Power Tech Consultants

ISPAT GURU

Heat and mass balance, energy conservation, and carbon footprint reduction in limestone calcination plant

By

Satyendra Kumar Sarna

https://www.ispatguru.com/

20.05.2023

Power Tech Consultants

ISPAT GURU

Introduction

- Lime (quick lime) is an essential material for making of steel.
- Lime (CaO) is used as a flux material for the removal of impurities in the form of slag in steelmaking.
- Lime is porous, has higher surface area, has high reactivity, and is hygroscopic.
- Lime for steelmaking is expected normally to show high reactivity. A large number of pores exist on the surface.
- High lime reactivity is because of its porosity. Temperature and time of calcination play an important role in the reactivity of lime. The reactivity of lime is also dependent on the homogeneity of lime, the degree of thermal decomposition of limestone, and the specific surface area of the lime.

Power Tech Consultants

ISPAT GURU

Introduction

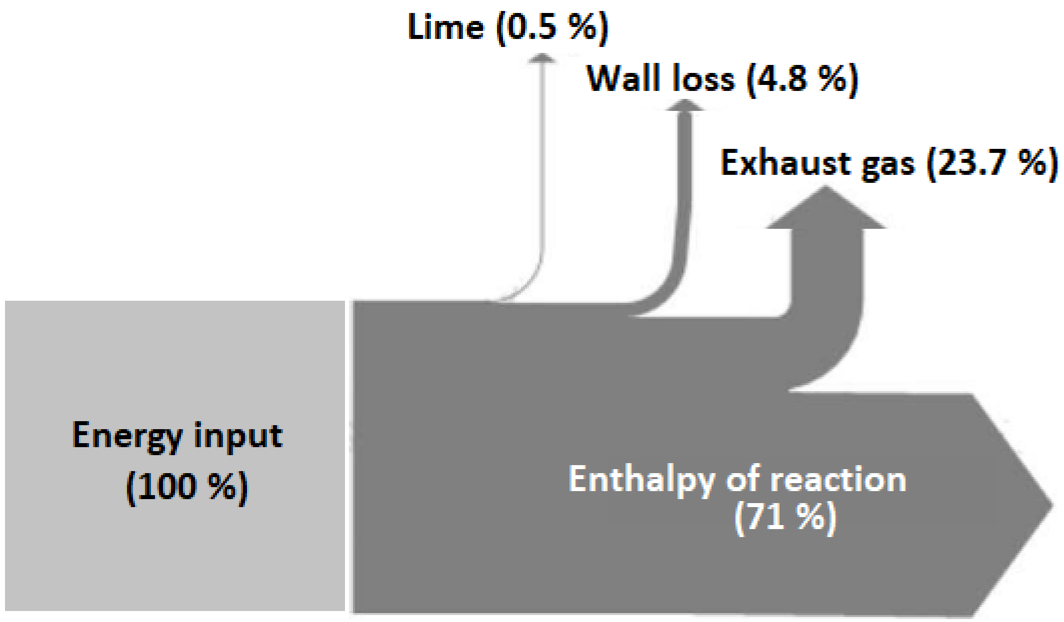
- Lime is produced by calcining limestone ($CaCO_3$) in a lime kiln. Desired quality of lime is to be achieved with low level of energy consumption.
- Lime production is an energy intensive process characterized by high emissions of CO_2.
- The main energy consumption of lime production is located in the calcination process and accounts for the major percentage of the total energy consumption.
- The fuel consumed during the calcination represents around 50 % of the production costs of lime.
- The calcination stage also accounts for 99 % of the impact of lime production on global warming.

Introduction

- Lime calcining reaction is $CaCO3(s) = CaO(s) + CO2(g)$, $\Delta HR = +168$ kilojoules /mol.
- The forward reaction is favoured by higher temperatures. The reaction proceeds only if the partial pressure of CO2 (carbon di-oxide) in the gas above the solid surface is less than the decomposition pressure of the CaCO3.
- As per the reaction 100 tons of calcium carbonate on dissociation produces 56 tons of lime and 44 tons of CO2.
- The activation energy of the calcination reaction is normally between 155 kilojoules / mol to 251 kilojoules / mol, with values predominantly nearer to 210 kilojoules/mol. These values are compared with the theoretical value (at equilibrium) being between 163 kilojoule s/ mol to 172 kilojoules / mol.

Introduction

- The uncertainty derives from the inherent complexity of the calcination process.
- The reaction depends on several parameters, e.g. chemical composition of the limestone, limestone grain size, surrounding gas composition, and ambient temperature.
- Figure shows a typical Sankey diagram of a lime kiln



Power Tech Consultants

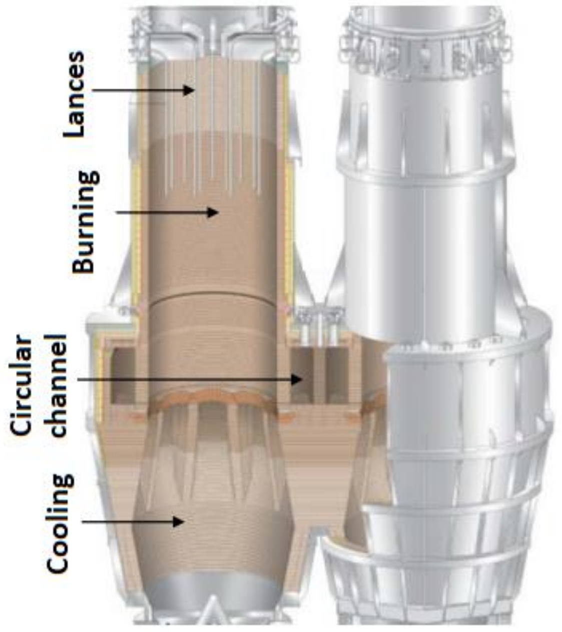
ISPAT GURU

Types of lime kilns

- Lime kilns are of two types: (i) rotary kiln, and (ii) shaft kiln.
- Rotary kiln can be a long kiln of a short kiln with a pre-heater and a contact cooler.
- Shaft kilns constitute majority of all the kilns presently being used for the production of lime. The types of shaft kilns are (i) mixed feed shaft (MFS) kiln, (ii) parallel flow regenerative (PFR) kiln, (iii) annular shaft (AS) kiln, and (iv) other types of kilns.
- Shaft kilns are vertical in design, up to 30 m (metres) in height and with a diameter of up to 6 m. For this type of kiln, the limestone is fed in at the top of the kiln and it progressively makes its way down through the different stages of the kiln until it is discharged at the kiln bottom as lime.
- The limestone calcination in a shaft kiln is a complex process is mainly dependent on a variety of influencing parameters. These are (i) operating parameters (throughput, quantity of fuel and air, kind and composition of fuel, and ambient temperature), (ii) dimension parameters (diameter, solid bed height, length of cooling zone, and thickness of the wall), and (iii) kind of limestone (mean particle size, particle size distribution, quantity of calcite and magnetite, thermal conductivity, and reactivity).
- Since the interaction of these parameters is largely unknown, the optimization of the process as well as the design of the kiln is strongly empirical.

PFR kiln

- PFR kiln is presently the most important and most established lime kiln type.
- For standard PFR lime kilns the volume of the burning zone is designed in such a way that the material can be fully calcined at an average burning temperature of 950 deg C to 1,050 deg C.
- Based on these boundary conditions the retention time of the kiln charge in the burning zone is normally around 8 hours. These process conditions used in PFR kilns results into production high reactive lime.



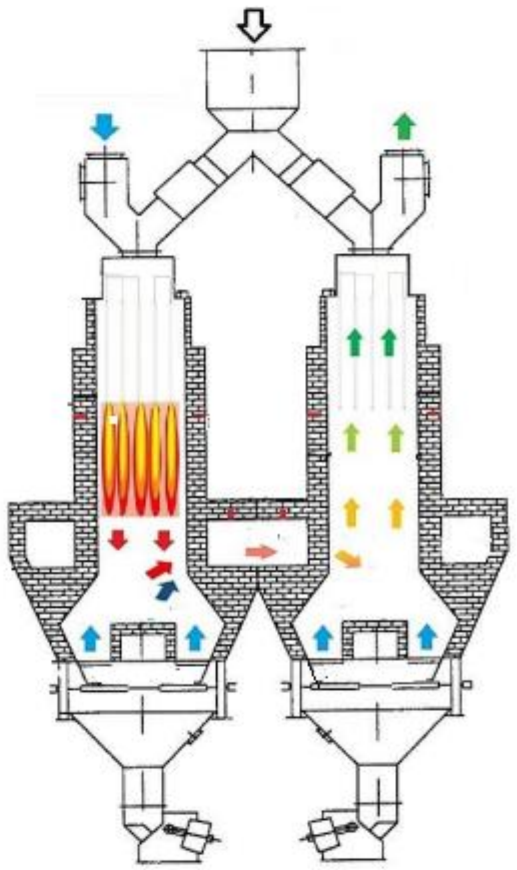
Circular PFR kiln

Power Tech Consultants

ISPAT GURU

PFR kiln

- PFR kiln has two vertical shafts with a connection channel in their middle section, and the burning takes around 11 to 12 minutes during operation on one of these shafts.
- The production of hot gases result from the burning is passed through the connection channel to the other shaft, and it exits the kiln after preheating the limestone in the preheating section and passing the filters.
- At the end of the burning in the first shaft, after adjusting the needed conditions, the combustion begins in the other shaft, and the hot gases come out of the adjacent shaft, and in this way, the calcination process of limestone continues within the shafts steadily.
- The time needed for burning in a shaft and its shift between the two shafts is known as the time cycle which lasts around 13 to 14 minutes.

