Process Performance Analysis In Cement Industry

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Abstract: The aim of this study is to apply a quality control chart which is based on the process capability indices C_p or C_{pk}, for online process control. This chart determine the statistical state of the process and determine the process capability for producing items conforming to the specifications simultaneously .This chart is simple to apply and does not warrant and tedious computations as well as save the time for monitoring the process quality. This chart was applied through experimental test results obtained from cement manufactory, Beni- Suef, Egypt. This chart proved to be effective for monitoring the process performance. Therefore, this chart can be used as a quality tool in industrial applications for optimizing the manufacturing process quality control.

Keywords: control charts, process capability indices, cement industry.

1. INTRODUCTION

Process capability study is a method of combining the statistical tools developed from the normal curve and central charts to interpret and analyze the data representing a process. The purpose of the process capability study is to determine the variation spread and to find the effect of time on both the average and the spread. The administration analysis and use of process capability study should be an integral part of the quality engineering function. The process capability refers to the evaluation of how well a process meets specifications or the ability of the process to produce parts that conform to engineering specifications, process control refers to the evaluation of process stability over time or the ability of the process to maintain a state of good statistical control. These are two separate but vitally important issues that we must address when considering the performance of a process and so the assessment of process capability is inappropriate and statistically invalid to assess with respect to conformance to specifications without being reasonably assured of having good statistical control. Before evaluating the process capability, the process must be shown under statistical control i.e. the process must be operating under the influence of only chance causes of variation and also ensure that the process data is normally distribution. A process may produce a large number of pieces that do not meet the specifications, even though the process it self is in a state of statistical control (i.e. all the points on the $\bar{X}$ and R chart are within the 3 sigma limits and vary in random manner). This may be due to the lack of centering of the process mean in other words, the actual mean value of the parts being produce may be significantly different from the specific nominal value of the parts. If this is the case, an adjustment of the machine to move the mean closer to the nominal value may solve the problem. Cement industry plays a crucial role in economic development of any country. The manufacturing process of cement consists of mixing, drying and grinding of limestone, clay and silica into a composite mass. The mixture is then heated and burnt in a pre-heater and kilin to be cooled in an air-cooling system to form clinker which is the semi finished form. This clinker is cooled by air and addition with gypsum to form cement. The organization process of cement manufacturing wet and dry method is shown in figure 1.

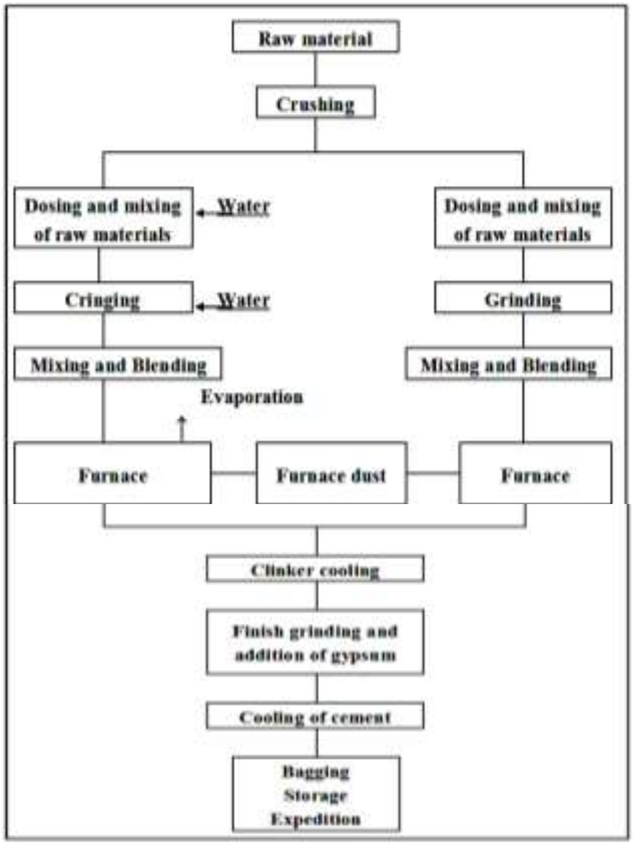


Figure 1: *Organizational processes typical of cement manufacturing wet and dry methods*

There are two basic methods to produce cement are the wet and dry manufacturing processes. The main difference between wet and dry process is the mix preparation method prior to burning clinker in the kiln. In wet process water is added to the raw materials to form a raw thick slurry whereas the dry process is based on the preparation of fine powdered raw meal by raw materials grinding and drying. The choice of the process is mainly based on the nature of the available raw material when the moisture content in raw materials is more than 20% and up to 45% the wet method is preferred to the dry method. The wet process is more energy intensive and expensive than the dry process as it required the wet slurry to be evaporated before calcinations. The comparison of dry process and wet process is shown in Table 1

Table 1 *Comparison of dry process and wet process.*

Criteria	Dry process	Wet process
Fuel consumption	Low	High
Time of process	Lesser	Higher
Quality	Inferior quality	Superior quality
Cost of production	High	Low

This study was applied through experimental results obtained from Egyptian cement company, Beni-Suef, Egypt [dry process]. Arjun, K. and Kotz, S. [1] Developed a new process capability index C_{pq}. The new C_{pq} was defined and discussed mathematically. The researchers compared the new process capability index with old approved index C_{pm}. The bias and variance of C_{pq} are less than of C_{pm} as was showed in the comparison. The researchers recommended to use the new process capability index C_{pq} with sample size ≥ 20. Pearn, W. L. and Lin, P.C. [2] Investigated the behaviour of the actual process yield in terms of the number of nonconformities for processes with a fixed index value of $C_{pk}= C_{pm}$ with different degrees of process centering, The process capability indices such as C_p, C_{pk} and C_{pm} have been defined. The researchers applied the process capability indices with real data to decide which process capability index is better. The results show that, the process capability index C_{pm} is better for customer protection. Hsin-Hung, Wu. [3] Studies the relationship among the loss function, process capability indices and control charts aimed to establish goal control limits. The implementation of target cost concept are explained in this study. By applying the target cost philosophy the quality of product are improved. He concluded that:

1. Reducing process variation is not enough to solve quality problems.
2. Reducing process variation should be used along with bringing the process mean to the target value

Kun-Lin Hsieh. and Lee-Ing. Tong. [4] Tried to use both process capability index with quadratic quality loss function together to analyze the process capability with the consideration of qualitative response data. This new technique can help the producers to compare their processes quality and cost with other competitors. Rezaie, K. et al [5] Showed how to use the process capability indices (C_p, C_{pk}, C_{pm}) and the process performance indices (P_p, P_{pk}, P_{pm}) to evaluate and predict the performance of the process. The researcher also introduced how to judge the process is capable by the C_p value and C_{pk} value, the C_p value of 1.33 is the most commonly acceptable, and C_{pk} greater than 1.33 means the process is capable and C_{pk} lower than 1 the process is never capable. This research did not was the mentioned indices in any application. Đorđe Vukelić1 et al [6] Developed a software for statistical process control. The software using the measured data of a production process to evaluate the process stability and the quality. The software importance for real time data during the process and the result produced quickly in less time. The problem of this method in statistical analysis is needs the production, designing, manufacturing , and control process to be fully automated. Pandey and Banskota [7] Described general process of cement production from exploration of limestone deposit to production of clinker and finally cement. Exploration of limestone comprises area selection, target definition, reserve calculation, resource evaluation and reserve definition. After exploration, mining is taken up. Quarried limestone is stockpiled and then is blended with other raw material like clay/shale, silica, iron are in required proportion they concluded that, Limestone (CaO)-85%, clay (SiO_2, $A_{12}O_3$ or Fe_2O_3) 13% other additive (SiO_2, $A_{12}O_3$) <1% is typical proportion of raw mix design. MgO should not exceed 6% at final composition from raw. These all raw materials are blended in required proportion and heated at high temperature upto 1400˚C – 1450˚C in kiln to produce clinker. Cement is produced by grinding clinker with gypsum (3-5%).Angus Jeang and Chien-Ping Chung [8] Developed a new process capability index C_{pmc} considered process quality and production costs beside the old considered parameters of process mean and variance. An example for the new process, capability index C_{pmc} was discussed and found that the new process capability index C_{pmc} can differentiate between alternative designs in terms of cost and quality which can not been done with the traditional process capability indices. Rami Hihmat Fouad and Adnan Mukattash [10] Used statistical process control tools such as (pareto diagram cause and effect diagram, check sheets, process flow diagram, scatter diagram, histogram and control charts) on a product of a company specialized in steel production. The study found that the tensile strength is the vital problem and account for 72% of the problems, this result found by pareto diagram. Also the study mentioned that the company needs education and training programs for the management and line staff. Mahesh and Brabhuswamy [11] illustrated the step by step procedure adopted at a soap manufacturing company to improve the quality of products. The objective of this study is to reduce the variability in the process through on - line quality control techniques. The statistical process control tools used in this study are :-

1 - Variable control charts [X bar and R charts],
2 - Attribute control chart [U- chart],
3 - Pareto chart.
4 - Cause and effect diagram.

Data was collected at various stages of the manufacturing process and the detailed analysis was done. They concluded that to reduce the number of products falling outside the specifications, there are two types of strategies. The first one is to reduce the variability in the manufacturing processes. The second one is to shift the process mean toward the center. Jiujun Zhang et al [12] Developed new adaptive control chart which integrates both exponentially weighted moving average procedure with generalized ratio test statistics. The developed chart can join the process mean and variability in one chart. Asghar Ghasemi and Saleh Zahediasl [13] Presented the procedures for checking normality of data in statistical analysis. The main tests for assessment of data normality are illustrated in this study. They concluded that :-

1 - The assumption of normality needs to be checked for many statistical procedures, namely parametric tests, because their validity depends on it.
2 - If the data are normally distributed, the result would be a straight diagonal line.
3 - If p- value in the probability plot greater than 0.05, indicates normal distribution of data.

Subramani and Balamurali [14] Proposed capability based control charts method in industrial application for on – line process control the relative performance of the capability based control charts for variables is assessed with that of existing usual control charts for variables, namely x bar chart and R-chart. This method is simple to apply and does not warrant any tedious computations both for control charts and for computing process capability indices. The proposed method also been illustrated with a numerical example. Moussacab and merabet [15] Suggested a new numerical method for the raw material mixture in a cement management program. The mathematical approach and the design of the cement quality management software are presented in this study. The results obtained in this study show that, the suggested numerical method can be used in the preparation of mixture at the cement factories for all types of clinker. Also, this numerical method leads to the conception of practically useful general software which remains a true alternative. Fasil A. and Omprakash S. [16] studies the mixing of raw materials process and composition of raw mill feed, kiln feed as well as formed clinker to reduce the variation in clinker quality. They presented the equations for calculation the important quality ratios in cement mixture such as lime saturation factor (LSF), silica ratio (SR) and alumina ratio (AR). They concluded that, LSF, SR, and AR and variations in clinker quality, it can be decreased by carrying out various steps at different level which reduces the deviations of blending efficiency raw will feed, kiln feed and clinker compositions and its minerals. Tibor and Janons [17] Presented the theoretical background and application details of statistical process control (SPC) based performance evaluation of on – line analyzers. The applicability of the concepts is illustrated by a case study based on data collected from an on – line chemical process industry. Typical patters that show out of control status of the system are also presented. To check the normality of the residuals, an easily applicable and interpretable tool is proposed. They concluded that:-

1 - Statistical process control can be effectively used to support the development and maintenance of on - line process analyzers.
2 - Off-line laboratory tests mostly take more than time. This time delay can cause control problems resulting in economic loss.

