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Improving Clinker Production Coal Utilization Using Six Sigma Methodology in Mugher Cement Factory

BY

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Improving Clinker Production Coal Utilization Using Six Sigma Methodology in Mugher Cement Factory

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Declaration

I hereby declare that the work which is being presented in this thesis entitled "**Improvement of clinker production coal utilization in Mugher Cement** " is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been accordingly acknowledged.

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Abstract

Six sigma is the process improvement tools which can be applied in various sector for defect minimization and better utilization of resource using DMAIC methodology. A DMAIC methodology is used to identify which output parameter needs to be give more priority to get a better result.. Thus, in this research which focuses on improvement of clinker production coal utilization without affecting the clinker quality production, an integration of six sigma with design of experiment was performed. The tool integration major significance was, it provides a mechanism to narrow down the source of variation to be more explicit and for optimizing the responses.

This research was conducted by first identifying the major response variable from quality & resource utilization. Therefore, from coal utilization perspective, coal consumption for the 3rd line kiln and from quality point of view, C_3S and free lime content was selected by first conducting a brainstorming session with company professionals .Thus, the identified factors which affect this variables were determined by conducting brainstorming session and with considering the highest coal consumption month ,which was August,2018 to study the potential causes .As a result ,from the root cause analysis, different factors were identified. Among them, kiln feed (proportioned raw material) such as Lime Saturation Factor(LSM), Silica Moduli(SM) and Refractory Moduli(RM) were selected to observe their influence in coal consumption by considering their quality target range of each material obtained from the quality department of the case company .

From the analysis result ,the optimized coal consumption was found at the setting of LSM=97,SM=2.4 and RM=5.5 which give a specific coal consumption of 116kg coal per ton of clinker production while the company average specific coal consumption during April,2018-March,2019 was 127kg to produce a ton of clinker. In addition to these, the quality level of the produced clinker, particularly the C_3S and free calcium content were within the preset and expected quality target levels.

Finally, based on the found improved setting, a controlling mechanism for sustaining the material proportioning target and uniformity was suggested. In addition, a guiding framework was proposed for implementation of continual improvement of resource and quality improvement in Muger Cement Factory.

Key word: Six Sigma, Coal utilization, Clinker production, Design of Experiment

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Acronyms

OPC: Ordinary Portland Cement

PPC: Portland Pozzolana Cement

ECSD: Ethiopian Cement strategy Development

LSM: Lime saturation Factor

SM: Silica Moduli

RM: Refractory Moduli

C_3S: Tri calcium silicate

C_2S: Di-Calcium silicate

C_3A: Tri-Calcium Aluminate

C_2AF: Calcium Alumino-Ferrite

DOE: Design of Experiment

DMAIC: Define, Measure, Analysis, Improve and Control

CCR: Central Control Room

Chapter One Introduction

1. Introduction

1.1 Background and Justification

Manufacturing company now a days are seeking for a mechanism for a better utilization of resource since efficient utilization of resource can ensure optimized production, competitiveness in the market and overall performance improvement .Hence, to ensure those improvement, a mechanism should be there to control the work processing variability at the lowest level.

Six-sigma is one of the tools that can be applied to improve the performance of a given operation. It is a process improvement tools as Pfeifer, T. et al(2004) described that Six Sigma seeks to improve the quality of process outputs by identifying and removing the causes of defects (errors) and minimizing variability in manufacturing and business processes. The distinct advantage of applying six sigma project as one of improvement tool is, since it is a strict, focused and highly effective implementation of proven principles and techniques which aims at error-free business performance target in reducing the error to 3.4 per one million opportunity this is done by DMAIC(Design, Measure, Analyze, Improve and Control) process improvement model (Pande and Holpp, 2002). Customer focus and key business initiatives are two focus features that distinguish Six Sigma from quality models such as Quality Circles and Total Quality Management Abramowich (2005).Furthermore, Voelkel (2002) also refer that "Six sigma blends management, financial and methodological elements to make an improvement to processes and products concurrently".

Six Sigma is all about process performance and it is a customer-driven approach that can be applied by first measuring the defect level in the existing operation, then working on minimizing those defect up to zero. As a result, reduced cost due to minimized rework and create customer satisfaction. For any objectives of a business e.g if a given organization want to be more competitive in quality, cost,.etc six sigma can help make the company best at what it does by focusing on the area of improvement.

In the new Era of the Development of industrialization, the growth of competition across the Globe Makes companies to strive for the improvement in Quality, Cost and Responsiveness as a major strategy to sustain in the Market .Such competition is very common in the cement sector.

Ethiopian cement industry development strategy, 2015 reports shows that Cement is the second most consumed material on the planet next to water. Beside this, Summaries of both regional and global publication strongly confirm that the cement demand in Africa in general and East Africa region in particular has shown increasing trend. The major drivers for the growth are increasing government investment in infrastructure expansion and rehabilitation, Steady population growth, rapid urbanization, housing deficits and infrastructure gap .

As studies of Getachew etal(2013) shows that, Ethiopian Cement production sector is booming these days to meet the current demand for massive construction of infrastructures, which is growing from time to time and related as well to economic growth of the country. Currently, the number of cement factories grew to 20 and annual cement production increased from 2.7 million tons to 15 million tons and Per capita cement consumption increased from 39 kg to 62 kg, which is still minimal compared to Sub-Saharan average of 165 kilograms according to reporter news, 2016.

Mugher cement factory is one of the oldest, government owned company in Ethiopia. Which produce ordinary Portland (OPC) and Portland pozzolana (PPC) cement using clinker as a major component and pumice and gypsum as additives . It hast three production lines such as 1st , 2nd and 3rd line started operation in 1984, 1989/90 and 2011 respectively for production of clinker as well as cement. This Factory produces clinker by burning proportioned mix of raw material (limestone, sand and clay) at a rate of 5000 ton/day. Presently, this part of the process is undertaken only in Mugher branch of the plant using three different kilns lines in which, all the kiln uses coal (3000ton/day production rate for 3rd line ,1000ton/day each for 1st and 2nd production lines).

Cement is an essential component in the construction and development of infrastructure such as houses, dam, bridges .. etc. The hydraulic or pozzolanic additions bring about that the pastes of these cements have usually different properties, particularly the rate of strength development (early strength), heat of hydration, resistance to corrosion factors W.kurdowski (2013). These property are due to the availability of clinker constituent, C_3S, C_2S, C_3A, C_2AF called clinker mineralogical composition. Which has a great impact in determining the strength development of the final product . Cement clinker is manufactured primarily from limestone, clay, sand and iron oxide-bearing materials as raw materials ,crushing and grinding of the raw materials, mixing them intimately at certain proportions and blended then finely comminuted to form the raw meal and burning them ,usually in a rotary kiln at a temperature of approximately 1450 ºC Lawrence CD(1998) . The material sinters and partially fuses to promote the formation of the clinker phases. The principal phases in the cement clinker are tri-calcium silicate C_3S, di-calcium silicate C_2S, tri-calcium aluminate C_3A and calcium alumino ferrite C_2AF Lawrence CD (1998)

The major controls made in the production of clinker are the process and quality parameters control. In this production, there are various factors which determine a good operating burning zone that produces uniform, quality clinker with minimum fuel consumption as Gerald L. Young etal (2004) .The controls involve, raw meal quality ,the feed raw material quality, raw material mix proportions, free lime content, coal heating value, coal fines and ash composition ,coal firing rate ,clinker cooler operations are some of the major once.

From cement Production operation, Clinker (kiln process) is a highly energy demanding process. According to Ethiopian cement strategy (2015) and world bank (2017) report, Cement manufacturing is an energy-intensive process and the kiln process consumes more than 90% of the cement manufacturing energy and the cost is up to 40% of total production costs. Beside this, clinker is the major component for producing OPC and PPC cement also the Quality of finished product is determined by the quality of this material. Therefore, the research main focus becomes the clinker production process.

This thesis will show how to use Six Sigma concept to improve coal utilization by maintain quality clinker production of Mugher cement factory, by first defining the project goal then measure the rework and coal resource wastage level in the existing process then analyze the data and find the root cause, provide improvement proposals and control the improved process's to ensure sustainable results.

1.2 Problem Statement

In the current operation of the clinker production, the third line kilns use a coal as a source of energy for producing clinker with the designed coal consumption of 110 kg of coal to produce a ton of clinker. However, referring the company consumption report from April,2018-March,2019 shows that the average specific coal consumption to produce a ton of clinker was 127kg while the daily log sheet control record shows that the minimum consumption is in the range of 117-120 kg /ton of clinker. Hence, working on improving the coal utilization will save a significant amount of cost for the factory.

Beside this, every year for producing OPC and PPC cement, Gypsum and Pumice additives are mixed with Clinker for PPC and Only gypsum for OPC cement production. Since, the quality of the finished product mainly depends on the quality clinker used .When the finished product failed to meet the specified requirement, additional good quality clinker should be used to correct the defective product. For example in the first half of 2011E.C budget year around 3milion Birr worth of clinker was used to correct the defective cement. Hence, this poor quality clinker creates not only a rework cost but also customer dissatisfaction due to longer waiting time and delay of delivery.

Therefore, this research focus was on how to improve the utilization of coal by maintaining or without affecting the specified quality level of clinker production by using the concept of six-sigma.

Research Question

- What is the impact of energy and quality in the current performance of the company?
- How six sigma concepts can be applied for improving coal utilization by keeping acceptable quality level of clinker production?

1.3 Objective

1.3.1 General Objective

The General objective of the study is, to improve coal utilization in clinker production without compromising clinker quality using six-sigma methodology in Mugher cement factory.

1.3.2 Specific objectives

Specific objectives are:

- To define measurements for improvement in quality and energy utilization
- To measure the existing defect levels in clinker
- To experiment an improvement method that alleviate the energy and rework problem
- To test the Impact of implementing six sigma in the improvement of Energy and Quality

1.4 Significance of the Study

The findings from this research would help the cement companies to evaluate and develop their own improvement strategies and to find a competitive age in the market. Furthermore, this research can be used as one input reference for further research.

Since six sigma implementation research project in cement sector is rare, it will add additional information to the body of research in cement production.

1.5 Scope and Limitation

This research focus is, on the existing technology doing an improvement focusing on process parameter control. The raw data and tests will only be taken from the Mugher branch of the plant focusing on the 3rd line kiln. When this experiment is conducted, there was a limitation in selecting all the input factors and screening out the most significant factors and the level of their impact on the response variable. This is due to unavailability of measurement system in the current operation of the plant and some of the measuring instruments were not functional. To mention some, coal heating value, fines of the input kiln feed and the coal..etc.

1.6 Organization of the study

The rest of this thesis part is structured as follows. In the literature review part ,an overview of six sigma and design of experiment techniques, a review of different articles on the concept of six sigma and its application, design of experiment related research were covered. This part offers some context for the next section. After literature review, the next part was a research methodology. In this section, a detailed description of the method of data collection, methodological framework which clarify and give a guideline on how six sigma can be applied with context of coal utilization. The next part, data collection and analysis demonstrate using the concept taken from different research & using the methodological frame work, an in depth study of the improvement of coal utilization starting from data collection and using DMAIC integration with design of experiment was performed.

Using the analysis result found from the previous section, discussion of the result & putting a mechanism for control input material control for keeping the optimized setting also proposed. In addition, an implementation plan for future operation for the factory also suggested.

Finally, the thesis ended with a conclusion and recommendations and by suggesting further research area.

Chapter Two

2. Literature Review

2.1 Organization of the Literature

For the review made in this chapter,a systematic literature review techniques were used for the purpose of reviewing the research relating to six sigma project success and to identify a series of literature based questions for guiding the actual experimental phase of this research.

This chapter consists of, an overview of six sigma and design of experiment techniques, about six sigma and statistical techniques, a review of different articles on the concept of six sigma and its application, Design of experiment related research and the final part will be a summary of all the concept covered in this chapter.

2.2 Six sigma and design of experiment (DOE) Techniques

A DOE is a statistical approach which is used to experiment design and analysis. It is the major tool used in six-sigma for modeling the effect of one or more process factor on the selected output or response. In DOE, the effect of all the factors of interest can be studied by a single trial by reducing the experimental schedule required and providing information on key process interactions. Depending on the Types of experiment needed, a DOE is categorized as single factor, two-level, factorial designs, Taguchi methods, mixture methods, and response surface models. D. Dixon, et al (2006)

Design of experiment is the procedure used for the improvement of a given process condition and to get the product set characteristics. These techniques are very essential to companies with a low production cost, minimum use of energy, .. etc . D.Granato1 and V. Maria(2014)). This has been revealed in different researches such as G.Antony, etal(2014) apply the design of an experiment to first identify which process parameters are the most significant and which are less when it gives a response. Based on the result, methanol and catalyst concentration were the major influencing, time and temperature was low influence process parameters. Furthermore, DOE can be used with six sigma methodology to enhance the DMAIC methodology improvement stage to get an optimized process parameter by iteratively improving those input process. Different researches have also revealed the integrative effect of six sigma and DOE. A study of Amol.J.Gangai and G.R.Naik(2014) made on optimizing process setting without compromising the quality of a product, showed that six sigma with the design of experiment tool and using Minitab statistical software revealed that it is possible to get an optimum setting.

2.3 Six Sigma Overview and Methodology

Six Sigma was first developed and matured between 1985 and 1986 in Motorola Harry, M(1998). It was developed from being a simple process improvement methodology to a broader companywide philosophy.

According to different six sigma researchers perspective, the definition of six sigma covers from a statistical tool used for the improvement of a given process or product variations to management strategies used for the improvement of a given business.

As G. Knoweles (2011) described, six sigma has a statistical definition that measures how far a process deviates from perfection and have set a target for the defect level which is 3.4 per million opportunity. The author explained that it has a long term business strategy to reduce cost through the reduction of variability in product and process. On the other hand L.Fonseca (2014) also raise similar concept with the definition of G. Knoweles (2011) that six sigma should not only considered as a simple statistic tool rather it should be taken as one of a strategic management approach that should be aligned with the business goal and customer requirement.

According to Ecks (2001) definition, six-sigma has to be linked to organization goal. When six sigma project implemented in GE, it was provided the company with major returns on investment. In 1996 G.C, cost of $200milon and return of $150milon, in 1997 cost of $400milon and return of $ 600milon and the increment continued in the subsequent years. G. Knoweles (2011)

The other definition is given by P.Pande and L.Holp (2002) describe that Six Sigma provides a better way to manage a given business by putting the customer first and using facts and data to drive better solutions. As the author illustrates that the major improvement efforts focus on three areas, i.e improving customer satisfaction, reducing cycle time and reducing defects. There are many tools which can be applied to improve the performance in quality or other organizational performances but six sigma has a unique character from the previous quality improvement that it is a customer-focused approach in which it always seeks a way to fulfill customer requirement especially the external customer. It has a positive impact on the major return on investment as explained above in GE company. Furthermore, six sigma changes how management operates when managements learn on how to use the tools and concept, it will result in a new approach to thinking, planning and implementing to accomplish the results

Another definition which is almost similar perspective with the previous authors, given by Pande and Holpp (2002) describes, six sigma is one of business improvement methodology which can be used to improve business capability by reducing process variations. "The name "Six Sigma" derives from statistical terminology; Sigma (σ) means standard deviation. For a normal distribution, the probability of falling within a ±6 sigma range around the mean is 0.9999966. In a production process, the "Six Sigma standard" means that the defective rate of the process will be 3.4 defects per million units.

In contrast to the aforementioned definitions and benefits of six-sigma, other researchers argue that six sigma has a limitation especially in promoting innovations and creativity since it is focusing on optimizing what a given organization already have or focusing on fixing problems not creating. As Goh, T.N(2002) states that six sigma most likely important for those organization in which their first priority is to avoid non-conformances. In addition Anderson, et al(2006) described that since the main focus of six sigma is on the economic and current static to CTQs aspects, it will distract the attention to unexpected or delighting customer features as in the Kano quality model.

