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Analysis of cement production process and review of control strategies and methods

Abstract. To develop an effective control mechanism for any industrial process it is imperative to have a deep and wide ranging understanding of the process itself. This is especially true in the case of a cement grinding circuits, which is a very complex process with very complex dynamics and multivariable environment, where all the elements are interconnected. This article is aimed at providing an in-depth analysis of the cement production process in Ghana, which is mainly limited to grinding clinker into cement and its packaging and distributing. The main equipment of grinding circuits is described and the best configurations are discussed. The second part of the article discusses the most popular control methods in use for cement grinding circuits at cement plants all over the world and the ways to select the most effective control strategies for achieving higher production rates and more efficient energy use. The control strategies used by GHACEM, the largest Ghana cement producer, are also discussed.

Keywords: control; cement grinding circuit; algorithm ;control strategy; ball mill; grinding; industrial processes.

Ghana has been one of Africa's fastest growing economies over the past decade. Between 2000 and 2009, gross domestic product (GDP) per capita rose by 63% [3, 8]. If the growth rates of the past decade are projected forward, the much-discussed aim of Ghana becoming a middle-income country in the near future looks plausible. The recent discoveries of oil make this goal seem even more achievable. However, if such growth rates are to be maintained, Ghana will almost certainly need to undergo a major advance in terms of its industrial capabilities. The best point of departure to see what is needed is to ask what Ghana's current industrial capabilities are and where those capabilities came from.

The construction industry in Ghana, as in other parts of the world, is huge and a crucial segment in economic development.

No matter what one does, there is construction, as it cuts across all sectors. Being among the top drivers of the Ghanaian economy, including agriculture, manufacturing and mining, its importance cannot be overemphasized, especially as the country is one of the most active economically in West Africa.

From a low point in the 1970s and 1980s, the share of construction in the GDP has moved up from 4.5% in 1975 to 8.5% by the turn of the century and has been doing about the same levels since. The sector grew by 10% in 2008 but registered a negative growth rate of 1% in 2009 due to the global economic recession [3].

The rapid growth of the construction sector has led to increasing demand for cement over the past decade. The contribution of the construction sector to GDP rose from US$1.1 billion in 2006 to US$2.5 billion in 2010.Demand for Portland cement was estimated to be about 4.5 million mt in 2009.1 Demand increased to 4.8 million mt in 2010 and is forecast to rise further to 5.5 million mt in 2012. This represents an annual growth rate of 7.0%. [8]

Table 1

Cement demand and production forecast

YEAR	TOTAL DEMAND(MT)	TOTAL PRODUCTION(MT)	DEFICIT(MT)
2008	4239666	2400000	1839666
2009	4536442	2400000	2136442
2010	4883994	2400000	2483994
2011	5193773	3400000	1793773
2012	5557335	3400000	2157335
2013	6330543	4400000	1930543
2014	7003675	4400000	2603675

From the analysis of table 1, it is clear that demand far outstrips supply. The shortfall is estimated at around 2 million metric tons. This deficit is met with imports from other countries including Nigeria and China, in the last few years.

Structure of the cement industry

Ghana has a very large cement grinding capacity, which is led by GHACEM, a unit of Norway's SCANCEM that is, in turn, part of Germany's HEIDELBERGCEMENT.

Prior to the market liberalization of 2000, the cement industry was a monopoly, with Ghana Cement Works Limited (GHACEM) as the only domestic producer. There are now three domestic producers. Two of the plants are based in the south of the country and the other in the north. GHACEM has two plants, at Tema and Takoradi, with a total production capacity of about 2.4 million mt; and Diamond Cement has a grinding mill located in the Volta region with a capacity of 1.2 million mt. Savanna Cement Ghana Limited, a fully integrated plant with a plant capacity of 300,000 mt, is located in the Northern region. Its clinker production unit began operating by March 2012. The main issues facing the industry are high utility tariffs especially for electricity, power outages and the high cost of fuel. Demand for cement in Ghana has been outrunning supply. One producer is now aiming to increase its production capacity by 1 million mt per annum through the installation of additional plant and the upgrading of its packing facility

The company produces two main types of cement, both of which are supplied in bulk and in bags.