Varma and Sirisha [18] This study analyzes an existing processing management system in a cement factory in India. During the last two decades (80's and 90's), major technological advancements took place in design of cement plant equipment/systems. The analysis shows that there are strong areas such as opencast lime stone mining, lime stone crushing & stacking, raw material handling & Grinding, coal grinding, preheater kiln & cooler, clinker grinding (cement mill), packing plant & Loading plant, quality control. It also provides the brief description about the machinery used in each stage and its working principles. Cement industry has come a long way in technological up gradation, production and quality. Orssatto et al [19] Used statistical method of quality control such as control chart and process capability ratio to evaluate the performance of the process of sewage treatment station. They concluded that the generated shewhart charts demonstrated to be a good alternative for the process statistical control, by the means of process capability ratios the researcher found that the process is not capable to follow the environmental legislation. Ghazi and Alam [20] Applied seven quality control tools such as histogram, check sheet, pareto chart, cause and effect diagram, defect concentration diagram, scatter diagram and control charts on a data from spur gear production company. The researcher aimed to increase the process output, improve the method, reduce the overhead, and minimize the waste. The study recommended that the company must install modern equipment and train and motivate the employees. Yerriswamy Wooluru Swamy, D.R. and Nagesh, P., [21] Have carried out a theoretical and experimental study aimed to evaluate process capability analysis for boring operation. The case study in this research was conducted in an automotive industry and monitored using process capability indices C_P , C_{pk}, C_{pm} and C_{pmk} to show the importance of process capability analysis for monitoring and ensuring the product quality to satisfy the customer's requirements.

They concluded that :-

1 - The process must be shown under statistical control and process data is normally distributed before evaluating the process capability.
2 - Among all the process indices C_{pmk} does provide more capability assurance with respect to process yield than the other two indices C_{pk} and C_{pm}.

Singh and Masuku [22] Presented the basic and important assumption based on normal distribution in terms normality test. The concept of normality and how to test the normality of data have been illustrated. This study described, the tools for normality in terms of standardized data transformation, they concluded that normality is one of the most important aspects for statistical analysis. Mondal, S.C. and Kundu, S. [23] Studied process capability indices for univariate and multivariate process. Process capability indices are applied to measure performance in a multistage locomotive wheel manufacturing process. The wheel manufacturing process has three stages namely press forging, rolling and heat treatment. Process capability indices are analysed for the mentioned multistage manufacturing processes and the results are compared to identify the most accurate multivariate process capability index to evaluate multiple quality characteristics for the wheel manufacturing. They concluded that, the data which are collected must to be normally distributed, and the process must to be statistically controlled. Tsamatsoulis [24] Studied the control of cement grinding/mixing process in an industrial mill regarding SO_3 content has been effectively simulated taking into account all its fundamental sides and particularities. Based on a simulator, two controllers of different philosophy have been studied: A classical proportional-integral (PI) controller as well as a nonlinear one (step changes, SC) consisting of certain classes of SO_3 output ranges that result in certain levels of discrete corrections of gypsum feed. Initially, the simulator was implemented for grinding of a single cement type each time. Totally, three cement types were investigated. The controllers have been parameterized and compared using the minimal standard deviation of SO_3 as a criterion. Both provided satisfactory SO_3 consistency, but PI was more efficient against SC as with the double sampling period, the same minimum standard deviation was obtained leading to equal results with half the sampling actions. The simulation was also realized in milling of several cement types. A feed forward part was added to the feedback loop to face the case of cement type changing. The results of operation of this kind of controller in an industrial milling system contribute greatly to the improvement in cement quality. Babagana [25] Examined the statistical performance of some capability indices such as C_p and C_{pk}. The values of capability indices C_P and C_{pk} were computed and reported in the capability plot histogram together. The quality condition of the production based on the analysis presented and shows satisfactory better performance of the production. The results indicates that C_p and C_{pk} measure both greater than one, then the processes have the potential to meet specifications as long as the mean is probability centered. Kundi and Sharma [26] They presented analysis models to assess the efficiency of cement industry. This study examines the impact of size and owner ship on efficiency of cement firms in addition, target value of inputs and out put of firms to reach the optimum level of efficiency have been provided, they concluded that, the comperbensive analysis of efficiency of cement firms will help the managers and policy makers to formulate appropriate strategy to enchance their efficiency. Resmi R. and Pradeepa K., [27] Presented the optimum mixture combination for the raw materials to improve the quality and productivity of whit cement production. The statistical tools used for the study was the Design of Experiments. Design of Experiment was used to determine and optimum mixture for clinker production. They concluded that, the optimum mixture for clinker production occurs when the amount of lime is 80%, sand is 9% and clay is 10%.Adeoti O. A. and Olaomi J. O. [28] Proposed capability index based control chart for variables with a specified process capability index C_p value. The proposed chart is able to address the issue of control and capability simultaneously. The control chart constant to construct the process capability index based control chart has been provided. A numerical example is presented to demonstrate the application of the proposed chart. The result shows that the proposed control chart performs better in monitoring and assessing processes simultaneously. The objective of this study is to investigate the process performance in cement industry by applying control charts for variables with specified process capability indices.

3. STATISTICAL ANALYSIS

The statistical analysis is utilized for making decisions about process based on an analysis of the information contained in sample from the process. Therefore, statistical methods provide the principle means by which product is evaluated and the manufacturing process improved. For any quality control program to be effective, the data collected by the testing laboratory should be analyzed and studied.

Process Monitoring:

In industrial plants, process variables must be maintained within specified limits in order for the plant to operate properly. Process monitoring plays a key role in ensuring that the plant performance satisfies the operating objectives. For most industrial plants, many important quality variables cannot be measured on-line. Instead, samples of the product are taken on in infrequent basis and sent to the quality control laboratory for analysis. Consequently, statistical process control techniques are implemented to ensure that the product quality meet the specifications. The major objective in statistical process control is to use process data and statistical techniques to determine whether the process operation is normal or abnormal. The classical statistical process control techniques that are based on quality control charts such as $\bar{x}$-chart and R-chart. Control charts, merely consists of measurements plotted versus sample number, and control limits that indicate the upper and lower limits for normal process operation. Traditional Monitoring Techniques: In this section, two relatively simple but very effective process monitoring techniques quality control charts, and process capability have been considered.

Quality Control Charts

Statistical process control is an effective method for improving industrial plants quality and productivity. Many tools may be utilized to in effect, allow the industrial plant to make necessary adjustment to improve quality. Figure 2 illustrates the typical control chart.

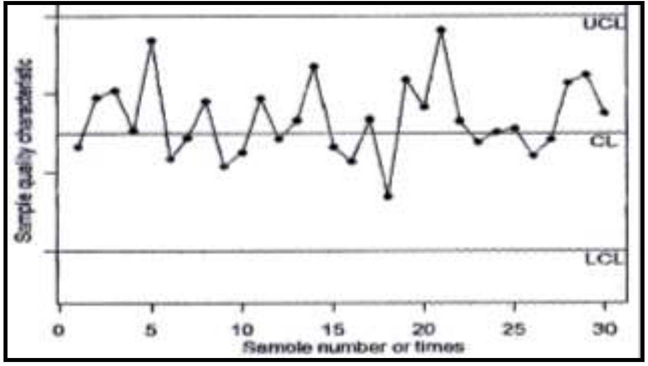


***Figure 2 The** typical control chart [9]:*

Traditional control charts for variables:

$\bar{X}$-Chart :

An $\bar{x}$-chart is used to monitor the average value, or mean of a process over time. For each subgroup, the $\bar{x}$ value is plotted. The upper and lower control limits (UCL, LCL) define the range of inherent variation in the subgroup means when the process in control.

In order to construct $\bar{x}$ – chart, the following steps must be followed:-

a - Estimate the sample mean for ith sample, $\bar{x}$

If x_1 , x_2 , ……, x_n is a sample of size, n, then the mean of i th sample, $\bar{x}$, is

$$\bar{X} = \frac{x_1 + x_2 , \ldots\ldots + x_n}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (1)$$

Typically, n will be small, often either 4, 5, or 6

b - Estimate the range of ith sample, R,

$$R = X_{max} - X_{min} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2)$$

c - Estimate the grand mean, $\bar{\bar{X}}$:

Let $\bar{x}_1$, $\bar{x}_2$, … $\bar{x}_m$ be the average of each sample, then the grand mean, $\bar{\bar{x}}$, is

$$\bar{\bar{X}} = \frac{\bar{X}_1 + \bar{X}_2 + \ldots\ldots + \bar{X}_m}{m} \quad \ldots\ldots\ldots\ldots(3)$$

where

m = Samples are available, each containing in observations on the quality characteristic, usually at least 20 to 25 samples.

d - Estimate the mean of range values , $\bar{R}$

$$\bar{R} = \frac{R_1 + R_2 + \ldots\ldots + R_m}{m} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

e- Estimate the upper control limit, UCL lower control limit, LCL, and the center line, CL, of an $\bar{x}$-chart as [9]:

$$UCL_{\bar{x}} = \bar{\bar{X}} + A_2\,\bar{R} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

$$CL_{\bar{x}} = \bar{\bar{X}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

$$LCL_{\bar{x}} = \bar{\bar{X}} - A_2\,\bar{R} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

$$б = \frac{\bar{R}}{d_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

Where, б : Process standard deviation.

The constants A_2 and d_2 depend on sample size, n, (the number of units per sample). The value of the constants A_2 and d_2 can be obtained from statistical quality control table 2.1 [9]:

R-Chart:

An R-chart is a control chart that is used to monitor process variation when the variable of interest is quantitive measure.

In order to construct R-chart, estimate the upper lower control limit (UCL_R and LCL_R), and the center line CL_R of an R-chart as [9]:

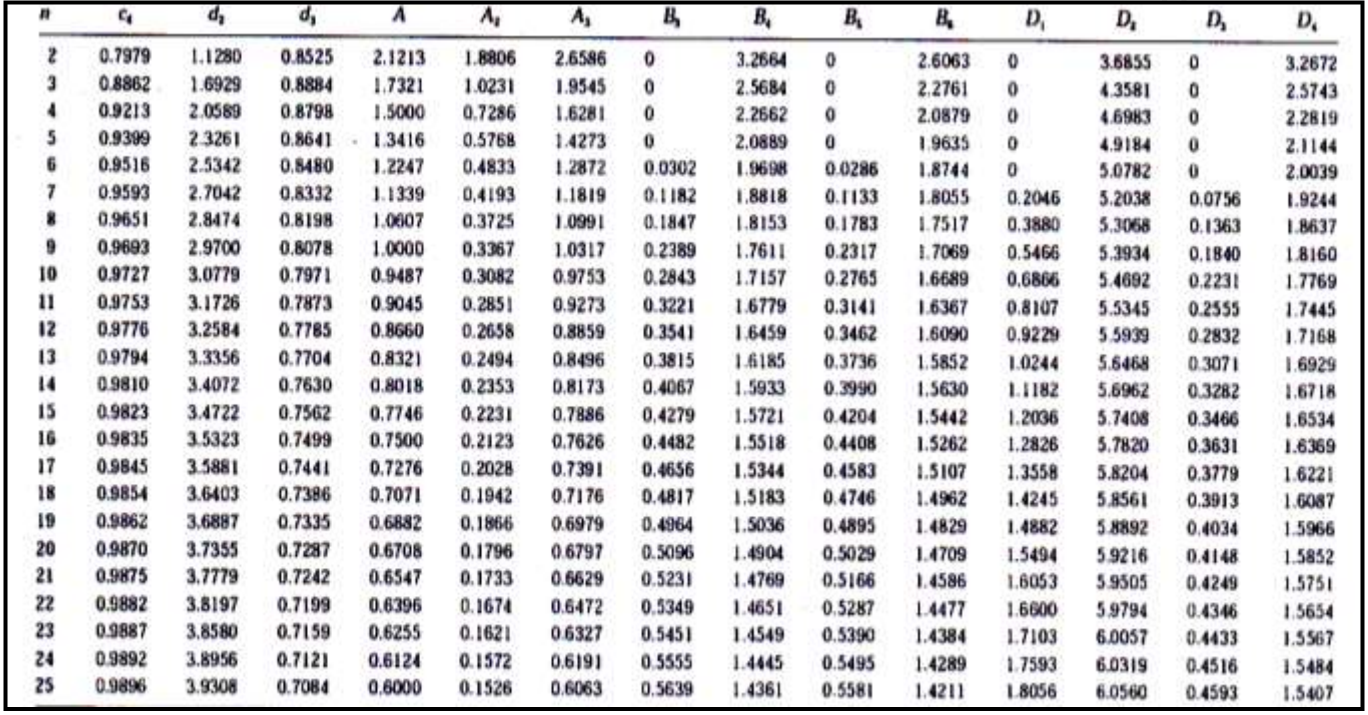
$$UCL_R = D_4\bar{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

$$CL_R = \bar{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots \ (10)$$

$$LCL_R = D_3\bar{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots(11)$$

The constants D_3 and D_4 depend on sample size n. The value of the factors D_3 and D_4 can be obtained from statistical quality control table (see table 2) [9]:

Table 2 *Constants Used for Estimation and Construction of Traditional Control Charts [9]:*



n	c_4	d_2	d_3	A	A_2	A_3	B_3	B_4	B_5	B_6	D_1	D_2	D_3	D_4
2	0.7979	1.1280	0.8525	2.1213	1.8806	2.6586	0	3.2664	0	2.6063	0	3.6855	0	3.2672
3	0.8862	1.6929	0.8884	1.7321	1.0231	1.9545	0	2.5684	0	2.2761	0	4.3581	0	2.5743
4	0.9213	2.0589	0.8798	1.5000	0.7286	1.6281	0	2.2662	0	2.0879	0	4.6983	0	2.2819
5	0.9399	2.3261	0.8641	1.3416	0.5768	1.4273	0	2.0889	0	1.9635	0	4.9184	0	2.1144
6	0.9516	2.5342	0.8480	1.2247	0.4833	1.2872	0.0302	1.9698	0.0286	1.8744	0	5.0782	0	2.0039
7	0.9593	2.7042	0.8332	1.1339	0.4193	1.1819	0.1182	1.8818	0.1133	1.8055	0.2046	5.2038	0.0756	1.9244
8	0.9651	2.8474	0.8198	1.0607	0.3725	1.0991	0.1847	1.8153	0.1783	1.7517	0.3880	5.3068	0.1363	1.8637
9	0.9693	2.9700	0.8078	1.0000	0.3367	1.0317	0.2389	1.7611	0.2317	1.7069	0.5466	5.3934	0.1840	1.8160
10	0.9727	3.0779	0.7971	0.9487	0.3082	0.9753	0.2843	1.7157	0.2765	1.6689	0.6866	5.4692	0.2231	1.7769
11	0.9753	3.1726	0.7873	0.9045	0.2851	0.9273	0.3221	1.6779	0.3141	1.6367	0.8107	5.5345	0.2555	1.7445
12	0.9776	3.2584	0.7785	0.8660	0.2658	0.8859	0.3541	1.6459	0.3462	1.6090	0.9229	5.5939	0.2832	1.7168
13	0.9794	3.3356	0.7704	0.8321	0.2494	0.8496	0.3815	1.6185	0.3736	1.5852	1.0244	5.6468	0.3071	1.6929
14	0.9810	3.4072	0.7630	0.8018	0.2353	0.8173	0.4067	1.5933	0.3990	1.5630	1.1182	5.6962	0.3282	1.6718
15	0.9823	3.4722	0.7562	0.7746	0.2231	0.7886	0.4279	1.5721	0.4204	1.5442	1.2036	5.7408	0.3466	1.6534
16	0.9835	3.5323	0.7499	0.7500	0.2123	0.7626	0.4482	1.5518	0.4408	1.5262	1.2826	5.7820	0.3631	1.6369
17	0.9845	3.5881	0.7441	0.7276	0.2028	0.7391	0.4656	1.5344	0.4583	1.5107	1.3558	5.8204	0.3779	1.6221
18	0.9854	3.6403	0.7386	0.7071	0.1942	0.7176	0.4817	1.5183	0.4746	1.4962	1.4245	5.8561	0.3913	1.6087
19	0.9862	3.6887	0.7335	0.6882	0.1866	0.6979	0.4964	1.5036	0.4895	1.4829	1.4882	5.8892	0.4034	1.5966
20	0.9870	3.7355	0.7287	0.6708	0.1796	0.6797	0.5096	1.4904	0.5029	1.4709	1.5494	5.9216	0.4148	1.5852
21	0.9875	3.7779	0.7242	0.6547	0.1733	0.6629	0.5231	1.4769	0.5166	1.4586	1.6053	5.9505	0.4249	1.5751
22	0.9882	3.8197	0.7199	0.6396	0.1674	0.6472	0.5349	1.4651	0.5287	1.4477	1.6600	5.9794	0.4346	1.5654
23	0.9887	3.8580	0.7159	0.6255	0.1621	0.6327	0.5451	1.4549	0.5390	1.4384	1.7103	6.0057	0.4433	1.5567
24	0.9892	3.8956	0.7121	0.6124	0.1572	0.6191	0.5555	1.4445	0.5495	1.4289	1.7593	6.0319	0.4516	1.5484
25	0.9896	3.9308	0.7084	0.6000	0.1526	0.6063	0.5639	1.4361	0.5581	1.4211	1.8056	6.0560	0.4593	1.5407

The Process Capability Index:

It is usually necessary to obtain some information about the capability of the process. That is, the performance of the process when it is operating in control. The basic capability indices commonly used in manufacturing industries are C_p , C_{pk}. These indices explained and estimated in the following sections. [5, 25]:

Process capability Index_C_P:

It simply relates the process capability to the specification range and it does not relate the location of the process with respect to the specifications values of C_p exceeding 1.33 indicate that the process is adequate to meet the specifications [5]. Values of C_p between 1.33 and 1.00 indicate that the process is adequate to meet specifications but require close control. Values of C_p below 1.00 indicate the process is not capable of meeting specifications. If the process is centered within the specifications and is approximately "normal" then C_p = 1.00 results in a fraction nonconforming of 0.27%. it is also known as process potential.

C_p can be estimated as [5, 25]:

$$Cp = \frac{UsL - LsL}{6\,б} \quad \text{……..............................}(12)$$

Where,

USL= Upper specification limit for quality characteristic.
LSL= Lower specification limit for quality characteristic.
б = Process standard deviation.

Process capability index C_{pk}:

It considers process average and evaluates the process spread with respect to where the process is actually located. The magnitude of C_{pk} relative to C_p is a direct measurement of how off-center the process is operating. It assumes process output is approximately normally distributed. If the characteristic or process variation is centered between its specification limits, the calculated value for C_{pk} is equal to the calculated value for C_p. But as soon as the process variation moves off the specification center, it is penalized in proportion to how far it's offset. C_{pk} is very useful and very widely used. Generally, a C_{pk} greater than 1.33 indicates that a process is capable in the short term [5]. Values less than 1.33 tells that the variation is either too wide compared to the specification or that the location of the variation is offset from the center of the specification. It may be a combination of both width and location. C_{pk} measures how far the process mean is from the nearer specification limit in terms of 3 sigma distances. C_{pk} works well only for the bell-shaped (Gaussian) distribution. For others it is an approximation. $C_{pk} = C_p$ only when the process is perfectly centered.

C_{pk} can be estimated as]5, 25]:

Whe $C_{pk} = \min \left[\frac{USL - \bar{\bar{X}}}{3\,б} \text{ or } \frac{\bar{\bar{X}} - LSL}{3\,б} \right]$ ……………. (13)

$\bar{\bar{X}}$ = Grand average.

To achieve the potential capability, the process will have to be in statistical control and the mean will have to be adjusted so that it is closer to the target or nominal value.

Normal Probability Plots:

Probability plotting is a graphical method for determining whether sample data conform to a hypothesized distribution based on a subjective visual examination of the data. The general procedure is very simple and can be performed quickly. Probability plotting typically uses special graph paper, known as probability paper; that has been designed for the hypothesized distribution. To construct a probability plot, the observations in the sample are first ranked from smallest to largest observation. That is, the sample $x_1, x_2, \ldots, x_n$ is arranged as $x_{(1)}, x_{(2)}, \ldots, x_{(n)}$, where $x_{(1)}$ is the smallest observation, $x_{(2)}$ is the second smallest observation, and so forth, with $x_{(n)}$ the largest. The ordered observations $x_{(j)}$ are then plotted against their observed cumulative frequency 100 (j-0.5/n) on the appropriate probability paper. The plotting position can be estimated by the following equation [13]:

P-P = 100 (i - 0.5) ÷ n ……………………………..(14)

Where,

i = rank ,
p-p = plotting position in percent ,
n = Sample size.

On a normal probability plot, data that flow a normal distribution will appear linear (a straight line), see figure 3.

Figure **4** Illustrates data that does not come from a normal distribution.

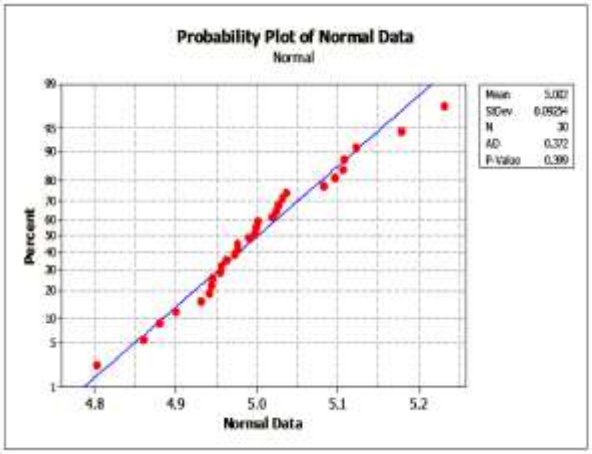


Figure 3 *Probability of normal data [13]:*

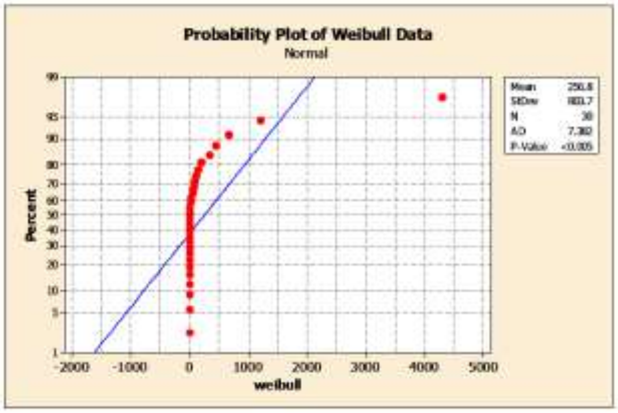


Figure 4 *Probability plot of not normal data [13]:*

The P-value on the plot legend is based on the computed Anderson- Darling statistic and provides an objective assessment of the hypothesis that the data is normally distributed (comes from a normal distribution). If the P-value is small (usually less than 0.05) then the data is not normal (does not come from a normal distribution) [13]:

Control charts for variables with specified process capability index C_p

The control limits for the control charts with specified Cp value are given as [14]:

$\bar{X}$-chart:

The Upper Control Limit, UCL$_{\bar{x}}$

UCL$_{\bar{x}}$ = $\bar{\bar{x}} + A^{*2} \left(\frac{}{T} \right)$ …………………….....(15)

The Center Line, CL$_{\bar{x}}$ C_p

$CL_{\bar{x}} = \bar{\bar{x}}$ ……………………………….. (16)

The Lower Control Limit, $LCL_{\bar{x}}$

$LCL_{\bar{x}} = \bar{x} - A^{*2}\left(\frac{T}{C_p}\right)$ ……………………..….(17)

Where, T = Tolerance = USL – LSL

R-chart :

The Upper Control Limit, UCL_R

$UCLR = D^{*4}\left(\frac{T}{C_p}\right)$ …………………………...(18)

The Center Line CL_R

$CLR = D^{*}\left(\frac{T}{C_p}\right)$ ……………………..……..(19)

The Lower Control Limit, LCL_R

$LCLR = D^{*3}\left(\frac{T}{C_p}\right)$ ………………………..… (20)

The above control limits can be used to construct the $\bar{x}$ - chart and R-chart with specified C_p value for sample size, n, $(2 \le n \le 25)$.

The values of the constants, D^{*}, D^{*2}, D^{*3} and A^{*2} of the control charts for variables with specified index C_p , are presented in table 3 [14].

