utilities.

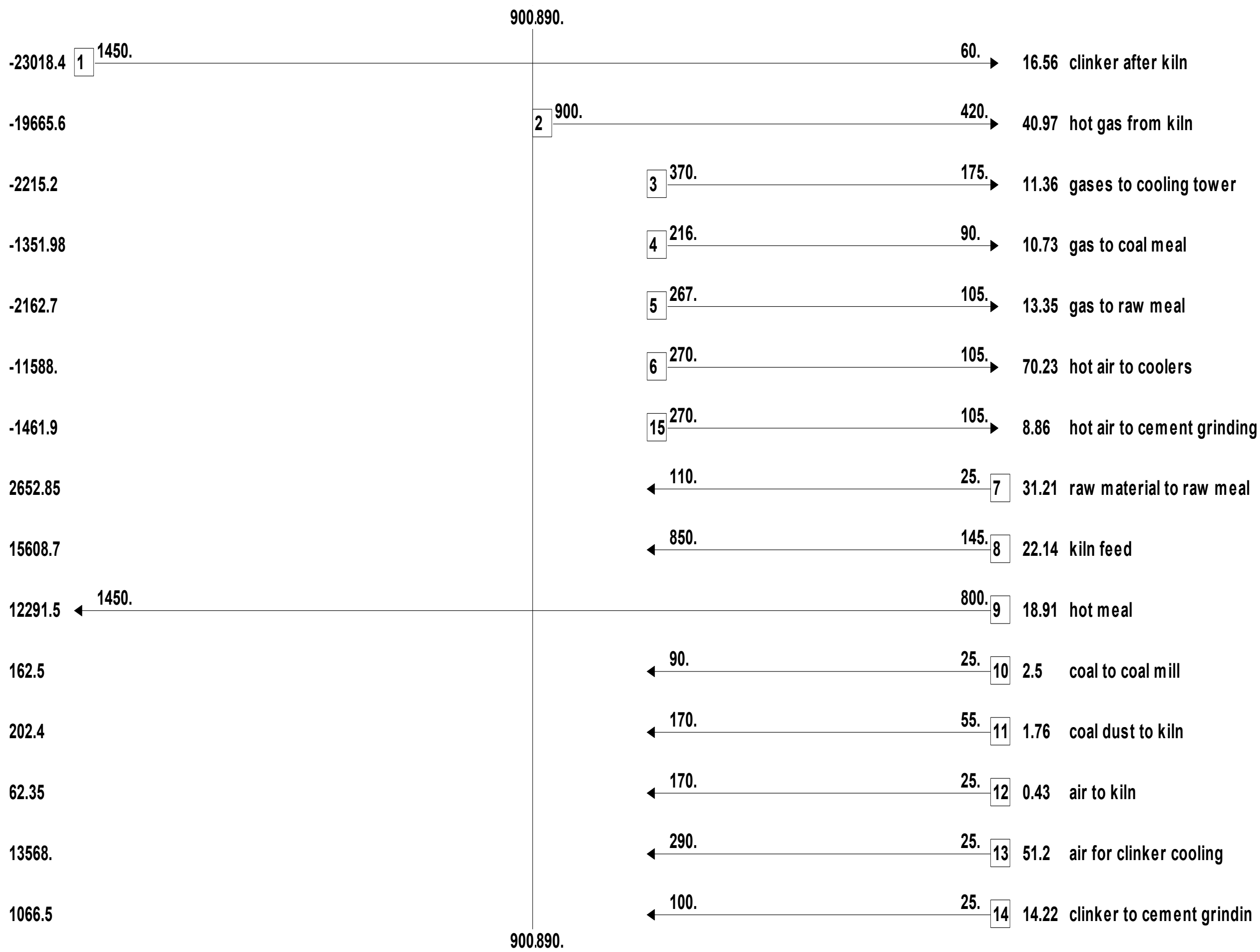


Figure 4.13 Grid Diagram

The grid diagram shows the flow of heat and the pinch Temperature for both hot and cold streams. This diagram also use develop a heat exchanger network for new cement factory according to the pinch principle.

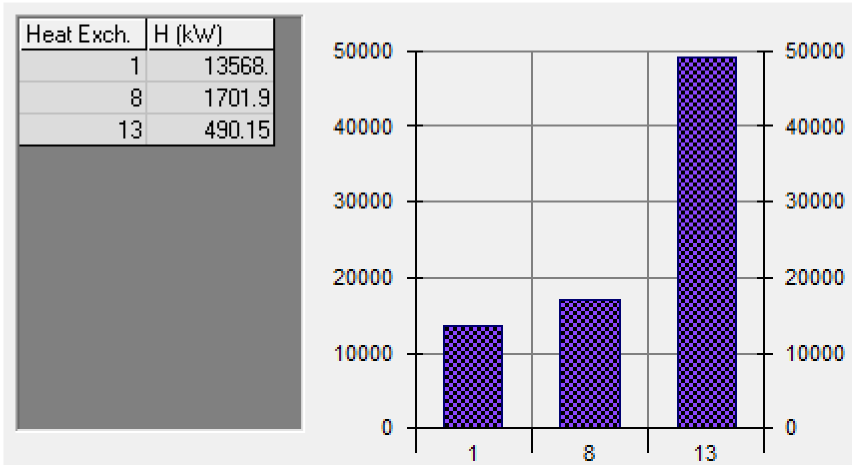


Figure 4.14 Heat Transfer across the pinch

For new cement process Heat Exchanger I have seen 15,760.05 KW of heat transfer across the pinch. When compare with the existing cement process it minimize the amount of heat that cross the pinch and violate the pinch principle. It indicates it require another modification to minimize the violation of pinch principle during the design of heat exchanger network for Ethio Cement PLC.

4.6. Estimation of Minimum Energy Cost and Heat Exchanger Network Total cost

The company use 100% South Africa coal Consumption Daily depend upon production. For 1000 ton of clinker production they use 200 ton of coal.

Utility cost for heating condition they use 20 $^{KWH}/_{Ton\ of\ Clinker}$

Cooler air power consumption is equal to 9 $^{KWH}/_{Ton\ of\ Clinker}$.

Total power per tone of clinker is equal to 102 KWH.

1 KWH = 0.56 Birr.

Similarly the South African coal cost equal to 7292.74 birr.

- Unit cost of heating utility (C_{UH})

$$\frac{7292.74\ birr}{20\ KWH} = 364.64\ \frac{birr}{KWH}$$

$$364.64\,\frac{birr}{KWH} \times 7200\,\frac{H}{yr} = 2{,}625{,}386.4\,\frac{birr}{KWyr}$$

- Unit cost of cooling utility (C_{UC})

$$\frac{57.12\ birr}{9\ KWH} = 6.35\ \frac{birr}{KWH}$$

$$6.35\ \frac{birr}{KWH} \times 7200\ \frac{H}{yr} = 45{,}696\ \frac{birr}{kwyr}$$

Now I can calculate Total Operating energy cost

i. Operating cost = $\sum_{u=1}^{2} Q_U \times C_U$

$$Q_U = Duty\ of\ Utility\ U, KW$$

$$C_U = Unit\ cost\ of\ Utility\ U, \frac{birr}{KW\ yr}$$

$$U = Total\ number\ of\ utilities$$

Operating Cost = ($1481.6\ KW \times 2{,}625{,}386.4\ \frac{birr}{KWyr}$) + ($17{,}330.53KW \times 45{,}696\ \frac{birr}{kwyr}$)

$$= 4{,}681{,}708{,}388\ birr/yr$$

ii. Capital Cost

For new heat exchanger network we can calculate the capital cost by using the following formula and Hint software to all stream and utilities.

$$C = a + bA^c$$

a, b and c are constant value according to the type of heat exchanger A area which required to construct the new Heat exchanger. Areas (A) are existing in Hint software which is the area required for my work 23,778.6M^2. A (CS-SS) exchanger, means the Heat exchanger is made from carbon steel and from stainless steel, and cost of such exchanger can be determined using the appropriate cost model. The Value of Cost data of an exchanger with various materials of construction are finding from difference chemical engineering books and reference. (31)

a = 30800

b = 1339

c = 0.81

I am selecting a Direct Contact Heat Exchanger for our company. It has own constant value or cost coefficient value based on Heat exchanger type.