Analysis of cement production in Ghana

The cement production process in Ghana is different from that of more conventional cement producing counties in the world in that Clinker and gypsum are imported, while limestone is sourced locally. GHACEM, which is the largest of the producers, uses about 24% local limestone as filler, following ISO specifications for the production of cement.

GHACEM imports clinker and gypsum from Spain and China. The imported clinker and other products are stored in cement silos before they are sent to the grinding circuits with the help of the bulk-handling crane as shown in figure 1. In order to achieve the desired setting qualities in the finished product, a quantity (2–8%, but typically 5%) of calcium sulfate (usually gypsum or anhydrite) is added to the clinker and the mixture is finely ground to form the finished cement powder. This is achieved in a cement mill, which is described in more detail in the next section.

Approximately 75% of the feed to the cement grinding circuit are clinker and the rest of the feed are “additives” which includes grinding aids. The surface area or the Blaine index measures the quality of cement. The unit of the Blaine index is m^2/kg, and this index is determined by the Blaine air permeability test. The surface area of the cement powder depends on size distribution of cement particles; smaller particles have larger surface area. If the particle size distribution is known, the Blaine index can be successfully predicted.

The cement clinker grinding circuit reduces the feed from 80% passing size between 10 and 20 mm to 100% passing 90 microns. The size reduction takes place in a two- compartment ball mill; the first compartment of the mill is shorter than the second compartment. The coarse clinker is ground in the first compartment where larger balls (80, 60, 50 mm) are used and the fine grinding is done in the second compartment where smaller balls (below 25 mm) are used. A diaphragm separates the two compartments and allows only particles below a certain size to pass to the second compartment. Ground material exits the mill through the discharge grate, which prevents grinding balls from leaving the mill. A proportion of material, mostly fines, is “air-swept” out of the mill. The final product is the fine fraction of the air classifier and the coarse fraction returns to the mill.

The grinding process is controlled to obtain a powder with a broad particle size range, in which typically 15% by mass consists of particles below 5μm diameter, and 5% of particles above 45 μm. The measure of fineness usually used is the "specific surface area", which is the total particle surface area of a unit mass of cement. The cement is either delivered to end-users in bags or as bulk powder blown from a pressure vehicle into the customer's silo. This process is represented in the flow diagram below describing the cement production process in Ghana.

