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A Review on Design and Thermal Analysis of Rotary Kiln for Lime Production

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Abstract— In this paper, thermal energy analysis of three zones of a lime production process, which are preheater, rotary kiln and cooler, is performed. In order to perform a proper quantitative estimation, the system was modeled using energy balance equations including coupled heat transfer and chemical reaction mechanisms. The complex nature of the lime calcining process with its long time delays, variable feed characteristics, changing operating conditions, non-linear chemical and thermal reaction rates makes the rotary lime kiln difficult to operate The thermal stress of cement burner is analyzed in finite element simulation through the ANSYS to simulate the temperature field and thermal stress field of the cement burner in actual use. Based on the simulation results, this paper puts forward the damage reason of the cement burner and inferences its damage form. The operational efficiency of the kiln is based on various parameters like inclination angle, temperature, rotation speed, material flow rate and discharge rate. This paper briefly discusses the various industrial application of the rotary kiln in various sectors considering the vital factors

Keywords- *Rotary Kiln, Dryer, Incinerator, Heat Treatment.*

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I. INTRODUCTION

A lime kiln is used to produce quicklime through the calcination of limestone (calcium carbonate). The chemical equation for this reaction is

$CaCO_3 + heat \rightarrow CaO + CO_2$

This reaction takes place at 900 °C (at which temperature the partial pressure of CO_2 is 1 atmosphere), but a temperature around 1000 °C (at which temperature the partial pressure of CO_2 is 3.8 atmospheres) is usually used to make the reaction proceed quickly. Excessive temperature is avoided because it produces unreactive "dead-burned" lime. Rotary lime kilns are large steel tubes that are lined on the inside with refractory bricks. They are slightly inclined from the horizontal and are slowly rotated on a set of riding rings. Lime mud is introduced at the uphill, feed end and slowly makes its way to the discharge end due to the inclination and rotation. A burner is installed at the downhill or discharge end of the kiln where fuel is burned to form an approximately cylindrical flame Heat transfer from this flame and the hot combustion gases that flow up the kiln dries, heats, and calcines the counter-flowing lime solids[1].

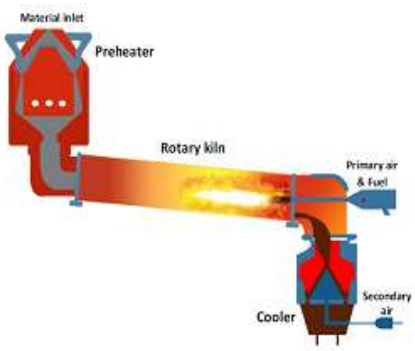

Fig. 1. Schematic view of the lime production process.

The lime industry is actively engaged and committed to sustainable development—a philosophy that focuses on meeting our construction needs today without depleting future resources. Limestone industry production process has a big impact on the environment which is why a lot of investment projects headed in this direction. Process automation and information technology are industrial areas which offer the biggest and most satisfying challenges in terms of combining traditional engineering skills with technological innovation. The demands on cement industry in relation to productivity, quality and price, means an ever increasing need to improve the quality products, to productivity increase improvement of products quality, modernization of the technological flow and environmental quality[2]. Each method has its merits and demerits. The merits of vertical shaft kiln include: (a) Simplicity of construction and operation (b) Low initial cost (c) High thermal efficiency (d) High volumetric efficiency (e) Minimum decrepitation of solid products and minimum erosion of refractory linings due to slight movement of particles relative to each other Rotary kilns (Figure 1) are used for a range of mineral processing operations. Kilns range in size from 2–6 m in diameter and can be 50–225 m long with an operating mass of up to 3000 t. Two of the most common applications are for cement production and sponge iron production. Hatch has developed a proprietary one-dimensional kiln model to evaluate designs for clients. This tool has been utilized for a variety of pyrometallurgical applications including ferrovanadium, nickel carbonate, nickel laterite, iron ore reduction, and spodumene (lithium) production. In this paper the direct reduction of iron ore to sponge iron is used as an example. Numerical optimization techniques are ideally suited to automate the calculations and allow the analyst to investigate a large number of scenarios and goal functions.

The goals of lime kiln automation are:
- improve lime quality
- increase kiln production
- improve fuel efficiency
- increase refractory life
- improve kiln information gathering and processing

In most lime kilns these goals are not being met because:
- process sensors are unreliable and inaccurate,

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• the instrument loop controllers used cannot maintain the process variables at the set points,

• accurate, dynamic kiln process models that can automatically calculate and adjust kiln set points to produce quality lime at optimum efficiency have not been developed.

• kiln operators have varying and sometimes conflicting operating methods that prevent efficient and stable kiln operation from one shift to the next,

• long process time delays, particularly with respect to product temperature control, make operation of the kiln difficult because operators must remember their past actions for several hours in order to correctly interpret current kiln conditions[3].