Also we have other value

Pay-back period = 10 years

Interest Rate = 5

Lang factor = 1

$$Capital\ cost = 3{,}730{,}650\ {}^{birr}/_{yr}$$

From my Hint software similar to the existing cement factory the cost of new cement factory which is discuss below

$$Operating\ cost = 4{,}681{,}708{,}388\ birr/yr$$

$$Capital\ cost = 3{,}730{,}650{}^{birr}/_{yr}$$

$$Total\ cost = 4{,}685{,}439{,}038\ {}^{birr}/_{yr}$$

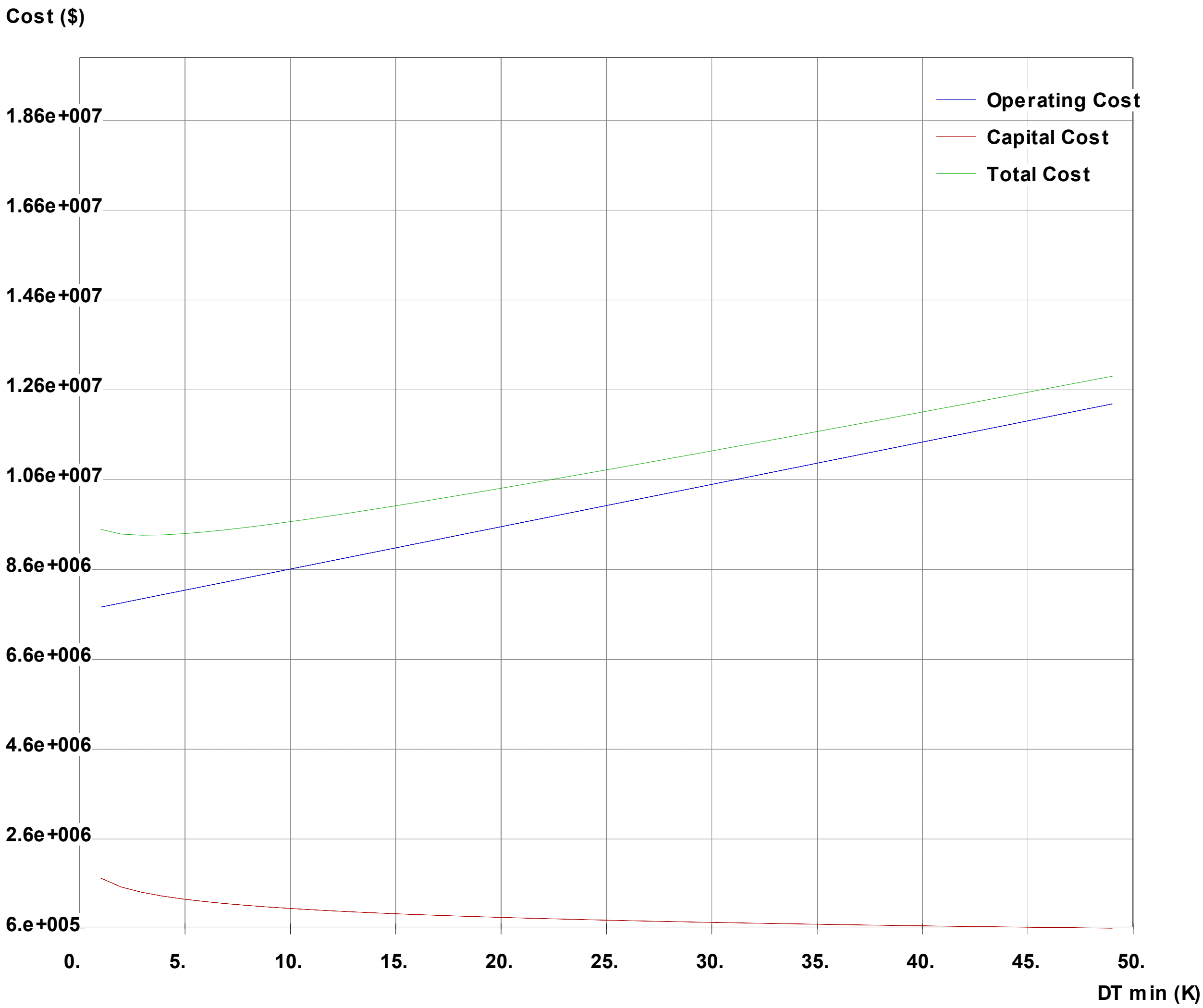
But the existing cement processes from the Hint software have the following cost value

$$Operating\ cost = 21{,}055{,}155{,}000{}^{birr}/_{yr}$$

$$Capital\ cost = 2{,}754{,}321.9{}^{birr}/_{yr}$$

$$Total\ cost = 21{,}057{,}909{,}321\ {}^{birr}/_{yr}$$

When comparing the two values the new cement process design have low total cost than the existing cement process it save almost.



Cost Target vs DT min

4.7. Table Algorithm for minimum utility calculations

Graphical constructions are not the most convenient means of determining energy needs. A numerical approach called "Problem Table Algorithm" PTA was developed by Linn Hoff & Flower (1978) as a means of determining the utility needs of a process and the location of the process Pinch. The PTA lends itself to hand calculations of the energy targets. For the problem data from Table 1.3 (Grid representation is shown in Fig. 1.8) streams are shown in a schematic representation with a vertical temperature scale. Temperature interval boundaries are superimposed which is $\Delta \mathbf{T_{min}}$ =10℃ .

The first steps are set up of shifted temperature interval from the stream supply and target temperature by subtracting $\frac{\Delta T_{min}}{2}$ (5℃) from hot stream and adding $\frac{\Delta T_{min}}{2}$ (5℃) to the cold stream.

Table 4.5 Shifted temperatures for the data from previous Table

No	Stream name	Type	T_s(℃)	T_t(℃)	T_s*	T_t*	C_p(kw/k)
1	Clinker after kiln	Hot	1450	60	1445	55	16.56
2	Hot gases from kiln	Hot	900	420	895	415	40.97
3	Gases to cooling tower	Hot	370	175	365	170	11.36
4	Gases to coal meal	Hot	216	90	211	85	10.73
5	Gas to raw meal	Hot	267	105	262	100	13.35
6	Hot air to coolers	Hot	270	105	265	100	70.23
7	Hot air to cement grinding	Hot	270	105	265	100	8.86
8	Raw material to raw meal	Cold	25	110	30	115	31.21
9	Kiln feed	Cold	145	850	150	855	22.14
10	Hot meal	Cold	800	1450	805	1455	18.91
11	Coal to coal mill	Cold	25	90	30	95	2.50
12	Coal dust to kiln	Cold	55	170	60	175	1.76
13	Air to kiln	Cold	25	170	30	175	0.43
14	Air for clinker cooling	Cold	25	290	30	295	51.20
15	Clinker to cement grinding	Cold	25	100	30	105	14.22

Second step in each shifted temperature interval calculate a simple energy balance from

$\Delta Hi = [\sum Cp\ cold - \sum Cp\ hot]\ \Delta Ti$

Where ΔHi = the heat balance for shifted temperature interval i

ΔTi = the temperature difference for shifted temperature interval

Third step cascade any surplus heat down the temperature scale from interval

Table 4.6 Temperature interval Energy Targeting Table

Shifted Temp.	Temp. Difference	(Σ Cph - Σ Cpc)	Δ Hi (kW)
1455-1445	10	-18.91	-189.1
1445-895	550	-2.35	-1293
895-855	40	38.62	1545
855-805	50	16.48	824
805-415	390	35.39	13802
415-365	50	-5.58	-279
365-295	70	6.10	404.6
295-265	30	-45.10	-1363
265-262	3	33.99	101
262-211	51	47.56	2398
211-175	36	58.29	2079
175-170	5	56.10	277.8
170-150	20	44.42	884
150-115	35	66.56	2322
115-105	10	35.35	351.3
105-100	5	21.13	104.6
100-95	5	18.63	-357.7
95-85	10	-74.03	-740.3
85-60	25	-84.76	-2119
60-55	5	-83	-415
55-30	25	-99.56	-2489

The last column in table 3 indicates whether an interval is in heat surplus or heat deficit. It would therefore be possible to produce a feasible network design based on the assumption that all “surplus” intervals rejected heat to cold utility and all “deficit” intervals took heat from hot utility. However, this would not be very sensible because it would involve rejecting and accepting heat at inappropriate temperatures.