Based on the above definitions, it can be easy to conclude that Six Sigma provides a systematic way to achieve business performances improvement and customer requirement starting from each process that is involved in a given organization. In addition, if that improvement procedure is properly controlled and standardized, it can be used for the further continuous improvement program. Furthermore, since each Six Sigma project involves a team with people from different knowledge and hierarchical levels, it will develop employees' problem-solving approach and skill.

2.3.1 Why six sigma?

Six Sigma can benefit a given organization or business by making an effort on identifying the cause of process variation and the defects, it will allow creating consistency of purpose. Greg Brue (2002). Here are the basic results that could be found from the implementation of six-sigma:

- Money
- Customer satisfaction
- Quality
- Impact on employees
- Growth
- Competitive advantages

As the author observes, at the start of implementing six sigma, most of the participant considers six sigma as if only useful for the manufacturing sector, it may not consider customer complaint, may use difficult to understand statistics, etc but six sigma link people, process and business for successful achievement of the project. In any business, it can bring a tangible result by focusing on the customer need and organization goal. Since six-sigma is a project based task and demand the involvement of well aware employee, creating awareness to the involved people and project management skill for the experts who lead this team should be a pre-requisite to achieve the project goal.

As Graeme Knowles (2011), six-sigma can improve financial performance and profitability, reduces the cost of poor quality, reduce waste, to be responsive to and focused on the customer, to improve product and service performances and contributing to organizational learning. From the financial and profitability aspect, the different company shows an increase in profit after they implement six sigma such as Motorola claims to have saved $ 414bilion, increased sales by a factor of 5 and increased profits by 20% each year Pande et al(2000).In the case of GE during 1996-1998G.C six sigma related saving were about $2bilion, their others.

2.3.2 Six Sigma benefit

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2.4 Six sigma in terms of statistic

As Pande etal(2000) definition, the Greek letter “sigma” or “σ" ” stands for standard deviation. It is a way of describing how much a given process or product has variation exist in a set of data, a group of an item or a process. Standard deviation is a statistical term which is used to describe how much variation exists in a data, a group of items, or a process. P. Pande and L. Holpp (2002),

The author provides a practical example to make clear the concept of ‘standard deviation’ e.g *" suppose that you run a business that delivers pizzas to nearby offices. You make pretty good pizzas and have lots of customers. According to your contract with your customers, pizzas will be delivered fresh and hot between 11:45 a.m. and 12:15 p.m. This allows customers to get their orders in time for lunch (their "requirement"). You have also agreed that if a pizza is delivered before 11:45 or after 12:15 (a "defect"), you will discount* their next order by 50 *percent. Because you and your staff people get a bonus for on-time delivery, you are all very motivated to deliver the pizzas during the half-hour window the customers want.*

So based your delivery , if you deliver only about 68 percent of your pizzas on time, your process is at only a "2 sigma" level. If you deliver 93 percent on time, which sounds good, you are operating at only a "3 sigma" level of performance. If you get 99.4 percent of them there on time, you're operating at "4 sigma." To be a Six Sigma pizza shop, you would have to have on time pizza delivery 99.9997 percent of the time! That's practically

perfect. In fact, for every million pizzas you make (a lottamozzarella), you'd end up with only three or four late deliveries."

Table 1: Sigma level

Σ	Defects in parts per million (PPM)
2 σ	308,537
3 σ	66,807
4 σ	6,210
5σ	233
6 σ	3.4

2.5 Six sigma Methodology

Caulkin (1995) defines a process as "continuous and regular action or succession of actions, taking place or carried on in a definite manner, and leading to the accomplishment of some result; a continuous operation or series of operations." Six Sigma studies the process and modify them in a way that it will create business benefits. Graeme Knoweles (2011)

In six sigma, every activity is considered as a process or part of a process and this process is characterized by:

- Average performance
- Variation B. Radha Krishnan and K. Arun Prasath(2013)

The Six Sigma DMAIC (Define, Measure, Analyze, Improve, and Control) and Define-Measure-Analyze-Design-Verify (DMADV), is an approach which is used as a roadmap for problem-solving and product/process improvement. DMAIC methodology looks like a linear and explicitly defined, but it is an iterative approach. In addition, prior knowledge of different statistical tools and techniques such as, design of experiment, Pareto.., etc is necessary for determining which tools are useful in each phase B. Radha Krishnan and K. Arun Prasath(2013).

The DMAIC method stresses on data analysis and fact-based decision making by providing a well-structured method for investigation of reasons for leading to the problem. The core agenda of the DMAIC method is reducing variation in a process to achieve high conformance quality in customers' terms

Table 2: DMAIC Phases and the appropriate tool to use

No.	DMAIC Phases	Description	Tools used
1	Define	Define Phase is the first phase and critical phase of Six Sigma improvement process. In this phase, the leaders of this project ▪ Create a Project Charter, ▪ Create a high-level view of the process, and ▪ begin to understand the needs of the customers of the process	▪ Project Charter ▪ Process Flowchart ▪ SIPOC Diagram ▪ Stakeholder Analysis ▪ DMAIC Work Breakdown Structure ▪ CTQ Definitions ▪ Voice of the Customer Gathering
2	Measure	It is a critical phase throughout the life of the project and when the team focuses on data collection initially they must focuses on the two points . to determine the start point or baseline of the process and the 2nd is to look for clues to understand the root cause of the process	▪ Process Flowchart ▪ Data Collection Plan/Example ▪ Benchmarking ▪ Measurement System Analysis/Gage RandR ▪ Voice of the Customer Gathering ▪ Process Sigma Calculation

3	Analyze	This phase is often interconnected with the Measure Phase. When the team reviews the data collected during the Measure Phase, they may adjust the data collection plan to include additional information. The analysis continues as the team analyzes both the data and the process, then to narrow down and verify the root causes of waste and defects.	▪ Histogram ▪ Pareto Chart ▪ Time Series/Run Chart ▪ Scatter Plot ▪ Regression Analysis ▪ Cause and Effect/Fishbone Diagram ▪ 5 Whys ▪ Process Map Review and Analysis ▪ Statistical Analysis ▪ Hypothesis Testing (Continuous and Discrete) ▪ Non-Normal Data Analysis
4	Improvement	At this phase if the project team is satisfied with the data, it is time for the project team to collect and determine improvement idea .A structured improvement effort can lead to innovative and bring an elegant solutions	▪ Brainstorming ▪ Mistake Proofing ▪ Design of Experiments ▪ Pugh Matrix ▪ QFD/House of Quality ▪ Failure Modes and Effects Analysis (FMEA) ▪ Simulation Software
5	Control	At this phase the project team begin to document exactly how they want to pass that structure on to the employees who work within the process	▪ Process Sigma Calculation ▪ Control Charts (Variable ▪ and Attribute) ▪ Cost Savings Calculations ▪ Control Plan

2.6 DMAIC/DMADV flow

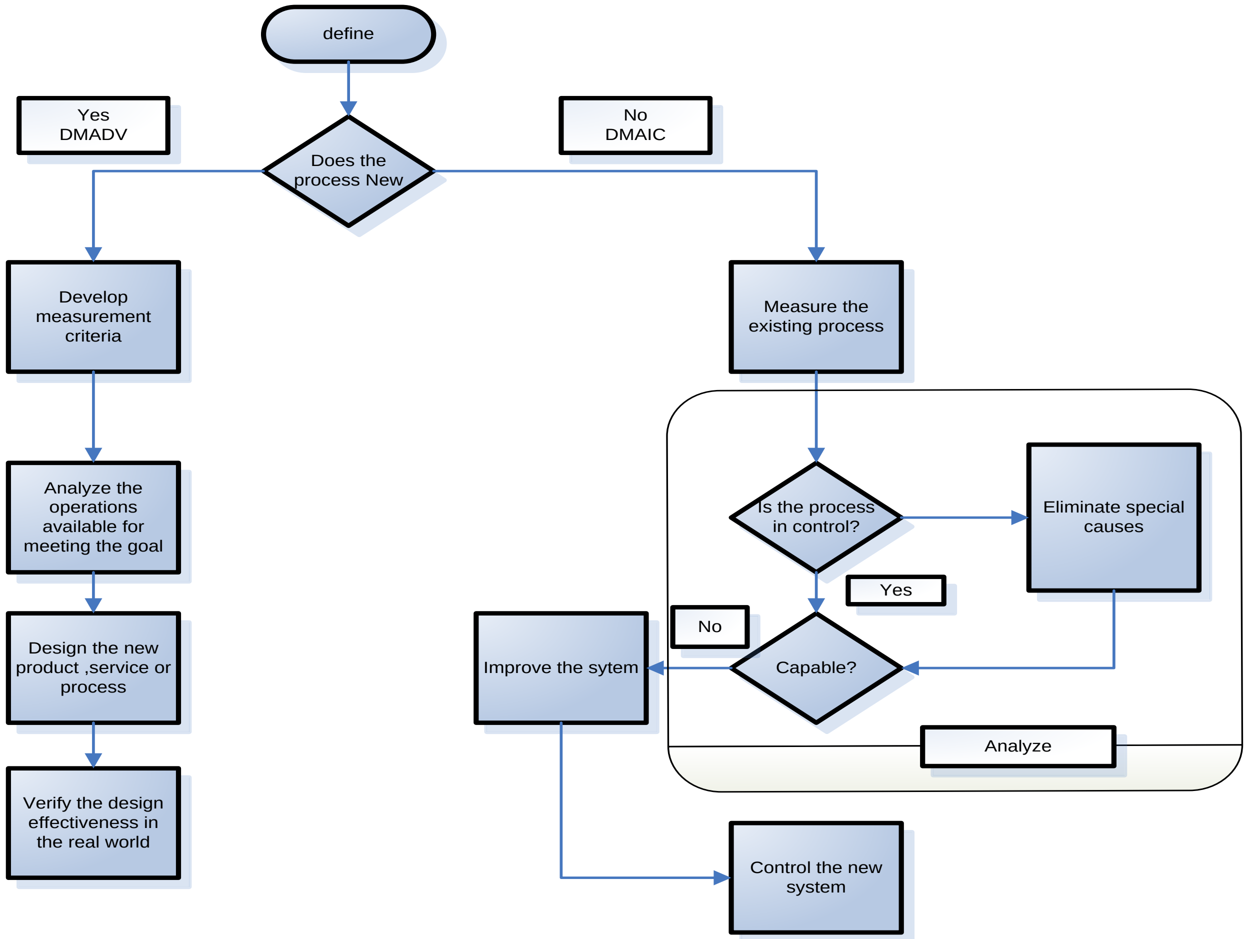


Figure 1: The DMAIC/DMAV process flow (H. Abualsauod ,2015)

2.7 Six sigma application in Energy improvement or optimization

2.7.1 Energy improvement Research

Currently, different techniques are used for the optimization of energy. From the recent study, by M.Mandic(2017) in the optimization of electrical train energy consumption, by first developing sequential quadratic programming and using a computer program for simulation of train movement, a significant amount of energy was able to capture. In this study, prior to implementing to the whole type of train, the developed model was first tested in the test case of a few sections, and then on real cases of energy consumption for passenger and freight train.

2.7.2 Six sigma in Energy utilization improvement

According to John K.(2003) definition, Six Sigma is a methodology which can provide a common language and problem-solving platform that can be applied in all aspects of the business on an equal playing field. Since Six Sigma is a structured approach for solving different kinds of problem with a strong focus on statistics and use a proven methodology to sustain the improvement for long-lasting, it can be used as an improvement or optimization methodology in energy utilization. S.Ojha and N.Verma(2018) have been used six sigma and lean principle, to study the energy wastage in various process of the small and medium industry. In their research, they use value stream mapping tool to understand the flow of material and information to pinpoint the wastage point. Based on their observation, the high energy wastage was seen in the production of reject. In other studies by J. Kane, etal (2003) indicates that Six Sigma methodology was implemented to identify and realize energy efficiency improvements and maintain it well for the future. In this research, the integration of six sigma methodology with energy makes energy professionals to add a new tool for improvement of energy. The author shows that integrating six sigma methodology with traditional energy management reduces total energy cost and assist in achieving the challenging goal of holding total global energy use.

On the other aspect, a study conducted by P.Gaholt (2012) Energy management through six sigma research made in the medium and micro level industry indicated that the level of energy efficiency not only depends on the technological factors but also non-technological factors. In this research, a model was developed for analyzing empirical data from selected industries by using multiple regression analysis. In addition, the identification of the key variables that affect efficiency has been identified using ANOVA (sequential sum of square). Hence, the areas that need more focus on improving or optimizing energy have been identified in this case study.

2.7.3 Implementation of six sigma

In this section different research publication has been reviewed in related to the implementation of six sigma. The categories of the application area are manufacturing (large scale to Small and medium), services, construction industries etc. In each review the study of the research approach, the methodology used, the result and contribution of each paper and research gap is reviewed.

In the case of the construction industry which has a different nature from the manufacturing sector in the aspect of project oriented work process, have been reviewed. According to Seung et al (2008) research, uses six-sigma to estimate the defect rate in a more quantitative and organized way. The research focus was to apply six-sigma by developing a general methodology on the construction operation. For improvement of quality and productivity, an integration of lean (for optimal performance improvement of resource, reliability of planning and elimination of waste) and six-sigma principle was applied. Two case studies (iron reinforced bar assembly process and deck plate installation process) have been presented and process simulation analyses were used to observe the performance changes. In the case of iron, the process was evaluated based on the relationship of productivity and cost, the simulation result showed, the changes of sigma level which vary along with the process reliability that was measured by variations of the performance indices. From the analysis, to minimize the process variation cycle time and cost, the efficient amount of iron to keep in stock was determined. For determining the optimum resource buffer size and most efficient process control to maintain a higher sigma level, cost information was used .In general, in this research, in both case studies show that even though the nature of this sector is different from manufacturing, an improvement in the project performance was shown from traditional construction. The six sigma principle provided more benefits by obtaining an optimized solution. It is one of the tools that can be used to continuous improvement of a product or service.

According to Valles etal(2009) research done in Six Sigma project conducted at a semiconductor company, it was possible to determine the key factors, identify the optimum levels or tolerances and improvement opportunities by using DMAIC methodology. The major factors that were found through a design of experiments (DOE) were identified and controlled. Before the implementation of six sigma project, the level of sigma was 3.35 sigma level and the gain after implementing was 0.37 sigma that represents the elimination of 1.88% of nonconforming units or 18,788 PPMs.

For effective implementation of six sigma in a given business organization different researcher recommend ‘the key ingredients’ for improvement of the performance which will lead the organization to achieve the customer requirements and its business goal. Those are upper management support, organizational infrastructure, training, application of statistical tools are mentioned in Henderson and Evans (2000) studies. According to J. Antony and R.Banuelas(2002) key ingredients are defined as those factors that are essential to the success of the implementation of any quality improvement initiative. According to this study, around 11 key ingredients are listed such as management involvement, cultural change, organizational infrastructure ,training, project management skill, project prioritization and selection, reviews and selection, linking six sigma project to business strategy, linking six sigma project to the customer, linking six sigma project to human resources and linking six sigma project to supplier. The research main focus was on how organization priorities these key ingredients. The survey shows that top management commitment and involvement are identified as the most important one and linking the six-sigma to supplier, training and employee take the least. In addition to this, six sigma project are selected based on their impact on business performance, profitability and customer satisfaction.

Another research conducted by Kolhe.G etal,(2018) which focuses on the implementation of six sigma in process industry on the human aspect, tries to develop a model. The author used different methodology to generate a model for effective implementation of the Six Sigma in Indian organizations for achieving Process Excellence, such as, by study six sigma literatures, comparing between various process excellence initiatives and finally by reviewing various quality award models in India ..etc . and then implementing six sigma in the selected two case company called Larsen and turbo limited to validate the model developed. From the implementation result, the author tries to put a strategy for the whole organization in Indian. Those strategies are implementation strategy should be different in different sizes of the organization and a given strategy should depend on the organizations existing culture and structure are some of the points that are addressed in this research. Even though this research main focus was on soft skill or human aspect, it was limited to one engineering organization.

Since the different type of industries like chemical, service organizations may demand a different strategy.