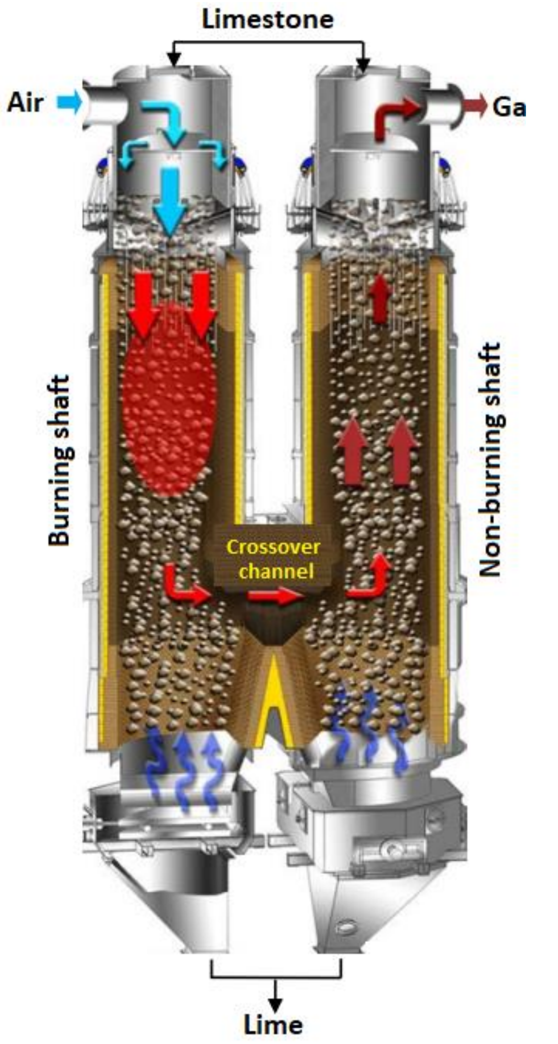


Power Tech Consultants

ISPAT GURU

PFR kiln

- PFR kiln is a modern kiln with two-shafts defined by alternating burning and non-burning shaft operation.
- Because of the conditions of parallel flow of the kiln charge and the combustion gases in the burning shaft the PFR kiln is perfectly suitable for the production of soft burnt, high reactive lime. In addition, with regenerative preheating of the combustion air, the burning process provides for the lowest heat consumption of all modern lime shaft kilns.
- As the calcination process consumes a large quantity of heat and most of the energy from fuel combustion is released at the upper end of the burning zone, the process temperatures in PFR lime kilns are relatively low.
- Figure shows characteristic feature of a PFR kiln, which consists of two interconnected vertical shafts of either rectangular or circular cross sectional shape. Each shaft is subjected to two distinct modes of operation, burning and non-burning mode.
- While one shaft operates in the burning mode (supplied by fuel and combustion air), the other shaft operates in the non-burning mode.

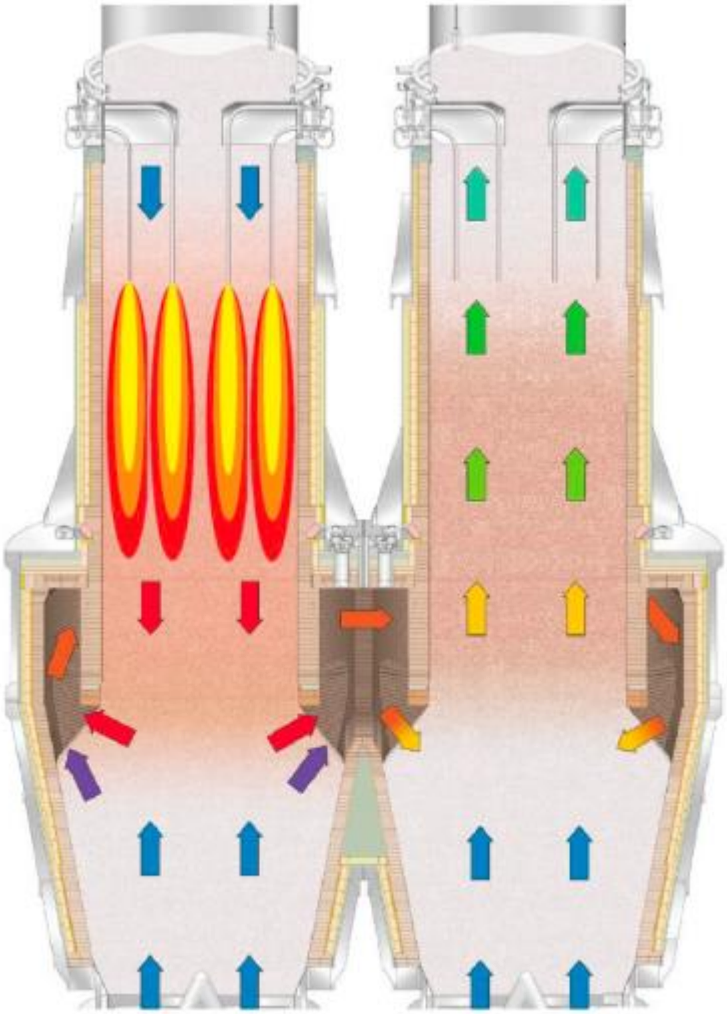


Power Tech Consultants

ISPAT GURU

PFR kiln

- In burning mode, one shaft is characterized by the parallel flow of combustion air / gases and limestone, whereas, in non-burning mode the other shaft is characterized by the counter-current flow of off-gases and limestone.
- The kiln charge, which is well screened limestone or dolomite, has a typical grain size of 50 mm to 100 mm but can also be smaller - 15 mm to 50 mm - or even larger - 60 mm to 150 mm.
- The kiln shafts are completely filled with the material to be processed and the kiln charge passes the lime kiln at a speed of around one meter per hour.
- The air and combustion gases flow through the void space which is around 40 % of the volume.
- A uniform heat distribution over the cross section of the kiln shafts and an appropriate temperature profile are preconditions for producing good lime quality in a PFR lime kiln.