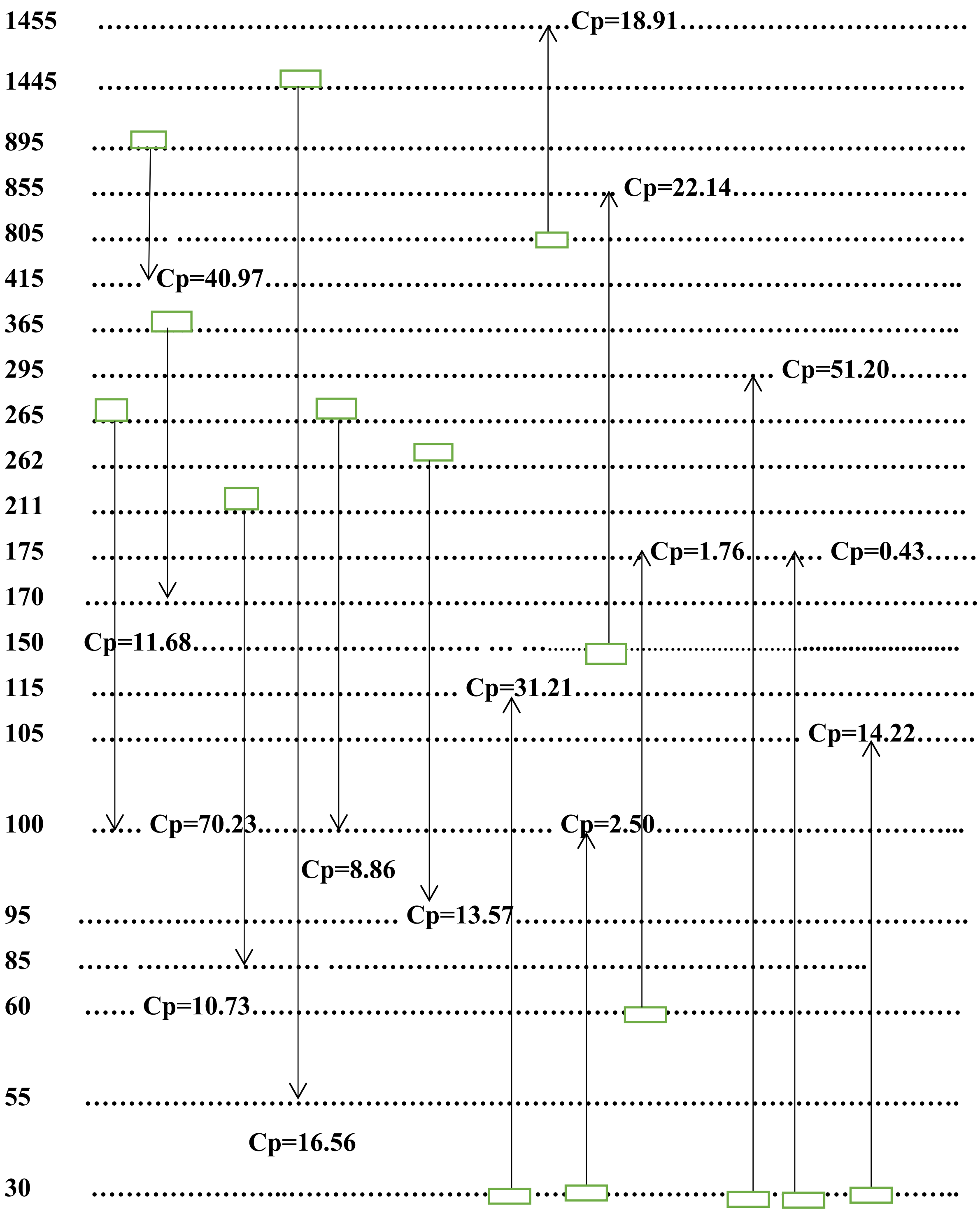


Figure 4.15 Grid Representation of hot and cold stream

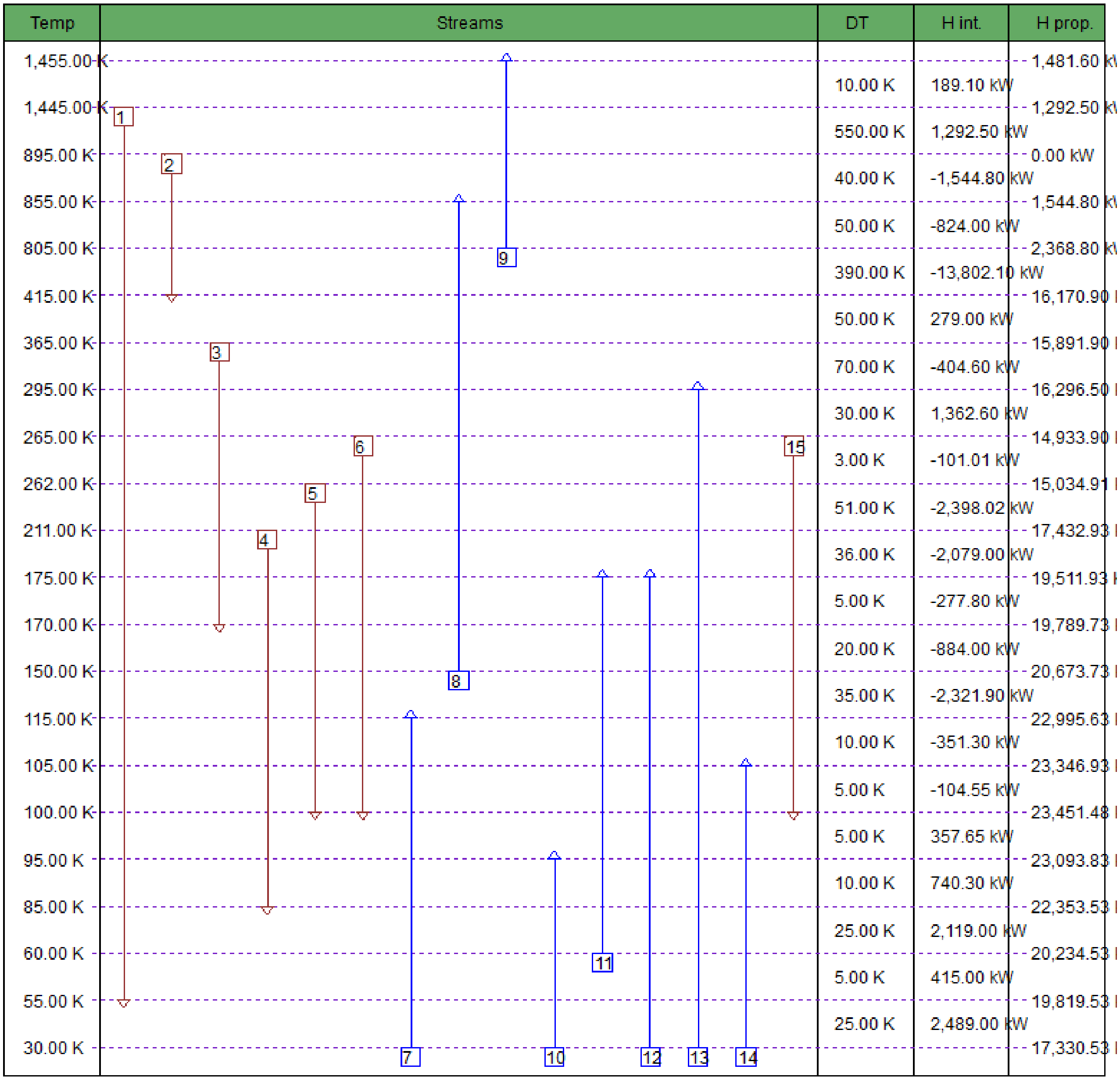


Figure 4.16 Energy target calculations with the Problem Table Algorithm for the problem of above Table with a minimum temperature difference of 20. By using Hint

Third step cascade any surplus heat down the temperature scale from interval to interval. This is cascaded in figure below. Hot streams in an interval are hot enough to supply a deficit in the cold streams in the next interval down. Figure 5.14 shows the cascade for the problem. First, assume no heat is supplied to the first interval from hot utility, Figure 5.14a. The first interval has surplus of 189.1 KW, which is cascaded to the next interval. This second interval has a deficit of -1293KW, which leaves the heat cascaded from this interval to be -1481.6KW. In the third interval, the process has a surplus of 1545KW, which leaves 63.2KW, to be cascaded to the next interval, and so on. Some of the heat flows in Figure 5.14a are negative, which is infeasible. Heat cannot be transferred up the temperature scale. To make the cascade feasible, sufficient heat must be added from hot utility to make the heat flows to be at least zero. The smallest amount of heat needed from hot utility is the largest negative heat flow from Figure 16.18a, that is 1481.6KW. In Figure 5.14b, 1481.6KW is added from hot utility to the first interval. This does not change the heat balance within each interval, but increases all of the heat flows between intervals by 1481.6kW, giving one heat flow of just zero at an interval temperature of 895℃. More than 1481.6KW could be added from hot utility to the first interval, but the objective is to find the minimum hot and cold utility, hence only the minimum is added. Thus from Figure 16.18b, ΔH_{min} = 1481.6KW and ΔC_{min} =17330.53KW. The point where the heat flow goes to zero at $T*$ = 895◦C corresponds to the pinch. Thus, the actual hot and cold stream pinch temperatures are 900◦C and 890◦C respectively.