In a specific sector, implementation of six-sigma has shown a successful result in the performance improvement of an organization. An implementation made on the food industry in Taiwan uses a systematic and disciplined approach to achieve the goal of Six Sigma quality level Hung and Sung (2011).In this study, the case company decides to implement six sigma due to the customer encountered a problem in the finished product. After the approval of the project, a team was formed which was led by a champion of the project with a black belt team formation and two projects were chosen based on the customer complaint and using the DMAIC methodology. At the start of the project, the defect rate was 0.45% (Baseline), and after implementation, during a six-month period, this fell to below 0.141% (goal).

Six Sigma has a wide area of application starting from small industry to large, service giving to the manufacturing industry. The survey made for evaluation of Portuguese small and medium level industries application level of six sigma targeting on the 2012 Excellent SMEs as L.Fonseca (2014) showed that 49% of the industries didn't have an opinion about the value addition by implementing six sigma and58% of them have a low level of knowledge and 3% of them don't agree on it. The main reason was the companies believed that the existence of a satisfactory improvement mechanism, "the satisfaction with existing Management Systems and the present Quality levels. In this study, for a given organization to use a management improvement effectively there should be a brainstorming session to see the available options with regard to bringing superior performance and improved profitability

To use six sigma as an optimization tool, different kinds of statistical tools have been used in the previous researches.

2.7.4 Implementation of six sigma with integration of Design of experiment

In the current operational management researches, researchers revealed that the benefit of integrating various coinciding management practices for better competitiveness Madhuc (2011). One of the practice is integrating Six Sigma with DoE. Those studies show that DOE tool has a benefit to strengthen the six sigma, by narrowing down the source of variation to be more explicit and for optimizing the responses are a major significance.

Looking through different research, according to A. Prashar (2015) study goal on the application of Six Sigma/DOE Hybrid framework for improving damping force generation process in a shock absorber assembly unit, tries to demonstrate the integration effect. The study used a case study research methodology. In this study, for filtering the process parameter in the analysis phase Shainin's Component Search Technique (CST) followed by Taguchi Orthogonal Arrays (OA) at the 'improve' phase were used for optimal parameter setting. On the other hand, a literature review was conducted by focusing on the research which effectively used classical, Shanin and Taguchi DOE with DMAIC approach by R. Kumar and Ramkumar (2017). In their survey, they find out that it has a wide scope of usage for improvement of the "process parameter setting" and to improve the problem recurrence in different sectors i.e in service, manufacturing, public …etc. In their conclusion, in the current organization, those research were used for finding the "optimal setting" for control factors together with six sigma DMAIC

2.8 Summary of literature review

From the previously reviewed literature, six sigma was defined as an improvement philosophy which can be applied in performance improvement or reduction of variability in the process. From time to time different tool integration has been developed for improvement of the quality of result and this technique is guided by DMAIC methodology. In each phase of the DMAIC a set of generic problem solving tools and techniques was applied. One of the tool is DoE . Those studies show that DOE tool has a benefit to strengthen the six sigma, by narrowing down the source of variation to be more explicit and for optimizing the responses is a major significance of integrating DMAIC with DOE.

Various research use six sigma with the integration of different statistical techniques for improvement of the quality of result but there was a few research which use six sigma and design of experiment for addressing the improvement in coal energy utilization by maintaining or without affecting the quality level of the product. Moreover, from the covered literature though six sigma was widely implemented in different sector, there is a gap on how it can be adopted to the specific case organization and be part of the organization system.

Therefore, in this research integration of six sigma and design of experiment for improvement in coal utilization while considering the effect in quality was addressed. In addition, a way of adoption of this system in a given company was proposed.

Chapter Three

3 Research Methodology

3.1 Research Design

The research design used for this study is a case study research since the study focus is in a particular case company which is Mugher cement factory. In addition, by doing an experiment on the selected variable identifying the effect on the improvement of the coal utilization also performed .Therefor , the nature of this research is an experimental research design.

The source of data is based on the primary and secondary data such as, actual data taken by direct observation of the process, past record of the process, Annual report of the factory, the recent survey of the cement development, cement related recent researches.. etc. (Cooper and Schindler, 2006) described that research design refers to how data collection and analysis are structured in order to meet the research objectives through empirical evidence.

3.2 Method of Data Collection

To carry out this research the study was used both primary and secondary data sources since the nature of the data is quantitative and qualitative. Collection of the necessary information is done by direct observation, from previous data, departmental interviews and other methods to understand the existing quality control methods used by the company, to identify the main quality problem of clinker production and coal consumption of kiln and the stage were the problem encounter and to know the main causes of this characteristics. This study focus department is raw material supplies, clinker production and quality assurance department division.

The collected data will include the physical, chemical test data, coal consumption, etc as given below

- **The Raw material input data** e.g limestone ,silica ,clay, other correctives composition
- **Sub process data**: e.g on process control of raw material content, Raw material proportion data, fines of the mixed raw material(raw meal) and kiln meal data, proportion of Lime saturation(LSM),Silica Moduli(SM), Refractory moduli(RM) in the kiln meal, per every hour data

- **Finished product (clinker)**: e.g C_3S,C_2S ,C_3A..etc content data ,on process control of free lime data, clinker liter weight data ,
- **Coal consumption**:- feed rate, fines ,grade, moisture content ,volatile composition..etc
- **kiln operation parameter:-**temperature ,pressure, amount of inlet air in the kiln, flame adjustment, inlet air temperature..etc

3.3 Data collection

In this summary, the type of data that needs to be collected is illustrated in table 4.The duration of time that the data need to be collected is classified in to two period .The first is a past record data collection which starts, from April, 2018-March, 2019 .With in this period, coal consumption, raw material input (kiln feed data) , sub process data and finished product(in this stage, clinker) was collected. Secondly, collection of process data while the plant is in an operation was collected for two weeks by direct observing the process.

Table 3: The type, duration and method of Data collection

No.	Type of Data	Data Collection duration		Data Collection method	Type of Data
		Previous period	in an operation data		
1	The Raw material input data	10 month	2 weeks	▪ Data collected while the operation is running ▪ company past record	Quantitative
2	Sub process data	10 month	2 weeks	▪ Data collected while the operation is running ▪ company past record	Quantitative
3	Finished product (clinker):	10 month	2 weeks	▪ Data collected while the operation is running company past record	Quantitative
4	Coal Consumption data on	10 month	1month	▪ Data collected while the operation is running ▪ company past record	Quantitative

3.4 A brief description about the Methodological framework

As given in Figure 2 , problem formulation was done by using a preliminary data collection of the specific coal consumption of each kiln & evaluation of the sector & company level resource & quality issues were identified & analyzed. As a result, from Mugher cement manufacturing process , clinker production was identified as a key process which influence the finished product quality & 90% of the cement energy consumption .However , as per the preliminary evaluation of the plant ,these part of the process was suffering from inefficient coal utilization & defects in clinker product. Therefore, the researcher decided to focus on these key area of the process for better improvement.

For addressing this problem, a review of previous research was conducted. Using those methodology used in the previous literature as an input, evaluation was made based on which method can bring a better improvement. In this stage from the critical analysis of different literature, six sigma was selected for its applicability in any kind of performance improvement; it can be used by integrating with different tool and for its improvement target level which is nearly zero.

At six sigma initiation stage , from cement production process identification of the process that should be covered in this research ,selection of the company professional for detailed analysis (brainstorming session), the necessary data review from CCR was performed .

Starting from define the DMAIC-stage activity, method used and output is described in **Table 4** as given below.

Table 4: DMAIC implementation process

	Define	Measure	Analyze	Improve	Control
Activity	▪ Selection of the specific production line for improvement ▪ Identifying the clinker production process ▪ Collection of specific coal consumption data for the specified kiln	▪ Identifying the specific quality and energy output/response variable	▪ Identifying the potential cause and ▪ selection of the factor for improving coal utilization	▪ identification of the impact of each factor and their interaction ▪ making a prediction ▪ determining the optimized setting	▪ achieving the target proportioned mix setting and keeping its consistency ▪ redefine goal for further improvement and keep the continual improvement
Method	Based on ▪ capacity of clinker production and ▪ Frequency of use	▪ Using pareto chart then ▪ impact analysis	▪ Conducting Brain storming and cause and effect diagram ▪ Categorizing controllable & uncontrollable	**Doing DOE using Mini Tab 17** ▪ Using Pareto chart and Analysis of variance(ANOVA) ▪ Using the quality target range which is obtained from quality assurance lab for the third line kiln feed	▪ Evaluation of the existing process of raw material kiln feed preparation starting from quarry to kiln feed

3.5 Methodological Frame work

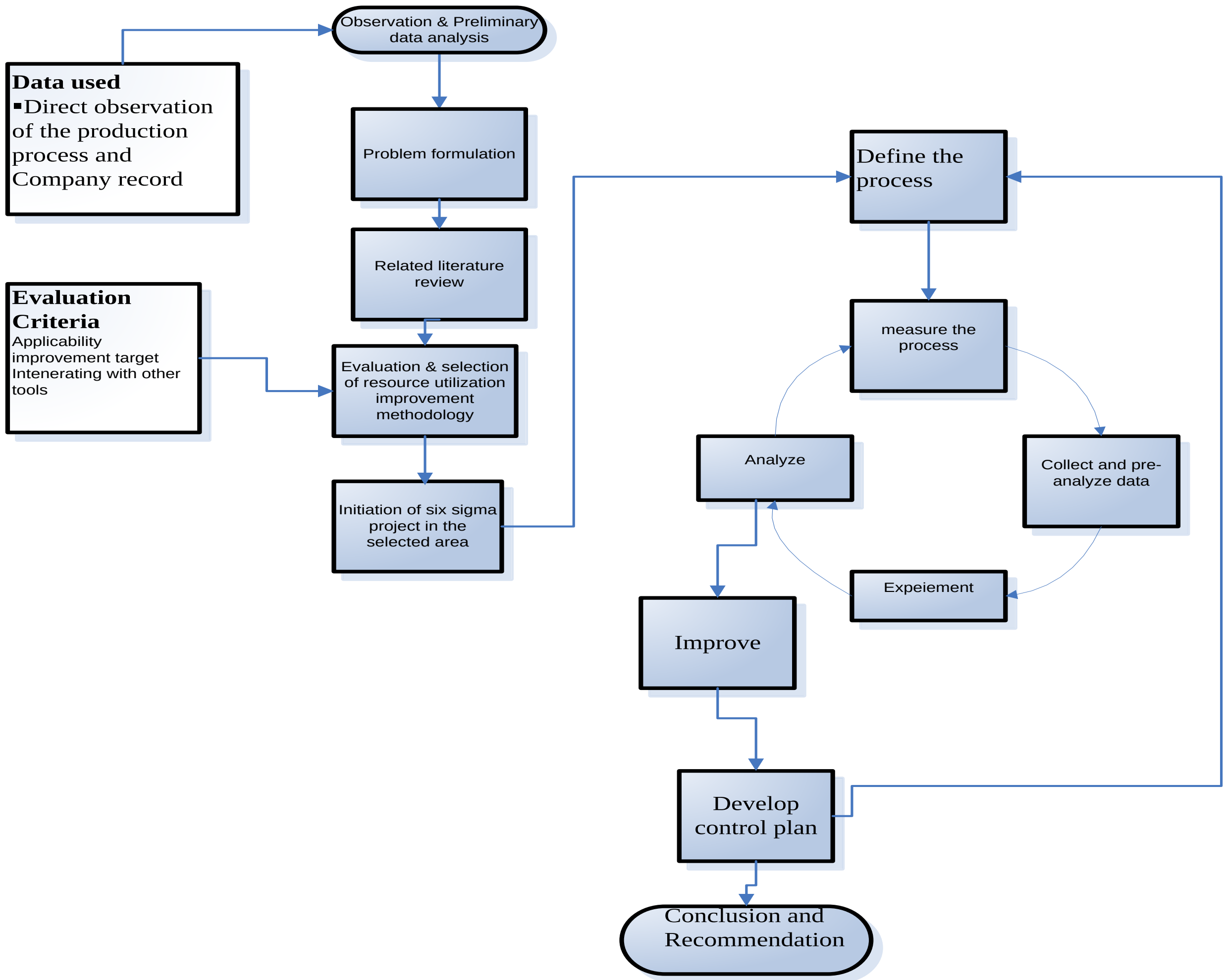


Figure 2: Methodological Framework

Table 5: Six sigma and DOE integration

No.	Phases	Integrated Activities	Six sigma activity	DOE activity	Tool used
1	Define	Define problem	identify the improvement activity and project objectives by studying the existing clinker production process using Flow chart and Process map	-	Flow chart Process map SIPOC diagram
		Provide a relevant background	Provide a background information about the company and the clinker production process from raw material to finished product by direct observation of the plant current production process	-	
		Choose a response variable	-	Choosing response variables for energy and quality of clinker by making a SIPOC diagram.	
		Set an objective	State a measurable objective to achieve during the course of this study	-	
2	Measure	Selection of measurement	Selection of a metrics and measurement system for improvement of clinker production process	-	Brainstorming Fishbone
		Measurement of base line data	Collection of a baseline data about clinker production quality and coal consumption	-	

			from the company record		
		List out the factors	-	Listing of all the factors that affect the response variable can be done by conducting a brainstorming session with the process engineers and quality experts and using a fish bone diagram	
		Categorize factors	-	From the listed factors classification of those factors as controllable and uncontrollable will be done by studying each factors effect on the response	
		Select a strategies for disturbing factor	-	The selected strategy for this experiment is randomization, in order to minimize or eliminate their effects on the response	
		Select ranges and levels	-	for the quantitative factors the range or target level and for that of qualitative factor the levels must be defined	
3	Analyse	Selection of experimental design	-	It include determining the number of factors ,the number of levels, the total number of run by examining all the potential factors impact on the response using Generalized linear model	Generalized linear models
		Evaluate trial runs	-	Before conducting the experimentation, some trial runs must be done to check whether there is an	

				experimental error and assumptions made in previous steps	
		Conduct the experiment and recollect data	-	By randomizing the order the experiment will be conducted as planned and the data will be recollected for more analysis	
		Analysis of interaction	-	After conducting the experiment and doing the interaction analysis by using Minitab 17 software, identification of the significant and insignificant effects and interactions will be done by and ANOVA.	
		Make a prediction Model	-	Using Minitab 17 software determination of the empirical mathematical model of response versus experimental factors	
		Optimization	-	Identification of best factor level settings from the given experiment	
6	Improve	Confirming testing	-	By using the new condition, conducting a conformation test for validating the result obtained from experimentation in those values should be performed	
		Make a conclusions and recommendations	-	Based on the result found from experimentation , conclusions and recommendation must be elaborated by using Graphics are encouraged	
		Implement new conditions	-	Setting the new conditions in the process or product	
7	control	Implement controls	-	Proposing a control plan to obtain the benefit proposed	