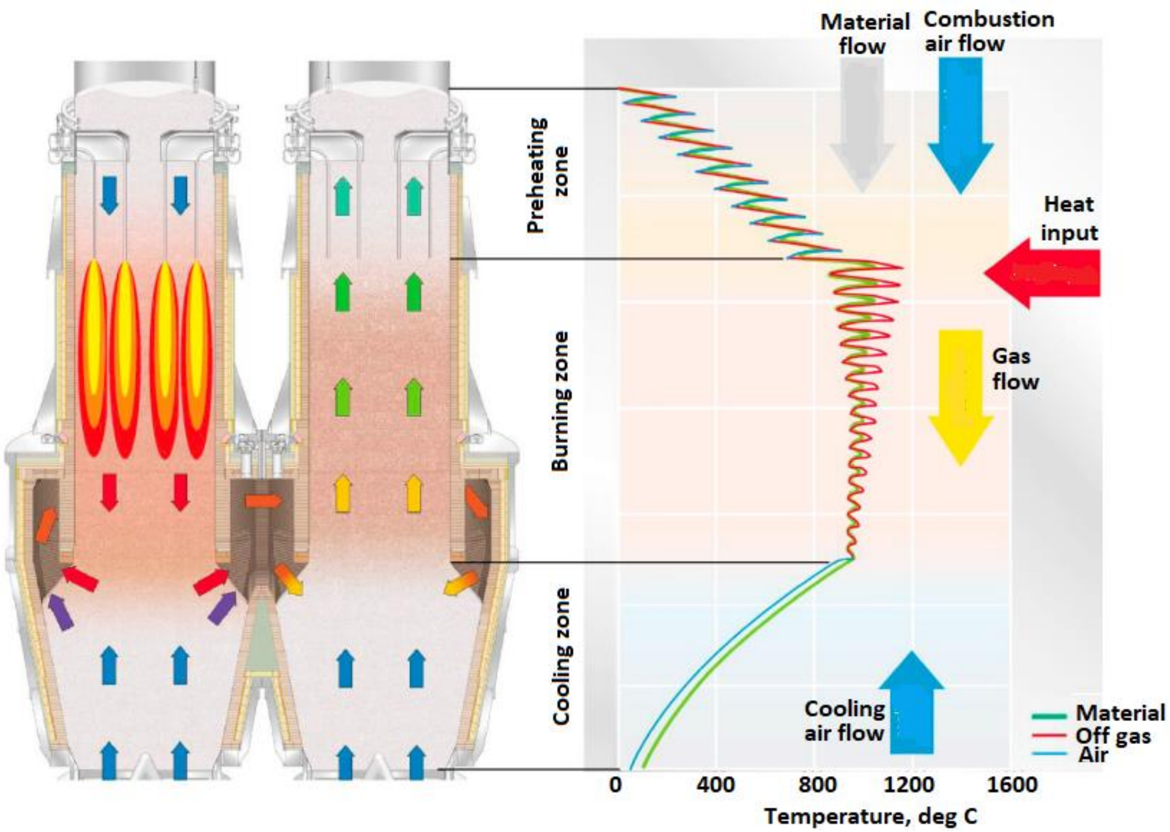


Power Tech Consultants

ISPAT GURU

Temperature profile

- The differently coloured lines in the temperature profile (right part of figure show the material as well as the air and the gas temperatures along the kiln profile.

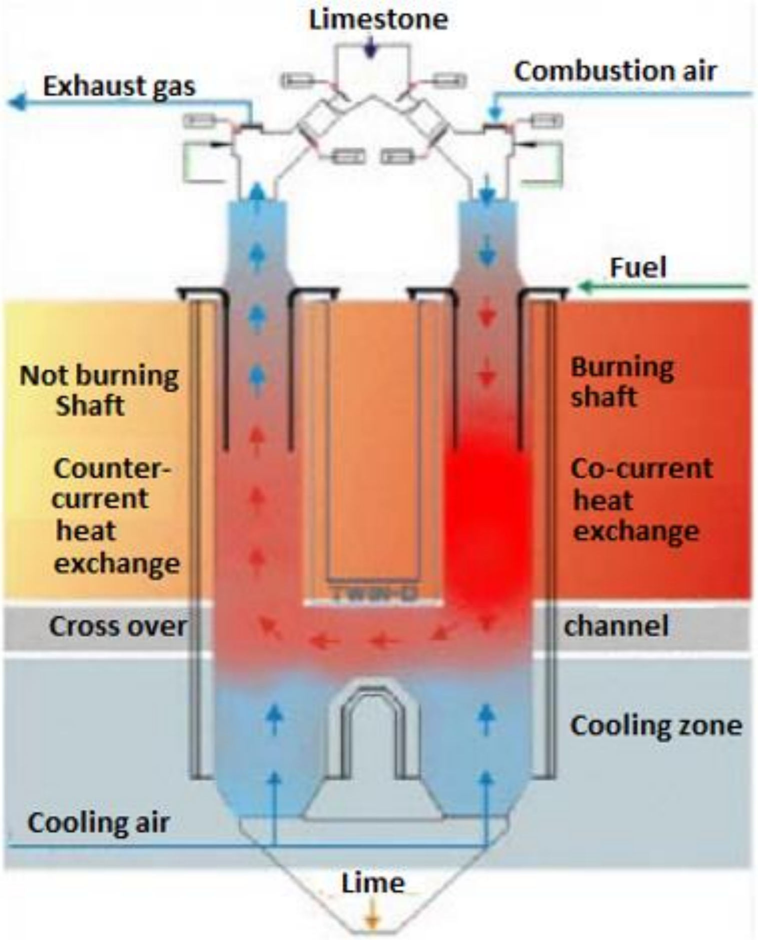


Power Tech Consultants

ISPAT GURU

Calcining process

- Combustion air is introduced under pressure at the top of the preheating zone above the limestone bed,
- The complete kiln system is pressurized.
- The combustion air is preheated by the limestone prior to mixing with the fuel.
- The combustion gases exit the burning shaft through a crossover-channel into the non-burning shaft.
- The off-gases transfer heat to the limestone during the non-burning mode and then the limestone reclaims the heat to the combustion air during the burning mode.



Power Tech Consultants

ISPAT GURU

Calcining process

- In standard PFR kilns, the volume of the burning area is designed so that limestone gets completely calcined at an average temperature of 950 deg C to 1,050 deg C.
- The calcination time in these kilns is considered averagely as 8 hours, according to the boundary conditions and the calcination cycle time
- Calcination of limestone involves a seven step mechanism.
- Heat Is to be transferred (i) to the material outer surface, then (ii) conducted through the calcinated outer shell to the internal reaction interface, where (iii) a chemical reaction occurs and the CO_2 evolved is to either (iv) react at the interface, or (v) diffuse from the interface to the outer surface and it then (vi) diffuses away from the surface to the surrounding atmosphere, and (vii) CO_2 from the surrounding atmosphere also diffuses to the reaction interface.

Power Tech Consultants

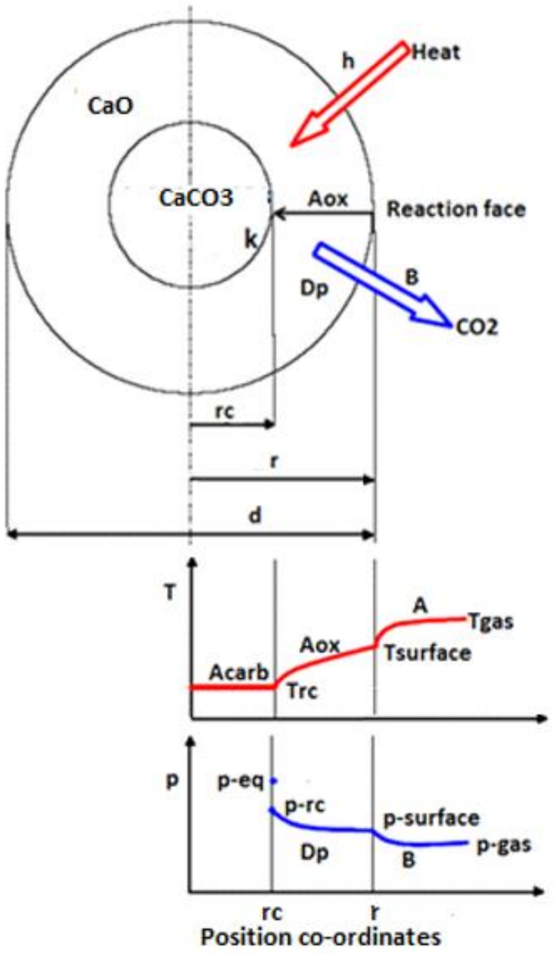
ISPAT GURU

Calcination process

- The calcination process can be explained using a partially decomposed piece of limestone, whose profiles of CO_2 partial pressure and temperature are shown in figure.

- The sample comprises a dense carbonate core surrounded by a porous layer. In the calcining kiln at a temperature Tgas heat is transferred by radiation and convection (symbolized by ‘h’) to the solid surface at a temperature of Tsurface.

- By means of thermal conduction (A) heat penetrates through oxide layer to reach the reaction front, where the temperature is Trc.



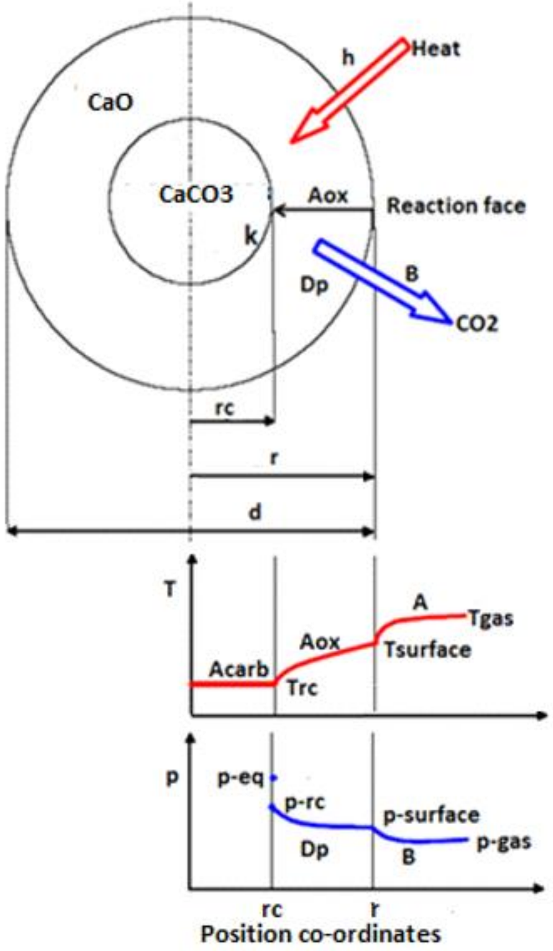
Profile of limestone during calcining

Power Tech Consultants

ISPAT GURU

Calcination process

- As the reaction enthalpy is several times higher than the internal energy, the heat flowing further into the core is negligible during the reaction. Hence the core temperature is only slightly lower than the front temperature. Once heat is supplied, the chemical reaction constant (k) then takes place for which the driving force is the deviation of CO2 partial pressure from the equilibrium (p-eq – p-f).
- The released CO2 diffuses (Dp) through the porous oxide layer to the surface and finally passes by convection (B) to the surroundings where the CO2 partial pressure p-surface exists.
- The chemical and physical properties of lime are influenced by the calcination which in turn is influenced by the conductivity, mass transfer coefficient, and diffusivity of the lime layer.