***Table 3** Control Charts Constants for specified C_p value*

n	D^2	D^3	D^4	A^2	D^*	D^{*3}	D^{*4}	A^{*2}
2	1.128	0	3.267	1.880	0.1880	0.0000	0.6142	0.3534
3	1.693	0	2.574	1.023	0.2822	0.0000	0.7263	0.2887
4	2.059	0	2.282	0.729	0.3432	0.0000	0.7831	0.2502
5	2.326	0	2.115	0.557	0.3877	0.0000	0.8199	0.2159
6	2.534	0	2.004	0.483	0.4223	0.0000	0.8464	0.2040
7	2.704	0.076	1.924	0.419	0.4507	0.0343	0.8671	0.1888
8	2.847	0.136	1.864	0.373	0.4745	0.0645	0.8845	0.1770
9	2.970	0.184	1.816	0.337	0.4950	0.0911	0.8989	0.1668
10	3.078	0.223	1.777	0.308	0.5130	0.1144	0.9116	0.1580
11	3.173	0.256	1.741	0.285	0.529	0.135	0.922	0.151
12	3.258	0.283	1.717	0.266	0.543	0.154	0.932	0.144
13	3.336	0.307	1.693	0.249	0.556	0.171	0.941	0.138
14	3.407	0.328	1.672	0.235	0.568	0.186	0.949	0.133
15	3.472	0.347	1.653	0.223	0.579	0.201	0.957	0.129
16	3.532	0.363	1.637	0.212	0.589	0.214	0.964	0.125
17	3.588	0.378	1.622	0.203	0.598	0.226	0.970	0.121
18	3.640	0.391	1.608	0.194	0.607	0.237	0.976	0.118
19	3.689	0.403	1.597	0.187	0.615	0.248	0.982	0.115
20	3.735	0.415	1.585	0.180	0.623	0.258	0.987	0.112
21	3.778	0.425	1.575	0.173	0.630	0.268	0.992	0.109
22	3.819	0.434	1.566	0.167	0.637	0.276	0.997	0.106
23	3.858	0.443	1.557	0.162	0.643	0.285	1.001	0.104
24	3.895	0.451	1.548	0.157	0.649	0.293	1.005	0.102
25	3.931	0.459	1.541	0.153	0.655	0.301	1.010	0.100

Control charts for variables with specified process capability index C_{pk} [14]:

$\bar{X}$ - Chart:

Where:

$M = \text{Target} = \frac{USL + LSL}{2}$

The Upper Control Limit, $UCL\bar{x}$

$UCL = \bar{\bar{X}} + A^{*2}k\left[\frac{\frac{T}{2} - |\bar{\bar{X}} - M|}{C_{pk}}\right]$ ……..……(21)

The Center Line, $CL\bar{x}$

$CL\bar{x} = \bar{\bar{X}}$ ……….……………………………(22)

The Lower Control Limit, $LCL\bar{x}$

$LCL = \bar{\bar{X}} - A^{*2}k\left[\frac{\frac{T}{2} - |\bar{\bar{X}} - M|}{C_{pk}}\right]$ …………..… (23)

Where

$M = \frac{USL + LSL}{2}$ …………………………(24)

USL = The Upper specification limit of the quality characteristic.

LSL = The Lower specification limit of the quality characteristic.

R-chart :

The Upper Control Limit, UCL_R

$UCL_R = D^{*4}k\left[\frac{\frac{T}{2} - |\bar{\bar{X}} - M|}{C_{pk}}\right]$ ……………...….. (25)

The Center Line, CL_R

$CL_R = D^{*}k\left[\frac{\frac{T}{2} - |\bar{\bar{X}} - M|}{C_{pk}}\right]$ ………………..…(26)

The Lower Control Limit, LCL_R

$LCL_R = D^{*3}k\left[\frac{\frac{T}{2} - |\bar{\bar{X}} - M|}{C_{pk}}\right]$ ………………….(27)

The above control limits can be used to construct the $\bar{X}$ chart and R-chart with specified C_{pk} value, for sample size n, $(2 \le n \le 25)$. The values of the constants $D^{*}k$, $D^{*2}k$, $D^{*3}k$ and $A^{*2}k$ of the control charts for variables with specified index C_{pk} are presented in Table 4. [14].

***Table 4** Control Charts Constants for specified C_{pk} value [14]:*

n	D2	D3	D4	A2	$D^{*}k$	$D^{*3}k$	$D^{*4}k$	$A^{*2}k$
2	1.128	0	3.267	1.880	0.376	0.000	1.228	0.707
3	1.693	0	2.574	1.023	0.564	0.000	1.453	0.577
4	2.059	0	2.282	0.729	0.686	0.000	1.566	0.500
5	2.326	0	2.115	0.557	0.775	0.000	1.640	0.432
6	2.534	0	2.004	0.483	0.845	0.000	1.693	0.408
7	2.704	0.076	1.924	0.419	0.901	0.069	1.734	0.378
8	2.847	0.136	1.864	0.373	0.949	0.129	1.769	0.354
9	2.970	0.184	1.816	0.337	0.990	0.182	1.798	0.334
10	3.078	0.223	1.777	0.308	1.026	0.229	1.823	0.316
11	3.173	0.256	1.741	0.285	1.058	0.271	1.845	0.301
12	3.258	0.283	1.717	0.266	1.086	0.307	1.865	0.289
13	3.336	0.307	1.693	0.249	1.112	0.341	1.883	0.277
14	3.407	0.328	1.672	0.235	1.136	0.372	1.899	0.267
15	3.472	0.347	1.653	0.223	1.157	0.402	1.913	0.258
16	3.532	0.363	1.637	0.212	1.177	0.427	1.927	0.250
17	3.588	0.378	1.622	0.203	1.196	0.452	1.940	0.243
18	3.640	0.391	1.608	0.194	1.213	0.474	1.951	0.235
19	3.689	0.403	1.597	0.187	1.230	0.496	1.964	0.230
20	3.735	0.415	1.585	0.180	1.245	0.517	1.973	0.224
21	3.778	0.425	1.575	0.173	1.259	0.535	1.983	0.218
22	3.819	0.434	1.566	0.167	1.273	0.552	1.994	0.213
23	3.858	0.443	1.557	0.162	1.286	0.570	2.002	0.208
24	3.895	0.451	1.548	0.157	1.298	0.586	2.010	0.204
25	3.931	0.459	1.541	0.153	1.310	0.601	2.019	0.200

By application the control charts for variables with specified process capability indices, when the process is under the state of statistical control, means that it satisfies the required conditions regarding the values of process capability indices C_p and C_{pk}.

Important Quality Ratios in Cement Mixture:

The quality of cement raw material and cement clinkers are evaluated by cement lime saturation factor (LSF), Silicate ratio (SR), and aluminum ratio (AR). LSF, SR, and AR are directly determined by the lime, silica, alumina, and iron oxide which are contained in cement raw material. The LSF, SR, and AR are critical cement parameters. In cement production, the LSF, SR, and AR must be controlled in reasonable range [7]:

Lime saturation factor, LSF:

Lime saturation factor (LSF) calculates the proportion of calcium oxide to the proportion of oxides of silica, alumina, and iron (Si, Al, and Fe) needed to form clinker.

The increase of lime saturation factor (LSF) means an increase of stone. The decrease of lime saturation factor means a surplus in the secondary materials. LSF Factor estimates by the following equation [27, 29]:-

LSF = ……… (28)

Where:

CaO - Calcium Oxide,
SiO_2 - Silica,
Al_2O_3 - Alumina ,
Fe_2O_3 - Iron Oxide

Silica Ratio, SR,

It calculates the proportion of silica to the proportion of the oxides of iron and alumina (Al_2O_3 and Fe_2O_3). Practically, it measures the ratio between the silica compounds and compounds that help in melting operations. Silica ratio (SR) estimates by the following equation [27, 29]:-

$$SR = \frac{S_iO_2}{Al_2O_3 + Fe_2O_3} \quad \text{...(29)}$$

Alumina Ratio, AR :

It measures the ratio of aluminum oxide to ferric oxide. Alumina affects the color, the malleability, and the resistance of cement to sulfate.

Alumina ratio (AR) estimates by the following equation [27, 29]:-

$$AR = \frac{Al_2O_3}{Fe_2O_3} \quad \text{...(30)}$$

EXPEREMENTAL WORK

Tested were carried out on the products of the cement clinker grinding process. Subgroups of five samples were sampled regularly from the out – coming products and the four oxides, calcium oxide (Cao), silica (Sio_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) were measured for each sample. Twenty-five subgroup of size five were used in the analysis. For measuring silica (Sio_2), Alumina (Al_2O_3), iron oxide (Fe_2O_3) and Calcium Oxide (CaO) of the tested samples, the Panalytical Clinker Instrument was used, see Figure 5.

Figure 5 *Panalytical Clinker instrument*

The measurements result of silica, alumina, iron oxide and calcium oxide for twenty-five subgroup of size five are presented in Table 5. Tested were carried out in quality control laboratory of cement company, Beni – Suef, Egypt.

Table 5 The *measurements result of silica, Alumina, iron oxide and calcium oxide.*

Subgroup No.		Silica (Sio_2)	Alumina (Al_2O_3)	Iron oxide (Fe_2O_3)	Calcium oxide (Cao)
1	1	21,00	5.68	3.51	66.46
	2	21.28	5.76	3.58	66.32
	3	21.41	5.82	3.58	66.18
	4	21.34	5.81	3.59	66.28
	5	21.02	5.82	3.59	66.81
2	1	21.06	5.77	3.58	66.41
	2	21.36	5.89	3.65	66.32
	3	21.46	5.84	3.61	66.25
	4	21.24	2.87	3.56	66.61
	5	21.48	5.87	3.60.	66.51
3	1	21.10	5.97	3.66	66.67
	2	21.75	5.87	3.62	65.11
	3	21.70	5.82	3.58	67.25
	4	21.60	5.77	3.58	67.57
	5	21.35	5.72	3.57	67.51
4	1	21.20	5.85	3.57	66.55
	2	21.46	5.84	3.54	66.48
	3	21.09	5.84	3.62	66.47
	4	21.17	5.84	3.54	66.09
	5	21.35	5.84	3.60	66.45
5	1	21.55	5.84	3.54	67.60
	2	21.50	5.78	3.58	67.55
	3	21.65	5.85	3.59	67.58
	4	21.97	5.93	3.62	68.06
	5	21.60	5.88	3.58	67.38
6	1	21.29	5.89	3.60	66.24
	2	21.46	5.84	3.61	66.23
	3	21.11	5.75	3.53	66.43
	4	21.05	5.82	3.54	66.57
	5	21.05	5.83	3.60	66.51
7	1	21.40	5.76	3.59	68.68
	2	21.80	5.81	3.57	68.85
	3	21.55	5.84	3.57	68.06
	4	21.40	5.78	3.53	67.94
	5	21.40	5.81	3.62	68.18
8	1	21.30	5.84	3.60	66.89
	2	21.11	5.89	3.62	66.73
	3	21.25	5.88	3.59	66.53
	4	21.48	5.87	3.60	66.40
	5	21.17	5.83	3.55	66.41
9	1	21.85	5.87	3.62	68.19
	2	22.20	5.87	3.60	68.54
	3	21.06	5.84	3.56	66.42
	4	21.90	5.83	3.59	67.87
	5	21.75	5.89	3.63	67.64
10	1	21.23	5.91	3.63	66.33
	2	21.15	5.86	3.61	66.41
	3	21.02	5.67	3.56	66.70
	4	21.40	5.76	3.65	67.05
	5	21.38	5.62	3.61	66.25
11	1	21.50	5.81	3.68	67.00
	2	21.14	5.81	3.68	66.39
	3	20.92	5.78	3.70	67.40
	4	21.15	5.81	3.60	67.00
	5	21.64	5.83	3.60	95.90
12	1	21.51	5.81	3.62	66.06
	2	21.27	5.87	3.63	66.35
	3	21.65	5.85	3.55	66.08
	4	21.34	5.91	3.61	66.35
	5	21.41	5.79	3.55	66.36
13	1	21.26	5.88	3.61	65.61
	2	21.71	5.95	3.66	66.91