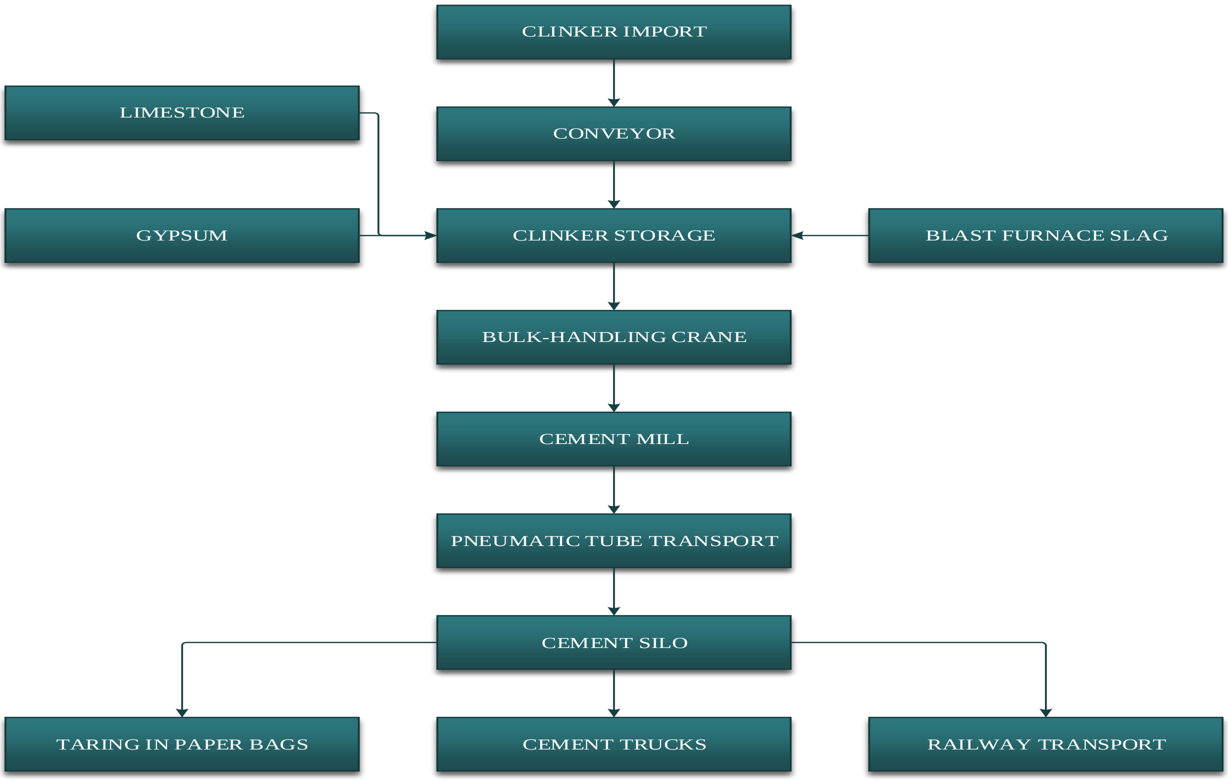

Fig. 1. *Cement production process in Ghana*

This grinding and packaging process, which is graphically represented in Figure 2 below, illustrate the cement production process in Ghana from the clinker storage stage to the point where the finished product is sent to the market.

