Clinker Cooler in Cement Factory

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ABSTRACT

Cement is adhesive substance and mixed with water to attach jointly bricks, crushed sand, aggregates, sands, etc in building of infrastructures. Limestone, clay, basalt, sandstone, gypsum, and other raw materials are utilized in the manufacture of cements which gives clinker after the burning process in the kiln at elevated temperatures. A clinker cooler lowers the clinker's temperature then grinds it to the medium size with in arrange of 10-mm to 25-mm nodules and recovers energy from the hot clinker's sensible heat by heating the cooled air. The most effective and economic average diameter of clinker particles is 0.02 m. There are several methods are exist to improve and optimize the working principles of grate clinker cooler. The most feasible and useful methods are by using heat recovery from the exhaust gases, increasing mass of cooling air by adding number of fans, increasing or decreasing grate speed based on the amount of clinker mass flow rate, changing mass flow rate of clinker, increasing residual time, changing operating conditions and design parameters such as length of bed and height of bed. The efficiency of a cooling system can be improved by raising the mass flow rate of cooling air energy and recovery energy. Recovery energy efficiencies can be enhanced by increasing cooling temperature energy, exergy, and recovery efficiencies. Energy efficiency and energy recovery efficiencies improve as grate speed increases. The cooling system's energy and exergy recovery efficiency were found to be improved by using heat recovery from exhaust air.

Key words

Cement, Clinker, Cement Plant, Clinker cooler

1. Introduction

Cement is adhesive substance which is a powdered substance and the primary and essential materials make plastic when mixed with water, which is used in soft and pasty condition to attach jointly bricks, crushed sand, aggregates, sands, etc in building of infrastructures and buildings to binding and paste materials together.

Based on the input raw materials used in the manufacturing process, cement standards will vary from country to country. Many Ethiopian cement plants manufacture Ordinary Portland Cement (OPC) or CEMM-I-42.5 grade, which contains 95% clinker and 5% gypsum, and Portland Pozzolana Cement (PPC) or CEMM-II-32.5 grade, which contains 67% clinker, 28% pumice, and 5% gypsum (Cement, n.d.). These standards will meet the requirements of Ethiopian National Standard EN 1177-1: 2005 or European Standard EN-197.

Limestone, clay, basalt, sandstone, gypsum, and other raw materials are utilized in the manufacture of cements. All of these raw materials will be crushed separately in the crushers and transferred to separate storage areas at the mother facility. After all of the essential ingredients have been apportioned and crushed to a fine size, it will be homogenized in homogenization silos (Tsamatsoulis, 2021). The homogenized raw meal will then be carried to a preheater to complete the drying process and facilitate the burning process in the rotary kiln at roughly 1500 degrees Celsius to react and generate clinker

Because the kiln unit's burning process takes place at high temperatures, the cement manufacturing process is linked to higher energy usage. The standard deviation for each raw material and the energy consumption per unit of production are used to determine the value of clinker production quality

Clinker nodules are formed at the kiln's hottest element, which has a temperature of around 1280°C. In the clinker cooler located on the rotary kiln's end tail, the hot clinkers must be cooled at a low temperature of roughly 100 OC. If at all feasible, the clinker is discharged from the front end of the kiln into the cooler in the shape of 10-mm to 25-mm nodules. To provide a phase composition that provides acceptable cementation characteristics, quick cooling of the clinker is necessary. It's also crucial that the heat exchange between the clinker and the air is efficient in order to offer optimal cooling while also optimizing heat recovery, which maximizes heat recovery to secondary and tertiary air, as well as the process requirements. All of these activities must be completed effectively and concurrently by the contemporary chiller.

In cement manufacturing, a grate clinker cooler system is employed, and the clinker burning system comprises of a clinker cooler, rotary kiln, and suspension pre-heater. A clinker cooler lowers the clinker's temperature and grinds and recovers energy from the hot clinker's sensible heat by heating the cooled air. The heated clinker is cooled using four distinct types of clinker coolers (grate, planetary, shaft, and rotary coolers). It has been demonstrated that grate coolers recover more heat than other types of coolers. A huge cooler is chosen for large-capacity facilities.

Grate coolers are an important part of the dry clinker production line, with their primary role being quick clinker cooling and heat recovery

. The clinker exits the rotary kiln at a high temperature of 1380°F and is cooled by fresh entering air at a temperature of 100°C via a cross-flow heat exchanger in a grate cooler . Hot air from the recuperation zone is utilized as a primary burning air (secondary air) and as a pre-calciner fuel after passing through the clinker layer (tertiary air). Multi-clones or electrostatic precipitators are used to send the leftover air to the stack (ESP). When clinker comes out of the kiln, it must be cooled quickly to provide the highest production of the compound that adds to cement's hardening qualities

The decomposed material is sent into the kiln, where it is calcined and then turned into clinker. The primary, secondary, and tertiary air supply the quantities required for calcinations and combustion. The extremely hot clinker then falls through the hood of the kiln onto the cooler grates, where it is cooled by air streams travelling vertically from the grates. A fixed grate and at least two movable grate are included in the cooler. The grates force the solid material to flow forward and spread due to their oscillating action. After passing through the last moving grate, the clinker is crushed and then delivered to the appropriate silo.