3.6 DOE model selection

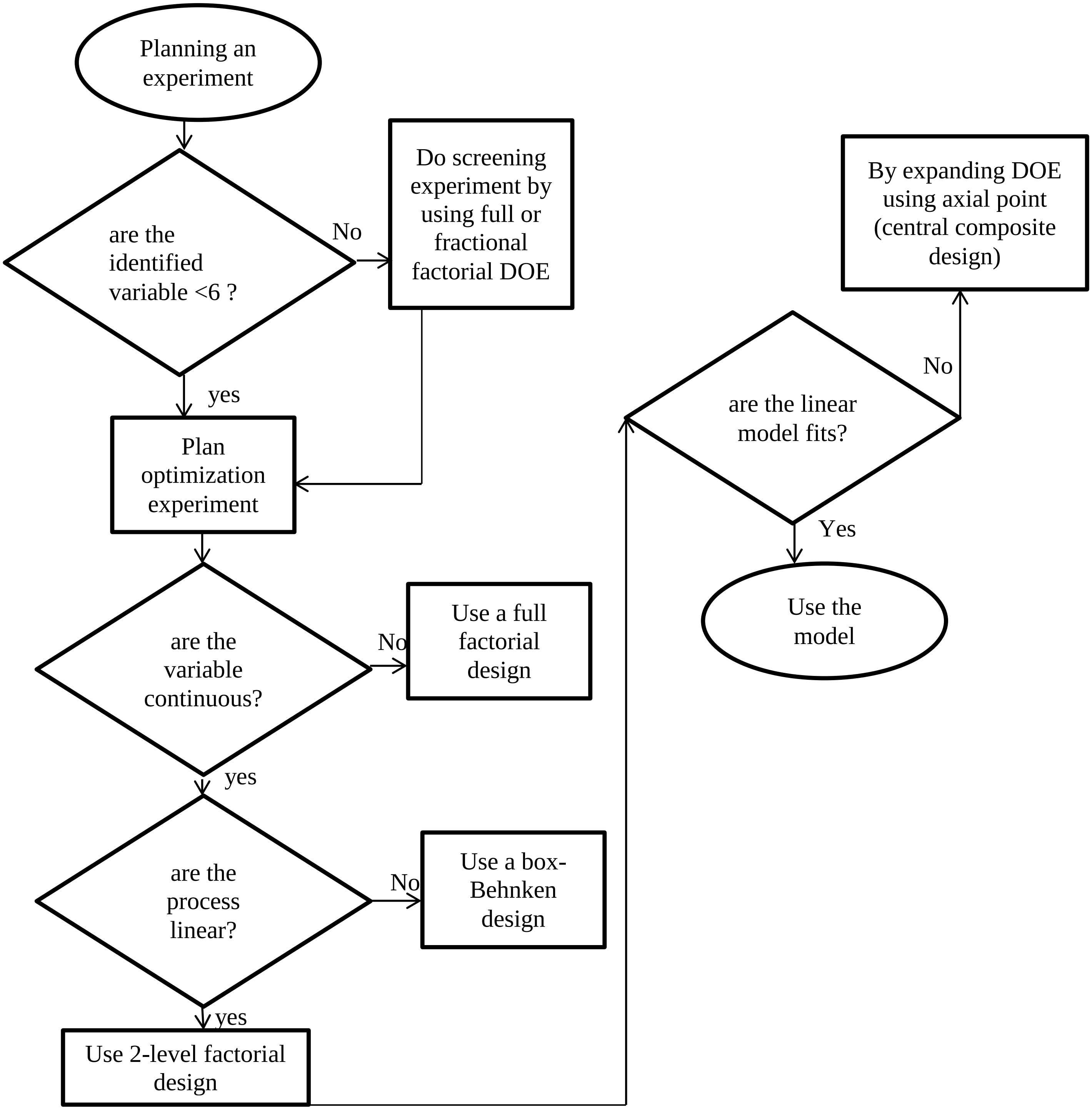


Figure 3: A methodology for the selection of the right Design of experiment (Minitab 17)

In the above figure, in planning stage before data collection or creating a design for data clarifying an objective and generating a plan for the experiment is the first priority. For getting the most information from each experiment the following activities will be performed

- Following a sequential experimentation process
- Defining the problem that should be addressed through experimentation
- Define the factor , response (Y) variable and the goal for Y
- Plan for the process of experimentation

Once the variables that affect the response is identified, further evaluation for the number of variables if they are above or below six will be done. when the number of variable is above six ,since running this amount of experimentation is an expensive and daunting task ,screening of the most significant factors out of all the listed variable can be done by using full factorial method.

In the case where the factors are below six, the next evaluation will be whether they are continuous or discrete .If they are discrete, a full factorial DOE will be used. If not, further checking of the process whether it is linear or not will be done .If the process is not linear the box benchem DOE will be used. If it is linear, evaluation of this process linearity model fitness. If it fits, use the developed model otherwise by expanding DOE using axial point (central composite design) can be used.

Chapter Four

4 Data Collection and Analysis

In this chapter, based on the collected data and using DMAIC methodology data analysis will be conducted. The first section will cover, defining the process of clinker production then measurement of the amount of defects in clinker production and the waste in coal consumption utilization (energy consumption) level of the kiln will be measured .Finally, analysis of the problem will be conducted by using design of experiment for identifying the optimized setting and proposing an improvement options.

4.1 Data Collection

Past and online record of process data were taken from CCR (central control room) and log book record of the company. The collected data include quantitative and qualitative data of the raw material (limestone, clay, sand),raw mill, kiln meal ,clinker and coal consumption by following the process of production of clinker. The data were collected from April, 2018-March ,2019 .

4.2 Background of the study

4.2.1 A Brief description of Mugher Cement Factory

Mugher cement factory is one of the oldest and biggest factories in Ethiopia. It produces PPC (Portland pozzolana cement) and OPC (ordinary Portland cement) cement with annual production rate of over 1.7 million ton of PPC and OPC cement in a continuous production process. The process of production is a dry type process. Under this factory there are three sub branches in which one of the plant(Mugher branch plant) is a full processing plant which produce OPC and PPC Cement and the rest two (Tatek and Addis Ababa branch plant) use the sub processed product called clinker delivered from Mugher plant to produce a PPC cement or finished product. Currently the Mugher branch plant has three clinker production lines namely first, second and third line with each capacity of 1000 ton/day for the first and second line, 3000ton/day for the third line. The first and second lines are old lines; currently it uses electrical and fuel energy. Unlike the old lines, the third line is a newly installed kiln line which has made the company to reduce the cost of energy by replacing heavy fuel oil by a bituminous coal as a major source of energy.

4.2.2 Overall production process of Cement in Mugher cement factory

The Production of cement pass through 6 major phases as described in the following section and as given in **Figure 4 (major process) and 5(detailed process)**. These are;

i. Raw material extraction/ Quarry
ii. Grinding, Proportioning and Blending
iii. Pre-heater Phase
iv. Kiln Phase
v. Cooling and Final Grinding
vi. Packing and Shipping

I. Raw material Extraction/ Quarry Phase

In the current production of cement in Mugher cement factory, most commonly used raw materials used for the production of clinker are

- Limestone,
- Sand
- Clay
- Limestone overburden

This raw material are found from the open face quarries of the company in Mugher and Mugher Derba quarry site . The composition of raw materials in each type of raw material are ,

- Limestone is the major source of calcium carbonate,
- sand is very rich in silica
- clay also very rich in iron and Aluminum oxide.

when a deficiency or excesses from the target is occur ,corrective material will be used.

II. Grinding, Proportioning and Blending Phase

The quarried material size reduction will carried out in two stage consecutive crushers .

After the two size reduction process is finished, further size reduction will be done by a horizontal ball mill. Since the factory uses a dry process of clinker production, the materials is grounded in a dry condition.

Before the raw material is get ready to feed for the kiln, each raw material will be analyzed and then proportion of mixing will be determined based on the target composition need to prepare for kiln meal chemical composition .Those chemicals composition that will be analyzed by the quality laboratory of the plant is

- Calcium Oxide (CaO),
- Silicone-di-Oxide(SiO_2),
- Magnesium Oxide(MgO),
- Iron Oxide(Fe_2O_3)and
- Aluminum Oxide (Al_2O_3)

In this stage , raw mix design will be done to determine the quantitative proportions of the raw components in order to give the clinker the desired chemical and mineralogical composition. Once, the type of clinker to be produced, with the process, raw materials and fuel available is fixed, the next task will be to calculate the proportion of the raw materials required in preparing the raw mix. The basis for calculation is the chemical composition proportion of the raw materials. such as by using the parameters

- LSF(lime saturation factory),
- SM(silica moduli),
- AM(aluminia Moduli) …etc

Then the Raw mix will be stored in a pre-homogenization pile after grinding raw mix to fine powder.

III. Pre-Heating Raw Material Phase

After the raw mix is finally ground, the material will be ready to face the pre-heating chamber. In Mugher the Pre-heating chamber consists of 5 vertical cyclones from where the raw material passes before it reach into the kiln. Pre-heating chamber uses the emitted hot gases from kiln. This will help the factory to save energy .

IV. Kiln Phase

A Kiln is a huge rotating furnace which is used for burning the raw material by passing the ground raw material mix from the cyclone preheater to the high temperature kiln. When the dried raw material pass through the kiln, the calcination (the carbonate constituents decompose into an oxide and carbon dioxide) then enter into the sintering zone. In the sintering (or clinkering) zone, the combustion gas reaches a temperature of 1450^0C to produce a black nodule called clinker. Since the produced clinker is hot by the time when it is discharged from the kiln, a grate cooler is used in Mugher cement factory.

A Coal is used as the primary fuel for burning and preheating of this raw materials .The burned material called clinker form a minerals which are responsible mainly for strength development. Such minerals are

- C_3S(alite),
- C_2S(belight),
- C_3A(aluminate),
- C_4AF(Ferrite) etc.

V. Cooling and Final Grinding

Once the clinker is formed in the rotary kiln, it will be cooled by means of forced air from a cooling ID fan. Clinker released the absorb heat when it is exposed to the ambient air and cool down to lower temperature. The Released heat by clinker is recycled back to the preheating chamber for preheating of the newly entered raw material.

After cooling the clinker reaches a rotating horizontal drum called grinding mill which is filled with steel ball for tumbling and crushing of clinker and other additives (Pumice and gypsum for PPC cement ,only Gypsum for OPC cement production) to form a fine powder called cement.

VI. Packing and Shipping

After grinding the cement powder will be conveyed to the storage silos. Furthermore, it will be packed and delivered in to 50kg bags or as a bulk form by means of bulk transportation truck s to the customer

4.2.3 Coal preparation plant

In the factory there is a separate plant for coal storage and grinding .Currently among the type of coal, a bituminous coal which is a bi-product of petroleum is used in this factory. It has a high calorific value, in which 5800-6200 kcal/kg of coal can generate. In the current production of clinker, the third line kiln uses a coal as a primary energy source. The preparation of fuel include crushing, blending and grinding. Since Coal is delivered with some moisture to prevent dust formation and fire during transportation. By passing hot gasses through the mill, it will combines the grinding and drying. The waste heat from clinker cooling can be used to dry the coal.

4.2.4 Quality control and assurance of Mugher cement factory

Quality of cement is maintained by using Ethiopian standard requirements and company requirements. The quality of finished product cement is assured by a regular analysis of raw material ,clinker and cement based on the company's developed inspection and quality assurance procedure. The finished product quality parameters are

- Two and Twenty eight days Cement compressive strength
- Setting time
- Expansion level
- Sulphate content

When a clinker is produced , the composition such as C_3S,C_2S, C_3A,C_4AF ,..give those quality characteristics and addition of Gypsum and pumice in clinker will have a significant impact to control the level of those quality characteristics. e.g addition of gypsum will increase the setting time and also improve the resistance for the chemical attack .

4.2.5 Process flow of cement production

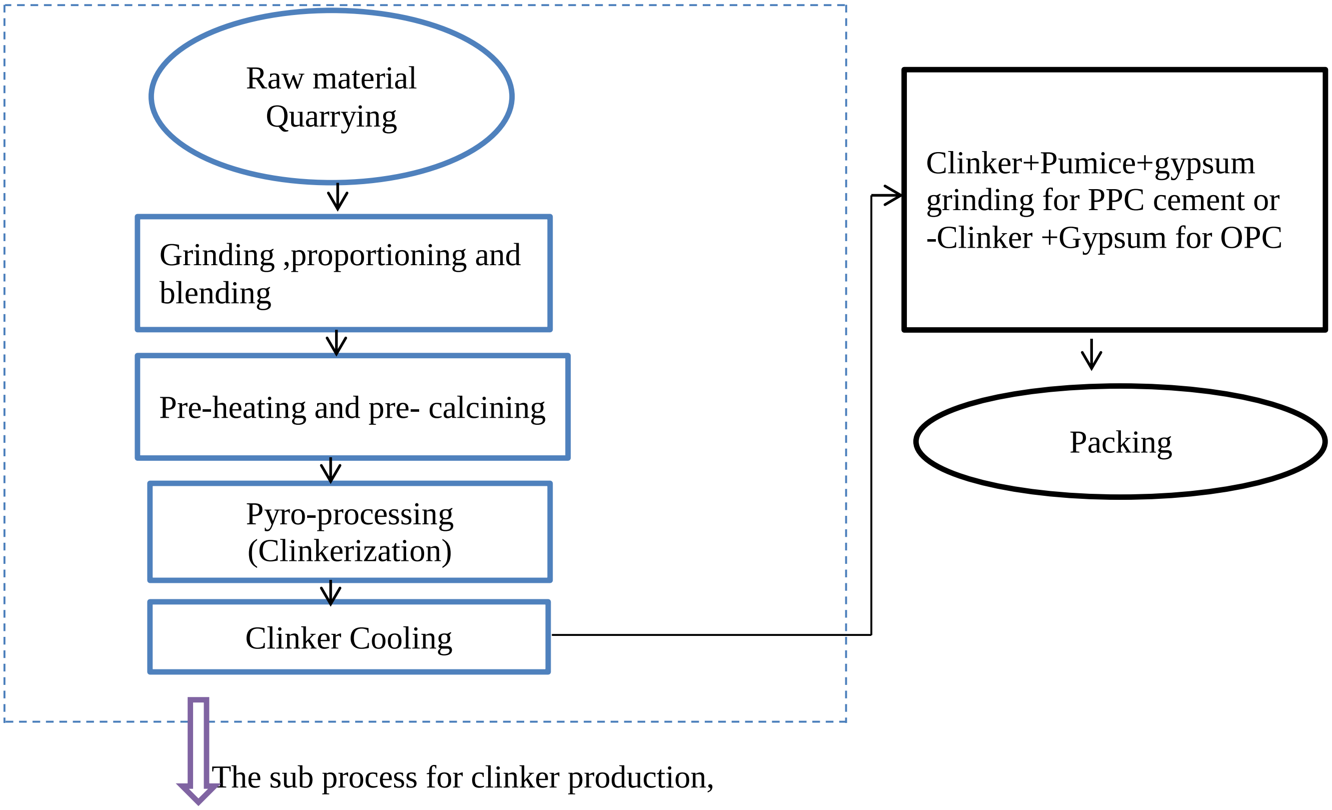


Figure 4: Cement production process flow diagram

4.3 Define phase

In this phase, identifying the focus of the study, stating the objective and selecting a response variable will be done by studying the current process using flow chart and SIPOC diagram.

4.3.1 The Focus of the study

From cement manufacturing process , clinker production process(kiln process) consumes more than 90% of the cement manufacturing energy and the cost is up to 40% of total production costs(Ethiopian Cement development strategy,2015 and world bank,2017 report). The production process in Mugher is a continuous dry process with six stage cyclone pre-heater and pre-calciner kiln.

In the current production of clinker with a kiln, a high consumption rate and inconsistency in the usage of coal is seen. From the daily consumption record as in **Table 6**, though the designed coal consumption for the kiln is about 110Kg/ton, the actual consumption (from Apr,2018-Mar,2019 consumption record) shows approximately 128kg/ton which is high as compared to the designed consumption .

As illustrated in **Table 7,** from the produced clinker during April, 2018 to Feb,2019 a defect were recorded.In this case to count the defect ,the quality clinker parameters are mention in table 2. Meanwhile, from the three kiln, the 3rd line kiln has more production capacity and the company use this kiln frequently. Therefore priority is given for improvement of the third line kiln coal (energy consumption) utilization without compromising the quality of clinker(i.e C_3S>50%,15<C_2S ,C_4AF(5-15%) ,Free CaO(1.5-2.5%),Litter weight(11250-1350kg/lit). Therefore, a kiln production process is the main focus of the study.

Table 6: Coal consumption data collected from April, 2018-Feb, 2019

No.	Monthly average consumption	Working days	Working hour	Specific Coal consumption (Kg. Coal/ton Clinker)
1	April,2018	17	320	135
2	May,2018	24	547	122
3	June,2018	11	216	134
4	July,2018	0	-	-
5	Aug,2018	24	379	142
6	Sept,2018	22	422	117
7	Oct,2018	21	384	130
8	Nov,2018	6	79	141
9	Dec,2018	0	-	-
10	Jan,2019	15	213	126
11	Feb,2019	23	465	124
12	March,2019	26	615	122
		Average		127 kg coal/ton clinker produced

Note: As presented in table 1, the working days per month varies from 6 to 24 days due to various reason such as , maintenance, power interruption, electrical and mechanical failure were the major.