Profile of limestone during calcining

Power Tech Consultants

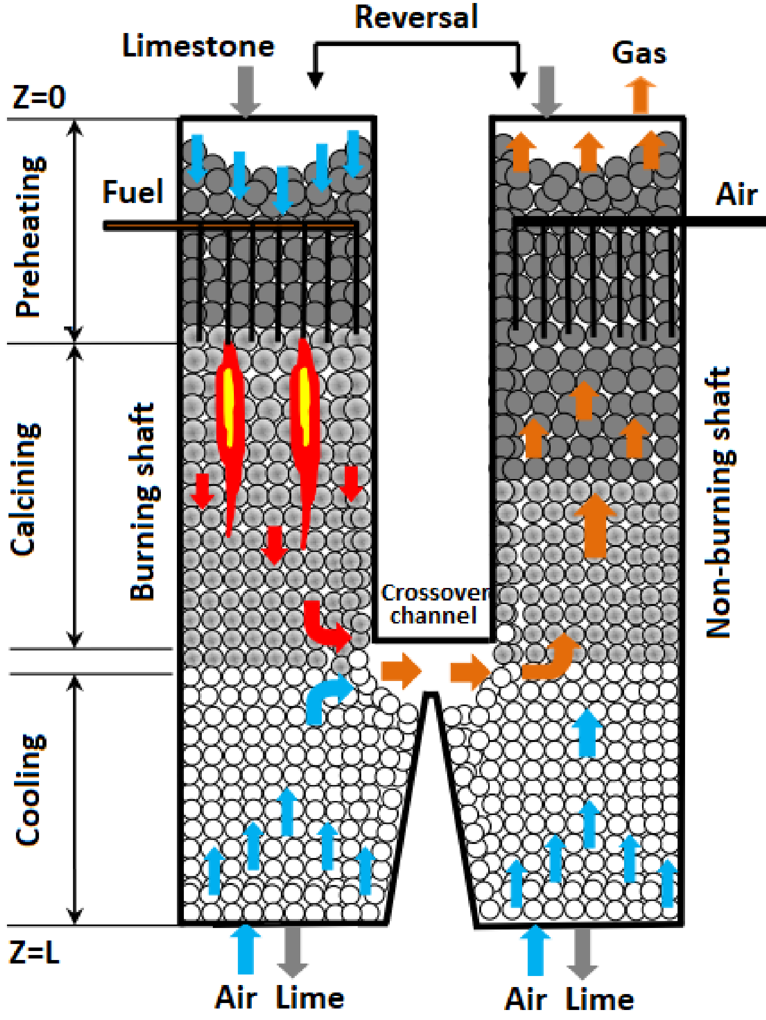
ISPAT GURU

Kiln zones

- Passing limestone (with or without a significant $MgCO_3$ content) through the kiln can be divided into three stages or heat transfer zones consisting of (i) pre-heating zone, (ii) calcining zone, and (iii) cooling zone.

- Preheating zone -Limestone is heated from ambient temperature to around 800 deg C by direct contact with the gases leaving the calcining zone composed mainly of combustion products along with excess air and CO_2 from calcinations.

- Calcining zone - Fuel is burned in preheated air from the cooling zone and (depending on the design) in additional ‘combustion’ air added with the fuel. In this zone, temperatures of greater than 900 deg C are produced. From 800 deg C to 900 deg C, the surface of the limestone starts to decompose. At temperatures above the decomposition temperature of limestone, i.e. 900 deg C, decomposition takes place below the surface of the limestone pieces. At a temperature of 900 deg C, these pieces leave the calcining zone and are sometimes found as residual limestone which is still trapped inside. If the pieces which are decomposed fully and still reside in the calcining zone, sintering occurs.



Power Tech Consultants

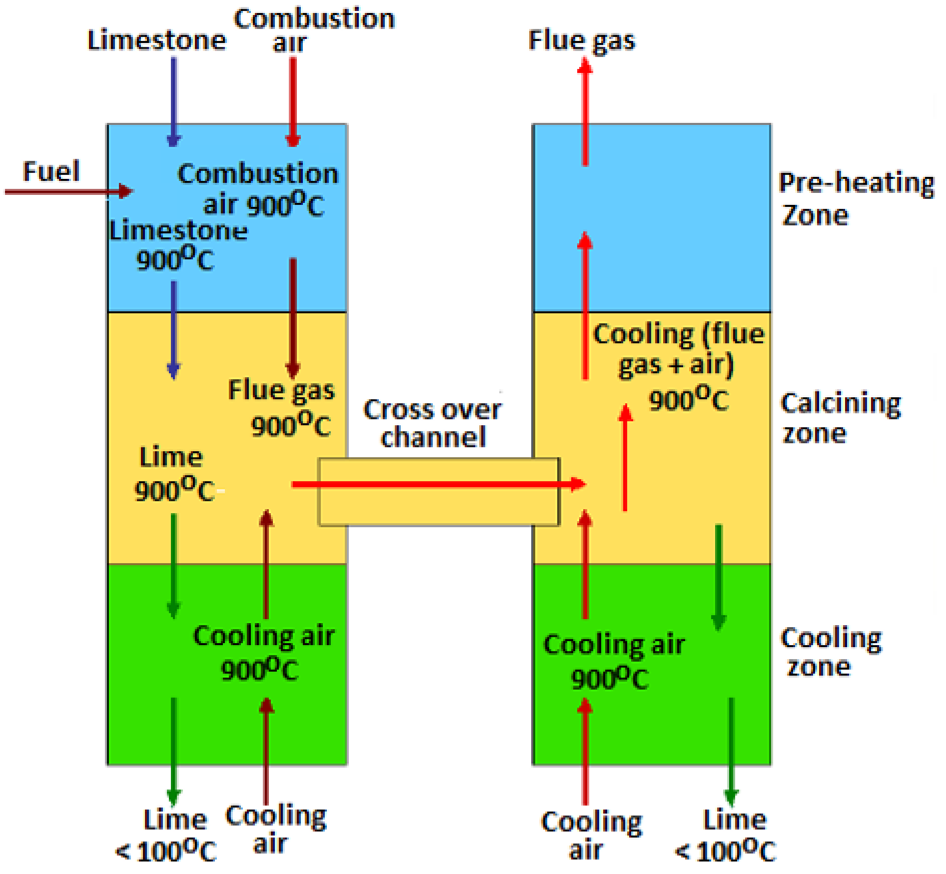
ISPAT GURU

Kiln zones

- **Cooling zone - Lime which leaves the calcining zone at temperatures of 900 deg C, is cooled by direct contact with 'cooling' air, part or all of the combustion air, which in turn is preheated. Lime leaves this zone at temperatures of less than 100 deg C.**