A heat exchange happens between the solid substance and vertically entering fresh air during clinker cooling. A portion of the hot air volume is used as secondary air in the kiln, another portion is used in the pre-calciner, and the remainder is used as exhaust air in the de-dusting filter. The efficiency of clinker cooling is determined by two factors: the recovery of heat from the material entering the cooler and the rate at which it cools, because quick cooling improves product quality

The energy recovery efficiency of the grate clinker cooler improves as the mass flow rate of the cooling air increases. The temperature of the output clinker and the temperature of the exhaust cooling air will rise when the input Clinker mass flow rate and residual time are increased. The exergy for both clinker and cooling air will grow as the heat exchanger between the clinker particles and the cooling air increases along the grate cooler length. We may raise clinker and cooling temperatures, heat exchange between them and the clinker, and cooling air exergies by slowing down the grate speed. As a result, the cooling of hot clinker in the grate clinker cooler is directly affected by the input clinker mass flow rate, residual duration, and grate speed

Clinker will induce minimal heat exchange between the clinker particle and the cooling air if the mass flow rate of cooling air is increased up to 2.68 kg/kg (optimum clinker mass flow rate). On the other side, increased energy and recovery efficiency will result. The clinker cooler experiences a 1.4 percent gain in energy efficiency and a 2.32 percent increase in energy recovery efficiency for every 5% increase in mass flow rate. The temperature of the clinker solid at the output decreases when the mass flow rate is increased. The enhanced air flow absorbs more energy and returns it as secondary and tertiary air to the rotary burner and pre-calciner, respectively. Despite the fact that increasing the cooling air mass flow rate lowers the air outlet temperatures, the system's primary sources of energy recovery, namely energy from secondary and tertiary air, are unaffected due to the minimal temperature decreases of these two parameters revealed that for varied mass flow rates of cooling air, temperatures of solid clinker and cooling are reduced throughout the length of the cooler (when increasing the cooling air mass flow). The secondary air zone, tertiary air zone, and exhaust air zone are the three sections in which the cooler's air temperature profile is split. When the mass flow rate of cooling air is increased by 5%, secondary, tertiary, and exhaust air temperatures are expected to fall by 0.2 percent, 1.2 percent, and 2.1 percent, respectively. The temperature of the clinker exit, on the other hand, is thought to decrease by 1.9 percent for every 5% increase in mass flow rate (Ahamed et al.,2012).

The entropy generation number grows linearly as the ratio of the inlet absolute temperature increases, as we can see from the notion of effect of input temperature on the quality of energy transfer among various types of heat exchangers. It is not pleasant to cool a hot clinker with air at a low temperature. The entropy generation number is weakly reduced when the ratio of heat capacity rates in stages 1 and 2 is compared. Because the specific heat of hot clinker at roughly 1380°C is substantially more than that of air at low temperatures of around 25°C, increasing the heat capacity rate reduces heat transfer irreversibility

A grate cooler is a basic heat exchanger in which the clinker travels over or against the cooling air flow, resulting in direct heat transfer between the heated clinker and the cold cooling air. The greatest feasible temperature of combustion air pulled from the cooler is required to provide maximum heat recovery from the clinker cooler for use in the kiln system for certain volumes of secondary and tertiary air. To have the greatest possible clinker cooling with the smallest possible cooling air volumes, the clinker must stay in the cooler for a certain amount of time and the cooler must accomplish the best possible clinker and cooling air distribution.

At a temperature of 1250°C–1400°C, the hot clinker from the kiln is released into the grate cooler. The solid loses heat to cross flow air as the clinker advances at a constant pace down the colder length. The air travels upward from the fan and underneath the clinker bed. In general, a portion of the air is sent to the kiln as secondary air, a portion to the calciner as tertiary air, and a portion is vented to the atmosphere. The air depressions generated at the exchanger's entry and departure separates the cooler into two zones: hot and cold zones. The cooler's walls are coated with refractory bricks. At a temperature of 100°C, the clinker is transported to silos (approx). The primary goal of a grate cooler is to recover heat from clinker using air, which is subsequently utilized for fuel combustion