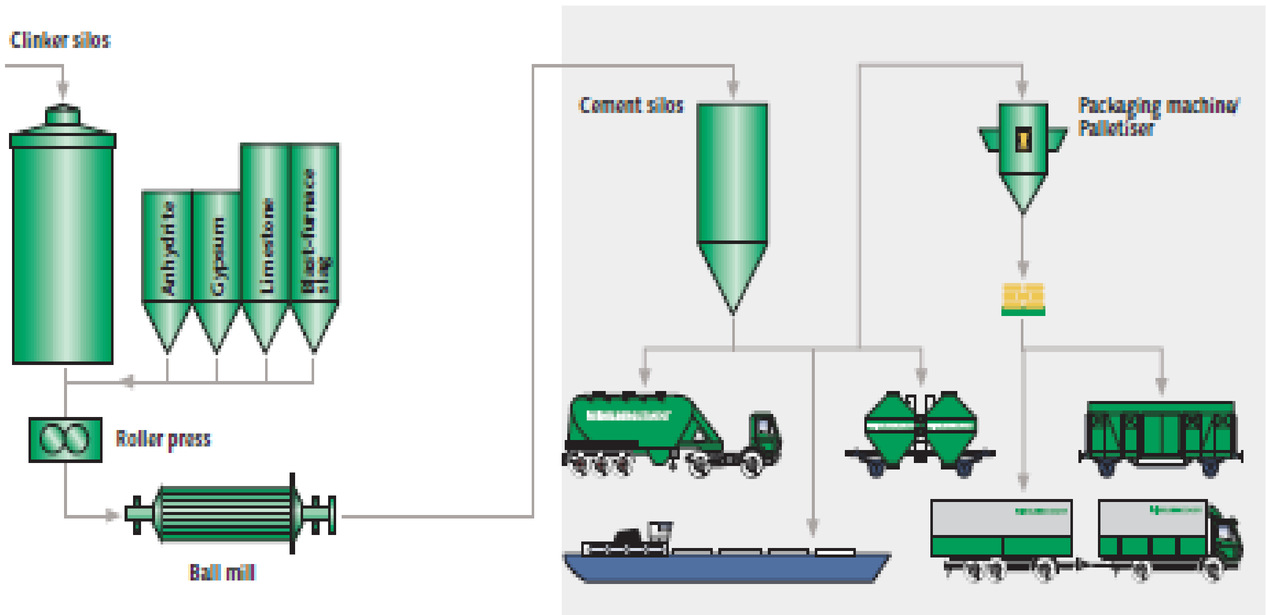

Fig. 2. *Technological of GHACEM Cement production plant*

Ball mill grinding circuit

The most common equipment for cement grinding is a ball mill – a horizontal steel tube filled with steel balls [1]. Material fed through the mill is crushed by impact and ground by attrition between the balls. For increased efficiency, the closed-circuit systems are widely used in cement grinding, in which the material exiting the ball mill is directed to the separator and divided into coarse and fine fractions. The coarse fraction is sent to the mill's inlet for regrind, whereas the fine fraction becomes the cement.

The grinding of clinker in the cement industry of Ghana is done using ball mills. Multi-tube ball mill measuring 3.2 x 15 m is used for fine crushing of limestone, marl, clinker, coal, chemical and ceramic raw materials, and other materials and ores. There are several configuration of the ball mill grinding circuit which are shown in Figure 3 below

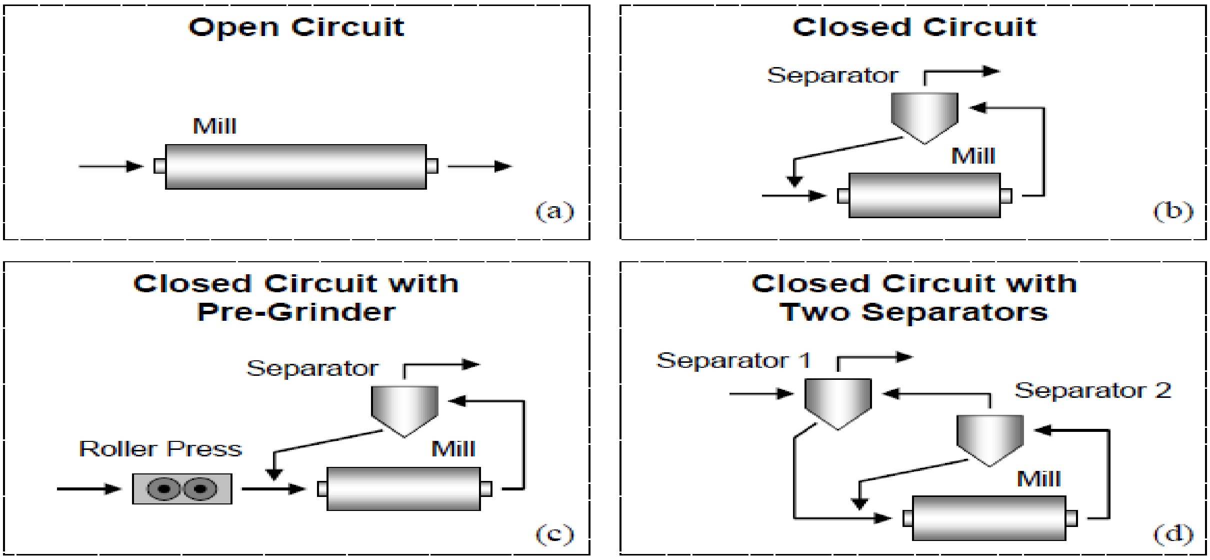

***Fig. 3.** Ball mill grinding circuit configurations*

In the open grinding circuit shown in Figure 3(a), clinker is fed into the mill, and the discharged material directly becomes the final product. Since all the clinker material should be reduced in size in just one pass, longer tube mills prevail in the open circuit installations and have a length-to-diameter ratio between 3.0 and 6.0. The open circuit has a tendency for over-grinding and allows for virtually no fineness control, as its only adjustable process parameters are the feed rate and the airflow through the mill [5].

A much higher efficiency and better process control are achieved when grinding in a closed circuit [2]). The main principal behind the closed circuit operation is to apply the grinding forces only to the coarse particles and to discharge the fine ones as soon as they have been reduced to the required size. For this, the closed circuits utilize separators and require shorter mills [7].