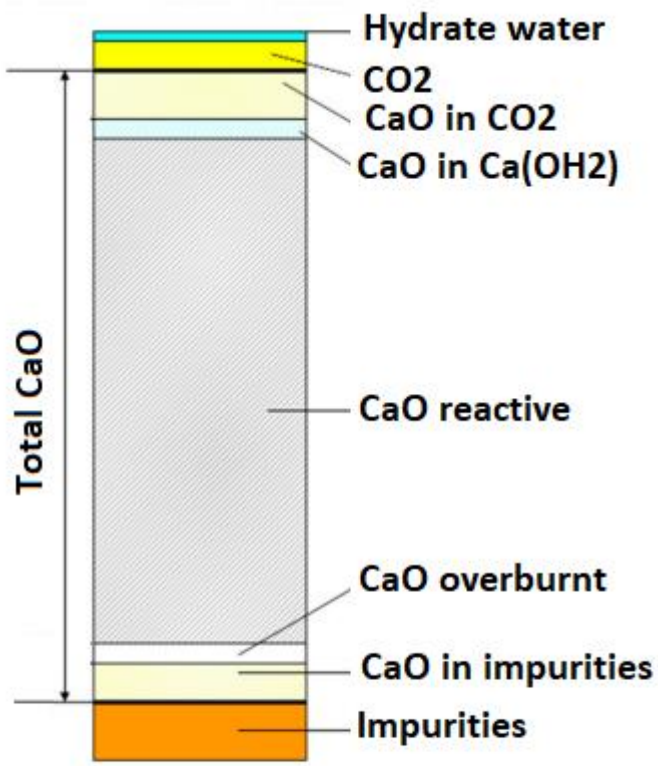
- **The residence time of the limestone-lime in a kiln varies depending on the type of kiln and type of final product needed. This period is found to be between six hours and two days.**

- **Lime is frequently referred to as light or soft, medium or hard burned depending on the extent to which it has been calcined. The degree of reactivity, i.e. reactivity to water, is found to decrease as the level of porosity increases.**



Characteristics of lime

- Limestone chemistry has a significant effect on lime chemistry, especially for the main impurities.
- Calcination also influences the resulting chemistry, and especially the CO_2 remaining content, due to incomplete calcination ($CaCO_3$ remaining) and the S content principally coming from the fuel.
- The principal characteristics of lime for steelmaking are chemical composition and degree of calcination, reactivity, grain size, and uniformity.
- The reactive content of lime (shown in figure) is a key parameter.

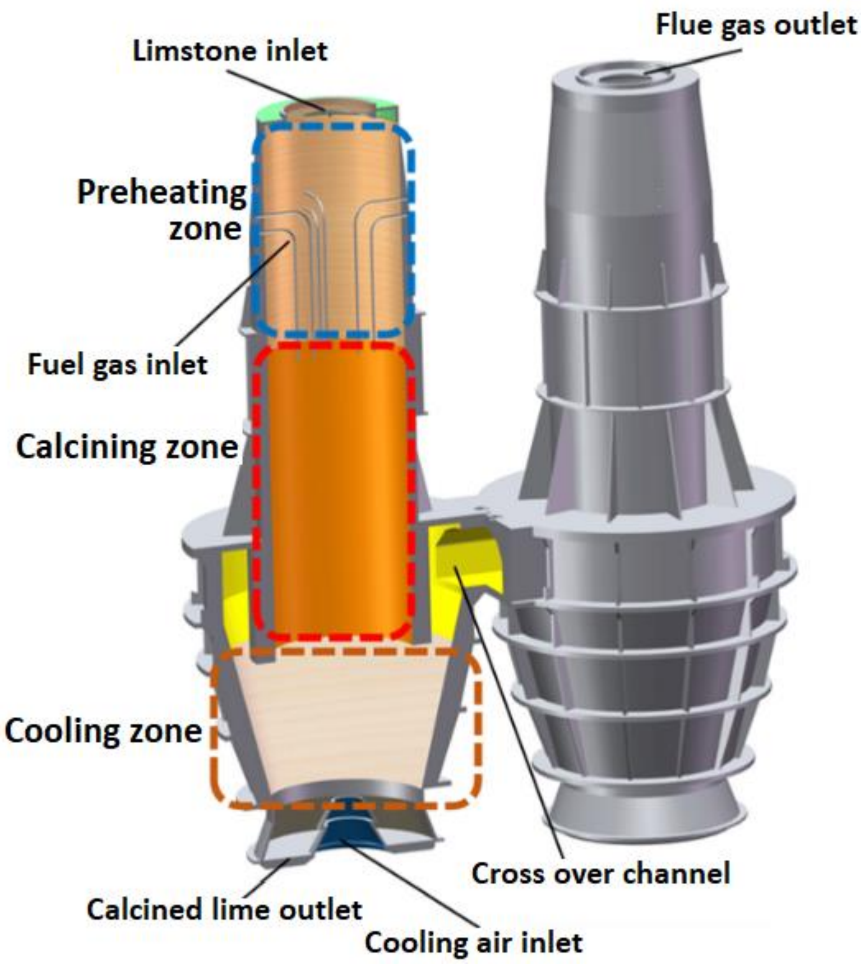


Power Tech Consultants

ISPAT GURU

Characteristics of lime

- As calcium oxide is ideally suitable to absorb sulphur dioxide (SO2), all lime kilns with low off-gas temperatures absorb almost all the SO2 from the fuel combustion.
- Due to the high thermal efficiency, the PFR lime kiln operates with the lowest off-gas temperatures of all lime kiln types. As a result almost all the sulphur contained in the fuel is transferred to the product lime and a small part to the bag house filter dust.
- For the production of low sulphur lime which is needed for the steel industry not only the sulphur content in the raw material but also the sulphur content in the fuel is to be taken into account.
- Integrated iron and steel plants operate their own lime kilns as captive units. These lime kilns are frequently fired with coke oven gas, converter gas or mixed gas and these gases contain almost no sulphur.



Mass and heat balance

- 1 ton of lime production in PFR needs around 1.8 ton of limestone and around 3,515 mega joules of heat energy.
- The energy efficiency of a lime kiln can be described by the heat rate. The heat rate is the quantity of energy which is consumed to create a certain quantity of reburned lime.
- Mass and heat balances are very important for the efficient working of the calcining process. There are several aspects which have influence on the mass and energy balance.
- Mass and heat balances need accurate detailed analysis as well as accurate determination of quantities of the input and output materials.
- Their calculations are normally carried out for improving the process.
- They are used in the examination of the various stages of a process, over the whole process and even extending over the total production system to ensure that process variables do not exceed the desired limits.

Mass and heat balance

- In a PFR lime kiln, the input materials are limestone, fuel, and air while the output materials are lime, flue dust, and flue gas.
- Limestone besides $CaCO_3$ can have in it some quantity of $MgCO_3$ (magnesium carbonate) contains varying proportions of silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), sulphur in form of sulphide or sulphate, phosphorus in form of P_2O_5, potash (K_2O), and soda (Na_2O). The two main impurities are silica and alumina with iron as the third.
- During the calcination reaction, CO_2 produced goes to the flue gas while CaO and MgO goes to the product lime.
- During the calcination process some fines get generated. These fines are carried away by flue gas in the form of flue dust. Part of the flue dust is recovered in the air pollution control equipments such as bag filters and electrostatic precipitators.
- Some constituents of input materials reacts with oxygen or undergo sublimation. The products of these reactions goes to the flue gas.

Mass and heat balance

- The other constituents in the limestone are heated and cooled in the kiln consuming the heat energy. A part of these constituents goes to the flue gas while the balance part which is the major part become the constituents of lime. They affect the quality of lime needed for steelmaking. The lower is their percentage, better is the lime quality.
- Lime stone has moisture. The moisture content varies with season, being lowest in summer and highest in rainy season. This moisture gets evaporated in the kiln and goes to flue gas. The evaporation of moisture needs energy.
- In a kiln, 100 % calcination of lime does not take place. Hence, the produced lime has a very small percentage of carbonates (CaCO3, MgCO3) in it.
- Lime has hydroscopic properties and hence it picks up some moisture from the atmosphere. Hence the moisture pick up by the lime is to be considered in mass balance.

Power Tech Consultants

ISPAT GURU

Mass and heat balance

- Besides limestone, other two input materials are fuel and air. Air is introduced into the kiln as combustion (primary) air and as cooling (secondary) air. Both the types of air are preheated in the kiln before they take part in the combustion reaction. In PFR kiln only the primary air takes part in the combustion reaction.
- For mass balance, normally complete combustion of fuel is considered and the combustion products are determined by combustion reactions which are taking place because of the combustible fuel components.
- Normal combustible fuel components are carbon, carbon mono-oxide, hydrogen, and hydro-carbons.
- Solid and liquid fuels contain ash which is to be considered in the mass balance.