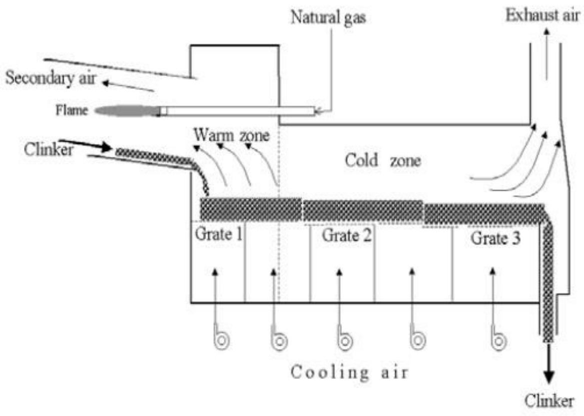

Figure 1 Scheme of the clinker cooler

Figure 2 Clinker stored on field after cooled phase

The raw mill, cooler, pre-heater, and rotary kiln are the primary energy consumers in the cement production. The plant's overall energy loss typically accounts for 35-39 percent of the total energy intake. The exhaust gas, chiller, and radiation heat transfer from the kiln cell all contribute to this energy loss. As a result, the primary focus should be on increasing the cement industry's energy usage rate. To achieve optimum clinker cooling with the lowest air cooling volumes, the clinker must be kept in the cooler for a particular amount of time. The specific heat consumption is the most important metric for calculating the amount of thermal energy used in clinker production and determining the cooler's optimal performance (Verma et al., 2021).

2. Overview of Clinker Cooler

There was different research done by different scholars on cooling process and system optimization on grate clinker cooler in cement factory on the cooling process of clinker. Although in our country there are a number of huge cement plant those use Grate clinker cooler for the process of cooling clinker. The standard of cooling capacity for these systems was determined by the clinker producing plant's capacity.

The clinker cooler is important equipment in the cement-making process. In many cement plants, it is also called as a grate cooler or cement cooler. Its role is mainly to cool down and transport the cement clinker formed in rotary kiln at very high temperatures. It will provide enough heat exchange between the hot clinker (1300 OC) from the rotary kiln and fresh air from the surrounding region, allowing the material to cool down below
100 OC and increase clinker quality and grindability. At the same time, the clinker cooler will deliver hot air to the rotary kiln and calciner, making it one of the most important components of heat recovery in the cement manufacturing process. The main purposes of a clinker cooler in the cement manufacturing process are to enhance clinker quality and cement grindability. The recovery of clinker waste heat improves the rotary kiln's heat efficiency and lowers heat consumption. Cooling reduces clinker temperature, making clinker transportation and storage easier.

2.1 Types of clinker cooler

Some essential requirements for the design and selection of a clinker cooler for a cement plant would include a low investment price, the most advantageous cooling rate for high-quality clinker, low clinker ejection temperature, the least possible impact on the environment, elevated heat recovery, low power utilization, low wear and repairs price, and reliable to operate, causing minimal downtime, and easy to control so it delivers a steady flow of combustion air at an affordable price (Steuch, 2014). To cool down heated clinker, several coolers are available. Among them the nostly know are Traveling grate cooler, Reciprocating grate cooler, Claudius Peter Eta Cooler,and rotary type cooler(Equipment, 2020).

2.1.1 Claudius Peter Eta Cooler

Claudius peter eta cooler is a family of Grate cooler which is a quench type cooler. Claudius peter eta cooler is the modern types of clinker coolers which is mainly used in many cement plants now a days. There are 10-14 fans used to cool down the hot clinker based on clinker production capacity of the plant. Hot clinkers enter from one end of the rotary kiln and are forced onto the grate bed by moveable and fixed grate plates to generate a specified thickness of material layer. To exchange heat with the clinker, cold air from beneath the grate bed blows vertically through the opening in the grate plates. Typically, the grate cooler is placed behind the rotating kiln. Components of Claudius Peter eta Cooler are Lanes, Hydraulic piston, Fans, Air ballast, Hammer crusher and Over head cranes, etc.

Figure 3 (b) Claudius Peter Cooler and (b) Chain Rope

Figure 4 Clinker Crusher and (b) Cooling Fans of Claudius Peter Cooler

Cooling Fans: Cooling fans are used to circulate cold air through the cooler and to reduce the temperature of the clinker from 1500 to 100 degrees Celsius. There are totally 14 fans i.e,7 fans on the right side and the other 7 fans on the left sides of Claudius peters great coolers. Also there are other fans used to cooling kiln equipments.

Figure 5 Internal of Claudius Peter Cooler with Crusher of clinker

In the eta coolers, the clinker will crystallize. Due to this there is a hammer crusher available at the end tail of Claudius Peter Eta Coolers to crushing the clinker to diameter of 25mm.

Figure 6 Internal of Claudius Peter Cooler with Crusher of clinker

2.1.2 Rotary type cooler or Open Clinker Cooler

The rotary cooler was the earliest used clinker cooler to cool down the hottest clinker in cement manufacturing process. Its outside resembles that of a rotating kiln, and it features refractory lining and flights on the inside. Clinker enters from one end, and flights lift and spread it. At the same time, cold air enters from the opposite end and heats up by contacting the clinker countercurrent. The rotary cooler has a diameter of (2-5) m and a length of (20-50) m, is usually located on the tail part of the rotary kiln in all cement processing factory.

Figure 7 Rotary type cooler and internal view of it

3.Modeling of Grate cooler

In the modeling process of grate clinker cooler there different assumptions that we have to following (Ahmad et al., 2013). Based on several investigations, the following assumptions are made for the improvement and modeling of grate clinker coolers in cement plants (Touil et al., 2005).