A. Cement Kiln

In cement manufacturing industry cement clinker is produced from caco3 by using rotary kiln of length 63m and 4.3m in diameter with an average production capacity of 3000tonnes per day. The initial temperature while entering decomposition zone is 850°C then increased to 900°C and 1450°C while entering transition zone and sintering process zone and final temperature of sintering zone is 1300°C and different types of alternative fuels were used in these cement kiln for combustion . Incement kiln chrome-free brick with the addition of TiO2 is improved all properties as well as the coating ability and corrosion resistance of the brick that exhibit a good thermal stability and an excellent chemical resistance clinker raw meal. This brick has qualities needed in the hot zone of rotary cement kiln . The cement is made of clinker and grinded gypsum and produced from a burned mixture of limestone and clay, for this process rotary kiln is used for making cement clinker. The length of the kiln is 124.4m and inner diameter is 4.2m with 4% slope[4] .

B. Calcination

The limestone calcination as energy intensive production process from unhydrated lime is often performed in continuously operating rotary kiln through the chemical reactions takes place in the bed of raw material as well as in the gas phase . Inclined kiln is used to produce sodium metasilicate from Soda – Ash and produce calcined product of lime and dolomite in glass melting . Large amount of Sugar – Ash materials are produced as a by-product in the sugar industry. These materials can be re – cycled with the use of rotary kiln in the lime industry at calcinations temperature in the zone of 950 - 1000°C . According to Les Edwards, Rotary kiln have been used successfully for many years to produce calcined coke for the aluminium industry. Calcinations process is performed in rotary kiln with the temperature around 1350°C. Retention time depends on the size of the limestone as well as calcination temperature. In this calcinations process both vertical and horizontal kilns were used. On vertical kilns, the limestone moves downward and the hot gases flow upward through the limestone. These kilns usually use limestone sizes between 0.13 to 0.2m and operating temperature is between 900 to 1000°C. Vertical kilns are fuel efficient but limited in capacity. On horizontal kilns, the kiln body rotates allowing the limestone to tumble and exposing all of the surfaces to hot gases. These kilns usually use limestone size varying between 0.04 to 0.05m which allows for quick heating and short residence time but the ideal size for calcining limestone is between 0.0125 to 0.02m . Calcinations of limestone has been carried out in a rotary kiln under certain operating variables such as limestone type, feedrate, rotational speed, inclination angle. In this process limestone feedrate has the strongest effect on the temperature and calcinations fields where as inclination angle and rotation speed are relatively less important. The physical parameters of the kiln are 5.5m long, 0.61m OD and 0.406ID. The kiln is lined with 0.092m of plicast tufflite over a 0.002m layer of insulating fibre . Kiln is used for the calcination of calcium carbonate (limestone) in the regeneration of Kraft pulping chemicals and in the production of industrial calcium oxide (quicklime)[5].

C. Manufacturing

A rotary kiln is used in iron manufacturing industry which has two zones namely preheating zone and reduction zone and can mix the solid charge as it heats and reduces the simultaneous mixing which helps in the dilution of CO2 concentration formed around the iron ore particles. In ironmaking plant direct reduction rotary kiln is used for the prereduction of the titani-ferous iron ore. The hot prereduced iron is discharged at a temperature of about 1100˚C in to kiln hoppers. The similar type of rotary kiln is used for making aluminium in aluminium remelting plant from aluminium scrap. The length of the kiln is 4.8m and diameter is 3.5m with 5 to 35° inclination. Aluminium scrap is charged and liquid aluminium is discharged through the front aperture with the melting capacity of 4T aluminium scrap per hour but filling capacity is 8T per hour. Rotary kiln is also used in the production of sarooj with 200kg/hr production capacity by burning specific clay soil that posses adequate quantity of silica, alumina, and iron oxides. The external diameter of the kiln is 1.2m, overall length of the kiln is 3.17m, and operating temperature is 750°C, material feed rate is 200kg/hr with speed of rotation of cylinder is 30rpm Rotary kiln is also used in pellet induration process, a complex process in pellet production under the premises of the maximum productivity and minimum fuel consumption with sufficient mechanical strength and thermal stability . A pilot rotary kiln, used to manufacture activated carbon from eucalyptus wood, length of the kiln is 3.7m internal and external 0.30m and 0.60m with 2 to 6° slope and rotation speed is 1 to 3 rpm. The processing temperature is between 800-1100°C . Kiln is used for mixing of glass powder slurries in concrete manufacturing to improve mechanical properties[6].