Subgroup No.		Silica (SiO_2)	Alumina (Al_2O_3)	Iron oxide (Fe_2O_3)	Calcium oxide (Cao)
	3	21.37	5.73	3.57	66.35
	4	21.70	5.93	3.61	66.06
	5	21.46	5.98	3.63	66.28
14	1	21.22	5.80	3.60	66.59
	2	21.17	5.84	3.63	66.33
	3	21.45	5.73	3.53	66.09
	4	21.70	5.93	3.61	65.99
	5	21.46	5.70	3.53	66.16
15	1	21.27	5.47	3.53	66.09
	2	21.10	5.71	3.71	65.60
	3	21.00	5.71	3.47	65.30
	4	21.27	5.74	3.53	66.12
	5	21.25	5.68	3.49	65.95
16	1	21.00	5.68	3.51	66.00
	2	21.18	5.65	3.47	66.18
	3	21.35	5.84	3.60	66.14
	4	20.70	5.65	3.46	64.68
	5	21.19	5.63	3.46	66.34
17	1	20.20	5.59	3.46	63.74
	2	20.95	5.63	3.60	64.59
	3	21.02	5.67	3.56	66.17
	4	20.30	5.63	3.44	63.81
	5	21.51	5.81	3.62	66.27
18	1	21.36	5.57	3.60	66.08
	2	21.34	5.72	3.50	65.96
	3	21.44	5.63	3.60	66.17
	4	21.27	5.81	3.57	66.35
	5	21.00	5.64	3.59	64.65
19	1	20.65	5.57	3.54	66.14
	2	21.02	5.59	3.52	67.25
	3	21.40	5.65	3.59	67.88
	4	20.30	5.59	3.52	64.86
	5	20.53	5.62	3.48	65.20
20	1	21.14	5.59	3.54	66.56
	2	21.44	5.86	3.50	66.43
	3	21.10	5.66	3.56	66.60
	4	21.39	5.67	3.58	66.40
	5	21.30	5.60	3.55	65.73
21	1	20.75	5.74	3.53	65.15
	2	20.80	5.71	3.49	64.83
	3	21.20	5.86	3.50	66.00
	4	20.50	5.61	3.54	64.16
	5	20.85	5.86	3.50	64.75
22	1	21.10	5.74	3.53	65.28
	2	21.30	5.71	3.47	66.52
	3	21.30	5.70	3.53	66.05
	4	21.25	5.55	3.54	66.40
	5	21.20	5.74	3.53	65.96
23	1	21.36	5.57	3.60	66.42
	2	20.90	5.71	3.51	65.25
	3	20.80	5.71	3.47	64.98
	4	21.10	5.72	3.51	65.80
	5	21.20	5.77	3.58	66.20
24	1	21.09	5.72	3.57	66.18
	2	21.10	5.66	3.56	65.95
	3	21.27	5.81	3.57	66.33
	4	21.41	5.82	3.58	66.18
	5	21.10	5.66	3.56	66.08
25	1	21.40	5.65	3.59	66.08
	2	21.39	5.67	3.58	66.25
	3	21.10	5.93	3.61	66.37
	4	21.11	5.75	3.53	66.41
	5	21.09	5.72	3.57	66.44

RESULTS AND DISCUSSION

The calculated results obtained from the experimental tests carried out on the cement industry are presented in this section. The calculated results are discussed from the viewpoint of the investigation of process capability of the cement clinker quality.

Cement clinker lime saturation factor (LSF):

To assess the statistical stability of the cement clinker Lime Saturation Factor (LSF) data, the usual $\bar{x}$-chart and R-chart must be constructed. These charts constructed based on the calculated values of tested twenty-five subgroup of size five. Equation (28) was used to calculate the Lime Saturation Factor (LSF) of cement clinker. These calculations are presented in Table 6 for twenty five subgroup of size five.

Table 6 The *calculated results of the cement clinker lime saturation factor (LSF)*
[Target = 98.5, USL= 99.5 and LSL= 97.5]

Subgroup No.	measurements				
	X1	X2	X3	X4	X5
1	97.75	96.25	95.43	95.85	97.87
2	97.21	95.64	95.27	96.65	95.53
3	97.03	92.49	95.84	96.77	97.75
4	96.74	95.66	97.05	96.23	95.99
5	96.93	97.11	96.45	95.74	96.32
6	95.84	95.24	97.12	97.44	97.28
7	99.16	97.76	97.55	98.11	98.33
8	96.83	97.24	96.44	95.37	96.70
9	96.48	95.66	97.12	95.93	96.05
10	96.15	96.68	97.99	96.75	95.94
11	96.18	96.70	99.10	97.63	94.10
12	94.84	96.08	94.34	95.76	95.76
13	95.06	95.04	95.97	93.93	95.07
14	96.77	96.50	95.33	93.85	95.44
15	96.02	96.04	96.03	96.05	96.03
16	97.07	96.70	95.55	96.42	96.93
17	97.19	95.19	97.21	95.80	95.15
18	95.86	95.60	95.58	96.24	95.08
19	98.87	98.97	98.19	98.38	97.93
20	97.46	95.67	97.54	96.06	95.59
21	96.70	96.11	95.98	96.45	95.53
22	95.50	96.62	95.90	96.85	96.1
23	96.36	96.32	96.35	96.31	96.36
24	96.85	96.59	96.21	95.42	96.77
25	95.59	95.85	96.70	97.1	97.23

Equations (1) and (2) were used to calculate the sample average ($\bar{X}$) and sample range (R) for the tested samples of the Lime Saturation Factor (LSF) data. These calculations are presented in Table 7.

Table 7 The *calculated results of sample mean ($\bar{X}$), and sample range (R) of the cement clinker Lime Saturation Factor (LSF)*

Subgroup No.	sample mean (X)	sample range (R)	Subgroup No.	sample mean (X)	sample range (R)

1	96.63	2.44	14	95.578	2.92
2	96.06	1.94	15	96.034	0.03
3	95.976	5.26	16	96.534	1.52
4	96.334	1.39	17	96.108	2.06
5	96.51	1.37	18	95.672	1.16
6	96.584	2.2	19	98.468	1.04
7	98.182	1.61	20	96.464	1.95
8	96.516	1.87	21	96.154	1.17
9	96.248	1.46	22	96.194	1.35
10	96.702	2.05	23	96.34	0.04
11	96.742	5	24	96.368	1.43
12	95.356	1.74	25	96.494	1.64
13	95.014	2.04		$\Sigma\bar{X}$=2409.267	ΣR = 46.68

Equations (3) and (4) were used to calculate the grand average ($\bar{\bar{x}}$) and the mean of sample range ($\bar{R}$) of the lime saturation factor (LSF) data. Equations (5), (6), and (7) were used to calculate the upper control Limit (UCL_X), center line (CL_X) and lower control limit (LCL_X) respectively for the usual $\bar{x}$-chart, of the lime saturation factor (LSF) data. Equation (8) was used to calculate the standard deviation (б) of the lime saturation factor (LSF) data. Equations (9), (10) and (11) were used to calculate the upper control limit (UCL_R), center line (CL_R), and the lower control limit (LCL_R) respectively for the usual R-chart of the lime saturation factor (LSF) data. The results of these calculations are presented in Table 8.

Table 8 *The calculated results of LSF data*

Symbol	The calculated value
$\bar{\bar{X}}$	96.370
$\bar{R}$	1.868
$UCL_{\bar{X}}$	97.448
$CL_{\bar{X}}$	96.370
$LCL_{\bar{X}}$	95.293
Б	1.11
UCL_R	3.949
CL_R	1.868
LCL_R	0.0

Figure 6 shows *the usual $\bar{x}$-chart and R-chart for Lime Saturation Factor (LSF) data.*

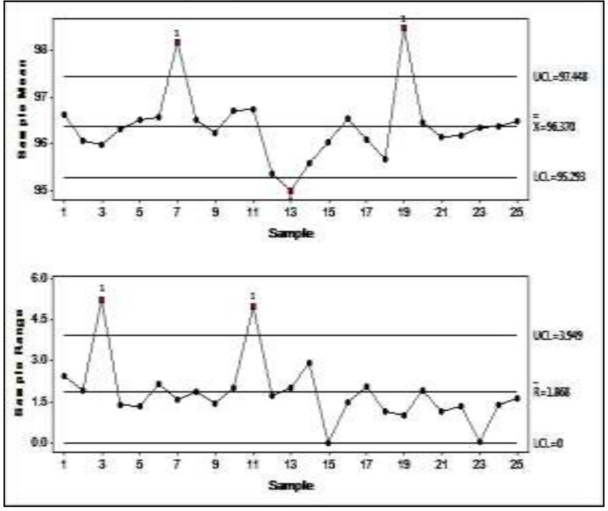


Figure 6 *Usual $\bar{X}$ -chart and R-chart for LSF data*

As indicated from figure 3.1, all plotted sample mean ($\bar{X}$) and sample range (R) values are not within the control limits on both usual $\bar{X}$ -chart and R-chart and their indications of shift. Hence, it is concluded that the lime saturation factor (LSF) data not under statistical control and the process operating under influence of assignable causes of variation, i.e., the process is not stable over time (out of control). For validity the normality of the cement clinker lime saturation factor (LSF) data, the normal probability of these data must be plotted. MINITAB-17, statistical software has been used to perform the normal probability plot, see Figure 7.

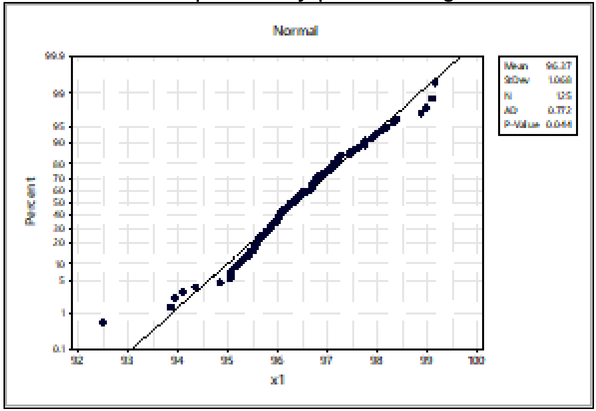


Figure 7 *Normality plot for cement clinker Lime Saturation Factor (LSF) data.*

From this figure the p-value = 0.044 is less than significance level (α = 0.05); when p-value < α , mean that the data are not distributed normally. Thus, it is concluded that, the lime saturation factor (LSF) data can be regarded as taken from non normal operation process. MINITAB-17, statistical software has been used to perform process capability analysis for lime saturation factor (LSF) data, see figure 8.

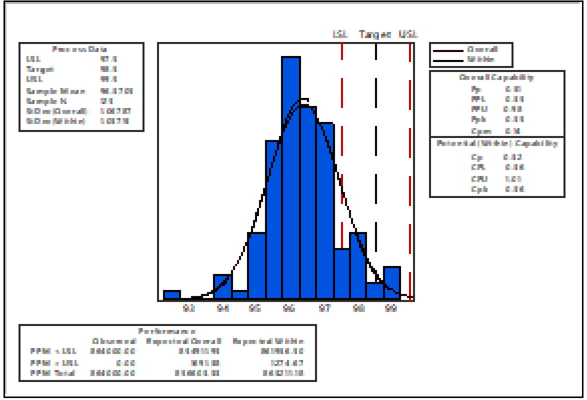


Figure 8 *process capability analysis for LSF data*

From this figure, the grand sample mean ($\bar{\bar{x}}$) = 96.370, i.e., shift from the target value (98.5). The process capability indices C_p and C_{pk} values are 0.32 and – 0.36 respectively. This case study analysis reveals that C_p is not equal C_{pk} which implies that, the process is not exactly centered. A C_p value (0.32) less than 1.00, it indicates the process is producing product that does not conform to specifications. A negative C_{pk} value indicates that the average is outside the specification limits. Equations (15), (16) and (17) were used to calculate the upper control limit (UCL_X), center line (CL_X) and lower control limit (LCL_X) respectively for the $\bar{X}$ -chart with specified process capability index $C_p = 1$. The calculated value of UCL_X, CL_X and LCL_X are 96.60, 96.25 and 95.81 respectively. Equations (18), (19) and (20) were used to calculate the upper control limit (UCL_R), center line (CL_R) and lower control limit (LCL_R) for the R-chart with specified process capability index $C_p = 1$. The calculated values of UCL_R, CL_R and LCL_R are 1.64, 0.77 and 0.0 respectively. Figure 9 shows the $\bar{X}$ -chart and R-chart with specified process capability index $C_p = 1$ for cement clinker lime saturation factor (LSF) data.