- The heat capacity of the air used to cool the clinker is considered to be uniform and constant throughout the grate clinker cooler.
- The solid clinker will be homogeneous in particle size and porosity.
- It is considered that the air movement with the solid clinker is cross flow.
- In the bed, there is a consistent distribution of air.
- Conductive heat transmission occurs in both the horizontal and vertical directions.
- The heat capacity of the clinker intake and output is the same in each stage.
- The tiny particle conveyed by air flows is thought to be minimal because of its light weight and ease of traversing the grate openings.
- In both the hot and cold zones, the clinker bed is consistent and rectangular.
- The surface velocity of air passing through the bed determines its flow.
- Each segment of the grate cooler has the same clinker and air output temperature.
- The clinker is made up of uniform spherical particles with an average diameter of 15 mm and a bulk density of 1500 kg/m3, and the cooler has a rectangular ceiling with two outputs.
- The initial temperature of the clinker on the first grate is the same as at the kiln's exit,
- the air flow at the bed's entry is characterized by a superficial velocity u0 and an average pressure Pa,
- the quantities of fine particles transported by air flows and crossing the grates slits are negligible,
- The position of the limit between the hot and cold zones of the clinker cooler is fixed.

Table 1 Studies done on optimizations of grate clinker coolers by different scholars

S.No	Author name and year of publication	Input parameter	Output parameter	Result	Optimization methods used
1	(Ahamed et al., 2012)	• masses of cooling air and clinker, • cooling air temperature, • grate speed	• improving the energy, exergy and recovery efficiencies of a grate cooling	• Increasing mass of cooling air will increase energy and recovery energy efficiencies of a cooling system. • Increasing grate speed will increase Energy efficiency and energy recovery efficiencies. • Using heat recovery from the exhaust air will increase energy and exergy recovery efficiencies of the cooling system. • Changing mass flow rate of clinker and mass flow rate of cooling air will save energy cost.	• Changing the operational parameters such as; mass flow rate of cooling air, cooling air temperature and mass flow rate of clinker
2	(Taweel et al., 2018)	• Behavior of clinker and cooling air • mass clinker flow rate • cooling air mass flow rate • residual time and grate speed • Energy and exergy balances	• distributions of temperature, energy and exergy for cooling air and hot clinker • predicting the temperatures of secondary air, tertiary air, and exhaust air,	• A rise in heat exchange between the clinker particles and the cooling air; will increased the exergy for both clinker and cooling air along the grate cooler length. • A decrease in the mass flow rate of the cooling air increased the clinker temperature, the cooling air temperature, heat exchanger between clinker and cooling air. • Increasing of residual time will increases of clinker temperature, in the cooling air temperature, in the heat exchange between the particles of clinker and cooling air, in the clinker exergy and in the cooling air exergy. • Decreasing of grate speed will increase clinker and cooling temperatures, heat exchange between them and the clinker and cooling air exergies.	• waste heat recovery from the clinker cooler system
3	(Shao et al., 2020)	• mass flow rates, inlet temperatures, and outlet temperatures of the cooling air and clinker	• the sensible heats of secondary and tertiary air, air discharged, clinker discharged,	• The sensible heats of secondary and tertiary air, air discharged, clinker discharged, and the surface dissipation heat account for 50%, 40%, 9%, and 1% of the total heat flowing in the system, respectively	• recovering the exhaust air

4	(Touil et al., 2005)	- Particle diameter - Grate frequency - Cooling air pressure - Cooling air flow rate - Cooling air temperature	- exergy analysis - heat exchange between the air and the clinker - entropy production of the cooler	- Increasing the cooling air temperature reduced the cooler's entropy output. - Heat recovery from the exhaust air will aid in the pre-heating of the cooling air and reduce external exergy losses. - The entropy generation number increases linearly as the ratio of the inlet absolute temperatures increases. - The mass velocity of the air and the ratio height of the bed on the average diameter of clinker particle do not have practically any effect on the entropy generation number.	
5	(Oyepata et al., 2021)	- clinker cooler length and width - ambient temperature - clinker cooler derives speed and fans speed - clinker and air mass flow rates	- heat transfer and multiphase fluid flow analysis as relating to specific number of air to clinker in clinker cooling system.	- with inlet air temperature of 32 ^{O}C, inlet mass flow rate of air at 0.45kg/s at clinker 0.15kg/s has the optimal energy recovearable efficiency(70%) into the system with secondary air at 817 ^{O}C and low outlet clinker temperature of 68 ^{O}C.	- design of clinker cooler with the right specific number of air
6	(Oyepata et al., 2020)	- mass flow rate of cold air - hot clinker entering the cooler in a longitudinal direction	- ratio of clinker to cold air which is 1: 2.5 in kg/s, while clinker bed height investigated are 0.3 m, 0.4 m and 0.6 m. - ANSYS solver.	- high outlet clinker temperature is attained with low clinker bed height - Clinker outlet temperature decreased with increase in bed height.	- Clinker bed height
7	(Hökfors et al., 2015)	- oxy-fuel combustion, biomass fuel, Coal, Petroleum coke, Used car tires	- maintain product quality	- To increase clinker production by introducing oxygen, which would improve fuel combustion and, at the same time, allow possibilities for increasing the fuel feed rate.	- Introducing new combustion technologies