Power Tech Consultants

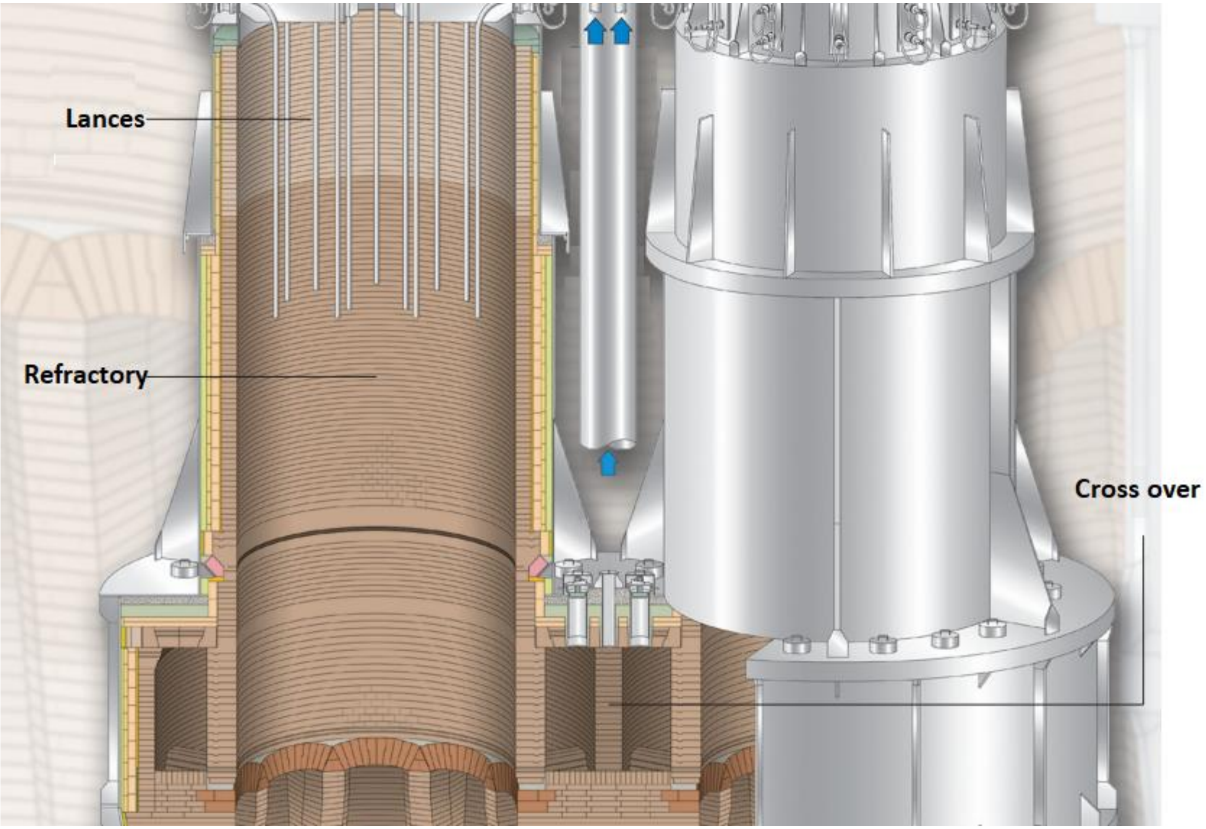
ISPAT GURU

Mass and heat balance

- For complete combustion, excess air is to be supplied than what is needed as per stoichiometric requirement, and because of this excess air flue gas analysis indicates some oxygen content. In case of PFR kiln, this oxygen is in addition to the oxygen of the cooling air.
- In case of incomplete combustion, some combustible components of the fuel are carried to the flue gas.
- Part of nitrogen in the air, and part of sulphur present in the fuel and limestone gets converted to oxides of nitrogen (NOx) and oxides of sulphur (SOx) which gets reflected in the flue gas analysis. In case of PFR kilns most of the sulphur goes to the product lime.
- In the kiln dust gets generated because of the characteristics of limestone and lime as well as their movement in the kiln. Major part of this dust is collected by the air pollution control equipment.
- Dust escaping through the pollution control equipment is determined and represented by the content of particulate matter (pm) in the flue gas.

Mass and heat balance

- During the operation of the kiln, there is possibility of some irregularities taking place such as a built up (scaffolding) in the kiln or some slippage taking place in the kiln. The kiln irregularities have influence on the mass balance.
- Kiln is lined with refractory. Refractory lining gets eroded or damaged during the kiln operation. The products of refractory damage influence the mass balance analysis.



Power Tech Consultants

ISPAT GURU

Mass and heat balance

- Kiln calcining efficiency can be determined and compared using the formula for thermal efficiency proposed by Robert Boynton, former director of the National Lime Association in the USA.
- Thermal efficiency (%) = [theoretical heat requirement x available oxide content(%)]/total heat requirement.
- This can be presented mathematically by the efficiency equation: E = (Hc x Ls) / (Cf x Mf), where E is the efficiency of the calcining process, Hc is theoretical heat of calcination per ton for pure quicklime (CaO plus MgO) in mega joule per ton, Ls is the available lime content (as CaO and MgO) of the lime, Cf is the calorific value of fuel in mega joule per kilogram, and Mf is the mass of fuel used per ton of lime in kilogram per ton.
- For all practical purposes, value of Hc can be taken as 3,200 mega joule per ton of CaO for a pure calcite limestone. For a pure dolomite the figure is lower at 3,020 mega joule per ton. Hence in case of dolomitic limestone (containing some MgO), it is necessary to adjust the value of Hc for 'dolomitic' limestone.

Power Tech Consultants

ISPAT GURU

Mass and heat balance

- Heat balance can be very complicated, but with increasing availability of computers, the complex energy balances can be set up and manipulated quite readily and hence used in everyday process management to establish the thermal efficiency of the process so that necessary action can be taken to optimize fuel use and conserve energy.
- Heat balance analysis is normally done to find where the potential exist for saving the heat energy.
- Heat balance needs determination of heat input and the heat losses which are taking place because of the temperatures of the products and flue gas as well as the heat loss through the kiln wall.

Mass and heat balance

- Heat input to the kiln is (i) heat generated by the combustion of fuel, and (ii) sensible heats of lime stone, fuel, and combustion air.
- Heat input to the kiln is to meet the heat needed for the endothermic calcining reaction to proceed and to compensate for the heat losses which are taking place in the kiln.
- Heat losses from the kiln are (i) sensible heat of lime being discharged from the kiln, (ii) sensible heat of the flue gas coming out from the kiln, (iii) heat loss because of the radiation from the kiln shell, and (iv) heat loss from various kiln openings.
- The quantity of energy leaving out the shell depends on the proportions, temperature profile and insulation of the kiln. For energy efficiency, insulation is the most obvious tool for minimizing this kind of heat loss. This problem can be minimized by using a refractory lining with double bricks. In a lime kiln, heat losses from the shell normally increases with the increase in the lining life and can be around 10 % to 15 % of the energy input at end of the lining life.

Power Tech Consultants

ISPAT GURU

Mass and heat balance

- In the present day scenario several mathematical models are available which carry out the complicated calculations for mass balance and heat balance in different areas of the lime kiln. These models provide accurate results.
- The automatic control system being provided for the modern day lime kilns incorporates these models.
- With the automatic control system, the kiln operators are not only being continuously informed about various parameters resulting from heat balance and mass balance so that they can take corrective action well in time in case of deterioration in some area of the kiln to get optimum performance from the kiln.

Power Tech Consultants

ISPAT GURU

Energy conservation

- Lime production is an energy intensive process characterized by high emissions of CO_2.
- Calcination is the most energy intensive step in the lime production process, hence the energy efficiency of the kiln has a large impact on emissions.
- Because of the optimization of the production process, the lime industry has made a lot of progress in terms of energy efficiency, still, lime industry looks at a multitude of ways to reduce energy consumption even further.
- However, lime production is limited by the laws of physics and chemistry. The theoretical minimum energy needed for the chemical reaction which transforms limestone to lime, is 3180 mega joules per ton of lime.
- This number assumes complete conversion of limestone into lime. In reality, not all limestone is converted to lime.

Energy conservation

- The main energy loss through the boundaries of the kiln is the energy loss with the exhaust gases contributing with more than 10 % of the efficiency loss.
- Improvements on both the energy and the energy efficiencies can be achieved through a better control of the operational parameters of the kiln such as limestone / fuel supply ratio, excess of combustion air, size and size distribution of the limestone fed to the kiln, and exit temperature of the lime.

Power Tech Consultants

ISPAT GURU

Energy conservation

- For example, limestone typically contains 1 % of water which evaporates in the kiln and leads to increased energy use.
- Other aspects, such as the specification of the desired lime, grain size, humidity of the limestone, fuel quality and residual CO2 content in the lime product all play a role as well.
- Also, the type of kiln has a major impact on the energy consumption per ton of lime. Long rotary kiln has highest specific energy consumption while PFR kiln has lowest.
- All modern lime calcination plants are equipped with modern, energy efficient technologies.
- Moreover, as the technology evolves, further improved thermal efficiency is going to be achieved, but options are very limited, because of the theoretical minimum energy input needed for calcination reaction.