	Infeasible Cascade		Feasible Cascade	
	▼	0	▼	1482
	-189.1		-189	
	▼	-189.1	▼	1293
	-1293		-1293	
PINCH	▼	-1481.6	▼	0
	1545		1545	
	▼	63.2	▼	1545
	824		824	
	▼	887.2	▼	2369
	13802		13802	
	▼	14689	▼	16171
	-279		-279	
	▼	14410	▼	15892
	404.6		404.6	
	▼	14815	▼	16297
	-1363		-1363	
	▼	13452	▼	14934
	101		101	
	▼	13553	▼	15035
	2398		2398	
	▼	15951	▼	17433
	2079		2079	
	▼	18030	▼	19512
	277.8		277.8	
	▼	18308	▼	19790
	884		884	
	▼	19192	▼	20674
	2322		2322	
	▼	21514	▼	22996
	351.3		351.3	
	▼	21865	▼	23347
	104.6		104.6	
	▼	21970	▼	23451
	-357.7		-358	
	▼	21612	▼	23094
	-740.3		-740	
	▼	20872	▼	22354
	-2119		-2119	
	▼	18753	▼	20235
	-415		-415	
	▼	18338	▼	19820
	-2489		-2489	
	▼	15849	▼	17331

Figure 4.17 The heat cascade principle -target prediction by "problem table" analysis a, infeasible and b, feasible

4.8. The Minimum Energy Heat Exchanger Network

Knowing the minimum heating and cooling energy requirement, we can proceed with the design of heat exchanger network. According to Linnhoff and Hindmarsh, the appropriate procedure is to design two sub networks of exchangers. One is above the pinch temperature and the other below the pinch. I continue with my case study on this entire section to illustrate the step-by step method of designing a minimum energy heat exchanger network. First Design above the pinch temperature which Determine the inlet or outlet temperatures for each stream. Match a hot stream with a cold stream. In my case, I can match each hot stream with the cold stream. The heat load remaining from the hot stream is determined by subtracting heat load of each of the cold stream from the hot stream. The temperature can also be determined after each matching. Design below the pinch the procedure for determining the minimum number of exchangers below the pinch temperature is analogous to that of above the pinch. The difference is that I allowed rejecting heat to a cold utility. The Grid Diagram shown in Fig 5.15 is the concept for a heat exchanger network of Cement production with maximized heat recovery 43,208.5 KW. When this recovered heat is converted in to money it saves 33,757.28ETB/hour or approximately 243,052,454.3 Ethiopian Birr per year.

When doing a retrofit of an existing heat exchanger network, it is not feasible to eliminate all pinch violations since it would become too costly. Instead the cost of the changes must be evaluated on basis of the savings they achieve. To develop new heat exchanger network for existing cement processes the main focus on eliminating hot utility below the pinch temperature and cold utility above the pinch Temperature.

Table 4.7 Summary for existing and new process

Utility	Current (existing)	New process
Heating	7,611.5 KW	1,481.6 KW
Cooling	23,460.4 KW	17,330.53 KW
Total	31,071.9 KW	18,812.16 KW

Heat transfer across the pinch for current process was 29,931.6 KW and for new one 15,760.05 KW.

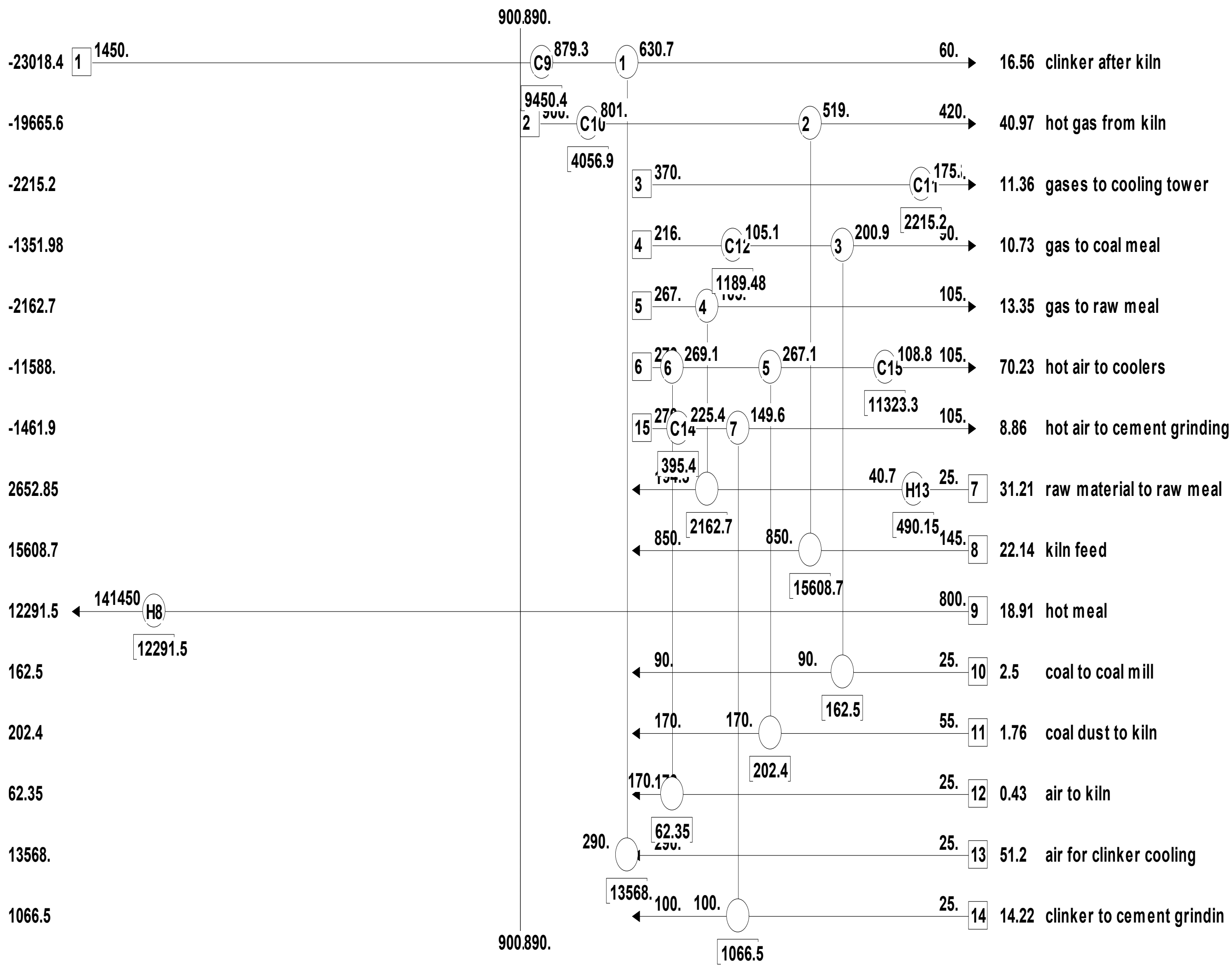


Figure 4.18 Grid Diagram of Retrofit Concept Design of Cement Factory

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Pinch Technology is known as a powerful tool in designing and optimization of processing systems. This technology is used in Cement production plant industries and causes appropriate application of temperature differences in the HENs and the cycle modification.

This project results showed considerable potential for energy targeting in cement production in case of Ethio Cement factory (ECF). The main target is maximizing the energy recovery thereby minimizing the external requirements for heating and cooling duties which minimizes the energy consumption. Generally for this work, the $\Delta T\text{min} = 10°C$ was selected as minimum temperature difference between hot and cold streams. The targets for hot and cold utility were 1,481.6 kW and 17,330.5 kW respectively and the maximum heat recovery obtained was 43,830.4 kW.