8	(Shao et al., 2016)	• heat transfer and pressure drop • superficial velocities of air chambers and thicknesses of clinker layers on different grate plates	• A multi-objective optimization model of air distributions of grate cooler with cross-flow heat exchanger analogy	• The total air volumes of optimized schemes decrease 2.4%, • Total power consumption of cooling fans decreases 61.1% • The outlet temperature of clinker decreases to 122.9 °C which shows a remarkable energy-saving effect on energy consumption.	• Superficial velocities of cooling air in nine air chambers and thicknesses of clinker layer on three grate plates.
9	(Shao et al., 2017)	• superficial velocities of air chambers and thicknesses of clinker layer on different grate plates	• cooling air distributions • convective heat transfer principle and entropy generation minimization analysis • average diameters of clinker particles and amount of air chambers	• The most effective and economic average diameter of clinker particles is 0.02 m and the amount of air chambers is 9. • Heat recovered is lower but energy consumption of cooling fans is much higher for particles with average diameter of 0.01 m or 0.015 m compared with particles of 0.02 m. • For particles with average diameter of 0.025 m, 0.03 m or 0.035 m, both energy consumption of cooling fans and heat recovered are higher compared with particles of 0.02 m.	• Number of air chambers
10	(Shao et al., 2019)	• Cooling air distribution of the grate cooler is fixed • clinker layer thickness on three grate plates are considered as design variables.	• Entropy generation • temperature difference and pressure drop	• Optimal thickness of the three plate's measure 0.75m, 0.5m, and 0.84m, whereas energy consumption of cooling fans decreases by 19.58% compared with the operating scheme.	
11	(Ma et al., 2020)	• heat balance of the grate cooler • heat transfer and viscous dissipation	• optimal operating parameters of the grate cooler • The equivalent thermal resistance network model	• The fan power consumption was 25.44% lower, and the heat recovery efficiency was 88.43%, which was improved by 11.35%. • The optimal operating parameters were affected by the local heat load.	

		• lowest fan power consumption	• Kirchhoff's law.	• The diameter of clinker particles within the allowable industrial range, the clinker with particle diameter of 0.02 m had the optimal performance. • Different local heat load distribution impacted the optimal structural and operating parameters of the entire system.	
12	(Sutawijaya & Kayi, 2021)	• high temperatures • operating system • the quality of the initial feed material	• cement production process	• Cement Management Quality (CMQ) software • Root Cause Analysis (RCA) software	• automation principle
13	(Tsamatsoulis, 2021)	• speed • pressures of fixed and moving grate • time constants, • steady-state variables,	• transfer functions • signal's noise	• PID controller • The combination of a robustness constraint with a performance criterion, maximum sensitivity, and integral of absolute error, respectively, leads to controllers	• proportional-integral-differential (PID) controller of clinker cooling in grate coolers
14	(Atmaca & Yumrutaş, 2015)	• mass flow rate of cooling air • temperature of cooling air	• recover heat from hot clinker produced in rotary kiln (RK)	• By increasing mass flow rate the first- and second-law efficiencies of the RK can be • Changing the operating conditions in Grate Clinker Cooler provides reduction in energy consumption • The applications prevent the emission of 674.66 tons of CO2 per year to the atmosphere.	• application of insulation on the system
15	(Dincer, 1999)	• recuperation air • cooler efficiency • clinker outlet temperature	• characteristics of the cooler • Conserve energy and increase the production.	• The total recuperation air, entering the kiln for getting used in better combustion, is found as 0.792 Nm3/kg.cl. • To establish a desirable cooler, it's essential that the new cooler must have at least 73% efficiency to produce the same recuperation air.	• Replacing the old clinker cooler by advanced grate clinker cooler
16	(Okoji et al., 2021)	• Cooling air • Clinker mass flow rate	• Grate cooling system's energy, exergy and recovery efficiency	• rise in cooling air mass will increase a cooling system's energy and exergy • The utilization of heat recovery efficiencies will improve the exhaust air cooling system, energy and exergy recovery	• grate clinker cooler parameter

				• Emission can be reduced by raised both secondary air and tertiary temperature via optimization of the grate clinker cooler parameter.	

According to a research carried out by (Ahamed et al., 2012), The energy, exergy, and recovery efficiencies of a grate cooler were improved by using operational input parameters such as cooling air and clinker masses, cooling air temperature, and output parameter. The value of energy and exergy efficiency of the base clinker cooler was 81.02 percent and 53.7 percent, respectively, but the energy and exergy recovery efficiency of the system was 51.2 percent and 43.1 percent. The energy and energy recovery efficiencies of the clinker cooling system improve 1.1 percent and 1.9 percent, respectively, with a 5% increase in mass flow rate of cooling air (Ahamed et al., 2012).