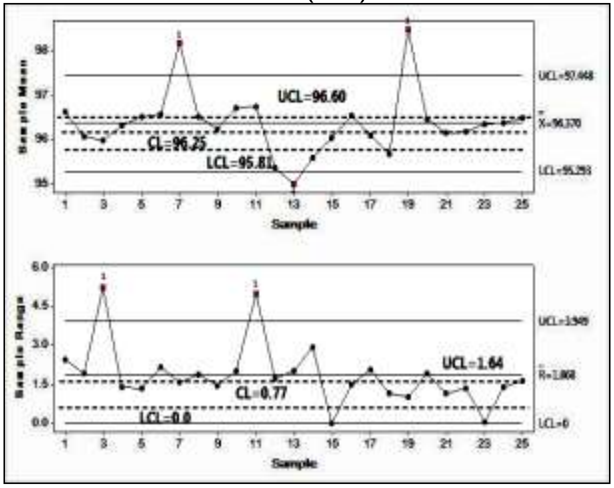


Figure 9 *$\bar{X}$-chart and R-chart with specified $C_p = 1$ for LSF data.*

As indicated from figure 9, that, all plotted sample mean ($\bar{X}$) and sample range (R) values are not with the control limits on both $\bar{X}$ -chart and R-chart. Hence, it is concluded that the process is not under statistical control and the process is not capable of meeting specifications. Equations (21), (22), and (23) were used to calculate the upper control limit (UCL_X), center line (CL_X) and lower control limit (LCL_X) respectively for the $\bar{x}$-chart with specified process capability index $C_{pk} = 1.33$. The calculated values of UCL_X, CL_X and LCL_X are 97.30 , 96.25 , and 95.20. Equations (25), (26), and (27) were used to calculate the upper control limit (UCL_R), center line (CL_R), and lower control limit (LCL_R) respectively for the R-chart with specified process capability index $C_{pk} = 1.33$. The calculated values of UCL_R, CL_R, and LCL_R are 4, 1.9 and 0.0 respectively. Figure 10 shows the $\bar{X}$ -chart, and R-chart with specified process capability index $C_{pk} = 1.33$ for lime saturation factor (LSF) data.

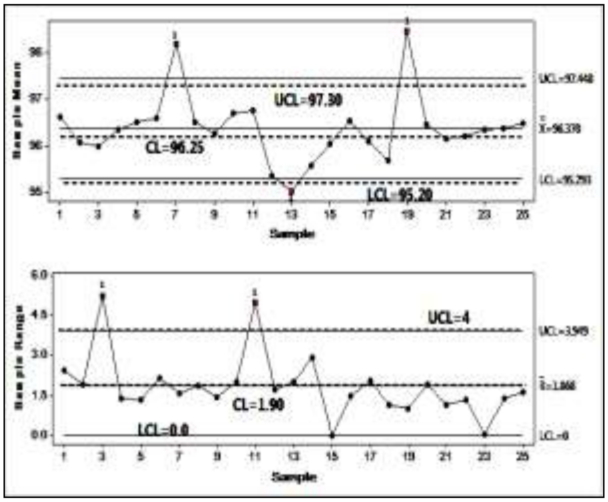


Figure 10 ***$\bar{X}$**-chart and R-chart with specified $C_{pk} = 1.33$ for LSF data.*

As indicated from figure 10 that, all plotted sample mean ($\bar{X}$) and sample range ($\bar{R}$) values are not within the control limits on both $\bar{X}$ -chart and R-chart. Hence, it is concluded that the process is not under statistical control and the process does not satisfies the process capability index $C_p = 1.33$. and the process not capable for producing product that conforms to specifications. This conclusion agrees with the results obtained when applied the usual $\bar{X}$ -chart, R-chart and process capability analysis individually for the same data, see Figures 6 and 8. From the previous discussions, it is concluded that, the cement manufacturing process is not capable for producing clinker with lime saturation factor (LSF) within the requirement specifications.

Cement clinker Silica Ratio, SR:

To assess the statistical stability of the cement clinker silica (SR) data, the usual $\bar{X}$ -chart and R-chart must be constructed. These charts constructed based on the calculated values of tested twenty-five subgroup of size five. Equation (29) was used to calculate the silica ratio (SR) of cement clinker. These calculations are presented in Table 9.

***Table 9** The calculated results of cement clinker silica ratio (SR)*
[Target = 2.25, USL = 2.30 and LSL = 2.20]

Subgroup No.	measurements				
	X1	X2	X3	X4	X5
1	2.29	2.28	2.28	2.27	2.24
2	2.22	2.24	2.27	2.26	2.27
3	2.20	2.30	2.31	2.31	2.30
4	2.25	2.27	2.23	2.25	2.26
5	2.30	2.30	2.30	2.31	2.29
6	2.25	2.27	2.28	2.25	2.24
7	2.29	2.33	2.30	2.30	2.27
8	2.26	2.22	2.25	2.27	2.26
9	2.31	2.35	2.24	2.33	2.27
10	2.23	2.23	2.28	2.28	2.32
11	2.27	2.23	2.21	2.25	2.30
12	2.28	2.24	2.30	2.24	2.30
13	2.24	2.26	2.30	2.28	2.24
14	2.26	2.24	2.32	2.28	2.32

15	2.30	2.29	2.29	2.30	2.32
16	2.29	2.33	2.26	2.28	2.34
17	2.24	2.27	2.28	2.24	2.28
18	2.33	2.32	2.32	2.27	2.28
19	2.27	2.30	2.32	2.23	2.26
20	2.31	2.30	2.29	2.31	2.33
21	2.24	2.27	2.27	2.25	2.23
22	2.28	2.32	2.31	2.34	2.29
23	2.33	2.27	2.27	2.29	2.27
24	2.27	2.29	2.27	2.28	2.29
25	2.32	2.32	2.28	2.28	2.27

***Table 10** The calculated results of sample mean ($\bar{X}$), and sample range (R) of the cement clinker silica ratio (SR).*

Subgroup No.	sample mean (X)	sample range (R)	Subgroup No.	sample mean (X)	sample range (R)
1	2.272	0.05	14	2.284	0.08
2	2.252	0.05	15	2.30	0.03
3	2.284	0.11	16	2.30	0.08
4	2.252	0.04	17	2.262	0.04
5	2.30	0.02	18	2.304	0.06
6	2.258	0.04	19	2.276	0.09
7	2.298	0.06	20	2.308	0.04
8	2.252	0.05	21	2.252	0.04
9	2.30	0.11	22	2.308	0.05
10	2.262	0.09	23	2.286	0.06
11	2.252	0.09	24	2.28	0.02
12	2.272	0.06	25	2.294	0.01
13	2.264	0.06		$\Sigma\bar{X}$= 56.977	ΣR = 1.43

Equation (3) and (4) were used to calculate the grand average ($\bar{\bar{x}}$) and the mean of sample range ($\bar{R}$) of the cement clinker silica ratio (SR), data. Equation (5), (6), and (7) were used to calculate the upper control limit (UCL_X), center line (CL_X), and lower control limit (LCL_X) respectively for the usual $\bar{x}$-chart of the cement clinker silica ratio (SR) data. Equation (8) was used to calculate the standard deviation (б) of the cement clinker silica ratio (SR) data. Equations (9), (10) and (11) were used to calculate the upper control limit (UCL_R), center line (CL_R) and the lower control limit (LCL_R) respectively for the usual R-chart of the cement clinker silica ratio (SR) data. The results of these calculations are presented in Table 11.

***Table 11** The calculated results of SR data*

Symbol	The calculated value
$\bar{\bar{X}}$	2.279
$\bar{R}$	0.059
$UCL\bar{X}$	2.313
$CL\bar{X}$	2.279
$LCL\bar{X}$	2.244
Б	0.03
UCLR	0.125
CLR	0.059
LCLR	0.0

Figure 11 Shows the usual $\bar{X}$-chart and R-chart for cement clinker silica ratio (SR) data.

Equations (1) and (2) were used to calculate the sample average ($\bar{X}$) and sample range (R) for the tested samples of the cement clinker Silica ratio (SR) data. These calculations are presented in Table10

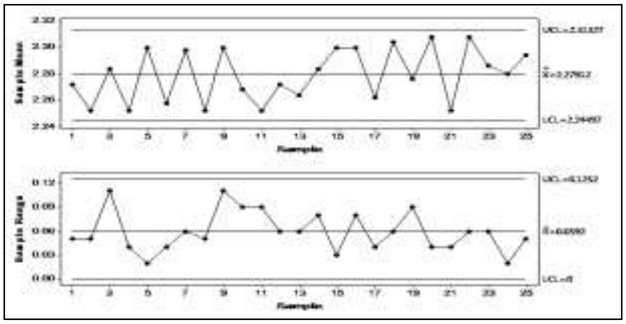


***Figure 11** Usual $\bar{X}$ -chart and R-chart for SR data.*

As indicated from figure 10 all plotted sample mean ($\bar{x}$) and sample range (R) values are within the control limits on both usual $\bar{x}$-chart and R-chart, and there no indications of shift. Hence, it is concluded that the silica ratio (SR) of the cement clinker data under statistical control. For validity, the normality of the cement clinker silica ratio (SR) data, the normal probability of these data must be plotted. MINITAB-17, statistical software has been used to perform the normal probability plot, see figure 12.

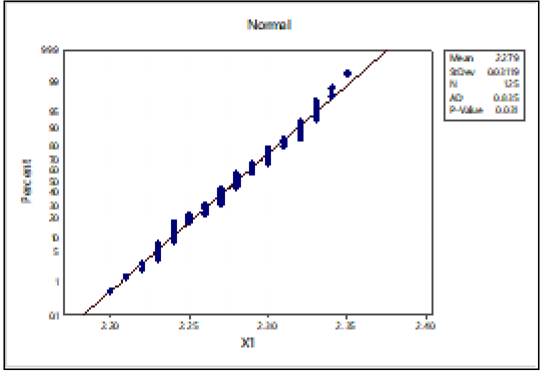


***Figure 12** Normality plot for cement clinker silica ratio (SR) data.*

From this figure p-value = 0.031 is smaller than significance level (α = 0.05), mean that the data are not distributed normally. Thus, it is concluded that, the cement clinker silica ratio (SR) data can be regarded as taken from non normal operation process. MINITAB-17, statistical software has been used to perform process capability analysis for the cement clinker silica ratio (SR) data, see figure 13.

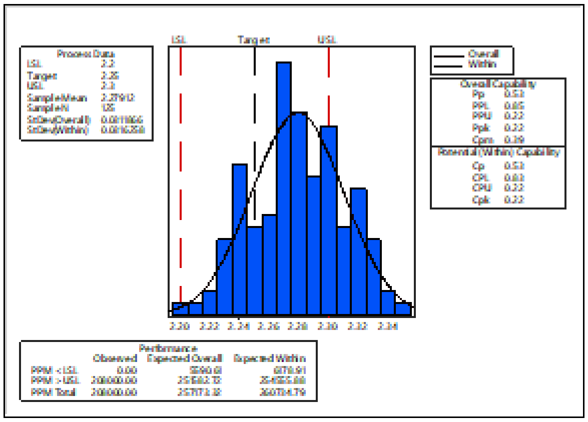


***Figure 13 Process** capability analysis for cement clinker silica ratio (SR) data.*

From this figure, the grand sample mean $(\bar{\bar{x}})$ = 2.279 i.e., shift from the target value (2.25). The process capability indices C_p and C_{pk} values are 0.53 and 0.22 respectively. This case study analysis reveals that C_p is not equal C_{pk} which implies that, the process is not exactly centered. A C_p value 0.53 less than 1.00, it indicates the process is producing product that does not conform to the specifications. Also, C_{pk} has a value (0.22) less than 1.00, it indicates the process is producing product that does not conform to specifications. Equations (15), (16) and (17) were used to calculate the upper control limits ($UCL_{\bar{x}}$), center line (CL_x) and lower control limit (LCL_x) respectively for the $\bar{x}$-chart with specified process capability index C_p = 1. The calculated values of UCL_x, CL_x and LCL_x are 2.30, 2.28, and 2.26 respectively. Equations (18), (19) and (20) were used to calculate the upper control limit (UCL_R), center line (CL_R) and lower control limit (LCL_R) for the R-chart with specified process capability index C_p = 1. The calculated results values of UCL_R, CL_R and LCL_R are 0.082, 0.039 and 0.0 respectively.

