Optimization and Environmental Impact of the Clinker Production Process in Cement Manufacturing

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Abstract:-

The clinker production process is a critical phase in cement manufacturing involving the transformation of raw materials into clinker through high temperature heating in a kiln. This paper explores the various stages of clinker production, including raw material preparation, preheating, calcination, and cooling. It also examines the energy consumption, environmental impacts, and potential optimization strategies to enhance efficient and reduce emissions. The findings suggest that advancement in kiln technology, alternative fuels, and raw materials substitution can significantly improve the sustainability of clinker production.

Keywords: - clinker production, cement manufacturing, raw materials, grinding and etc.

Introduction:-

An essential part of every economy is the cement industry. It is crucial and plays a catalytic function in driving economic growth. An essential step in making cement is heating the clinker in a rotating kiln. Energy efficiency might be improved by warm recovery from the surface of the furnace shell, making cement manufacture more environmentally friendly and long-term viable. This research examined a mechanical cement furnace in India to provide methods for calculating heat losses via the furnace's shell and the variables that affect these losses. Over the course of nineteen days, infrared thermography was used to track the temperature of the oven shell and the amount of heat that was lost through it. Among the modern-day industrial companies in India, the cement factory is among the most important and long-standing. From the constructing of a single-story factory to a massive multi-use structure, the cement industry is considered the most important component in nation-building. An essential part of modern India's industrial economy, the cement industry is thought of as a foundational part of the country's construction infrastructure. India has all the ingredients for rapid industrial growth: a plentiful supply of raw materials, skilled workers, modern machinery, and cutting-edge technology [1-2]. Literacy rates, skill development, healthcare access, and the pace of modernization have all been boosted by the widespread availability of cement, which has allowed for the construction of social facilities such as schools, community centers, training facilities, hospitals, and enough space for post offices and banks [3].

The implementation of canals and irrigation wells constructed with cement improves water conservation and increases agricultural productivity. The industrial structure contains a significant quantity of cement. The increase in cement production capacity promotes the growth of the capital goods sector through sustained demand for cement manufacturing machinery, replacement parts, and components [4]. Industries producing products dependent on cement, including asbestos cement sheets, cement pipes, cement-banded boards, and pre-stressed concrete items, can prosper with access to ready cement. Many state governments provide tangible benefits via sales tax exemptions or deferrals. Cement production facilities are typically located near the primary raw material, limestone. Numerous small cement plants have developed in areas with limited limestone resources, allowing large, medium, and mini cement facilities in diverse geographic locations to exploit local natural resources such as limestone, coal, and gypsum [5-6].

In terms of weather patterns, it plays a major role. Energy and climate pollution are at the root of the health problems and safety issues associated with cement production [7]. The importance of various sources of working capital is assessed by considering the many factors that impact the need for working capital in the cement manufacturing industry [8]. For a two-part series system without a defined strategy structure, create a condition-based maintenance optimization. Based on its growth in installed capacity, production, exports, and value addition since [10], the Indian cement industry has evolved in [9]. A research notion based on the macro level was utilized in the investigation.