D. Incinerator

Rotary kiln is used as waste incinerator, the cylinder is mounted at an angle of 1-2° and rotates at a speed of 0.2 to 0.3rpm, and diameter is 4.2m and 11.4m length. Two types of hazardous wastes are incinerated in the rotary kiln system having high caloric waste such as waste oil and solvents, with a calorific value of roughly 30MJ/kg and having low caloric waste an average value of 9 to 10MJ/kg. The burning temperature of the waste inside the kiln wall is 1200°C, mixing temperature of 1250°C and solid bed temperature of 3157°C with mass flow rate of 12.5kg/s Plasma combustion of hazardous medical waste process is done by using kiln with direct motion of burning hazardous medical waste and

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incandescent gases with the capacity of 150-200kg/hr. About 60% of organic part of the waste burn in this process. According to M.J.Gazquez.et.al rotary kiln is used for the removal of waste content and trace amount of sulphur from TiO2. Rotary kiln is used for refining of used oil generated from automotive industries in this refining process kiln is used as incinerator[7].

E. Thermal Processing

The broad application of the rotary kilns in a variety of industrial branches for thermal processing of residual materials with a different origin and mostly for fire treatment of hazardous wastes . The rotary kilns were used as rotary dryer to remove moisture and water from solid substances (olive stones), primarily by introducing hot gases into a cylinder, it act as a conveying device and stirrer. After the first extraction of olive oil from olive stone, still that contains oil which can be chemically subtracted by the drying process. The processing temperature is 427°C and cylinder inclination is 2°. Around 8 to 10% of moisture gets reduced by this process . Followed by this rotary kiln is used as a dryer for yerba mate heat treatment processing. The length of the kiln is 9.6m and internal diameter is 2.57m, the inclination of the cylinder is 60° with respect to horizontal axis. Material feed rate is 0.282kg/s and processing temperature is 120°C. Rotation speed of the cylinder is 10rpm . D.Peinado.et.al, reviewed that rotary kiln is used as a dryer employed in a hot mix asphalt (HMA) plant for heating and drying of the aggregates. The operating temperature is between 150°C and 200°C. For drying magnesite ore rotary kiln is used as a dryer with operating temperature of 100°C[8] .

F. Pyrolyser

The main purpose of a rotary kiln pyrolyser is to convert olive pits into char fated to the production of activated char. The capacity of plant is about 2000kg/hr of wet olive pit, distribution of pyrolysis products as function of the process temperature (50 - 750°C) at fixed biomass with flow rate of 1700kg/hr. operating temperature of 300 - 400°C and higher operating temperature is 800 to 900°C, length of the kiln is 20m and internal diameter is 1.6m. Rotary kiln is used for recycling of waste composite material (thermoset – based polymer composites) collected from the products such as automobiles, wind turbines and aircrafts . Rotary kiln is also used for transforming solid biomass into useful liquid and gaseous fuel in this process rotary kiln act as pyrolyser. The inclination of cylinder is of few degrees, with internal fins which help to mix and rotate the biomass in radial direction. The rotational speed of the cylinder is 10 to 100rpm and reaction temperature is above 350°C[9] .

II. GEOMETRICAL AND PROCESS PARAMETERS OF ROTARY KILN

the table. 1 based on the review done in this paper. The geometrical size of the kiln is based on the requirement of
production capacity. Fig. 3 illustrates the usage level of the rotary kiln in various applications

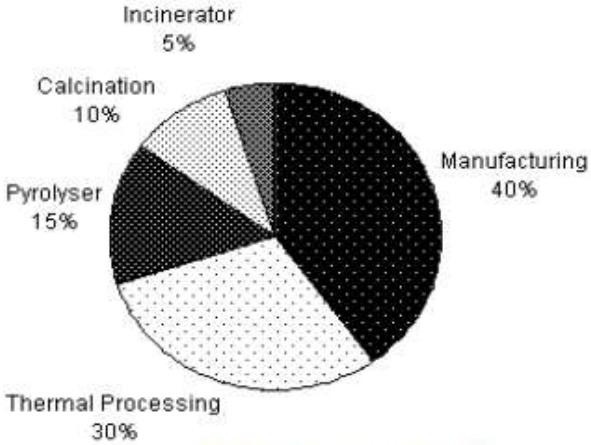

Fig.3. Allocation of application levels

Table 1: Geometrical and process parameters of rotary kilns in various processes

From the review it can be inferred that 40% is used in manufacturing sector, 30% is used in thermal processing applications, 15% is used as a pyrolyser, 10% is used for calcinations and 5% is used as an incinerator[10].