Energy conservation

- The electricity consumption in lime manufacturing is relatively low.
- Electricity is mainly used for operating some of the kiln equipment and mechanically crushing the limestone.
- Electricity consumption varies, but it is estimated to be around 60 kilowatt hour per ton (kWh/t).
- There is a relatively large quantity of waste heat in the exhaust gases of the shaft kilns, but relatively low temperature and presence of sulphur in the fuel are constraining factors for the recovery of the waste heat.
- Waste heat from the kiln can be used to dry limestone or in the crushing process.
- In addition, the waste heat can be used in other industrial processes in other areas of the steel plant with a heat demand or they can be used to heat buildings and generate electricity.

Power Tech Consultants

ISPAT GURU

CO_2 capture and storage

- Lime production is carbon intensive, however, lime industry is different from several other carbon intensive industries.
- CO_2 emissions from limestone calcination are high by the nature of the calcination reaction.
- The specificity of lime production is because of the fact that only one third of emissions comes from burning fossil fuels to heat the kiln, but the bulk of the emissions come from the chemical reaction which happen during the production process.
- Since close to two thirds of the emissions are linked to these chemical reactions, options to mitigate these emissions are limited without capturing the carbon.
- As per the lime calcination reaction 44 tons of CO_2 is released for every 56 tons of CaO (lime) produced. This combined with CO_2 emissions from heat generation in the process, which is predominantly from fossil fuels, results into a significant CO_2 release.

CO_2 capture and storage

- The release of CO_2 from the calcination process is not possible to avoid but in the heat generation significant reductions in net CO_2 addition to the atmosphere can be made by incorporation of renewable fuels in the process.
- CO_2 emissions efficiencies varies between different lime production technologies. The rotary kiln produces 1.2 ton to 1.8 ton of CO_2 per ton of product. The shaft kiln is more efficient producing around 1 ton to 1.3 ton of CO_2 per ton of product.
- Since PFR kilns have lowest specific consumption of fuel, specific CO_2 generation is also lowest from the PFR kilns
- Because of the fact that the cooling air is not used for combustion in PFR kiln process, the concentration of CO_2 in the kiln off-gases is between 20 % and 23 % and the concentration of oxygen is between 7 % and 11 %.

Power Tech Consultants

ISPAT GURU

CO_2 capture and storage

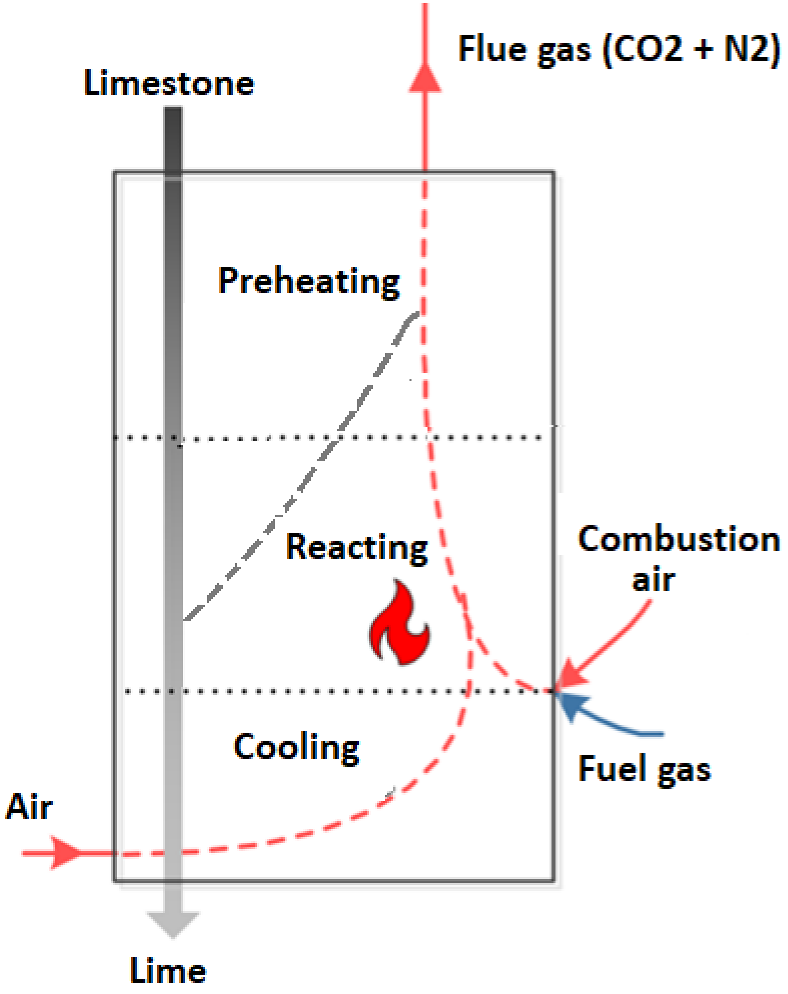
- There are several ways to reduce CO_2 emissions from combustion and from the lime product
- Reduction in combustion emissions can be reduced by (i) increased energy efficiency, (ii) fuel switch to low carbon fuels, (iii) fuel switch to non-fossil fuels, (iv) pre-combustion and post-combustion capture of CO_2 with storage or utilization, and (v) capture of CO_2 through oxy-fuel combustion with storage or utilization.
- Reduction in lime product emissions can be achieved by (i) post-combustion capture of CO_2 with storage or utilization, and (ii) capture of CO_2 through oxy-fuel combustion with storage or utilization.
- To achieve a near zero CO_2 emission in a lime plant, carbon capture technology with storage or utilization are the only viable options because of the CO_2 released from the process.

Power Tech Consultants

ISPAT GURU

CO2 capture and storage

- In conventional lime calcination processes, because of fuel combustion in the kiln, the CO_2 from limestone decomposition is mixed with the gas generated because of the fuel combustion in the kiln which forms flue gas.
- Hence, the purity needed for CO_2 transportation and storage cannot be achieved since the flue gas contains a large quantity of nitrogen. In case of PFR kilns, oxygen is also there in flue gas. Because of this, CO_2 capture needs a gas separation device which consumes a considerable quantity of separation energy.