Table 7: Clinker Quality Parameter from April,2018-Feb,2019

No.	Month	*No. of Test	Specific Coal Cons.(Kg .coal/ton clinker)	**average percentage in Clinker Quality Parameters per month					
				$C_3S>50\%$	$15<C_2S<30\%$	$C_3A(5-10\%)$	$C_4AF(5-15\%)$	Free CaO (1.5-2.5%)	Litter weight 11250-1350kg/lit
				Avg. $C_3S(\%)$	Avg. $C_2S(\%)$	Avg. $C_3A(\%)$	Avg. $C_4AF(\%)$	Avg. F.CaO(%	Avg. Lit weight (%)
1	April,2018	320	135	49.7	23.83	6.8	12.2	1.32	1308.9
2	May,2018	547	122	47.1	27.8	7.2	12.4	1.14	1276.8
3	June,2018	216	134	50	29.9	7.4	12.1	1.21	1319.3
4	July,2018	0	-	-	-	-	-	-	-
5	Aug,2018	379	142	42.6	31.8	8.9	11.2	1.7	1301.2
6	Sept,2018	422	117	42	33.1	8.7	11.4	1.32	1355
7	Oct,2018	384	130	48.1	26.7	8.6	11	1.46	1308.5
8	Nov,2018	79	141	40.6	35	8.3	10.8	1.2	1314
9	Jan,2019	213	126	24.4	50	8.8	10.6	1.78	1280
10	Feb,2019	465	124	48.5	26.7	8.1	11.2	1.12	1340
	Sum	3,025							Sum

Note :

* **Number of Test:** for counting the number of test, assumption were taken to take the number of inspection performed per each hour as the number of test .

** **Clinker Quality Parameters**

Quality of a given clinker is measured by its composition of Alite (C_3S), Belite

(C_2S), Aluminate (C_3A) , Ferrite (C_4AF) and free calcium oxide.

*****Number of defect**

Since the process is a continuous process, the number of defect is counted from each hour inspection test which failed to fulfill the quality requirement (target),

<u>**Clinker Quality parameter and their significance in cement**</u>

- **Alite (C_3S)** is the most significant constituent of clinker and cement it ranges >50% in normal Portland cement clinkers. It is tri-calcium silicate (Ca_3SiO_5) modified in composition and crystal structure by ionic substitutions.
    - It determine an early and later strength of cement (main strength constituent of cement)
    - For rapid hydration, high initial and good final strength
- **Belite (C_2S)** constitutes 15-30% of normal Portland cement clinkers. It is di-calcium silicate (Ca_2SiO_4) modified by ionic substitutions and normally presents wholly and largely as the P-polymorph.
    - It has low heat of hydration and contribute to late strength
- **Aluminate (C_3A)** constitutes 5-10% of most normal Portland cement clinkers. It is Tri-calcium aluminate ($Ca_3Al_2O_6$), substantially modified in composition and sometimes also in structure by ionic substitutions. It's main benefit are:-
    - Used for rapid hydration that promote early strength
    - Reacts with sulfate and undergoes volume expansion
    - Shrinks appreciably on hydration

- **Ferrite (C_4AF)** makes up 5-15% of normal Portland cement clinkers. It is a tetra-calcium alumino ferrite (Ca_4AlFeO_5), substantially modified in composition by variation in Al/Fe ratio and ionic substitution.
    - Contribute little or no for strength development
    - Gives normal cement its colors
    - Has moderate heat of hydration

From clinker production process the above quality parameters are inspected after clinker cooling process as shown in **Figure 5** below. On the other hand, for producing a quality clinker different input are necessary as given in the **Table 8(SIPOC diagram)**

Clinker production Process

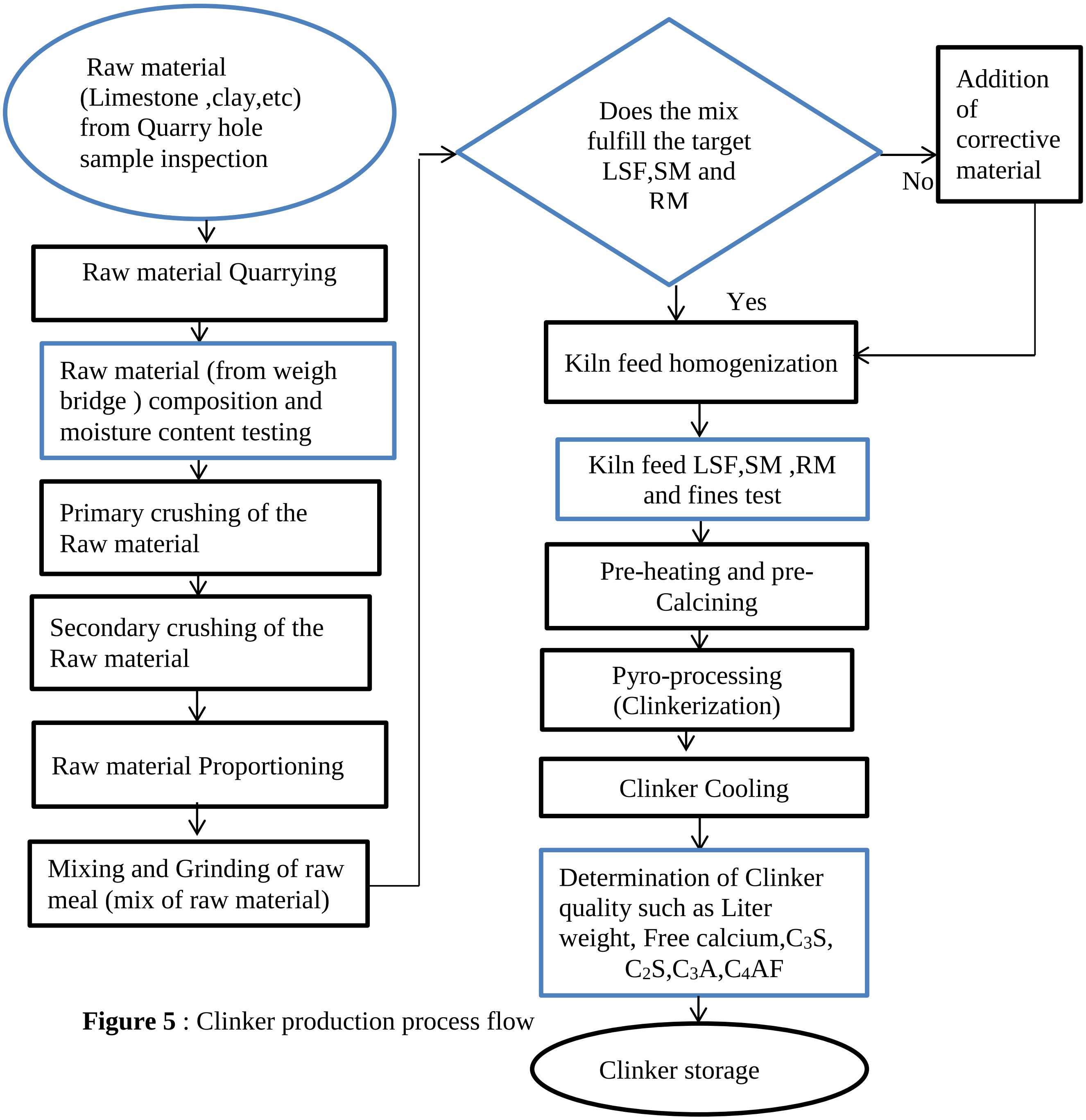


Figure 5 : Clinker production process flow

4.3.2 Description of a SIPOC diagram for clinker production

In addition to the process flow chart, a SIPOC diagram used to have a full image about who are involved in the value addition process starting from the raw material quarrying to finished clinker production. As the figure shows, the input materials are found from the companies own quarry while coal is supplied from the external supplier. Hence, input raw material quality can be controlled by the company's own quality assurance lab. In the case of coal, since it is supplied from the external supplier , the quality will depend on the inspection done by the company

Table 8: SIPOC diagram for clinker production

No.	Supplier	Inputs	Process	Output	Customer
1	Raw material prepartion & supplies team	Limestone,clay,sand quarry Excavator,damper,	Raw Material quarrying	Mined Limestone,silica,clay& lime stone overburden	clinker production team
2	Raw material prepartion & supplies team	Mined Limestone,silica,clay& lime stone overburden	Raw material size reduction (Primary and Secondary crushing) Crushing)	crushed limestone,silica,clay & limestone overburden	clinker production team
3	Raw material prepartion & supplies team	crushed limestone,silica,clay & limestone overburden	Raw material preparation (Proportioning and Grinding)	Raw mix design for mixing all the raw material	clinker production team
4	Raw material prepartion & supplies team	Raw mix design proportion	Mixing & Blending of the three raw material	milled & mixed raw material/Raw meal	clinker production team
5	Raw material prepartion & supplies team	Raw meal	Homoginization	kiln meal/feed	clinker production team
6	External coal supplier & Raw material preparation & supplies team	miled coal & kiln meal/feed	Pre-heating & pre-calcining	dried kiln feed	clinker production team
7	Raw material prepartion & supplies team	dried kiln feed	Clinkerization	hot clinker	cement mill
8	clinker production team	hot clinker	Clinker Cooling	cooled clinker	cement mill
			Clinker to storage		

4.3.3 Problem definition

i. Referring the kiln designed specific coal consumption for the third line kiln, it is 110kg/ton of Clinker production but from the daily data record taken from April,2018-March,2019(Refer **Table 6**) revealed that the kiln was working on average ,127Kg coal/ton of clinker produced. Similarly, as the data indicates, there is a chance to reduce this amount in a consistent way since the range of consumption reaches 24kg coal/ton.

ii. The produced clinker from April,2018- Feb,2019 Producing below the required quality Clinker i.e the quality parameters C_3S, C_2S ,C_3A,C_4AF free calcium content of clinker and litter weight has a target level as given in **Table 7** and based on this range some of the parameters shows an out of range result.

4.3.4 Objective of the project

- In the current production of clinker, identifying an optimized setting for consumption of coal in the 3rd line kiln by maintaining or improving the existing quality level using full factorial design of experiment method

4.4 Measure phase

In this phase, establishing of a baseline performance of how the current process of clinker and coal consumption is performing and selection of a metrics and measurement system

4.4.1 Response/output variable measurements

- For Quality
  - Percentage composition of C_3S , C_2S, C_3A, C_4AF , free lime content and Litter weight of clinker
- For Energy
  - Hourly consumption of Coal consumption

4.4.2 Clinker Quality measurement parameter

As illustrated in table 9,the data for defect in clinker was collected from April,2018-Feb,2019.The mentioned Clinker quality parameters are defined as the parameter that determine the characteristics of clinker in the finished product ,such as cement early and late strength, setting time..etc, .These parameter are C_3S,C_2S,C_3A ,C_4AF,Free calcium & litter weight of clinker .As indicated in Table 9, a quality target level is set for each parameters i.e C_3S>50%,C_2S(15-30%),C_3A(5-10%),C_4AF(5-15%), Free calcium(1.5-2.5%),litter weight 1250-1350 kg/lit. Since a cement production process is a continuous type of production, the defect in clinker per each month was determined by counting each test hour quality result .

To calculate the number of defect opportunity for clinker product, total test hour times the number of quality parameter that determine the quality characteristics for clinker was used. Hence the number of quality parameters that determine clinker quality was 6 as indicated in table 9.Total test hour (refer table 7) is 3025.Therfore, Number of defect opportunity =3025*6=18,150

The percentage defect =189/18,150=1.04 %, DPMO=10,413 referring process sigma table the current level of sigma level is approximately 3.8.

Table 9: Clinker Monthly defect level

No.	Month	Clinker Quality parameter						
		C_3S>50 %	C_2S (15-30%)	C_3A (5-10%)	C_4AF (5-15%)	Free calcium (1.5-2.5%)	Litter weight 11250-1350kg/lit	Total Defect/month
1	Apr,2018	4	3	0	0	7	2	16
2	May,2018	10	1	0	0	11	0	22
3	Jun,2018	4	1	0	0	2	1	8
4	Aug,2018	12	7	0	0	6	4	29
5	Sept,2018	14	12	2	0	12	8	48
6	Oct,2018	6	3	0	0	10	1	20
7	Nov,2018	1	1	0	0	1	0	3
8	Jan,2019	4	4	0	1	2	0	11
9	Feb,2019	9	3	0	0	14	6	32
	Total	64	35	2	1	65	22	189

Pareto chart of clinker unfulfilled quality parameter from April, 2018 to Feb, 2019

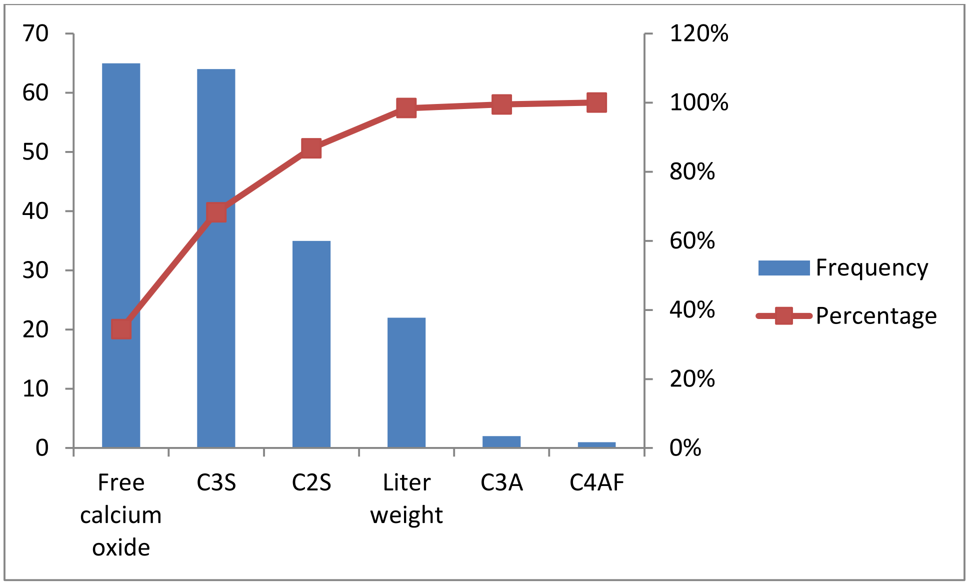


Figure 6: Pareto chart for clinker unfulfilled quality parameter

In the pareto analysis given in **Fig.6**,from the produced clinker the defect in free calcium oxide, C_3S and C_2S composition test takes around 85% contribution of the total defect formed .Thus, to decide on which quality parameter this research should focus, an impact analysis of those clinker quality parameter (C_3S,C_2S,C_3A,liter weight and free calcium) on finished product or cement was performed by doing a questionnaire evaluation with professionals who are involved in clinker production process and quality controlling (two senior chemist and two process Engineer were participated) activity in Mugher cement factory. The content of the questionnaire includes the impact of each clinker quality parameters (C_3S,C_2S,C_4AF..etc) on the cement quality such as ,two and twenty eight days compressive strength ,setting time when cement is mixed with water, expansion etc.

As the evaluation result shows in **Table 10**, C_3S and Free calcium oxide takes the highest rating. Therefore, from the pareto chart and impact analysis evaluation, C_3S and free calcium oxide is selected to be the major quality parameter to be considered when an improvement in coal consumption is made.