In the most common closed circuit shown in Figure 3(b), clinker along with additives first enters the ball mill, after which the ground material is divided by the separator into two fractions. The coarser fraction is sent back to the mill for an additional cycle of grinding, whereas the finer fraction becomes the final product.

More advanced types of closed circuits may include pre-grinders and multiple separators as shown in Figure 3(c) and 3(d). The latter configuration with two separators is used when the feed material already consists of many fines, which should be removed before introducing the feed to the mill [10].

The rest of the discussion will be devoted to the closed finish milling circuit shown in Figure 3(b). Being the most common circuit applied in the cement, it is implemented at the pilot cement plant and has generated the field data used in this dissertation.

The closed grinding circuit is comprised of four basic pieces of equipment: feeder, mill, elevator, and separator.

While the mill is performing the grinding work, the separator removes the finer particles from the mill discharge and prevents them from being over-ground, thereby, saving energy. By extracting part of the material from the grinding process, the separator creates vacant space inside the mill allowing more fresh clinker to enter the mill, and thus increases the production rate. The operation of the circuit is characterized by several parameters that are closely monitored at the plant. Fresh feed rate is a measure of the production rate and equals the cement flow rate. By sheer mass balance, the two values must be equal since neither accumulation nor generation of a new material takes place inside the circuit. During a steady-state operation, the feed rate also determines the filling degree of the mill, influences the grinding efficiency of the Process.

Table 2

Technical characteristics of ball-tube mill

Tube Ball Mill		Compartment	
		1	2
Outside Diameter	[m]	3.8	
Outside Length	[m]	15	
L/D Ratio	[–]	3.29	
Internal Diameter	[m]	3.61	3.69
Internal Length	[m]	7.64	8.13
Filling Degree	[%]	28.4	35.0
Charge Weight	[t]	47	142
Grinding media sizes	[mm]	Ø 50-80	Ø 18-25
Mill Motor Power	[kW]	2,611	
Mill Speed	[Rpm]	17.2	
Relative Speed	[%]	79.3	
Mill Air Flow	[m^3/h]	39,700	
Fan Motor Power	[kW]	150	
Production Rate	[Tph]	60*	

Table 3

Technical characteristics of High Efficiency Separator

High Efficiency Separator		
Casing Diameter	[m]	3.35
Rotor Diameter	[m]	1.69
Rotor Height	[m]	1.64
D/H Ratio	[–]	1.03
Separator Motor	[kW]	224
Separator Air Flow	[m3/h]	109,000
Fan Motor Power	[kW]	296
Cyclones (No. × Diam.)	[m]	4 × 2.4

The technical characteristics of the ball mill and the high efficiency separator are listed in tables 2 and table 3 respectively.

Control of Grinding Process

Process control is an essential part of the cement milling system. All new cement plants built today have a digital control system that provides all basic control operations through a computer interface. In most cases, new plants also acquire advanced control applications that enable automatic process control and analysis of the plant's operation in real time. Development of an effective control strategy requires a good knowledge of the dynamics of the milling circuit. The common approach in analysis tends to isolate different stages of the grinding process so that cause and effect can be clearly defined [11, 13, and 14].

However, the reality of cement production is that it involves a complex multivariable environment, where all the elements are interconnected. That is why a well-formulated mathematical model is an essential tool in understanding the operation of the grinding circuit as a system.

The advantages attributed to automation include higher production rates and more efficient use of energy. In addition, the automated systems typically govern the manufacturing process with less variability than human operators, which results in tighter control and consistency of the final product quality.

An effective process control system consists of:

- Instrumentation
- Hardware peripherals
- Control strategy

The field instrumentation measures the process value, the strategy compares this value with the target value and orders the hardware peripherals to open or close the "valve" that affects the observed process signal. The essence of any control strategy is the mathematical representation of the grinding circuit. The purpose of the control strategy is to determine what control variable to change, in what direction (decrease or increase), and how much [6]. The control strategies is divided into three categories:

- Regulatory
- Supervisory
- Optimizing

Developing an effective control of a grinding circuit is a complex undertaking due to many factors. The process is fraught with inaccuracies and has a lot of interacting process variables with substantially different dynamics, as well the influence of unmeasured disturbances and large time delays, rough operating conditions and inability to use precise and reliable sensors [10].