The average improvement in exergy and exergy recovery efficiency for the identical example is 0.9 percent and 1.5 percent, respectively. The energy and energy recovery efficiencies of the clinker cooling system rise by 2.0% and 0.4 percent, respectively, with a 5% increase in cooling air temperature. The average increase in exergy and exergy recovery efficiencies is determined to be 3.6 percent and 2.2 percent, respectively, in a comparable situation. The energy and energy recovery efficiencies of the clinker cooling system increase by 2.7 percent and 2.5 percent, respectively, with every 5% drop in clinker mass flow rate. Exergy and exergy recovery efficiencies were found to be augmented by 2.4 percent and 2.2 percent, respectively. The energy efficiency and energy recovery efficiency of the clinker cooling system improve by 3.5 percent and 1.4 percent, respectively, for every 9.1 percent increase in grate speed, up to 18.2 percent increase in grate speed. Exergy and exergy recovery efficiencies increased on average by 3.1 percent and 1.7 percent, respectively. The average grate clinker cooling system achieves 21.5 percent energy recovery and 9.4 percent exergy recovery efficiency with the help of heat recovery from the exhaust air. It has been discovered that adjusting the mass flow rate of clinker (i.e. 38.10 percent) followed by the mass flow rate of cooling air might result in significant cost savings (30.86 percent) (Ahamed et al., 2012).

According to the study performed by(Taweel et al., 2018) increased the clinker mass flow rate or residual time, increased the temperature of the clinker and the heat exchange between the clinker and cooling air and consequently on the exergy. The findings show that the temperature profiles of the clinker bed are invariably exponential in nature across the axial direction (along the cooler). In addition to lowering the temperature of the exit clinker, increasing the mass flow rate of air may promote quick cooling, which can aid in the grinding process. Because air enters the compartment from the bottom at ambient temperature, the temperature of the clinker at the bottom of the bed is always lower than the temperature of the clinker at the top (Taweel et al., 2018).

The numerical experimentation revealed that the specific number 2.2041 Nm3/kg with inlet air temperature of 32 OC, inlet mass flow rate of air at 0.45kg/s at clinker 0.15kg/s has the best energy recovearable efficiency (70 percent) into the system with secondary air at 817 OC and low outlet clinker temperature of 68 OC has the best energy recovearable efficiency (70 percent). Heat into the model clinker cooler with temperature from secondary air 692 OC and tertiary air 502 OC and the maximum heat loss to the environment via exhaust air 153 OC and clinker out outlet 168 OC, which has the lowest recoverable efficiency (57.52 percent) heat into the model clinker cooler with temperature from secondary air 692 OC and tertiary air 502 OC and the maximum heat loss to the environment via exhaust air 153 OC and clinker out outlet 168 OC. In conclusion, the data show that designing a clinker cooler with the correct specific proportion of air to clinker would enhance the overall cement manufacturing process, cement quality, maintenance costs, and firm profit margins (Oyepata et al., 2021).

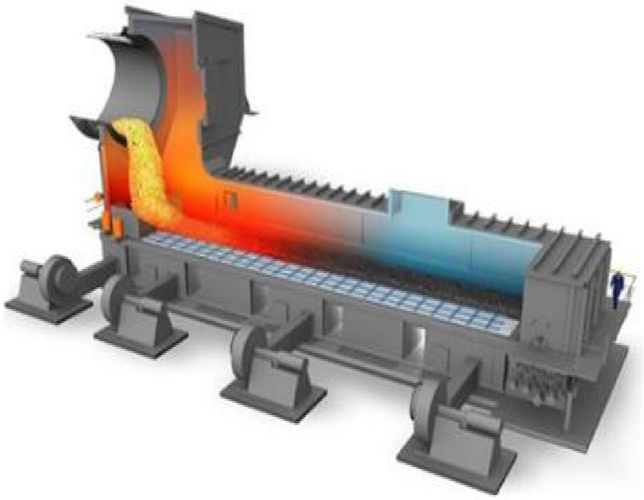

Figure 8 Cross-sectional view of clinker cooling process (Oyepata et al., 2020).

The study used a scaled down test rig prototype to replicate an actual clinker cooler system in a 25:1 ratio. In order to study the performance of the cooler based on modification in geometric parameters, a Computational Fluid Dynamics (CFD) simulation was performed on the 3D model of the scaled down clinker cooler. Based on numerical solutions of governing equations, the CFD tool was utilized to construct cost-effective simulations of actual flows. The mass flow rate of cold air entering the current clinker cooler and the clinker cooler test rig was constructed with a clinker to cold air ratio of 1: 2.5 in kg/s, and clinker bed heights of 0.3 m, 0.4 m, and 0.6 m were tested. According to the findings, high output clinker temperature can be achieved with low clinker bed height using these operating parameters for both the present operational plant and the scaled down 3D model analyzed in the CFD tool platform. This might be due to the fact that a low clinker bed prevents effective heat transmission between the clinker bed and the cold air stream. When comparing the modelled clinker cooler to the current clinker cooler, the modelled cooler performs 15% better in terms of recovered energy and 10% better in terms of energy efficiency. Furthermore, the simulated cooler's optimal heat of energy recovery efficiency is 70%, and the total energy input into the system was 316.0 kcal/kg of clinker (Oyepata et al., 2020).