A retrofit of a heat exchanger network of Pinch technology in a cement factory (ECF) which works 24 Hours per day and 300 days per year can save approximately 243,052,454.3 Ethiopian Birr per year. Nevertheless, the improvement in energy efficiency can be achieved on the process design side by improving the existing process heat transfer equipment. Coverage of the site demands is the most promising means of further improvement via waste heat utilization and power generation by hot gases. The use of excess heat can provide a way to reduce the use of primary energy sources and contribute to global CO2 mitigation. The results of this project would be used for energy analysis of cement factories and provide a recommendation for decisions on efficient retrofits, new concept designs, and energy planning and strategies. Nevertheless, the technical side requires more discussion and investigation for successful implementation. Generally, the adaptation of the pinch point techniques to the cement production process, allows targeting innovative cement production, calculating the optimal configuration of fuel feed, and finally reducing thermal energy needs and carbon dioxide emissions. The constraints related to use/management of waste fuels are of primary importance, and need to be better evaluated in future work.

5.2. Recommendation

Under this I recommended the general process improvement to the Ethio Cement Factory that improved to adapting this technology. In addition to energy conservation studies, Pinch Technology enables Process Engineers to achieve the following general process improvements:

- ✓ Update or Modify Process Flow Diagram: Pinch quantifies the savings available by changing the process itself. It shows where process change reduces the overall energy target, not just local energy consummation.
- ✓ Conduct Process Simulation Studies: Pinch replace the old energy studies with information that can be easily updating using simulation. Such simulation studies can help avoid unnecessary operating costs by identifying energy savings.
- ✓ Set Practical targets: By taking in account practical constrains (difficult fluids, layout, safety, etc.), theoretical targets are modified so that they can be realistically achieved. Comparing practical with theoretical targets quantifies opportunities “lost” by constraints -a vital insight for long term development.
- ✓ De-bottlenecking: Pinch analysis when specifically applied to debottlenecking studies, can lead to the following benefits compared to a conventional revamp:
    - Reduction in operating costs.
    - Decrease specific energy demand giving more competitive production facilities.
- ✓ In order to come up with detailed network design, it is recommended that future research consider taking more time than one month to do plant survey. Maximum energy recovery can be realized if pinch analysis combined heat and water. For optimum results, water pinch analysis should be done alongside heat pinch analysis. This would help to obtain maximum recovery electrical and fossil energy used in the plant.
- ✓ I can apply the pinch technology to retrofit the existing heat exchanger network without introduce any new heat transfer area only by relocation of the heat exchanger and re-matching between the streams.

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APPENDICES

A. Material Balance

The mass balance equation can be expressed in the rate from as ΣMin = ΣMout. From our boundary line

$$\text{Raw material to Raw mill} + \text{Coal to Coal mill} + \text{primary Air} + \text{Air to cooler} = \text{Gas to cooler vent fan} + \text{clinker to cement mill} + \text{Hot gas to cement mill}$$

1. Raw Material to Raw mill

The raw material content of clinker contain Lime stone (MgCO_3, CaCO_3) and Clay (CaO, MgO, CaSi).

Raw material amount

Feed Content	Mass Flow Rate (Tph)	LOI %	Percentage mass Base
Limestone	97.7625	22.3	79.69
Clay	25.9875	3.3	21.31
Total	123.75	25.62	100

The production capacity of the plant are equal to 1800 Tpd which is equal to 75000kg/hr. i.e. 1 ton = 1000kg and 1 day = 24 hr.

$$\frac{123750\text{kg/hr}}{75000 kgClinker/hr} = 1.65 \text{ kg/kg Clinker}$$

2. Specific air consumption of cooler

The velocities of each fan were measured at fan inlet using the dynamic velocity anemometer. The recorded values were tabulated as shown on Table below.

Velocity determine by Pitot tube/ anemometer and flow rate can be calculated from general equation, Flow Rate = Velocity × Duct Area

From above descriptions Specific air consumption of cooler is equal to the mass flow rate of cooling air. The Company have seven fan with own volume flow rate and Suction Pressure.

Fan properties

Fan	Volume flow rate(M^3/min)	Suction Pressure (mbar)
1	210	1118
2	206	1080
3	230	1059
4	700	1119
5	260	1140
6	400	1065
7	360	1160

$$mass\ flow\ rate = \frac{Volumetric\ Flow\ Rate}{Specific\ Volume} = \frac{\sum_1^7 \overline{V}}{V}$$

First calculate the specific volume from ideal gas law

PV = nRT

Where P = pressure of gas

V= volume of gas

n = amount of substance of gas (number of moles)

T = Temperature of gas

R = ideal/ Universal gas constant

Specific Volume (V) is the amount of volume of gas per mass of gas

$$v = \frac{V}{m} = \frac{RT}{P} \qquad (\frac{M^3}{Kg})$$

P equal to average of seven cooler fan pressures

R = 287 N.m/Kg.K

T = Reference Temperature

P = 1105.86 mbar………………………… 1mbar = 100 pa = 100 N/M^2

1 atm = 1.013×10^5 Pa, or very nearly 1 atm = 100KPa

$$v = \frac{V}{m} = \frac{RT}{P} = \frac{(287 \cdot \frac{N.m}{Kg.K}) \times (298K)}{1105.86 \times 100 \frac{N}{m^2}} = 0.7734\ \frac{m^3}{Kg}$$

Now I can calculate the amount of volumetric flow rate of cooler fans by adding all recorded value, which is $\sum_1^7 \overline{V}$.

$$\sum_{1}^{7} \overline{V} = V_1 + V_2 + V_3 + V_4 + V_5 + V_6 + V_7 = 2366\, \frac{M^3}{min}$$

Volumetric flow rate = 141960 $\frac{M^3}{hr}$

Finally the mass flow rate of cooling air become volumetric flow rate divided by specific volume

$$\dot{M}_a = \frac{\sum_1^7 \overline{V}}{V} = \frac{141960\ \frac{M^3}{hr}}{0.7734\ \frac{m^3}{Kg}} = 183553.142\, \frac{Kg}{hr}$$

Mass flow rate of cooling air per unit of product or clinker equal to the following value

$$\text{Ma} = \frac{\dot{M}_a}{clinker\ production\ capacity} = \frac{183553.142\ \frac{Kg}{hr}}{75000 kgClinker/hr} = 2.45\, \frac{Kg}{kgClinker}$$

Or

Ma = density of air × flow rate per unit of clinker

$$\text{Flow rate per unit of clinker} = \frac{\text{Volumetric flow rate}}{clinker\ production\ capacity} = \frac{141960\ \frac{M^3}{hr}}{75000 kgClinker/hr} = 1.8928\, \frac{M^3}{kgClinker}$$

Density of air = 1.293 $\frac{kg}{M^3}$

$$\text{Ma} = 1.293\, \frac{kg}{M^3} \times 1.8928\, \frac{M^3}{kgClinker} = 2.45\, \frac{Kg}{kgClinker}$$

3. Mass of fuel (coal) is calculated as the following step

1 kg clinker = 780 Kcal

1 kg of South Africa coal = 7500 Kcal

? X kg of South Africa coal = 780 Kcal

1kg SAc × 780 Kcal = X kg SA × 7500 $\frac{Kcal}{kgClinker}$

$$\text{Mc} = 0.104\, \frac{Kg}{kgClinker}$$

4. Mass of Primary air

The company has two fans Fan 1 for primary air to kiln and Fan 2 for primary air to Calciner

i. Fan 1:- To Kiln

Flow Rate Capacity = 70 $\frac{M^3}{min}$

Suction Pressure = 195 mbar

Atmospheric Temperature = 25 o_C

ii. Fan 2:- To Calciner

Flow Rate Capacity = 60 $\frac{M^3}{min}$

Suction Pressure = 170 mbar

Atmospheric Temperature = 25 o_C

I. Mass of Primary Air to kiln = $\frac{Volume\ flow\ rate\ of\ Pa\ funs}{Specific\ Volume\ of\ air} = \frac{\dot{V}}{v}$

V = RT/ P

$$V = \frac{(287\ .\frac{N.m}{Kg.K}) \times (298K)}{19500\ \frac{N}{m^2}}$$

$$V = 4.386\ \frac{m^3}{Kg}$$

$$Mpk = \frac{\dot{V}}{v} = \frac{70\ \frac{\dot{M}^3}{min}}{4.386\ \frac{m^3}{Kg}} = 957.6\ \frac{Kg}{hr}$$

Mass of primary air to kiln per unit of clinker = $\frac{Mpk}{Clinker\ production} = \frac{95.76\ \frac{Kg}{hr}}{75000kgClinker/hr}$

$$= 0.01277\ \frac{Kg}{kgClinker}$$

II. Mass of Primary Air to calciner = $\frac{Volume\ flow\ rate\ of\ Pa\ funs}{Specific\ Volume\ of\ air} = \frac{\dot{V}}{v}$