Table 10: Defect in Clinker impact on final product cement quality

No.	Clinker quality parameter	Cement quality parameter																
		2 days compressive strength				28 days compressive strength				Cement expansion				Setting time				Average.
		LI	MI	SI	VSI	LI	MI	SI	VSI	LI	MI	SI	VSI	LI	MI	SI	VSI	
1	Does C_3S has an impact				5			4		2				2				3.25
2	Does C_2S has an impact		3						5	2				2				3
3	Does C_4AF has an impact	2				2				2				2				2
4	Liter weight has an impact		3				3					4		2				3
5	C_3A has an impact		3			2				2							5	3
6	Does Free calcium oxide has an impact			4		2							5	2				3.25

Note : Where, Very Strong impact, VSI=5, Strong Impact , SI= 4, Medium Impact ,MI=3, Low impact, LI= 2 , In table 5 ,the analysis summary was taken from 3 experts (2 senior chemist and 2 process Engineers)opinion on the impact of C_3S,C_2S,C_3A,free calcium and litre weight on the quality(2 and 28 days compressive strength, setting time, etc) of finished product cement attached in **Appendix 1**

Referring the lickert evaluation result in table 10, the C_3S & the free calcium impact on 2 and 28 days compressive strength is above the significant impact level or has got SI =4 and VSI =5 with an average value of 4.5 . On the other hand, as compared to the considered six factors, the impact of C_3S and Free calcium oxide on cement quality shows the highest impact & according to the lickert scale it shows above medium impact level.

Specific Project focus (Redefining the problem)

- Reduction of defect in clinker by working on improving C_3S and free calcium oxide content.
- Energy optimization through improving kiln meal/feed composition, i.e LSF (Lime saturation factor),SM(Silica Moduli),RM(iron and Alumina Moduli or refractory moduli) , and Fineness of the kiln meal .

4.5 Analyse phase

In this phase, from the established baseline performance of clinker quality and coal consumption, identifying the factors which affect the output variable, classification of factors such as constant or controllable, uncontrollable, choosing the range for the quantitative and levels for qualitative factors by using a fishbone diagram and by conducting a brain storming session with process and quality expert in the case company.

4.5.1 Factors for high coal consumptions in the kiln

As in **Table 6**, an overview of the coal consumption rate from April, 2018-March, 2019 indication, in August, November, April and June, 2018 shows a higher consumption which was 142,141,135 and 134Kg per ton of clinker production. Out of this, August month consumption takes the highest which is 142Kg coal per ton of clinker production. The average consumption rate within 11 month (April, 2018-Feb, 2019) was 128 kg/ton. Moreover, a bar graph was used to study the detailed consumption rate from daily consumption data in August, 2018 month as depicted in **Fig 7.**

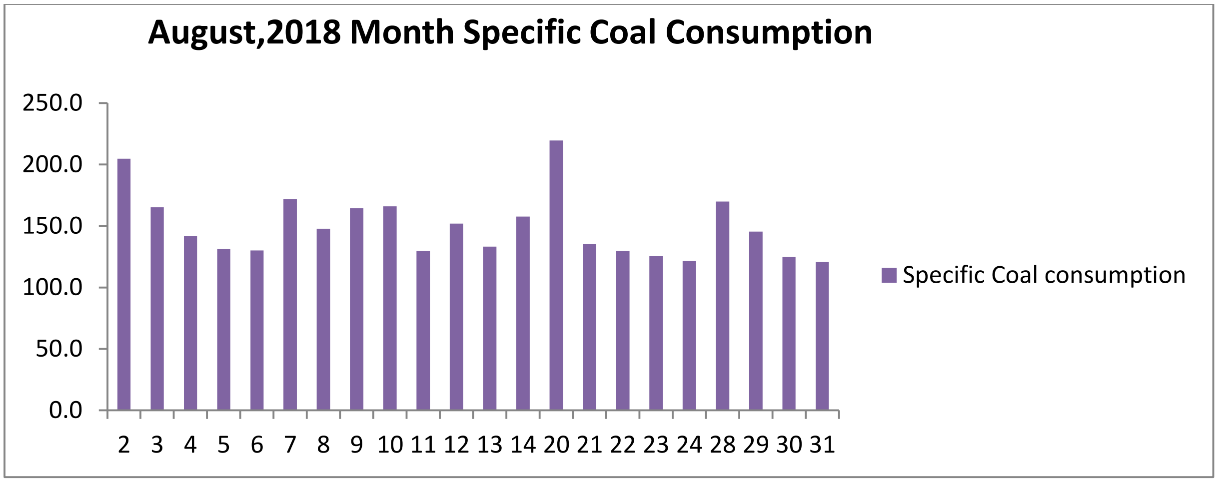


Figure 7: August, 2018 Month Specific Coal Consumption versus Daily Production

As in the above figure, August month highest consumption was recorded 219kg coal per ton of clinker production in the 20th of Aug , 2018 and the overall average consumption in this month was the highest of all month consumption which was 142kg coal. Therefore, conducting a brain storming session with two process and two quality experts on the date May,8-10,2019, identification of the influencing factors for high coal consumption in the third line kiln were carried out using this month as an indicator. From a brain storming meeting, a discussion was made with quality and process controlling team about the factors that contribute for high coal consumption and the quality target.

Before determining the factors, the team tries to make a detailed study of the process of clinker production using process flow & SIPOC diagram to have the best process knowledge .Then they brainstormed for potential causes from process, material, equipment point of view for high coal utilization using five whys .Next, from the mentioned factors, controllable & uncontrollable categorization was done based on the measures taken when this variable is getting an out of control situation. Based on this discussion, around 10 factors were identified and categorized as controllable and uncontrollable factors. The categorization was evaluated based on the following criteria

- Whether each factor has a controlling target,
- Currently the controlling activity is performed or not.

using a cause and effect diagram in fig 5, all the factors that contribute for high coal consumption were identified.

▪ **<u>Possible root cause for high coal consumption in the kiln</u>**

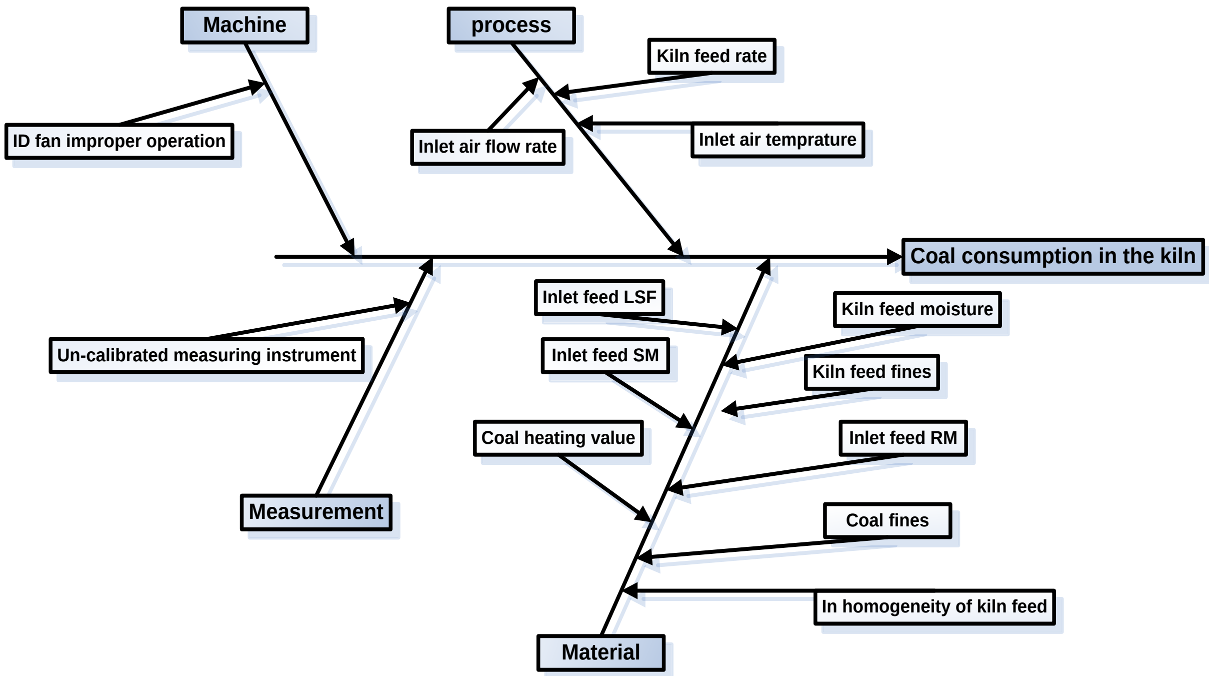


Figure 8: Root Cause for high coal consumption in the kiln

From the identified potential causes, before selecting the significant factors, the listed factors were categorized into controllable and uncontrollable .The controllable factors were defined as the factors which can be adjusted and has a range or level of operation during processing and that of uncontrollable factors are difficult to adjust during an operation rather there influence can be minimized by randomizing the experiment order. Therefore, in this categorization, from the controllable factors the significant once are selected for conducting full factorial experiment by adjusting the range of operation.

Controllable

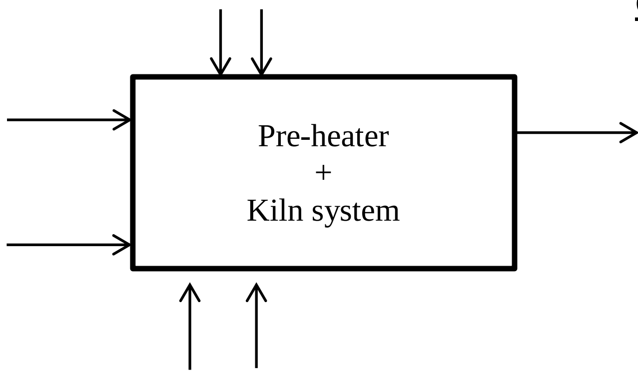
- Kiln feed Lime saturation factor
- Kiln feed Silica Moduli
- Kiln feed Refractory Moduli
- kiln feed fines(the fines test machine is not functional)
- kiln firing system (adjusted at one setting position)

Input

Kiln feed

(Raw material)

Coal



Output

Clinker

Uncontrollable factor

- Coal Heat value(not measured)
- Coal moisture content
- Kiln feed moisture content
- Inhomogeneity of kiln feed mix(no method for measurement)
- Coal fines(not measured)
- Inlet air temperature
- Inlet Air flow rate

From the controllable variables, kiln feed and coal fines test were stopped due to the fines testing machine is not functional in the current operation of the plant.

In the case of inhomogeneity of kiln feed, the team discussed that there is no any measurement method or a target for checking this significant factor in the current operation. Therefore, it is categorized as uncontrollable factor. Moreover, in the case of coal utilization, a test for coal heating value is very expensive test .Hence , to reduce this test, the current practice in the plant is ,to perform this test per every blended batch which is collected from each truck delivered from the supplier.

when different batch of coal is delivered to the plant, blending of all different batch of coal and use this for everyday consumption makes the researcher to take an assumption that the moisture content, heat value and burnability is more or less consistent throughout the operation .

Hence, for this experiment lime saturation factor, silica moduli and refractory moduli are selected to see their impact on consumption of coal in the production of clinker in the third line kiln.

These goals can be achieved simultaneously by making a control on C_3S or LSF (Lime saturation factor),SM (silica Moduli),C_3A or RM (Refractory Moduli).Hence, LSF,SM and RM factors are the significant factor for control of quality clinker production and coal consumption.

Table 11: The significant Factors selected for high coal consumption

No.	The major Factors/variables inputs
1	Lime saturation factor(LSF)
2	Silica Moduli(SM)
3	Refractory Moduli(RM)

Assumption

The composition of LSF(lime saturation factor) vary based on the limestone calcium carbonate composition .Hence, from the company raw material record ,frequent times the range of the raw material(limestone) lime saturation factor value were within the 98±1% range .Beside this, by the time when this experiment is conducted , the raw material composition was with in the mentioned range .Therefore ,assumption were taken to set the range of LSF =98±1%,SM=2.35-2.4%,RM=5.5-5.6%.On the other hand, the moisture content of the kiln meal and the coal is consider to be uncontrollable due to the reason if the delivered coal or kiln feed get moistures', there is no a separate dryer to reduce the moisture except passing in the pre-heater ,which cause the pre-heater to demand a high heat energy from the kiln . Hence to reduce the variability the experiment was conducted in the input materials (raw material and coal) that have been taken from one batch of material during the experimentation.

4.6 Improve Phase

In this stage a design of experiment (DOE) techniques were used for modeling the process performance in different conditions such as high and low setting of the input factor target range. Then, the identification of the impact of each factor and their interaction was done by doing an experiment and recollecting data. A DOE in these case helps to determine the optimized input values to maximize performance prediction also to find an optimized point.

4.6.1 Integrating design of experiment with improvement phase

In the previous section ,the analysis of factor that influence the coal consumption were identified as Lime Saturation factor, Silica Moduli and refractory moduli were the key factors. After identifying the factor, the next task was to fix the level of setting based on the available data and the cost of experimentation. Hence, a two level setting that is high and low were selected to look their influence in the response variable (coal consumption level). Therefore, in order to see their individual and interaction effect of all the three factors, a 2^3=8 experiment i.e a full factorial experiment was conducted. The low and high setting for each factor was given by LSM high=99,LSM low=97,SM high=2.4 ,SM low=2.35,RM high=5.6 and RM low=5.5,the targets ranges have taken from quality clinker production range.

The major steps that was followed during DOE experimentation is presented with four step procedure as given in the following section:

i. From the identified input factors, defining the level or range of operation is the first step. The target range is determined by the company quality assurance lab after analyzing the composition of the quarried limestone calcium carbonate. Setting the target has a benefit to fix the experiment point .Hence, the list of level and range are described in Table 8.

Table 12: List of factors, Range and level

No.	The major Factors/variables inputs	Range
1	Lime saturation factor	98±1%
2	Silica Moduli	2.35-2.4
3	Refractory Moduli	5.5-5.6

ii. Selection of a design: in this case based on the evaluation requirement placed in the methodology section Fig.2 and reviewed in table 9, a two level full factorial DOE method was selected.

Table 13: The evaluation was performed based on the following evaluation criteria

No.	Evaluation criteria	Evaluation
1	Are the identified variable <6	Yes, they are three in number(LSM ,SM and RM)
2	Are all the variables continuous?	Yes, all of them are continuous and measured in a continuous measurement i.e for each measurement range e.g LSM measurement can be any number in between 97-99 %,..etc
3	Is the process linear?	From the study of all of the three factors effect shows an increment or decrement to the response variable coal consumption. Therefore a linear assumption is considered for the entire variable.

iii. Collection of data (relative to the identified outputs): here in this stage Minitab 17 software was used to find a randomized setting of experiment. Randomization techniques were used for minimizing the effect of uncontrollable factors effect in the process while conducting the experimentation. Since the number of factors are three, a full factorial experiment was decided to conduct .The test running order is as illustrated in **Table 14** below.

Table 14: Test order as per the software randomization method

Std order	Run Order	Lime saturation	Silica Moduli	Refractory Moduli
6	1	99	2.35	5.6
1	2	97	2.35	5.5
8	3	99	2.40	5.6
4	4	99	2.40	5.5
5	5	97	2.35	5.6
3	6	97	2.40	5.5
7	7	97	2.40	5.6
2	8	99	2.35	5.5
6	1	99	2.35	5.6

iv. **Analysis of data and interpretation**: as described in the previous section, the selected setting for coal consumption optimization was governed by the quality target range. Therefore, in this phase based on the given point and experimental order , the experiment for finding the response in coal consumption was determined as displayed in **Table 15** .

Table 15: Full factorial experiment and the response

Std order	Run Order	Lime saturation	Silica Moduli	Refractory Moduli	Response variable		
					Coal consumption	Clinker quality	
						C_3S	Free calcium oxide
6	1	99	2.35	5.6	131	38.1	0.92
1	2	97	2.35	5.5	130	41.0	1.62
8	3	99	2.40	5.6	150	45.0	1.06
4	4	99	2.40	5.5	125	38.1	0.92
5	5	97	2.35	5.6	126	46.0	1.20
3	6	97	2.40	5.5	116	50.7	1.27
7	7	97	2.40	5.6	126	38.1	1.62
2	8	99	2.35	5.5	142	54.1	1.24
6	1	99	2.35	5.6	131	38.1	0.92

4.6.2 Factorial regression result and interpretation

Factorial regression analysis was used to study the interaction & the level of significance in coal utilization. In this study , there are three main effects, A,B and C, and 3 two-factor interactions, AB, AC, and BC, and 1 three-factor interaction, ABC .Using MINITAB 17, analysis result called analysis of variance (ANOVA) ,pareto chart and residual plots were used to interpret the result.