A research done by (Shao et al., 2020) based on experimentally analyzed the heat distribution of the grate cooler of the cement plant under steady operating conditions. According to the findings, the sensible temperatures of secondary and tertiary air account for around half of the overall heat. Around 40% of the total heat is accounted for by the sensible heat of the expelled air. The fraction of surface dissipation heat is around 0.4 percent, and the sensible heat of the discharged clinker is roughly 9%. A model of clinker cooling in the grate cooler was also created, and the mathematical model was validated using experimental data. Discussion of cyclic air strategies for inducing exhaust air to cool the clinker on the first and second grate plates based on the numerical model demonstrates that the scheme of inducing exhaust to the first grate plate is more effective for boosting heat utilization efficiency (Shao et al., 2020).

In terms of output increase, the oxygen enrichment case was correctly anticipated, however there was a mismatch when predicting the particular energy consumption. This is due to the fact that the operational process was not optimized, the process parameters were not precisely measured, and the test was too brief. When optimizing fuel and raw food feed rates, oxygen enrichment simulations provided beneficial findings for process parameter modifications such as oxygen concentration and temperature. There is potential to increase clinker production by 17.5 percent while lowering specific energy consumption by 11.8 percent by adding 1500 m3/h oxygen (95 percent vol. percent oxygen) to a cement process feed with 335.5 t raw meal per hour (Hökfors et al., 2015).

The addition of oxygen up to 4500 m3/h had no effect on the clinker quality when the fuel and raw food feed rates were not changed. When oxy-fuel combustion is introduced to the cement clinker manufacturing process, the simulation model forecasts quality and process changes reasonably well. It may also be used to assess other sustainability measures such as the use of low-grade fuels in combustion, as well as advances in energy efficiency and product quality (Hökfors et al., 2015).

Several Pareto optimization strategies are evaluated and compared, including minimal air volume, least pressure drop, and minimum power consumption. The minimal power consumption of cooling fans is used to make the final decision based on the comparison. It's worth noting that in our example study, the total power consumption of cooling fans at the final optimal design point attained drops by 61.10 percent, while the clinker output temperature drops by 122.89 °C, indicating a significant reduction in energy consumption when compared to operational data. According to the final optimum scheme, the clinker layer is thinner than the operational data. To put it another way, the loads of moving grate plates will be reduced while energy consumption will be reduced (Shao et al., 2016).

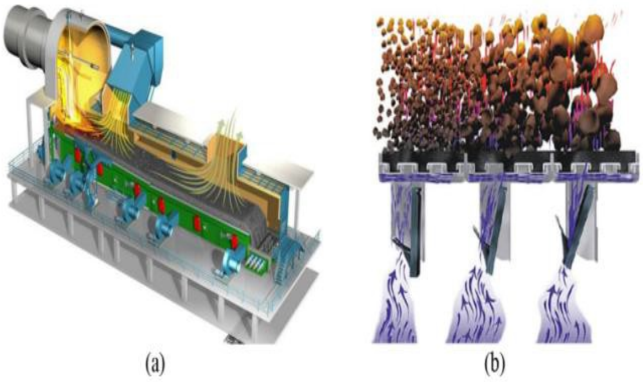

Figure 9 principle of grate cooler (Shao et., 2016).

Efforts have been made to optimize the PID controller managing the process by implementing dynamic models of clinker cooling. The model is based only on industrial data from the Halyps cement plant's chiller. The process model includes three transfer functions between the moving grate's speed and the static and moving grate's pressures. N-order dynamics are used to represent the two transfer functions between the speed and the two pressures, whereas first-order dynamics are used to express the third transfer function between the fixed and moving grate pressures. Dynamic parameters such as gains and time constants, steady-state variables, and dynamics exponents are all included in the models. Non-linear regression approaches were used to get the best model identification. The signal noise and model mismatch are expressed using high-efficiency autoregressive equations, while the load disturbances are described using a rectangular pulse. Based on the modeling results, the PID controller is designed using a loop-shaping approach, which uses the maximum sensitivity, Ms, of the open-loop transfer function as a restriction. This approach produces a collection of PIDs that meet a set of Ms Constraints. Because the control variable impacts both the process variable and a variable that causes a process disturbance, the control loop is especially fascinating. A simulator uses the IAE as performance criteria to find the best PID sets from those estimated during the design process, with the simulator's parameters consisting of a table of 35 inputs. When a robustness requirement is combined with a performance criteria, maximum sensitivity, and integral of absolute error, the result is controllers with Ms in the 1.2 to 1.35 range. Depending on the set-point setting, the IAE ranges from 4.2 percent to 4.8 percent. These findings support the theory that the cooler under investigation may be successfully managed by the PID (Tsamatsoulis, 2021).