V = RT/ P

$$V = \frac{(287\ .\frac{N.m}{Kg.K}) \times (298K)}{17000\ \frac{N}{m^2}}$$

$$V = 5.031\ \frac{m^3}{Kg}$$

$$Mpc = \frac{\dot{V}}{v} = \frac{60\ \frac{\dot{M}^3}{min}}{5.031\ \frac{m^3}{Kg}} = 715.6\ \frac{Kg}{hr}$$

Mass of primary air to kiln per unit of clinker = $\frac{Mpk}{Clinker\ production} = \frac{71.56\ \frac{Kg}{hr}}{75000kgClinker/hr}$

$$= 0.00954\ \frac{Kg}{kgClinker}$$

Mp= mass of primary air to kiln + mass of primary air to calciner

= 0.01277 + 0.00954

$= 0.0223\ \frac{Kg}{kgClinker}$

5. Mass of Exhaust gas from cooler ESP

First calculate volumetric flow, stand. Volumetric flow and mass flow rate depending on the following formulas:-

$$Qv = V \times A$$

$$V = \sqrt{\frac{(Dp \times 2 \times g)}{Gd\ at\ Tr}} \times K$$

$$\text{Gd at Tr} = \frac{\text{Pb} - \text{Ps}}{\text{Pt}} \times \frac{273}{273 + \text{Tb}} \times \text{Gd}$$

$$M = V \times Gd$$

Where Qv= volumetric flow rate

V=gas velocity

A=area of duct

DP=measured dynamic pressure

Gd =gas density at Tr point

Pb=barometric pressure

Ps=static pressure

Pt=atmospheric pressure

d= air density

But I have volume flow rate per unit of product (clinker) and density of gas from CCR (central control room)

V = $0.4\ \frac{M^3}{kg\ clinker}$ and d = $1.293\ \frac{kg}{M^3}$

Mes= $0.4\ \frac{M^3}{kg\ clinker} \times 1.293\ \frac{kg}{M^3}$

Mes = 0.5172 $\frac{kg}{kg\ clinker}$

6. Mass for preheater exhaust gas

Exhaust Gas Properties

Assume Exhaust Gas	%	Molecular weight
O_2	97.70	32
CO	2.3075	28
NO_X	0.0098	72

At standard temperature and pressure 1Kmol of gas = 22.414 M^3 volume occupied R= 8314.5 $\frac{J}{Kmol.\ K}$

$$\rho_{STP} = \frac{m}{v} = \frac{(O_2\% \ \times Mw) + (CO\% \ \times Mw) + (NO_X\% \ \times Mw\ )}{22.4\ \times 100}$$

$$\rho_{STP} = \frac{m}{v} = \frac{(97.7\% \times 32) + (2.3075\% \ \times 28) + (0.0098\% \times 72\ )}{22.4\ \times 100}$$

$$\rho_{STP} = \frac{m}{v} = 0.01425\ kg/M^3$$

Volume flow rate from CCR 95000 M^3/min

Mass flow rate of preheater exhaust gas = V $\times$ ρ_{STP}

Mpe = 81225 kg/ hr

Per unit of product become

Mpe = $\frac{81225\ kg/hr}{75000\ kg\ clinker/\ hr} = 1.083$ kg/kg clinker

7. Mass of clinker

Which value is our bases = 1kg/ kg clinker

8. Mass of Dust

From company 99% of the feed is going to the system the rest is returned as dust through preheater atmosphere.

Md = $\frac{12375 kg/hr}{75000 kg\ clinker/hr}$ = 0.165 kg/ kg clinker

Or we have raw meal feed which are 1.65 kg/kg clinker and 0.1 Dust content of exit gas

Md = 1.65 kg/kg clinker × 0.1

Md = 0.165 kg/kg clinker

9. Mass of coal conveying air

Mcca = density of air × flow rate

= 1.23 $kg/M^3 \times$ 0.05122 $\frac{M^3}{kg\ clinker}$

= 0.063 $\frac{kg}{kg\ clinker}$

10. Mass of kiln feed moisture

Mfm = 0.02 $\frac{kg}{kg\ clinker}$

11. Excess hot air out with clinker

Meha= 1.02 $\frac{kg}{kg\ clinker}$

12. Mass of hot gas to cooler

M= 250751.24 $\frac{kg}{hr}$

13. Uncounted loss

ul= 0.3981 $\frac{kg}{kg\ clinker}$

B. Specific Heat Capacity Calculation

Specific heat capacity of air and clinker at different temperatures can be calculated using the following correlation formula:-

$$Cp = A + (B \times T \times 10^{-6}) + (C \times T^2 \times 10^{-9})$$

The data of temperature specific heat

Material	A	B	C
Air	0.237	23	0
Clinker	0.186	54	0
Coal	0.262	390	0
Raw meal	0.206	101	-37
N2	0.244	22	0
O2	0.218	23	0
Co2	0.196	118	-43

Cp of hot clinker = $0.186 + (54 \times 1450°C \times 10^{-6}) + (0 \times 1450^{2}°C \times 10^{-9})$

= 0.2643kcal/kg K

Cp of cooled clinker = $0.186 + (54 \times 100°C \times 10^{-6}) + (0 \times 1250^{2}°C \times 10^{-9})$

= 0.19kcal/kg K

Cp of exit air = $0.237 + (23 \times 320°C \times 10^{-6}) + (0 \times 320^{2}°C \times 10^{-9})$

= 0.244kcal/kg K

Cp of coal = $0.262 + (390 \times 38°C \times 10^{-6}) + (0 \times 38^{2}°C \times 10^{-9})$

= 0.276kcal/kg K

Cp of coal flow air = $0.262 + (23 \times 75°C \times 10^{-6}) + (0 \times 75^{2}°C \times 10^{-9})$

= 0.263kcal/kg K

Cp of kiln fed (raw meal) =$0.206 + (101 \times 110°C \times 10^{-6}) + (-37 \times 110^{2}°C \times 10^{-9})$

= 0.217kcal/kg K

Cp of primary air = Cp of O_2 × 21% + Cp of N_2 × 78%+ Cp of CO_2 × 1%

= $0.22 \times 0.21 + 0.225 \times 0.78 + 0.19 \times 0.01$

= 0.2236kcal/kg K

C. Energy Balance

Data for energy balance

Mass of Coal	0.104 kg/kg cl

Raw material to raw meal	1.65Kg/Kgcl
Mass of primary air	0.0223 Kg/Kgcl
Mass of preheater exhaust gas	1.083 Kg/Kgcl
Mass of clinker	1Kg/Kgcl
Mass of dust	0.165 Kg/Kgcl
Mass of cooler air	2.45 Kg/Kgcl
Mass of exit gas from cooler	0.5172 Kg/Kgcl
Mass of coal flow air	0.063 Kg/Kgcl
Coal moisture	0.02 × (0.11 kg/kg cl) = 0.0022 Kg/Kgcl
Kiln fed moisture	0.02 Kg/Kgcl
Base temperature	28 ℃
Raw material to raw meal temperature	110 ℃
Hot clinker temperature	1250 ℃
Fresh air from Fan temperature	31 ℃
Exhaust air temperature	320 ℃
Dust in ph gas temperature	340 ℃
Coal temperature	38 ℃
Coal flow temperature	75 ℃
Cp of hot clinker	0.264 k cal/Kg K
Cp of raw material to raw meal	0.217 k cal/Kg K
Cp of cooled clinker	0.19 k cal/Kg K
Cp of primary air	0.224 k cal/Kg K
Cp of exit air	0.244 k cal/Kg K
Cp of fresh air	0.24 k cal/Kg K
Cp of coal	0.276 k cal/Kg K
Cp of coal flow air	0.263 k cal/Kg K
Cp of false air	0.24 k cal/Kg K
Cp of dust in ph gas	0.15 k cal/Kg K
Cp of coal moisture	1 Kg/Kg cl K
Cp of kiln fed moisture	1Kg/Kg cl K

Surface area of the kiln	498.4 M^2
Calorific value	7500Kcal/Kg cl

Heat input to the system

1. Heat of combustion (Q_c)
2. Sensible heat of coal (Q_{cs})
3. Sensible heat of primary air (Q_{ps})
4. Sensible heat of cooler air (Q_{ca})
5. Sensible heat of coal air (Q_{coal})
6. Heat of raw meal (Q_{rm})