However, an efficient control of the process is of great importance for increasing the productivity of the circuit and quality of the final product as well as for a significant reduction of the production costs especially with respect to energy saving which takes a high percentage of these costs.

Statistical analysis of control methods

Selecting an effective control technology is a very critical to achieve a properly working grinding circuit: there are several control technologies and mechanisms available. In a survey conducted by William, whose results are shown in Fig. 8 The majority of the respondents use PID control (63%). This is in contrast to the process industries in general where model predictive control dominates. More than half of all industrial controllers are of the PID-type. Multivariable control and expert system-based control are less frequently used but more often than other control technologies.

According to a study the done by [16] the control technologies most widely used in industry can classified according to this scale.

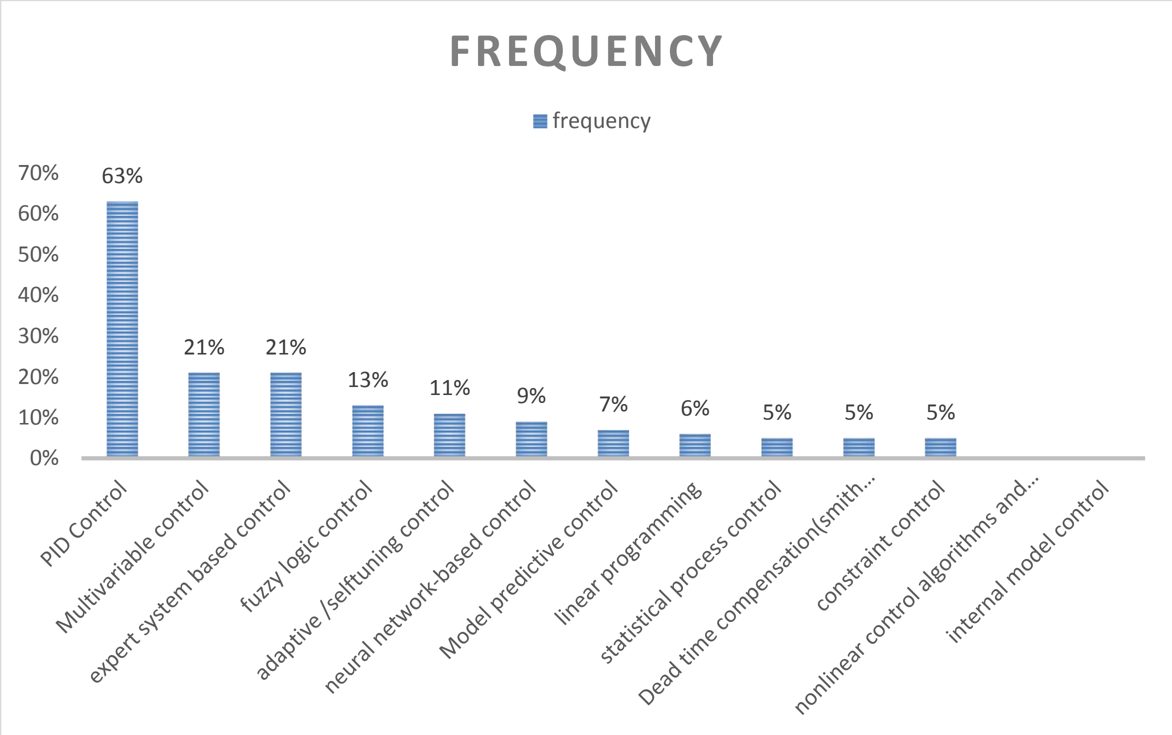

Fig. 4. *Frequency of control technologies used in milling circuits*

From his survey, the most commonly used models are the PID models which prevalent in about 63% of milling circuits. Multivariable and expert system based controls models are used in about 21% on industrial milling circuits. Other methods used in industrial milling circuits include fuzzy logic control(13%),adaptive /self-tuning control(11%),neural network-based, control(9%),Model predictive control(7%),linear programming(6%),statistical process control(5%),Dead time compensation(smith predictor)(5%),constraint control(5%).