Figure 14 shows the $\bar{X}$ -chart and R-chart with specified process capability index C_p = 1 for cement clinker silica ratio (SR) data.

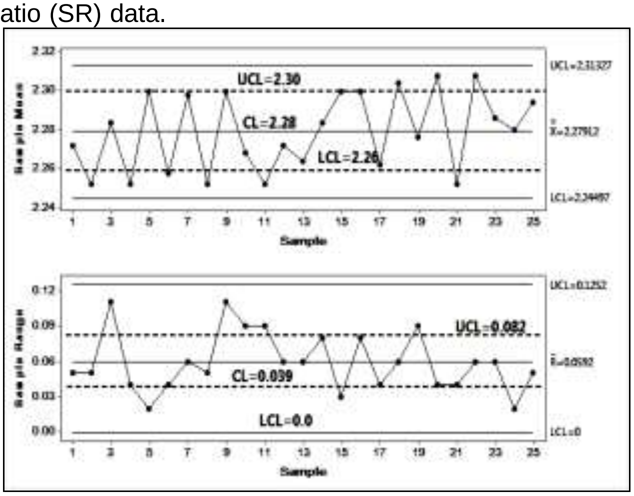


***Figure 14** $\bar{X}$-chart and R-chart with specified C_p = 1 for cement clinker silica ratio (SR) data.*

As indicated from figure 14, that all plotted sample mean ($\bar{X}$) and sample range (R) values are not within the control limits on both $\bar{X}$ -chart and R-chart with specified process capability index C_p = 1. Hence, it is concluded that the process is not under statistical control and the process is not capable of meeting product specifications. Equations (21), (22) and (23) were used to calculate the upper control limit (UCL_x), center line (CL_x) and lower control limit (LCL_x) respectively for the $\bar{x}$-chart with specified process capability index C_{pk} = 1.33. The calculated results values of UCL_X, CL_X, and LCL_X are 2.29, 2.28, and 2.276 respectively. Equations (25), (26) and (27) were used to calculate the upper control limit (UCL_R), center line (CL_R) and lower control limit (LCL_R) respectively for the R-chart with specified process capability index C_{pk} = 1.33. The calculated results value of UCL_R, CL_R and LCL_R are 0.022, 0.01 and 0.0 respectively. Figure 15 shows the $\bar{X}$ -chart and R-chart with specified process capability index C_{pk} = 1.33 for cement clinker silica ratio (SR) data.

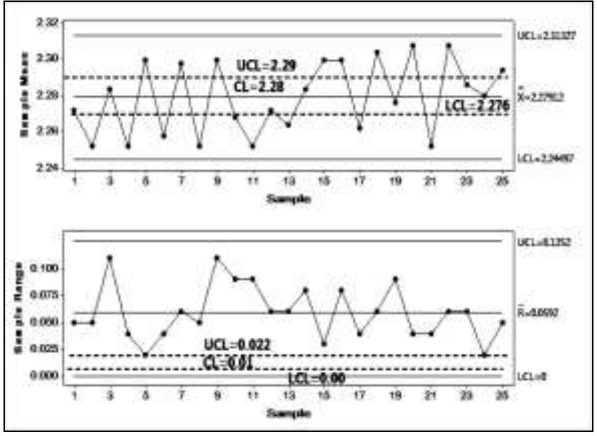


***Figure 15** $\bar{x}$-chart and R-chart with specified C_{pk} = 1.33 for cement clinker silica ratio (SR) data.*

As indicated from figure 15 that all plotted sample mean ($\bar{X}$) and sample range (R) values are not within the control limits on both $\bar{X}$ -chart and R-chart. Hence, it is concluded that, the process is not under statistical control and the process does not satisfies the process capability index C_{pk} = 1.33, and the process not capable for producing product that conforms to the requirement specifications. This conclusion agree with the results obtained when applied the usual $\bar{X}$ -chart, R-chart and process capability analysis individually for the same data, see figures 11 and 13 from the previous discussions, it is concluded that, the cement manufacturing process is not capable for producing cement clinker with silica ratio (SR) within the requirement specifications.

Cement Clinker Alumina Ratio (AR):

To assess the statistical stability of the cement clinker alumina ratio (AR) for cement clinker data, the usual $\bar{X}$ -chart and R-chart must be constructed. These charts constructed based on the calculated values of tested twenty-five subgroup of size five.

Equation (30) was used to calculate the alumina ratio (AR) of cement clinker. These calculations are presented in Table 12.

Table 12 *The calculated results of Alumina Ratio (AR) for cement clinker, [Target = 1.35, USL = 1.40 and LSL = 1.30]*

Subgroup No.	Measurements				
	X1	X2	X3	X4	X5
1	1.62	1.62	1.63	1.62	1.63
2	1.62	1.62	1.62	1.65	1.63
3	1.64	1.63	1.63	1.62	1.60
4	1.64	1.65	1.62	1.65	1.62
5	1.65	1.62	1.63	1.64	1.65
6	1.64	1.62	1.63	1.65	1.62
7	1.60	1.63	1.64	1.64	1.60
8	1.63	1.63	1.64	1.63	1.65
9	1.63	1.63	1.64	1.63	1.65
10	1.63	1.63	1.60	1.57	1.56
11	1.58	1.58	1.57	1.62	1.62
12	1.60	1.62	1.65	1.64	1.63
13	1.63	1.63	1.60	1.65	1.65
14	1.62	1.60	1.63	1.65	1.62
15	1.63	1.63	1.65	1.63	1.63
16	1.62	1.63	1.62	1.64	1.63
17	1.62	1.57	1.60	1.64	1.60
18	1.55	1.64	1.57	1.63	1.58
19	1.58	1.59	1.58	1.59	1.62
20	1.58	1.68	1.59	1.59	1.58
21	1.63	1.64	1.68	1.59	1.68
22	1.63	1.65	1.62	1.57	1.63
23	1.55	1.63	1.65	1.63	1.62
24	1.60	1.59	1.63	1.63	1.59
25	1.58	1.59	1.65	1.63	1.60

Equation (1) and (2) were used to calculate the sample average ($\bar{X}$) and sample range (R) for the tested samples of the cement clinker alumina ratio (AR) data. These calculations are presented in Table 13.

Table 13 *The Calculated results of sample mean ($\bar{X}$), and sample range (R) of the cement clinker Alumina Ratio (AR).*

Subgroup No.	sample mean (X)	sample range (R)	Subgroup No.	sample mean (X)	sample range (R)
1	1.624	0.01	14	1.624	0.05
2	1.628	0.03	15	1.634	0.02
3	1.624	0.04	16	1.628	0.02
4	1.636	0.03	17	1.606	0.07
5	1.638	0.03	18	1.60	0.09
6	1.632	0.03	19	1.592	0.04
7	1.622	0.04	20	1.604	0.1
8	1.63	0.02	21	1.644	0.09
9	1.63	0.02	22	1.62	0.08
10	1.598	0.07	23	1.616	0.1
11	1.60	0.05	24	1.608	0.04
12	1.628	0.05	25	1.61	0.07
13	1.632	0.05		$\Sigma\bar{X}$= 40.508	ΣR=1.24

Equation (3) and (4) were used to calculate the grand average ($\bar{\bar{x}}$) and the mean sample range ($\bar{R}$) of the cement clinker alumina ratio (AR) data. Equation (5), (6) and (7) were used to calculate the upper control limit (UCL_X), center line (CL_X), and lower control limit (LCL_X) respectively for the usual $\bar{x}$-chart of the cement clinker alumina ratio (AR) data. Equation (8) was used to calculate the standard deviation (б) of the cement clinker Alumina Ratio (AR) data. Equation (9), (10) and (11) were used to calculate the upper control limit (UCL_R), center line (CL_R), and the lower control limit (LCL_R) respectively for the usual R-chart of the cement clinker alumina ratio (AR) data. The results of these calculations are presented in Table 14.

Table 14 *The calculated results of AR data.*

Symbol	The calculated value
$\bar{\bar{X}}$	1.620
$\bar{R}$	0.049
UCL$\bar{X}$	1.648
CL$\bar{X}$	1.620
LCL$\bar{X}$	1.591
Б	0.026
UCLR	0.104
CLR	0.049
LCLR	0.0

Figure 16 Shows the usual $\bar{X}$ -chart and R-chart for cement clinker alumina ratio (AR) data.

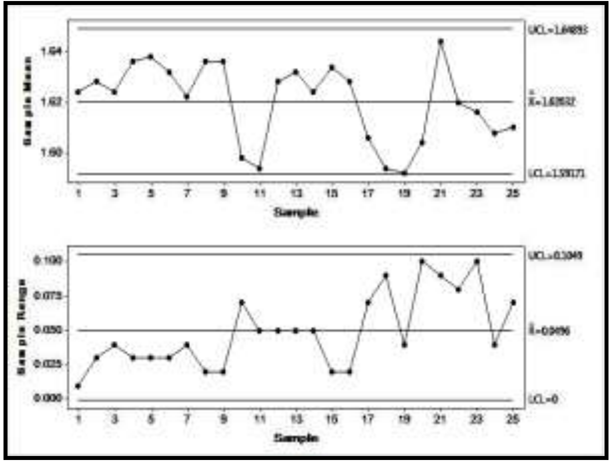


Figure 16 *Usual $\bar{X}$ -chart and R-chart for AR data.*

As indicated from this figure, all plotted sample mean ($\bar{X}$) and sample range (R) values are within the control limits on both $\bar{X}$ -chart and R-chart and there no indications of shift. It is concluded that, the cement clinker alumina ratio data under statistical control. For validity, the normality of the cement clinker alumina ratio data, the normal probability of these data must be plotted. MINITAB-17, statistical software has been used to perform the normal probability plot, see figure 17.

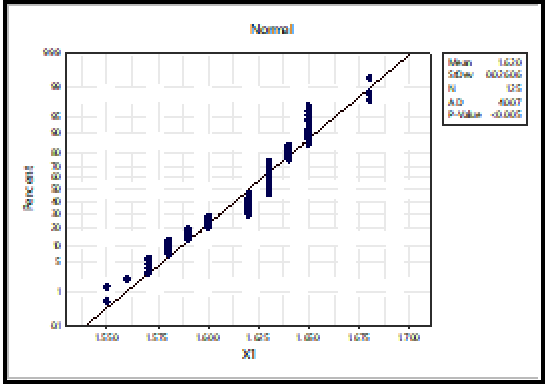


Figure 17 *Normality plot for cement clinker alumina ratio (AR) data*

From this figure p-value < 0.05 mean that the data are not distributed normally. Thus, it is concluded that, the cement clinker alumina ratio data can be regarded as taken from non normal operation process. MINITAB-17 statistical software has been used to perform process capability analysis for the cement clinker alumina ratio (AR) data, see figure 18.

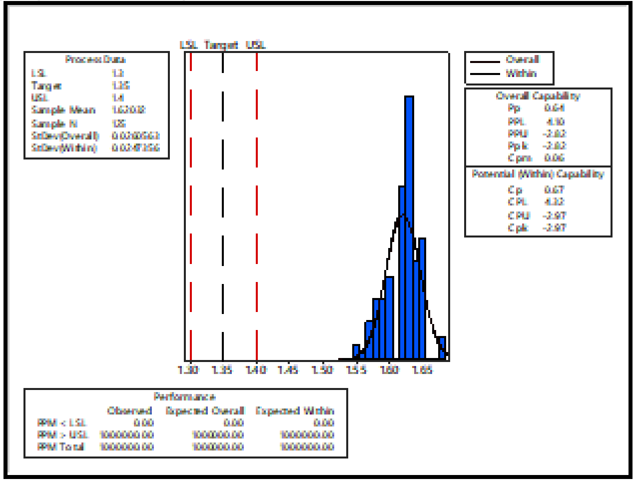


Figure 18 *Process capability analysis for cement clinker alumina ratio data.*

From this figure the grand sample mean $\bar{\bar{x}}$ = 1.62 i.e, shift from the target value (1.35). The process capability indices C_p and C_{pk} values are 0.67 and – 2.97, respectively. This case study analysis reveals that C_p is not equal C_{pk} which implies that, the process is not exactly centered. A C_p value 0.67 less than 1.00, it indicates the process is producing product that does not conform to the specifications. A negative C_{pk} value indicates that the average is outside the specification limits. Equation (15), (16) and (17) were used to calculate the upper control limit ($UCL_{\bar{X}}$), center line ($CL_{\bar{X}}$) and lower control limit ($LCL_{\bar{X}}$) respectively for the $\bar{X}$ -chart with specified process capability index C_p = 1. The calculated values of UCL_X, CL_X and LCL_X are 1.64, 1.62 and 1.60 respectively. Equations (18), (19) and (20) were used to calculate the upper control limit (UCL_R), center line (CL_R) and lower control limit (LCL_R) for the R-chart with specified process capability index C_p = 1. The calculated values of UCL_R, CL_R and LCL_R are 0.082, 0.038 and 0.0 respectively. Figure 19 shows the $\bar{X}$ -chart and R-chart with specified process capability index C_p = 1 for cement clinker alumina ratio (AR) data.