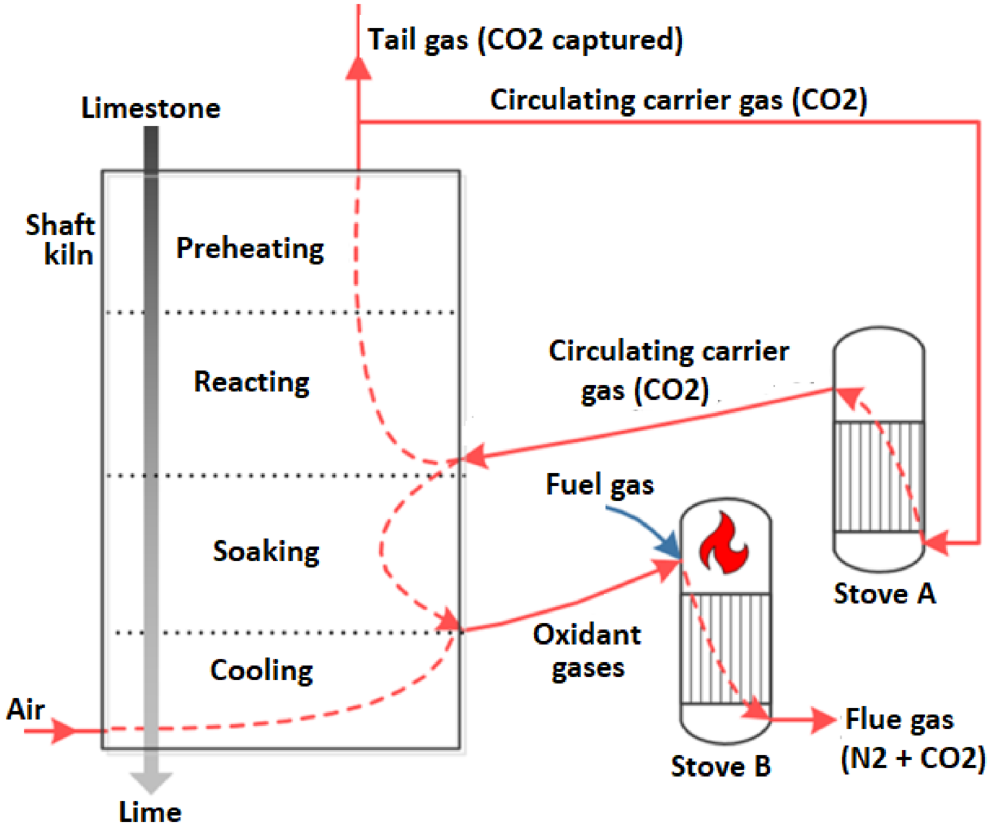


Power Tech Consultants

ISPAT GURU

CO2 capture and storage

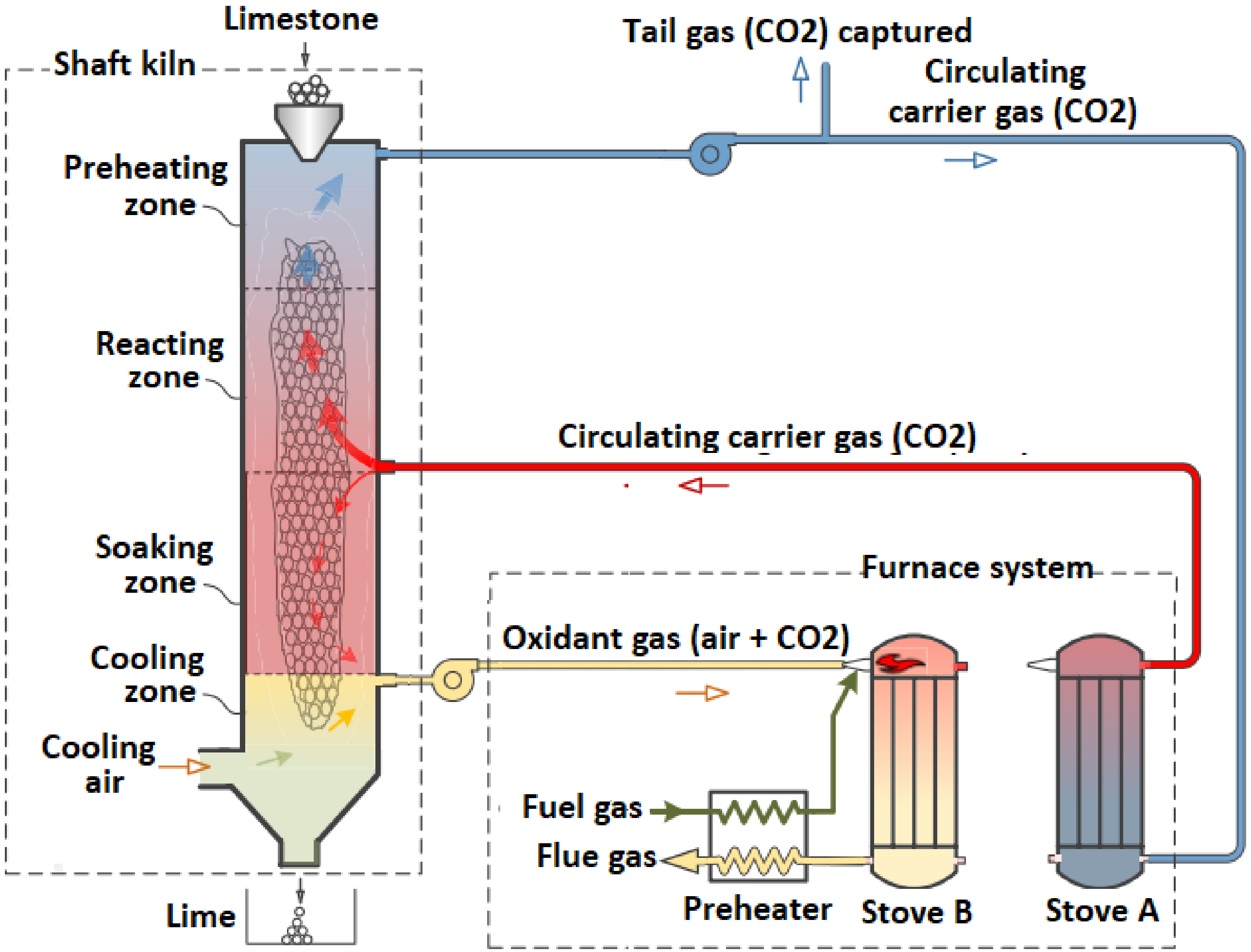
- A new lime calcination process with carrier gas heating and air cooling, as shown in figure is being developed.
- On the one hand, to avoid mixing the CO_2 from limestone decomposition with the flue gas of fuel combustion, the CO_2 used as the circulating carrier gas is used for heating the limestone.
- On the other hand, to avoid the carbonation of lime as well as to recover the heat carried by the lime, the air is used for cooling the hot lime.
- Hence, while obtaining qualified lime products, the tail gas of the new process is expected to be pure CO_2.
- As a result, the CO_2 from limestone decomposition, which accounts for around 70 % of the total carbon emission in lime production, can be directly captured without separation of nitrogen and CO_2.



Power Tech Consultants

ISPAT GURU

CO2 capture and storage



Flow scheme of the new lime calcining system

CO_2 capture and storage

- The principle of the reduction in CO_2 emissions of the new process is obvious, but its energy consumption needs to be clarified. In the new process, the partial pressure of CO_2 in the kiln is about five times that of conventional calcination, which means the new process has a greater initial temperature of limestone decomposition.
- Because of this, the temperature of the carrier gas discharged from the kiln top increases and can increase energy consumption.

CO2 capture and storage

- The new process has envisioned to a new system from the standpoint of industrial practice, which consists of a new shaft kiln with four processing zones and a furnace system.
- The shaft kiln is used to convert limestone to lime, and the furnace system is used to provide the heat needed for the conversion process.
- Compared with a conventional one, the new shaft kiln includes a soaking zone.
- Limestone enters the shaft kiln from the kiln top and slowly travels under gravity. Lime is formed and discharged from the bottom of the shaft kiln after preheating, reacting (decomposition), soaking, and cooling.
- The heat needed for the limestone decomposition reaction is carried into the shaft kiln from the furnace system by a circulating carrier gas.
- Majority of the circulating carrier gas enters the reacting zone, and a small part of the circulating carrier gas enters the soaking zone.

CO_2 capture and storage

- In the reacting zone, the rising carrier gas heats the limestone, and the limestone is heated and converted to lime and CO_2 is released.
- As a result, the temperature of the carrier gas along its flow direction gradually decreases and the mass flow rate gradually increases.
- The rising carrier gas continues to enter the preheating zone and preheat the limestone, but the limestone temperature does not reach the initial decomposition temperature.
- In the preheating zone, the temperature of the carrier gas gradually decreases along its flow direction but the mass flow rate remains unchanged.
- At the kiln top, part of the carrier gas is discharged as the tail gas and the rest of the carrier gas is recovered by a high-temperature blower and sent to the furnace system (stove-A) as the circulating carrier gas.

CO_2 capture and storage

- In the soaking zone, the heat conduction occurs in the material because of the temperature gradient in the material.
- The temperature gradient in the material gradually decreases until the temperature is evenly distributed.
- The carrier gas flows along the direction of the movement of the material and exchanges heat with the material.
- As a result, the carrier gas temperature gradually decreases so that it is equal to the material temperature and finally exits the shaft kiln from the bottom of the soaking zone.
- In the cooling zone, the air cools the material, and the air temperature gradually increases but its mass flow rate remains unchanged and finally exits the shaft kiln from the top of the cooling zone.
- The carrier gas discharged from the bottom of the soaking zone and the hot air discharged from the top of the cooling zone are mixed to form an oxidant gas and sent to the furnace system (stove B), thereby completing the entire cycle.

CO_2 capture and storage

- The new process has several advantages over the conventional process.
- The CO_2 generated from the limestone decomposition process is used as the carrier gas, hence, a tail gas with high-purity CO_2 can be obtained and captured, while the lime is cooled by the air to avoid carbonation.
- The heat is provided by combustion outside the shaft kiln, and hence, the flame and the harmful products of the fuel combustion do not contact the material, which improves the quality of the lime.
- By including the soaking zone, the cooling air is prevented from being mixed with the carrier gas in the reacting and cooling zones, hence, ensuring the purity of carrier gas.

CO_2 capture and storage

- Another promising technology for CCS (carbon capture and storage) is a pre-study performed by CEMENTA and Vattenfall where they show that it appears to be technically feasible to utilize electricity through plasma technology.
- The aim of this process is to produce a high CO_2 concentration in the flue gas which facilitates the capture of CO_2. Although, this is a costly method and expected to greatly increase the cost of lime production compared to conventional technologies. Another challenge to this technology is that it is electricity intensive.

Power Tech Consultants

ISPAT GURU

CO2 capture and storage

- Electricity can theoretically be used in the future to heat kilns.
- However, with present and foreseen power prices, this option is not economically viable. Moreover, this option is not yet technically feasible for the moment and needs further research.
- Solar heat can potentially be used to heat the kilns but they have to be heated to at least 900 deg C. High temperature Central Receiver Systems (CRS) with pressurized air can reach temperatures up to 1,000 deg C. However, this technology is still in an experimental phase, and needs further research.