Interpretation of analysis result

Step -1: Determination of the term which contributes the most in the response variable using Pareto chart.

The pareto chart was used to compare the relative magnitude and the statistical significance of both main and interaction effects. As shown in the **Figure 9**, a Minitab plots the effects in a decreasing order of their absolute values. The reference line in these case ,$\alpha = 0.15$, on the chart indicates which effects are significant. A pareto chart used for design of experiment has some differences from the 80/20 rule used for identification of the vital few .In mini tab analysis ,the pareto analysis indicates the factors which are statistically significance factors among all other factors . As indicated in **Figure 9**, the main effect, A and an interaction BC, are the most contributing factor ($\alpha = 0.15$). Moreover, we can observe that Lime saturation Factor (A) and silica Moduli to refractory moduli interaction (BC) are equally the largest effect because it extends the farthest. Beside this, the effect of silica moduli on high coal consumption is the smallest because it extends the least.

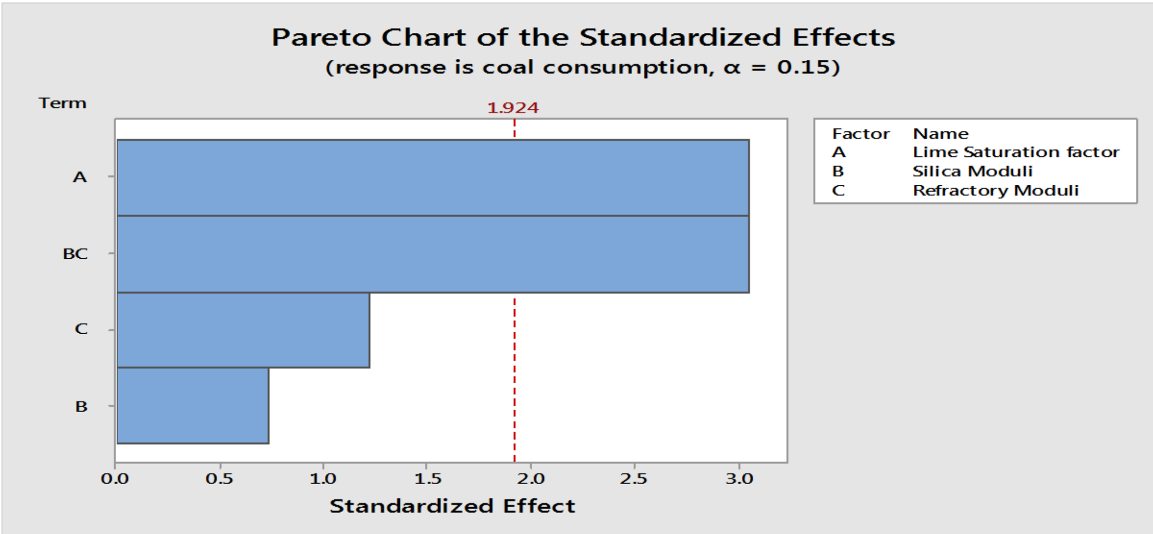


Figure 9: Pareto chart of the standardized effect plot

Step 2: Determination of the term which have statistically significant effects on the response

For determination of the relationship between the factors on the response variable and their statistical significance, comparison of the term with P-value was done. Hence, the Pareto chart as **Figure 9** indicates, factor A and BC are the significant factor since this two factors are fall above the red line value called the standardized effect value. In this case, if the value of $p<0.15$, then the factors are significant, otherwise they are categorized as less significant factors. Therefore, A and BC are the significant factors (Lime saturation factor (LMS) and Silica Moduli (SM) to Refractory Moduli interactions) are equally significant for the response variable (coal consumption). Therefore, the changes in these input factors can be associated with the changes in the response variable. For checking whether a given model term is statistically significant or not, the interpretation should base the following consideration:

- If the coefficient of a given factor is significant, the conclusion will be, not all level means are equal.
- If for a given term coefficient for a covariate is significant, the change in the value of the variable are related with changes in the mean response value.
- If an interaction term coefficient is significant, the factors and the response relationship depends on the other factors in the term. In such case, before interpreting the main effects, consideration should be given for the interaction effect.

Referring Table 16, the Key Results are: P-Value, Coefficients

- From the analysis result given, the main effect A (lime saturation factor) is statistically significant at the significance level of 0.15. Hence, the change in LSF or factor A, variables is associated with the changes in the response variable.
- There is no covariate in this model. Since there is no a significant term coefficient for a covariate
- For a two-way interaction terms, BC (Silica Moduli to refractory moduli interaction) is statistically significant. Hence, the relationship between each variable (B and C) and the response depends on the value of the other variable.

Table 16: Analysis of variance in coded coefficient

Coded Coefficients

Term	Effect	Coef SE	Coef	T-Value	P-Value	VIF
Constant		130.75	2.05	63.89	0.000	
Lime Saturation factor	12.50	6.25	2.05	3.05	0.055	1.00
Silica Moduli	-3.00	-1.50	2.05	-0.73	0.517	1.00
Refractory Moduli	5.00	2.50	2.05	1.22	0.309	1.00
Silica Moduli*Refractory Moduli	12.50	6.25	2.05	3.05	0.055	1.00

Step 3: Determining how well a given model fits the data

Referring Table 17, the Key Results are: S, R-sq, R-sq (adj), R-sq (pred)

- **Model summary**

S	R-sq	R-Sq(Adj)	R-Sq(Pred)
5.7892	87.33%	70.45%	9.93%

In these summary results, the model explains 87.33% of the variation in coal consumption. In these data, the R^2 value shows the model provides a good fit to the data.

Table 17: Analysis of variance

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	4	693.00	173.25	5.17	0.104
Linear	3	380.50	126.83	3.79	0.152
Lime Saturation factor	1	312.50	312.50	9.33	0.055
Silica Moduli	1	18.00	18.00	0.54	0.517
Refractory Moduli	1	50.00	50.00	1.49	0.309
2-Way Interactions	1	312.50	312.50	9.33	0.055
Silica Moduli*Refractory Moduli	1	312.50	312.50	9.33	0.055
Error	3	100.50	33.50		
Total	7	793.50			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
5.78792	87.33%	70.45%	9.93%

Step 4: Determining whether the proposed model meets the assumptions of the analysis

A. Check the validity of ANOVA assumption

The check for the validity of the ANOVA helps to see whether any trends or anomalies appear that would not be considered by the standard linear response models. Hence, based on this concept , as given in **Figure 10** ,a Residual plot was used to check the validity of ANOVA assumption. In this plot, there is a normal probability versus fits. The major assumptions is that all the error terms are identically and independently normally distributed with mean 0 and common variance sigma square.

Interpretation of Figure 10:

a. In **Figure 10** top left graph, most of the points are found around the blue line which indicate that the error terms are normally distributed .Hence, the assumption of normality is valid.
b. In **Figure 10** top right graph , the error terms versus the fitted values shows that half of the data are above and half of the data are below from the zero line which indicate that the assumption for the error terms mean zero is valid.

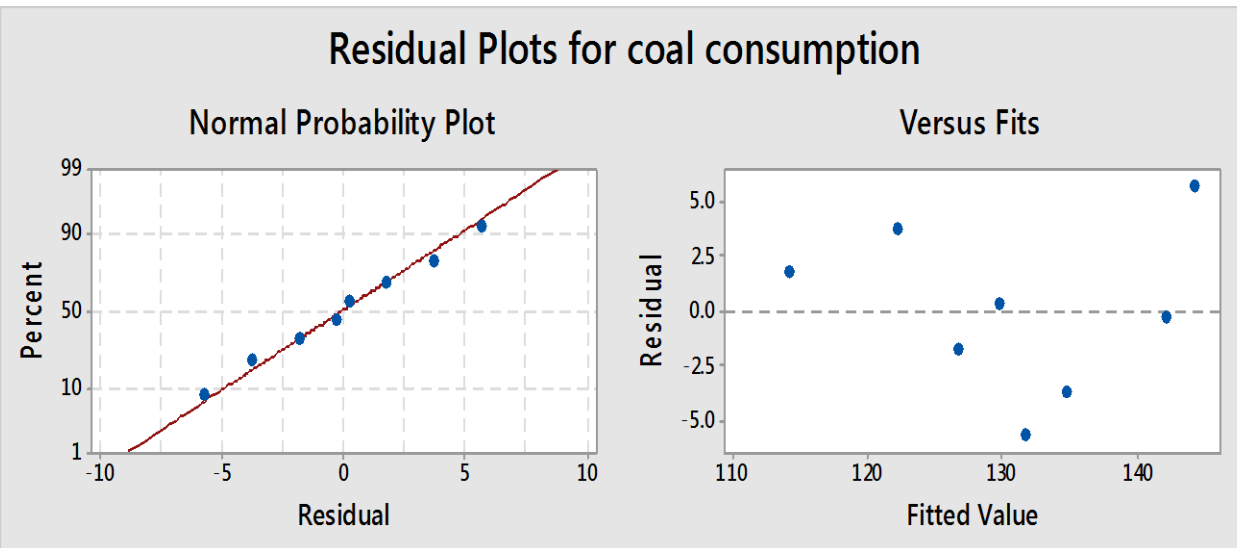


Figure 10: Residual plots for coal consumption

Hence, the linear assumption of the model which is given by the ANOVA is valid, the next task will be by using this model doing a Prediction at a different variable setting

B. Prediction for coal consumption

A predication for coal consumption using the given regression equation in these case is required for planning or institutionalizing the improvement found .Thus , before that the equation should verify that the results are in a predicted range by replicating optimum conditions as well as other points.

Regression Equation in Un-coded Units,

Coal consumption = 26284 - 270.2 Lime saturation Factor - 11255 Silica moduli + 52.5 Refractory Moduli + 115.0 Lime saturation Factor*Silica moduli

i.

Variable	**Setting**
Lime saturation Factor	97
Silica moduli	2.35
Refractory Moduli	5.5

Fit	**SE Fit**	**95% CI**	**95% PI**
123.375	1.90258	(117.320, 129.430)	(113.612, 133.138)

ii.

Variable	**Setting**
Lime saturation Factor	99
Silica moduli	2.4
Refractory Moduli	5.6

Fit	**SE Fit**	**95% CI**	**95% PI**
135.125	1.90258	(129.070, 141.180)	(125.362, 144.888)

The Optimized response in this experiment is 116kg.Coal/ton of clinker at the point **97, 2.4 and 5.5** of LSF, SM and RM respectively.

C. Validation of test : the optimum settings obtained from experimentation results and the prediction equation ,a confirmation test run was performed on three material proportioning setting

- at (LSF=97,SM=2.35,RM=5.5) setting =126kg coal/ton of clinker
- at (LSF=97,SM=2.4,RM=5.5) setting =121kg coal/ton of clinker
- at (LSF=99,SM=2.4,RM=5.5) setting =138 kg coal/ton of clinker

As summary result indicated in **Table 18**, the prediction result shows, it is almost closer to the empirically determined result except at the optimized point.

Table 18: Comparison of Experimental result with predicted result

No.	Tests	Predicted specific coal consumption at 95% CI	Empirically determined coal consumption in kg Coal/ton	Remark
1	LSF=97,SM=2.35,RM=5.5	(117.320, 129.430)	126	Within the range
2	LSF=97,SM=2.4,RM=5.5	116(optimized setting)	121	5kg difference
3	LSF=99,SM=2.4,RM=5.5	(129.070, 141.180)	138	Within the range

4.7 Control

The control phase is the last phase in DMAIC process. Based on the previous analysis, the possible settings are found and the critical input variables should be set to be controlled and the process outputs also monitored. Those control input factors are identified to be the lower lime saturation factor and silica moduli to refractory moduli interaction. Hence, the main objective of a control phase is to ensure that the activity to be a normal day to day activity. Hence, for achieving the target proportioned mix setting and keeping its consistency, a study of kiln feed preparation process was performed. Based on these, a proposal of prevention or corrective action plan was prepared.

4.8 Kiln feed preparation process

In the preparation of the input raw material (kiln feed improved) is a multi-stage and complex. This process in general consists of four major processing steps.

- Crushing (primary, secondary, etc.)
- Pre-homogenization and storage of crushed materials
- Grinding (diverse milling systems)
- Proportioning, homogenization, and storage of fine material

All those operation are assisted by online and an offline control equipment in which quality control laboratories are working with an integration with raw material preparation and the rest of processing activity.

The detailed information about the current kiln feed preparation process was collected by doing a physical observation of the plant when it is operating. Hence, as per the observation, the detailed step by step process is described as in the following section and with process flow diagram in **Figure 11.**

a. **Raw material extraction/ Quarrying**: In this process, since the major raw material for production of cement is limestone. It will be mined from quarry by blasting .The other raw materials such as clay and silica quarry also mined from their corresponding quarries and transported to the crusher .Beside these , correctives are material which are used in small quantity for correcting the chemical composition of raw mix to get in the required quality target. In this stage, a testand inspection will be performed on each raw material .e.g for limestone ,moisture content ,calcium carbonate and other oxide composition ,for sand and clay, moisture content and other oxide contents(iron, aluminum, calcium and magnesium oxide).The frequency of test for these specific test is set 'as required' not specified .
b. **Primary and Secondary Crushing**: after mining of the raw material, transportation by bolder truck to a primary crusher will undertake. After that, the crushed limestone will discharged into vibratory screen to separate out the muddy limestone particle. In this stage, the mud free limestone will fed into secondary crusher for further size reduction. In this phase a test is performed to check whether the quality requirement is fulfilled at this stage or not. The type of test performed for limestone is calcium carbonate composition,

moisture content and other composition .The frequency of test for crushed limestone is every hour, once a month for sand and every 15 days for that of clay.

c. **Pre-homogenization and storage of crushed materials:** pre-homogenization activity consists of storing or stacking and retrieval or reclaiming of the material **.**Blending each type of raw material pile before mixing each other is done by using a stacker and reclaimer .The blending operation is performed when the stacker receives crushed material from the incoming belt conveyor and this belt consist of movable carriage and drops the raw material moves to the stock piles. The main purpose of a stacker is to pile bulk material into a stock pile. A recliamer also used to layer the material in small thickness by dislodging from the entire cross section of the pile. Hence, after the raw material is blended longitudinally and circularly, it will fed into a hopper/bin by using a belt conveyor in which the three bin holds different raw material i.e limestone, sand and clay. Since the mined raw material specially the limestone calcium carbonate content vary day by day, to keep the homogeneity of this material, stocking in the stocker will be in a circular manner i.e putting it layer by layer every day. At this stage, from each pile of the raw material a test will performed .By taking a sample for limestone, Clay and sandstone from the blended pile , moisture content and the material composition test will be done with a frequency of every new pile for limestone, once a month for sand and every 15 days for clay.

d. **Raw mix Grinding and mixing**: from the previous section taken composition of each raw material, a raw mix deign will be done to determine the quantitative proportion of each raw material to produce a desired chemical and mineralogical composition of clinker. In this case, the basis for calculation is the chemical composition of the three raw material . Specifically, lime saturation factor, silica moduli, refractory moduli (the sum of alumina moduli and iron moduli).Hence, based on the proportion given by quality assurance lab, each raw material from their respective hopper will pass through a weigh feeder and mix and grinding operation will takes place. When the material reaches in this stage which is known as raw meal or raw mix, Lime saturation factor, silica moduli, refractory moduli and fines will be checked .If the sample can't fulfill the target level, corrective materials such as corrective limestone, silica .etc, will be added.

e. **Homogenization:** after the raw mill is fed into the homogenization silo, further material blending will carried out in this silo. In this phase after the blending operation is done, Lime saturation factor, silica moduli, refractory moduli and fines will be checked .In the current operation, fines test is not performed due to the test machine failure.