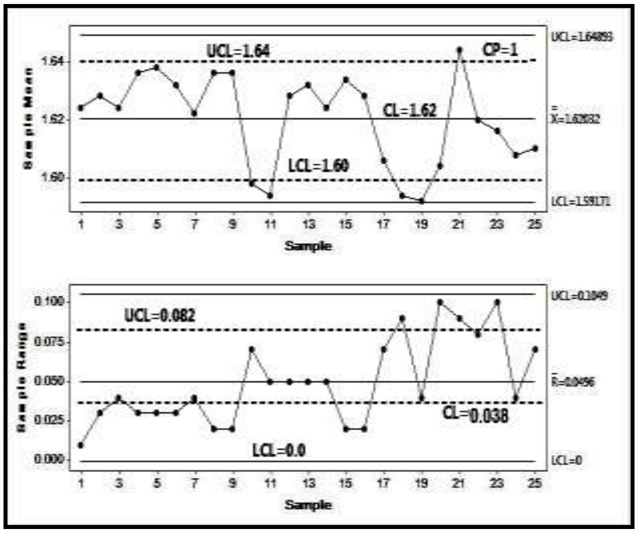


Figure 19 *$\bar{X}$ -chart and R-chart with specified C_p = 1 for cement clinker alumina ratio AR data.*

As indicated from figure 19, that all plotted sample mean ($\bar{X}$) and sample range (R) values are not within the control limits on both $\bar{X}$ -chart and R-chart. Hence, it is concluded that the process is not under statistical control and the process is not capable of producing product meeting the requirement specifications. Equation (21), (22), and (23) were used to calculate the upper control limit (UCL_X), center line (CL_X) and lower control limit (LCL_X) respectively for the $\bar{X}$ -chart with specified process capability index C_{pk} = 1.33. The calculated values of UCL_X, CL_X, and LCL_X are 1.69, 1.62 and 1.54 respectively. Equation (25), (26), and (27) were used to calculate the upper control limit (UCL_R), center line (CL_R), and lower control limit (LCL_R) respectively for the R-chart with specified process capability index C_{pk} = 1.33. The calculated values of UCL_R, CL_R, and LCL_R are 0.271, 0.128 and 0.0 respectively. Figure 20 shows the $\bar{X}$ -chart and R-chart with specified process capability index C_{pk} = 1.33 for cement clinker alumina ratio AR data.

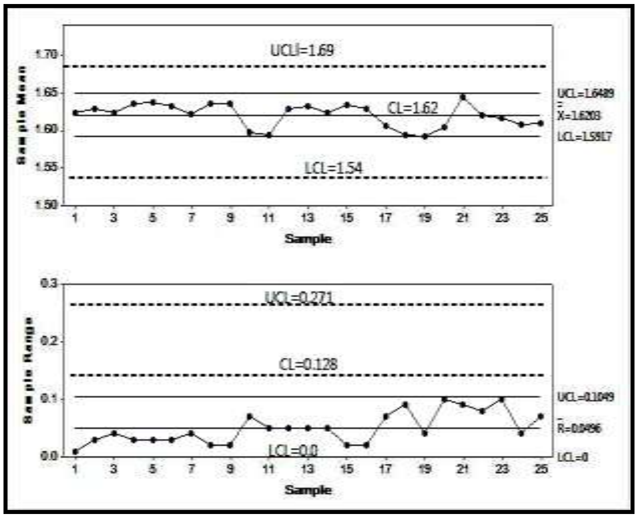


Figure 20 *$\bar{X}$-chart and R-chart with specified C_{pk} = 1.33 for cement clinker alumina ratio data.*

As indicated from figure 3.15, that, all plotted sample mean ($\bar{X}$) and sample range (R) values are not within the control limits on both $\bar{X}$ -chart and R-chart. It is concluded that, the process is not under statistical control and the process capability not capable for producing product that conform to the requirement specifications. This conclusion agree with the results obtained when applied the usual $\bar{x}$-chart, R-chart and process capability analysis individually for the same data, see Figures 16 and 18 from the previous discussions, it is concluded that, the cement manufacturing process is not capable for producing clinker with alumina ratio within the requirement specifications. From the previous results, it is concluded that the cement manufacturing process is not capable for producing clinker with lime saturation factor (LSF), silica ratio (SR), and alumina ratio (AR) within the requirement specifications.

CONCLUSION

* To study the behavior of the production process and to take a necessary action on the process, control charts must be used.
* Process capability analysis used to determine whether the manufacturing process is capable of producing units within the product specifications, several process capability indices have been developed among which the basic and widely used indices are C_p and C_{pk}.
* Control charts for variable with specified process capability indices combine the two stages controlling namely control charts and the process capability simultaneously. Therefore, this chart has the benefit of the usual control charts and the process capability indices.
* The control charts and the process capability indices into a single stage is simple to apply and does not warrant any tedious computations both for control charts and for computing process capability index.

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REFERENCES

[1] Arjun, K. and Kotz, S., "A New Process Capability Index", International Journal Metrika, Vol. 45, pp. 213-224, 1997.

[2] Pearn, W. L. and Lin, P.C., "Measuring Process Yield based on the Capability index C pm", International Journal Adv Manuf Technol,Vol.24,pp.503-508, 2004.

[3] Hsin - Hung, "Using target Costing Concept in Loss Function and Process Capability indices to Set up goal Control Limits", International Journal Adv Manuf Technol, Vol.24, pp206-213,2004.

[4] Kun-Lin Hsieh. and Lee-Ing Tong., "Incorporating process Capability index and Quality loss function into analyzing the process capability for qualitative data", International Adv Manuf Technol, Vol.27, pp.1217-1222, 2006.

[5] Rezaie, K. Ostadi, B. and Taghizadeh, M.R. "Applications of process Capability and process performance Indices", Journal of Applied Sciences , VOL .6(5), pp.1186-1191, 2006.

[6] Dorde Vukelic, Janko Hodolic, Tone Vrecic and Peter Kogej, "Development of a system for statistical quality control of the production process", facta universitatisseries: Mechanical Engineering , Vol. 6, N1, Pp. 75-90, 2008.

[7] Pandey and Banskota, "Process of cement production in Nepal", Bulletin of the Department of Geology, Tribhuvan University, Kathmandu, Nepal, Vol. 11, 2008, PP.71-78.

[8] Angus Jeang. and Chien-Ping Chung, " Process capability analysis based on minimum production cost and quality loss", Int J Adv Manuf Technol, Vol. 43, pp.710-719, 2009.

[9] Montgomery, D.C., Introduction to statistical Quality control, sixth Edition, John Wiley & Sons, Inc., 2009.

[10] Rami Hikmat Fouad, and Adnan Mukattash, "Statistical Process Control Tools: A Practical guide for Jordanian Industrial Organizations", Jordan Journal of Mechanical and Industrial Engineering, Vol.4, Number 6, pp. 693-700, 2010.

[11] Mahesh, B.P. and Prabhuswamy, M.S., "Process Variability Reduction Through Statistical Process Control for Quality Improvement", International Journal for Quality Research, Vol.4, No.3, 2010.

[12] Jiujun Zhang. Zhonghua, Li. and Zhaojun Wang , "A new adaptive control chart for monitoring process mean and variability", Int J Adv Manuf Technol, Vol.60,pp. 1031-1038,2012.

[13] Asghar Ghasemi, and Saleh Zahediasl, "Normality Tests for statistical Analysis: A Guide for Non-Statisticians", Int J Endocrinol Metab, Vol.10(2), pp. 486-489, 2012.

[14] Subramani, J. and Balamurali,S., "Control charts for Variable with Specified Process Capability Indices", International Journal of probability and stistics, Vol. 1(4), pp. 101-110, 2012.

[15] Moussaceb and Merabet, "Homogenization and Management of cement quality from raw materials to the finished product using a numerical method of mixture calculation", Arab J. Sci eng (2012) 37:41-57.

[16] Fasil A. and Omprakash S., "Minimization of variation in clinker quality" Advances in Materials, Vol. 2(2), PP. 23-28, 2013.

[17] Tibor Kulcsar and Janos Abonyi, "Statistical Process Control Based Peeformance Evaluation of on-Line Analysers", Hungarian Journal Of Industry and Chemistry Veszprem, Vol.41(1) Pp.77-82, 2013.

[18] Varma B.T.D. and Sirisha K.P., "Study of Processing and Machinery in Cement Industry", International Journal of Engineering and Innovative Technology (IJEIT) Volume 3, Issue 5, November 2013.

[19] Fabio Orssatto, Marcio A. Vilas Boas, Ricardo Nagamine, Miguel A. and Uribe-Opazo, "Shewhart's Control Charts and Process Capability Ratio Applied To A Sewage Treatment Station", Eng. Agric.,

Jaboticabal , Vol. 3, No. 4 Pp. 770-779, Jul./Ago. 2014.

[20] Ghazi Abu Taher, and Jahangir Alam, Md.,"Improving Quality and Productivity In Manufacturing Process By Using Quality Control Chart and Statistical Process Control Including Sampling and Six Sigma", Global Journal Of Researches In Engineering: G Industrial Engineering Volume 14 Issue 3 Version 1.0 Year 2014.

[21] Yerriswamy Wooluru Swamy , D.R., and Nagesh,P. "The Process Capability Analysis- A Tool For Process Performance Measures and Metrics – A Case Study", International Journal For Quality Research , Vol. 8(3) , Pp. 399-416, 2014.

[22] Singh, Ajay S. and Masuku, Micah, B., "Normality Data Transformation for Applied Statistical Analysis", International Journal Of Economics, Commerce and Management, Vol. 11, Issue 7, 2014.

[23] Mondal, S. C. and Kundu, S., "Application of Process Capability Indices To Measure Performance of a Multistage Manufacturing Process", 5th International 26th All India Manufacturing Technology, Design and Research Conference (Aimtdr 2014)December 12th-14th, 2014.

[24] Tsamatsoulis D., "Simulation of Cement Grinding Process for optimal Control of SO_3 Content", D. Tsamatsoulis, Simulation of Cement Grinding Process for Optimal Control of SO_3…, Chem. Biochem. Eng. Q., 28(1) 13-25 (2014).

[25] Babagana Modu,. "Simulation For Performance Analysis of Some Capability Indices on Net-Volume Content of 35cl Coca-Cola Soft Drinks", Scholars Journal of Physics, Mathematics and Statistics, Vol.2, PP. 283-288, 2015.

[26] Kundi and Sharma, "Efficiency analysis and flexibility: a case study of cement firms", Global Journal of flexible systems management, Vol. 16(3), PP.221-234. 2015

[27] Resmi R. and Pradeepa K., "Application of Statistical Quality control in Manufacturing process", Internation Journal of Innvative Research in Science, Engineering and Technology, Vol. 4, PP. 6-11, 2015.

[28] Adeoti O.A. and Olaomi, J.O., "Process Capability Index-Based control chart for variables", South African of Industrial Engineering, Vol. 28(2), PP. 28-36, August 2017.

[29] Cement Company, "Quality Control Manual" Beni-Suef, Egypt, 2018.