Heat out put from the system

1. Heat of reaction (Q_r)
2. Heat loss due to exit gas through preheater
3. Heat loss due to exit gas through ESP(Q_e)
4. Heat loss due to water evaporation(Q_{wv})
5. Heat loss through clinker
6. Heat loss due to radiation and convection

4.3.1. Heat Input

Base on 1 kg of clinker

1. Heat from the combustion of Coal

$$Q_c = M_c \times H_c$$

Where:- $M_c = mass\ of\ coal$

$H_c = Caloric\ value\ of\ coal$

$$Q_c = M_c \times H_c = 0.104 \frac{kg}{kg\ clinker} \times 7500 \frac{Kcal}{kg\ coal}$$

$$Q_c = 780 \frac{Kcal}{kg\ clinker}$$

2. Sensible heat from the coal

$$Q_{cs} = M_c \times C_c \times \Delta T_c$$

Where:- $M_c = mass\ of\ coal$

$C_c =$ specific heat capacity of coal

$\Delta T_c = Coal\ Temperature\ (T_C)\ minus\ reference\ Temperature\ (T_r)$

$$Q_{cs} = 0.104 \frac{kg}{kg\ clinker} \times 0.276 \frac{Kcal}{kg\ K} \times (38 - 28)K$$

$$Q_{cs} = 0.287 \frac{Kcal}{kg\ clinker}$$

3. Sensible Heat of Raw material to raw meal

$$Q_{rm} = M_{rm} \times C_f \times \Delta T_f$$

Where:- $M_{rm} = mass\ of\ Raw\ meal\ feed$

$C_f =$ specific heat capacity feed

$\Delta T_f = feed\ Temperature\ (T_f)\ minus\ reference\ Temperature\ (T_r)$

$$Q_{rm} = 1.65\,\frac{kg}{kg\ clinker} \times 0.217\,\frac{Kcal}{kg\ K} \times (110 - 38)\ K$$

$Q_{rm} = 25.78\frac{Kcal}{kg\ clinker}$

4. Sensible heat from cooler air

$$Q_{ca} = M_{ca} \times C_a \times \Delta T_{ca}$$

Where:- $M_{ca} = mass\ of\ cooler\ air$

$C_a =$ specific heat capacity of air

$\Delta T_{ca} = cooler\ air\ Temperature\ (T_{ca})\ minus\ reference\ Temperature\ (T_r)$

$$Q_{ca} = 2.45\,\frac{kg}{kg\ clinker} \times 0.24\,\frac{Kcal}{kg\ K} \times (31 - 28)K$$

$$Q_{ca} = 1.764\,\frac{Kcal}{kg\ clinker}$$

5. Sensible heat from primary air

$$Q_{Pa} = M_{Pa} \times C_{pa} \times \Delta T_{pa}$$

Where:- $M_{Pa} = mass\ of\ primary\ air$

$C_{Pa} =$ specific heat capacity of primary air

$\Delta T_{Pa} = primary\ air\ Temperature\ (T_{pa}) - reference\ Temperature\ (T_r)$

$$Q_{pa} = 0.0223\,\frac{kg}{kg\ clinker} \times 0.244\,\frac{Kcal}{kg\ K} \times (31 - 28)K$$

$$Q_{pa} = 0.0163\,\frac{Kcal}{kg\ clinker}$$

6. Sensible heat from coal conveying air

$$Q_{cca} = M_{cca} \times C_{cca} \times \Delta T_{cca}$$

Where:- $M_{cca} = mass\ of\ coal\ conveying\ air$

$C_{cca} =$ specific heat capacity of coal conveying air

$\Delta T_{cca} = coal\ conveying\ air\ Temperature\ (T_{cca})$

$- reference\ Temperature\ (T_r)$

$$Q_{cca} = 0.063\,\frac{kg}{kg\ clinker} \times 0.263\,\frac{Kcal}{kg\ K} \times (75 - 28)K$$

$$Q_{rm} = 0.779\,\frac{Kcal}{kg\ clinker}$$

7. Sensible heat from the moisture in the feed

$$Q_{mf} = M_{mf} \times C_{mf} \times\ \Delta T_{mf}$$

Where:- $M_{mf} = mass\ of\ moisture\ in\ the\ feed$

$C_{mf} =$ specific heat capacity of moisture in the feed

$$\Delta T_{mf} = (320 - 28)\ k$$

$$Q_{mf} = 0.02\,\frac{kg}{kg\ clinker} \times 1\,\frac{Kcal}{kg\ K} \times (320 - 28)\ k$$

$$Q_{mf} = 5.84\,\frac{Kcal}{kg\ clinker}$$

$Total =\ Q_c + Q_{cs} + Q_{rm} + Q_{ca} + Q_{pa} + Q_{cca} + Q_{mf}$

$$=\ 780\ \frac{Kcal}{kg\ clinker} + 0.287\,\frac{Kcal}{kg\ clinker} + 25.78\,\frac{Kcal}{kg\ clinker} + 1.764\,\frac{Kcal}{kg\ clinker} + 0.0163$$

$$\frac{Kcal}{kg\ clinker} + 0.779\,\frac{Kcal}{kg\ clinker} + 5.84\,\frac{Kcal}{kg\ clinker}$$

$= 814.466\,\frac{Kcal}{kg\ clinker}$

5.2.2. Heat Output

1. Heat of clinker reaction

For this calculation I have one equation which is called H.Zur Strassen empirical equation.

$$Q_{cr} = 4.11H_{Al} + 6.48H_{Mg} + 7.646H_{Ca} - 5.116H_{Si} - 0.59H_{Fe}$$

Chemical Components Properties

Chemical Components	Percentage (%)	Heat of formation ($\frac{Kcal}{kg\ clinker}$)	Heat for each (Q)
CaO	63.3	762	482.3
Al_2O_3	5.27	412	21.7
MgO	2.52	645	16.3
SiO_2	20.98	510	107.0
FeO_3	3.57	60	2.1

$$Q_{cr} = \sum Q = 482.3 + 21.7 + 16.3 - 107.0 - 2.1 = 411.2\,\frac{Kcal}{kg\ clinker}$$

2. Heat loss through the clinker at cooler outlet

$$Q_{cco} = M_{cco} \times C_{cco} \times \Delta T_{cco}$$

Where:- $M_{cco} = mass\ of\ clinker$

$C_{cco} =$ specific heat capacity of clinker at cooler outlet

$\Delta T_{cco} = clinker\ Temperature\ at\ cooler\ outle\ -\ reference\ Temperature\ (T_r)$

$$Q_{cco} = 1\,\frac{kg}{kg\ clinker} \times 0.194\,\frac{Kcal}{kg\ K} \times (148 - 28)K$$

$$Q_{cco} = 23.28\,\frac{Kcal}{kg\ clinker}$$

3. Heat loss through the dust in the exhaust gas

$$Q_d = M_d \times C_d \times \Delta T_d$$

Where:- $M_d = mass\ of\ dust$

$C_d =$ specific heat capacity of dust

$\Delta T_d = dust\ Temperature\ in\ exhaust\ gas\ -\ reference\ Temperature\ (T_r)$

$$Q_{cco} = 0.165\,\frac{kg}{kg\ clinker} \times 0.209\,\frac{Kcal}{kg\ K} \times (430 - 28)K$$

$$Q_{cco} = 13.863\,\frac{Kcal}{kg\ clinker}$$

4. Heat loss through evaporation of moisture

i. For kiln fed moisture removal

$Q_{kfm} = M_{kfm} \times\ Cpevaporation$ @ 320ºC

=0.02 × 373.7

= 7.474Kcal/Kg clinker

ii. For coal moisture removal

$Qcm = Mcm \times Cpevaporation$ @ 38ºC

= 0.02 × 0.104 × 410 Kcal/Kg cl

= 0.8528 Kcal/Kg clinker

5. Heat loss from exhaust gases

5.1. From preheater exist

$$Q_{pe} = M_{pe} \times C_{pe} \times\ \Delta T_{pe}$$

Where:- $M_{pe} = mass\ of\ exhuast\ gases$

$C_{pe} =$ specific heat capacity of preheater exist gas

$\Delta T_{pe} =\ Temperature\ of\ exhaust\ gas\ -\ reference\ Temperature\ (T_r)$

$$Q_{pe} = 1.083\,\frac{kg}{kg\ clinker} \times 0.2551\,\frac{Kcal}{kg\ K} \times (380 - 100)K$$

$$Q_{cco} = 77.356\,\frac{Kcal}{kg\ clinker}$$

5.2. From cooler outlet gases

$$Q_{cog} = M_{cog} \times C_{cog} \times\ \Delta T_c$$

Where:- $M_{cog} = mass\ of\ cooler\ outlet\ gases$

$C_{cog} =$ specific heat capacity of gases

$\Delta T_c =\ \ cooler\ outlet\ gas\ Temperature\ -\ reference\ Temperature\ (T_r)$