The control loop performance is monitored is online 40% of the time, daily, 32%and 18 percent on a weekly basis.

Only a few of the respondents are completely satisfied with the control loop performance (8%). A significant percentage of the respondents (38%) indicated that there was room for performance improvement. This could be because PID control is used predominantly for a process that is inherently multivariate [16].

Developing an effective control methodology depends greatly on a very good model of the grinding circuit.

The existing mathematical models of the grinding process are developed based on mass balance or energy balance equations, which describe the particle size reduction of the ground material as a function of the grinding time or in terms of the consumed specific energy. In both cases, the main parameters of the model are selection and breakage functions, which are generally not known, and their determination requires additional experimental studies.

The main idea in modeling all comminution processes, including the grinding process, is to obtain mathematical relations between the size of the feed and the size of the product. Particles in the feed repetitively reduce their size due to the imparting energy of the grinding media, which disrupts their binding forces.

The cement mills in Ghana Until recently, were controlled by the process control system CEMAT V4which at its height in popularity achieved a 35% market share. This system provides a regulatory and supervisory control. Today, this system is outdated. There is no more replacement equipment available for its basis, SIMATIC S5. In January 2009, the first step towards modernization was undertaken. The system shifted to SIMATIC PCS 7 with -CEMAT V7. Siemens developed CEMAT especially for the cement industry. CEMAT is the software package to monitor and control Siemens developed specifically for applications in the cement industry for over 35 years.

CEMAT Siemens is developing in the direction of the library control and monitoring functions including a complete set of functions in PLC control and HMI in accordance with the general standards of the cement industry. It does not however perform

- Closed-loop control,
- Positioning,
- Counting, proportioning,
- Valve control and much more.

Developed in close co-operation with Cement Manufacturers worldwide CEMAT allows engineers to operate a Cement Plant, to make Fault Diagnosis in a Cement Plant and to interlock drives, valves, process signals etc.

The decentralized process control system CEMAT was developed by engineers looking back on 35 years of experience in the cement industry. Their experience means that they know the exact requirements that need to be met by a process control system for the cement industry.

Conclusion

Cement production is a very important part of Ghana’s growing economy and from our analysis, there is a huge deficit that has to be met. This can only be done by an increase in production rates. Due to high costs of production this very difficult, but it has been proven that increased production efficiency go a long way to reduce these cost. Implementing and effective control strategy and method is one of the ways of making production more effective. An effective control strategy can only be developed and tested when there are good existing model of the technological process of cement grinding. GHACEM can improve their production effectiveness by instituting a good optimizing control strategy, which will decrease the use of energy and increase the production rate if it is applied properly.

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Анализ технологии производства цемента и обзор стратегий и методов управления

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Аннотация. Чтобы разработать эффективный механизм управления любым промышленным процессом, необходимо иметь глубокое и четкое понимание самого процесса. Это особенно актуально для технологического процесса помола цемента в шаровой мельнице, который представляет собой очень сложный процесс с очень сложной динамикой и многофакторной средой, где все элементы взаимосвязаны. Целью данной статьи является обеспечение точного и полного анализа процесса производства цемента в Гане, который в основном ограничивается технологическим процессом измельчения клинкера в цемент, его упаковкой и распространением. Дается описание основного оборудования контуров помола и обсуждаются их лучшие конфигурации. Во второй части статьи рассматриваются наиболее популярные методы контроля, которые используются для управления технологическим процессом помола цемента в шаровой мельнице на цементных заводах по всему миру, а также способы выбора наиболее эффективных стратегий управления для достижения высоких темпов производства и эффективного использования энергии. Также обсуждаются стратегии управления, используемые компанией «GHACEM», крупнейшим производителем цемента в Гане.

Ключевые слова: управления; измельчение; клинкер; контур помола цемента; методы контроля; стратегия управления; шаровая мельница; промышленный процесс.

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