<u>From Quarry to Kiln feed Raw material preparation process</u>

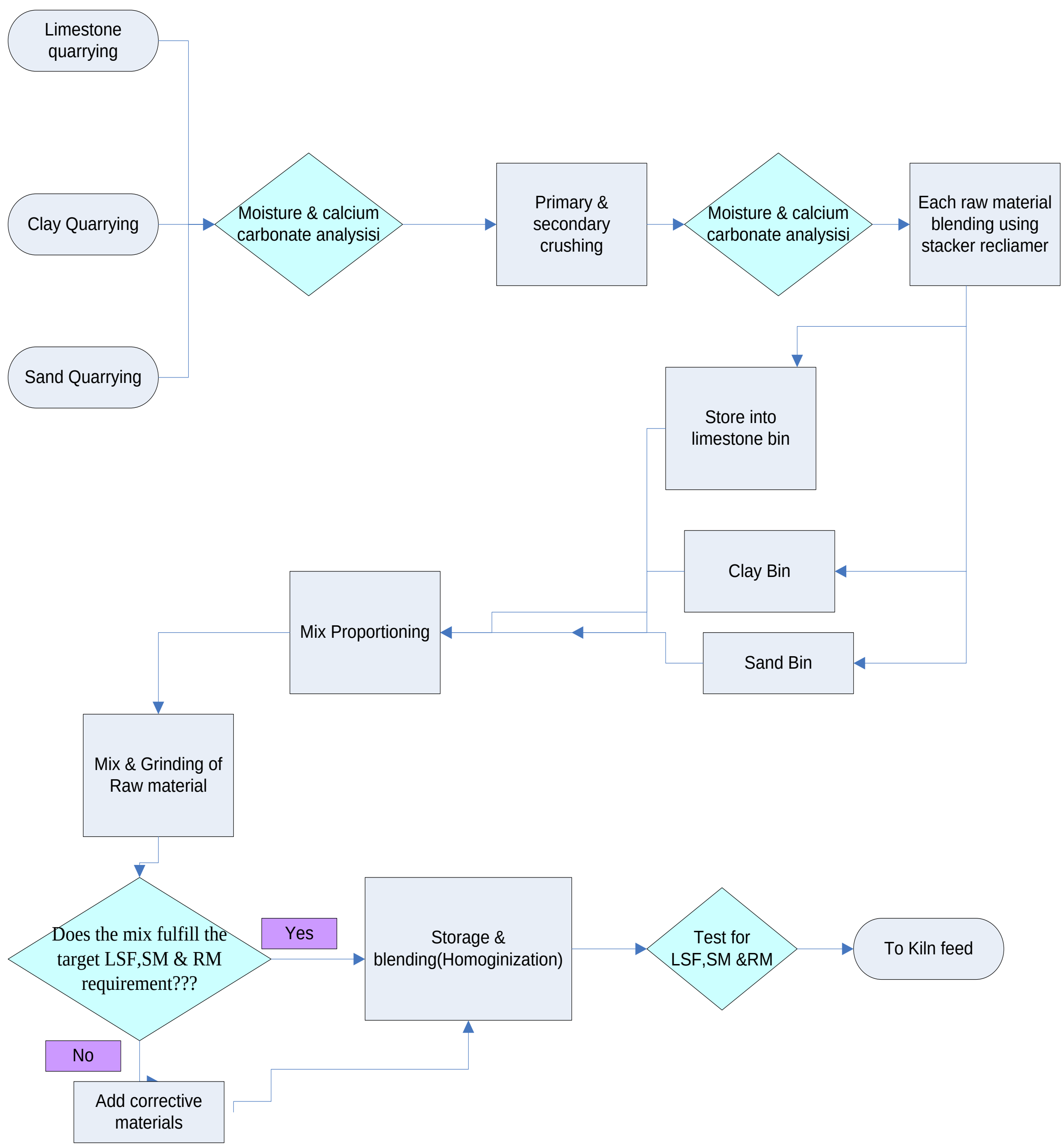


Figure 11: From Quarry to Kiln feed raw material preparation process

As illustrated in the process description and in the process flow diagram, the preparation of input kiln feed pass through different value addition, test and inspection process. In this process activity ,an out of target proportion can be identified after raw mix grinding and homogenization process while the correction activity can be performed only on raw mix grinding section .Moreover, there is a probability of an out of target kiln feed appearance after inspection is made from the homogenization silo . Hence, it is one of the limitations of the existing process. Hence, to alleviate this issue in the existing process condition the following improvement activity are suggested.

Table 19: control plan for improvement of Raw material proportioning

No.	Process **preventive**	Problem /limitation in the current operation	Causes of problem	Control mechanism	Frequency	Responsibility
1	Raw material quarry section	At the start of each raw material quarrying (limestone, clay and sand quarry), fluctuation in chemical composition particularly in limestone quarry appear and unavoidable.	▪ It may be caused by Nature of the mined place ▪ Method of quarrying	▪ Detecting at the start of the process ,by checking for the blast area that used for each batch preparation ,then giving more time in pre -blending operation by stacker reclaimer	Every new quarrying operation	Raw material preparation and supplies team
2	Mixing and grinding /raw meal section	▪ In proportioning section the correction of material mix(Raw mix) is done after looking the composition of previously transferred material to the next section rather checking it before coming	▪ Failure of online raw material composition analyser ▪ When each type of raw material didn't blended well	▪ To generate and set blending factor :which is the ratio of standard deviation of input raw meal to standard deviation of an output raw meal ▪ To set raw meal uniformity goals :for short term(hourly value upto 24hr) and long term (daily values over month) ▪ Since an online	Every new pile	▪ Quality assurance and clinker production team

				composition analyser is currently out of function, reduction of raw material variability by taking more time in pre-blending operation in the stacker reclaimer section should be done to prevent proportioning error		
		▪ Non –uniform raw meal preparation due to inadequate preparation of raw mix	▪ An availability of sufficient raw mix composition control mechanism			Quality assurance and clinker production team
3	Homogenization	At this stage, before 7 month, inspection was done to determine the fines and kiln feed proportion (LSM,SM and RM) but currently, only mix proportioning task is performed. In addition , there is no any inspection method to check whether the mix is properly homogenised or not since one of the cause for low quality and high coal	There is no a method to determine how much homogeneity is found after the homogenization process is carried out	a. placing a complete test procedure and requirement that include fines, proportioned mix composition check, uniformity/homogeneity of the feed material	▪ Every hour for Fines and proportioned mix ▪ Every 4hr	Quality assurance and clinker production team

		consumption is inconsistency of kiln feed entered into the burning process in the kiln				
	Corrective action					
1.	Mixing and grinding /raw meal section	an out of target mix proportion is delivered to the next homogenization silo	• When the raw material blending operation was not done properly • Inaccurate determination of the raw material composition	• Once an out of target mix is send to the homogenization silo ,no matter how the blending is done, an out of target situation won't be solved .Hence, to correct or minimize the effect ,a batch wise correction should be done in the raw mix and homogenization then transfer the material into the homogenization silo depending on the type of correction needed.	• As an out of target situation is appear for the consecutive 3 hr	Quality assurance and clinker production team

Chapter Five

5. Results and Discussions

In this part, a description and discussion of the major result found and their interpretation, how these result can be considered in developing a guiding framework, explanation of the finding from coal utilization improvement..etc was discussed.

5.1 Summary and Future implementation

At the start of this research, identifying the area of improvement in coal utilization without affecting the quality of clinker production was the main focus. At this stage, six sigma was used by first defining the current process of the clinker production , objective of the project. Then in measure phase, determining those output /response variable which is the focus of the study for better improvement task. Those study areas was identified as the 3rd line kiln coal consumption improvement without affecting the clinker quality parameter (particularly the C_3S and the free lime content of the clinker) .Therefore ,once this response variable is determined the next task was to identify the input factor which has the highest potential /significance to the increment of the coal utilization .These factors were determined by taking August ,2018 month ,which is the highest of all month coal utilization, to study those input factors. During this study, some of the variables are categorized uncontrolled due to unavailability of a method to monitor and take action during the operation as well as when this experiment is conducted and some of the test such as coal heating value is yet a very important character to be studied but not included in this study, due to the expensiveness of the test material used .Hence, to compromise the effect, a more blended coal was used during the experimentation to minimize the variation in the coal calorific value. Therefore based on the availability of test and their significance on burnability nature of the raw material input , selection of the three material proportion value such as Limes saturation factor, silica moduli and refractory moduli was undertaken. As a result, improvement of coal utilization using six sigma implementation have done on input raw material proportion chemical composition variation because of the variation in the kiln feed composition affect its burnability and eventually the fuel consumption. In these phase the six sigma was used by integrating with the design of experiment tool to enhance the analyze and improve section of the DMAIC to experimentally identify which is the optimal setting for efficient utilization of coal by taking the quality target level which is obtained from the quality assurance lab as a range of setting for theses experiment. This was done to ensure quality clinker production and improved coal utilization simultaneously. After a subsequent experimentation and analysis, a result has shown that from the chosen main factors lime saturation factor has shown a significant impact in coal utilization. Next ,the interaction effect of silica moduli to refractory moduli has an equal influence with the main effect A or lime saturation factor .In addition, the researcher also try to observe the impact of adjusting the input material target within the given setting on the response in quality particularly in C_3S and free lime content. The result shows that from eight experiments conducted only two of the test shows within the target clinker quality level.

Six sigma implementation guiding framework

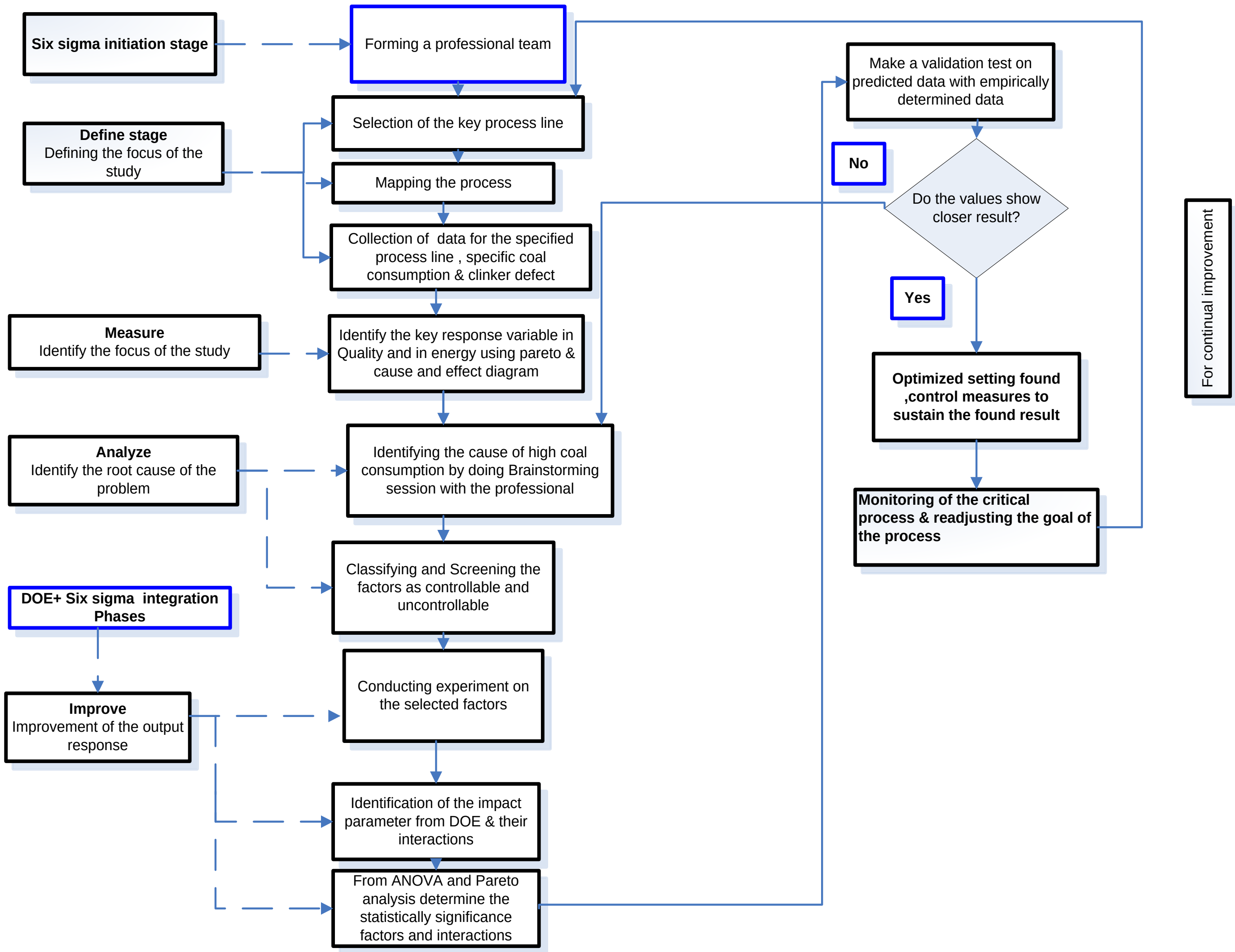


Figure 12: Six sigma implementation Framework

As figure 12 illustrated, the purpose of introducing this framework is targeting the case company coal utilization improvement and other process variability's, using this framework as a guideline for effective implementation of six sigma in the current situation of the factory .These model shows one cycle of improvement by starting with forming a multi-disciplined professional (quality professionals ,process Engineers,etc)team for studying the root cause of the variation in coal utilization and defect in produced clinker. Based on the identified variability, initiation of six sigma in the selected project using DMAIC phases .The full cycle can be constantly repeated until the process performance improvement reaches an optimal level .In each cycle, a target improvement goal setting is employed, in order to continually achieve a new level of improvement.

Chapter Six

6. Conclusion and Recommendation

Most of the six sigma methodologies were applied for manufacturing process for reduction of defect and improvement of process variability by integrating with various tools such as value stream mapping, Lean Manufacturing strategies, failure mode analysis to identify waste and process improvement solutions to enhance energy utilization. The integration of Six Sigma and design of experiment into the energy improvement process gives an additional arm for this research to model the process and identify the optimized energy level within the selected range of factors.

This research has explored how the coal energy utilization by the kiln can be improved by adopting six sigma methodology and design of experiment tools. The objective of the research was improvement of the 3rd line kiln coal utilization without affecting the quality of clinker.

According to the study result found, application of six sigma in the current process of the factory has an extensive benefit in

- Reduction in the cost of production of clinker, by reducing the 3rd line kiln coal utilization by an average of 2.73milion kg coal per annual production which is around 6milion birr as compared from the previous year's consumption.
- The implementation of efficient coal utilization has also a positive impact in good quality clinker production. Hence, by assuring and improving quality clinker production, reduction in cost of clinker used for correcting a defective product can be achieved.
- There is also a possibility to identify & eliminate the causes of variability occurring in the process by keeping the consistency of the kiln feed proportion ,consistent utilization of coal resource

Furthermore, from this study

- If further consideration is made for other variables which are not covered in this research, there is a room for a significant amount of energy saving .

As a Recommendation for improvement of the coal utilization, many factors can be considered for better understanding of their influence. However, in this research from the considered three factor, the experiment shows that raw material proportion setting improvement can improve around 116-120 kg coal to produce a ton of clinker. This could be achieved through the control of the input kiln feed chemical variation .The variation in these case may associate with the raw material quarrying operation ,the raw mix control and homogenization process before feeding into the kiln. Therefore, to ensure consistent coal utilization by maintaining the target quality level, emphasis should be given to storage and homogenization of raw materials and kiln feed in the current system.

6.1 Further Research

In this study, though the input kiln feed raw material fulfilled the quality target, there is a tendency of producing below quality clinker. Hence, the mentioned factors and setting the right quality target should be investigated further for bringing a better result in improvement of Quality clinker production and coal utilization in the third line kiln .Beside these, the effect of some of the factors such as raw material and coal fines ,moisture content and coal calorific values..etc should be studied further.

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Appendices

Defect in Clinker effect on final product cement quality impact analysis format

No.	Clinker quality parameter	Cement quality parameter																
		2 days compressive strength				28 days compressive strength				Cement expansion				Setting time				Average .
		LI	MI	SI	VSI	LI	MI	SI	VSI	LI	MI	SI	VSI	LI	MI	SI	VSI	
1	Does C_3S has an impact																	
2	Does C_2S has an impact																	
3	Liter weight has an impact																	
4	C_3A has an impact																	
5	Does Free calcium oxide has an impact																	