$$Q_{cog} = 0.5172\,\frac{kg}{kg\ clinker} \times 0.252\,\frac{Kcal}{kg\ K} \times (350 - 28)K$$

$$Q_{cco} = 41.97\,\frac{Kcal}{kg\ clinker}$$

6. Uncounted losses

$$Q_{cco} = 238.47 \frac{Kcal}{kg\ clinker}$$

C. Questions and data collection format

1. How much amount of Energy does Ethio cement consumed per years?

i. Electricity ____

ii. Natural gas ____

iii. Fuel ____

2. What is Average power consumption of national cement Share Company in MW?

2.1. For Raw Material preparation____

2.2. For pyro-processing ____

2.3. Finishing (Ball milling)____

3. What Methods does ECPLC Used for Energy auditing and for energy recovering system?

____

____

4. At what cost does ECPLC buy 1kw of energy from ELPA?

____

5. For how many days the fabric stops for maintenance or other reasons?

____

6. Are the existing processes as energy efficiency as they should be?

____

7. What changes can be made to increase the energy efficiency with out incurring any cost?

____

8. How much the Raw material to raw mill and raw meal silo capacity?

____

____

9. Kiln operated Capacity (Upper and lower limit)

____

10. Clinker produced capacity inside Kiln

____

11. Consumption of oil, coal and cooling water

____

12. The total heat load discharged to atmosphere from air coolers? In case of raw mill operation and raw mill not working

____

____

13. Flow rate of cooling tower

____

14. How many fans used to introduce air into cooler?

____

15. Kiln feed rate, Kiln fuel feed rate and Precalciner fuel feed rate

____

16. Clinker production rate per hour

____

23. Kiln speed, diameter and length

____

24. Volume flow rate of different gas and air

____

25. Actual volume of air

____

D. **Process streams that are selected for analysis**

Stream data of cement production with raw meal operation table

No	Stream name	Type	T_s(°C)	T_t(°C)	C_p(kw/k)	$\Delta H(kw)$
1	Clinker after kiln	Hot	1450	60		
2	Hot gases from kiln	Hot	900	420		
3	Gases to cooling tower	Hot	370	175		
4	Gases to coal meal	Hot	216	90		
5	Gas to raw meal	Hot	267	105		

6	Hot air to coolers	Hot	270	105		
7	Hot air to cement grinding	Hot	270	105		
8	Raw material to raw meal	Cold	25	110		
9	Kiln feed	Cold	145	850		
10	Hot meal	Cold	800	1450		
11	Coal to coal mill	Cold	25	90		
12	Coal dust to kiln	Cold	55	170		
13	Air to kiln	Cold	25	170		
14	Air for clinker cooling	Cold	25	290		
15	Clinker to cement grinding	Cold	25	100		

E. Information about Raw material, Kiln and Preheater

NO	DESCRPTION	VALUE	UNIT
1	CLINKER PRODUCTION	75	TPH
2	CONVERSION FACTOR DUST TO HOMOGINIZE SILO	1.65	
3	CONVERSION FACTOR DUST TO PREHEATER	1.53	
4	HEAT VALUE OF IMPORTED COAL	7500	KCAL/KG
5	HEAT VALUE OF JIMMA COAL	-	KCAL/KG
6	AMBIENT TEMPRATURE	25	°C
7	RAW MEAL FEED	123.75	TPH
8	PERCENTAGE OF IMPORTED COAL KILN OUTLET	90	%

9	PERCENTAGE OF IMPORTED COAL PRECALCINER	65	%
10	FUEL USED KILN OUT LET	4	T/H
11	FUEL USED CALCINER	6	T/H
12	VOLUMETRIC FLOW RATE OF PRIMERY AIR	7800	M3/HR
13	DENSITY OF AIR	1.23	kg/m3
14	SPECIFIC HEAT CAPACITY OF AIR	0.241	kCal/kgoC
15	TEMPRATURE OF PRIMERY AIR	25	°C
16	TOTAL COOLING FAN FLOW RATE	141,960	M3/HR
17	TEMPRATURE OF COOLING AIR	25	°C
18	SPECIFIC HEAT CAPACITY OF RAW MEAL	0.217	Kcal/kg-K
19	INLET TEMPRATURE OF RAW MEAL	110	°C
20	REFERENCE TEMPRATURE	20	°C
21	MOITURE CONTENT OF FEED	1	%
22	KILN SIZE	3.2*48	M
23	AVERAGE SURFACE TEMPRATURE OF KILN	270	°C
24	MASS OF COOLER EXIST GAS	30000	M3/HR
25	DUST CONTENT OF COOLER EXIT	0.1	kg/Nm3
26	SPECIFIC HEAT CAPACITY OF WATER	0.44	kCAL/KG.K
27	HEAT OF EVAPORATION OF WATER	540	Kcal/kg
28	SPECIFIC HEAT CAPACITY OF CLINKER	0.19	kCAL/KG.K
29	OUTLET TEMPRATURE OF CLINKER	70	°C
30	AMOUNT OF GAS OUTLET FROM CYCLONE 1	55,000	M3/HR
31	DUST CONTENT OF PREHEATER EXIT	100	g/Nm3
32	TEMPRATURE OF GAS OUTLET FROM CYCLONE 2	350	°C
33	TEMPRATURE OF COAL FEED	25	°C
34	SPECIFIC HEAT CAPACITY OF COAL	0.276	Kcal/kg-K

F. Vital pictures during the research work

Figure 1. Infrared thermo meter

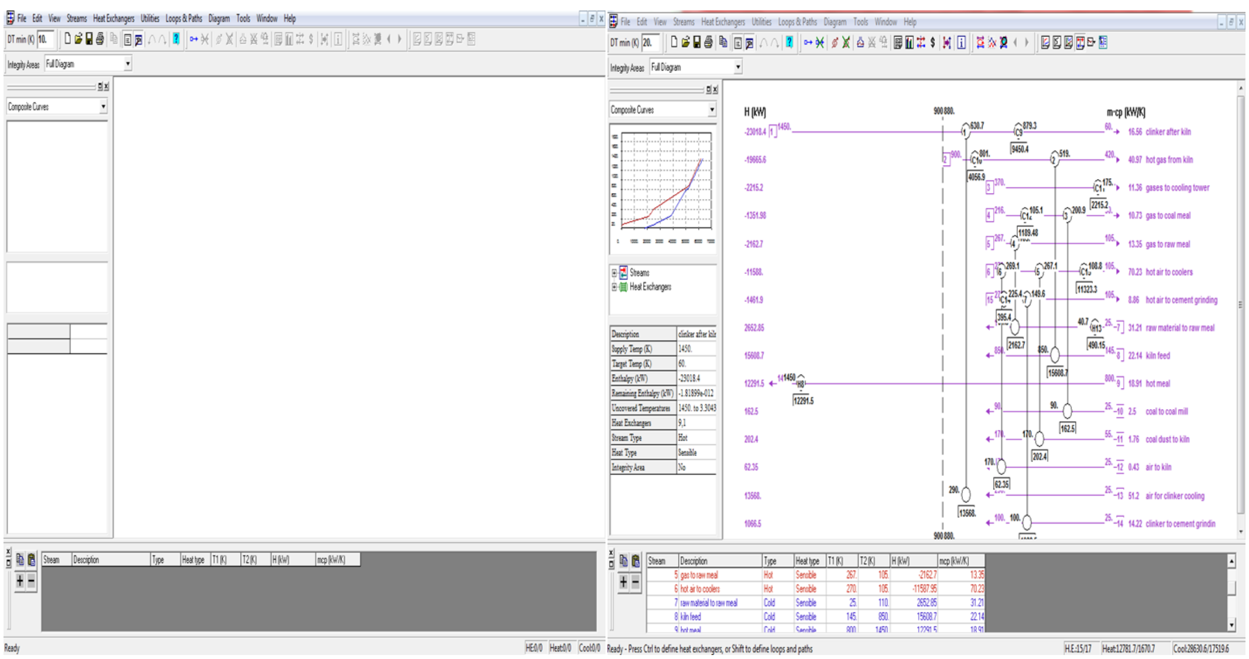

Figure 2. Hint Software partial display view

Figure 3. partial view of the control central room (CCR)

Figure 4. Site survey and Ethio Cement PLC view

Figure 5. Data collection and process identification period