According to the GCC and RK's performance evaluations and analyses, the clinker generation and quick cooling processes entail energy and exergy losses, and the process is influenced by specific parameters. The GCC and RK have first-law efficiency values of 85.1 and 60.8 percent, respectively, whereas their second-law efficiency values are 59.5 and 43.9 percent, respectively. GCC and RK systems are estimated to lose 4.5 and 7.6 MW of energy, respectively. The RK's SEC for clinker production has been calculated to be 3121.8 kJ/kg clinker. The findings indicate that the GCC and the rotary kiln should be studied jointly. Changing some operating settings in the GCC unit has a direct impact on the RK system's specific energy and coal consumption. The analyses reveal that the mass flow rate and temperature of the cooling air supplied to the GCC play a significant effect in the facility's energy management. The first- and second-law efficiency values of the GCC unit rose by 5.04 and 3.84 percent, respectively, for a 13 percent increase in the mass flow rate of the cooling air. The RK's first- and second-law efficiency values have also risen by 2.62 percent and 2.13 percent, respectively. Simultaneously, the unit's SEC has been reduced by 2.97 percent. The SEC of the RK was found to be reduced by 3.41 percent by increasing the GCC's cooling air temperature by 3.2 percent. The quality and kind of insulating materials utilized inside the cooler have a significant impact on the RK's performance. The first-law efficiency, second-law efficiency, and SEC values of the RK system are calculated as 62.4 percent, 48.7%, and 3008.2 kJ/kg clinker, respectively, after proper insulation and new refractory bricks are installed inside the cooler. After maintaining the facility's optimal conditions, the yearly total coal consumption was reduced from 53,285.68 tons to 52,560.24 tons, saving 725.55 tons of coal per year. The facility's annual CO2, NOx, and SO2 emissions rates are reduced by 674,659.16, 1015.62, and 2792.94 kg, respectively, by reducing coal consumption. In an RK operation, fuel consumption can be reduced by minimizing various losses that occur in the unit. According to the findings, improving combustion efficiency will be the most important factor affecting system efficiency. Some strategies that can help minimize energy consumption include minimizing heat losses by effective insulation, reducing the temperature of gases at the output through more effective heat transfer in the unit, and minimizing air and steam leaks through good sealing (Atmaca & Yumrutaş, 2015).

The total recovery air that enters the kiln for enhanced combustion is found to be 0.792 Nm3/kg.cl. It can be estimated that the present cooler is not an advanced cooler using the total amount of recuperation air and the cooler efficiency of 62.5 percent. To create a desirable cooler, the new cooler must have a minimum efficiency of 73 percent in order to provide the same recuperation air (Dincer, 1999).

The grate clinker cooler's energy and exergy efficiency are estimated to be 85.9% and 56.2 percent, respectively. The grate clinker cooler's energy and exergy recovery rates are estimated to be 75.9% and 45.4 percent, respectively. For every 5% increase in cooling air mass, the energy and exergy efficiency of a cooling system can be enhanced by 2.1 percent and 2.2 percent, respectively. Energy and exergy recovery were found to be increased by 8.5 percent and 9.2 percent, respectively, when heat recovery efficiency of the exhaust air cooling system were used. Raising both secondary air and tertiary temperature via optimization of the grate clinker cooler parameter can result in a 0.23 percent reduction in emissions (Okoji et al., 2021).

4. Conclusion

The efficiency of a cooling system can be improved by raising the mass flow rate of cooling air energy and recovery energy. Recovery energy efficiencies can be enhanced by increasing cooling temperature energy, exergy, and recovery efficiencies. Energy efficiency and energy recovery efficiencies improve as grate speed increases. The cooling system's energy and exergy recovery efficiency were found to be improved by using heat recovery from exhaust air. It has been discovered that adjusting the mass flow rate of clinker and the mass flow rate of cooling air can save energy.

Higher clinker and cooling air temperatures; increased heat exchange between the clinker particles and the cooling air; and increased exergy for both clinker and cooling air over the grate cooler length were all results of increasing the clinker mass flow rate. Due to the coefficient of heat transfer of the air-clinker system, a decrease in the mass flow rate of cooling air increased the clinker temperature and the cooling air temperature. This resulted in an increase of heat exchange between the clinker and cooling air, clinker exergy and cooling air exergy, respectively.

The clinker temperature, the cooling air temperature, the heat exchange between the clinker particles and the cooling air, the clinker exergy, and the cooling air exergy all increased as the residual time increased. The clinker and cooling temperatures, as well as the heat exchange between them and the clinker and cooling air exergies, increased when the grate speed was reduced.

The grate clinker cooler's energy and exergy efficiency are estimated to be 85.9% and 56.2 percent, respectively. The grate clinker cooler's energy and exergy recovery rates are estimated to be 75.9% and 45.4 percent, respectively. For every 5% increase in cooling air mass, the energy and exergy efficiency of a cooling system can be enhanced by 2.1 percent and 2.2 percent, respectively. Energy and exergy recovery were found to be increased by 8.5 percent and 9.2 percent, respectively, when heat recovery efficiency of the exhaust air cooling system were used

Thank You