III. PROCESS DESCRIPTION

lime production process consists of three zones, preheater, rotary kiln and cooler. Limestone (CaCO3) is charged into the preheater and heated with the counter current combustion products. Then, preheated materials enter the rotary kiln. Rotation of the cylindrical kiln and its inclination forces the materials to move slowly with homogeneous temperature to the kiln outlet. A gas burner resides at the end of the rotary kiln. Limestone absorbs heat by convective and radiative modes, and after reaching calcinations temperature, it will be decomposed to lime (CaO) and carbon di-oxide (CO2). The thermal energy produced by a natural gas burner is mainly consumed in the calcination reaction. Reaching the outlet of the rotary kiln, the material is discharged into the cooler where lime is cooledand the secondary air is preheater[11]

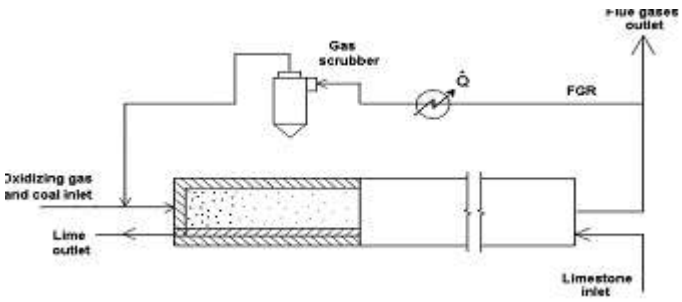

Fig. Process Description

IV. KILN AUTOMATION SYSTEM

The kiln automation system was developed to address many of the problems that hinder proper kiln operation. Four elements were identified as being essential for the successful automation of a lime kiln. They are the need for:

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• Accurate and reliable process sensors for all key kiln parameters,

• Instrument loop controllers that will automatically and continuously maintain kiln variables at their set point under all operating conditions. The controllers must be able to handle non-linear process characteristics that change over time and have long time lags,

• A supervisory control system that will adjust the instrument controller set points to maximize production of quality lime using the least possible amount of fuel,

• 141A production database to analyze kiln performance[12].

The ability to accurately measure and report kiln performance makes management information readily available and the evaluation of kiln performance possible. It also permits on-line kiln quality control analysis to be carried out and further enhancements in kiln operation to be implemented.

Process Sensors

All the required process sensors have been available on most kilns for a number of years. However, most mills do not have sensors that are accurate and available on a continuous basis. There are several reasons for this situation:

• Instruments have not been properly installed to give reliable operation,
• Instruments have not been maintained in good working order,
• Instrument signals that have a high noise component which most controllers are unable to effectively filter out,
• instruments whose failure mode is not recognized by many lime kiln controllers or operators[13].

No kiln automation system can function unless all the required sensors are kept in good working order. It is pointless to proceed with a kiln automation project unless there is a commitment to upgrade and maintain the kiln process sensors.

V. APPLICATIONS

A rotary kiln is a cylinder that rotates around its cylindrical axis and essentially operates as a device to exchange heat. The direct heated rotary kiln is broadly used for physical activation. Construction and position alignment of the kiln is very important for all the process. In thermal processing of residual materials with a various origin and predominantly for fire treatment of hazardous wastes rotary kiln are employed. In metallurgy they serve for heating of solid particles like oxide ores reduction, limestone calcination, cleaning of swarfs from machine oil. Furthermore, these units find a large application in the silicate, chemical and pharmaceutical industry also used as an incinerator and pyrolyser in minerals, metallurgical, cement, sugar and food industries. In these sectors they are used mainly for heating and drying of bulk materials with different dimension[14].

Rotary kilns find its numerous industrial applications in the field of waste lime recovery, proppent manufacture, activated carbon manufacture, sugar industry, food processing, pulp and paper industry, clays, thermal desorption of organic/hazardous wastes, mineral roasting, specialty ceramics, plastic processing, gypsum calcining, Tire pyrolysis, bauxite calcining, pigments, catalysts, phosphate production.

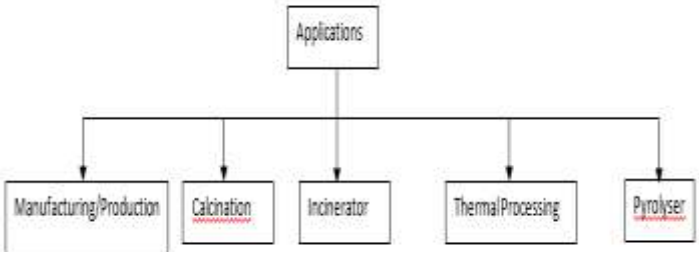

Fig.2. Various industrial applications of rotary kiln

VI. CONCLUSION

Longer residence time inside the preheated will recover more energy from outlet gases and will use this energy to increase temperature and calcinations percentage of preheated material. Increasing residence time inside the cooler is more effective than other zones of the lime production process. For instance, a 5-min increase in residence time inside the cooler has the same effect as a 10-min increase in residence time inside the preheated or rotary kiln: 3% fuel saving. The stress values are much less than the material yield strength hence within the safe working limits. It should be noted that since the kiln equipment is always under continuous use experiencing rotations with raw material load and inclined, the stress distribution is no longer uniform hence minimal gradual failure

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