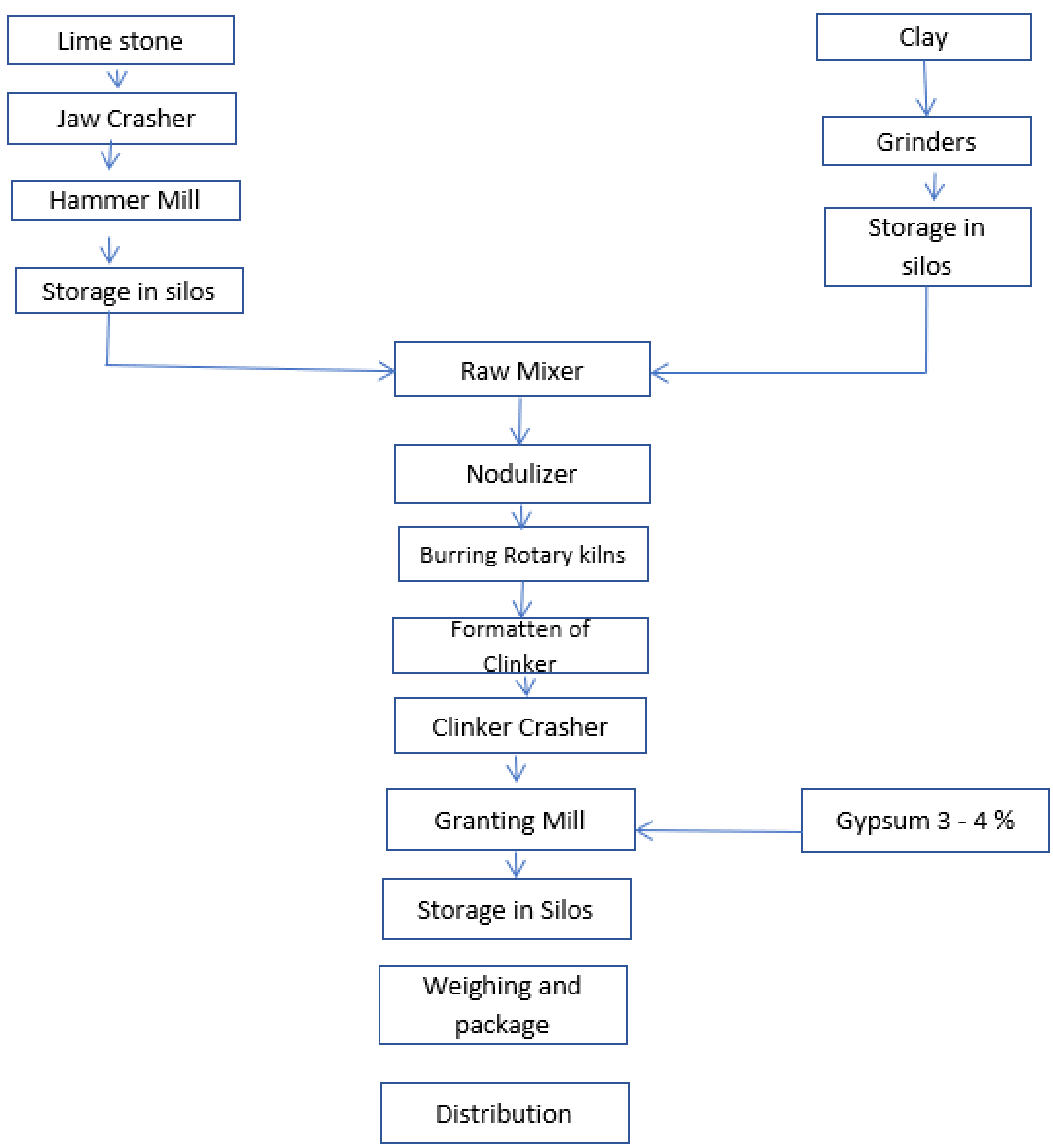
Shows the cement industry's possible production. Bhavani and Sanjay of the Indian Cement Industry looked at optimal random replacement models of continuously managed workers in an effort to find the feature that affects profitability [11]. It highlighted the potential for redundancy allocation to improve system reliability. A two-unit cold standby system with random life, repair, and wait durations distributions is studied using stochastic analysis [12–17].

The Mean Time to System Failure (MTSF), Availability, and several other metrics of the system models are going to be determined as the major purpose of the study.

- To carry out a comparison of the outcomes that were anticipated by the system models.
- To create comprehensive investigations and give recommendations for the advancement of industrial systems.

Ordinary Portland Cement (OPC) consists of 95 percent clinker and 5 percent gypsum, together with other components, generally referred to as gray cement [18-21]. This constitutes 70 percent of the whole consumption. The principal characteristics of cement are that its color should predominantly be gray with a greenish tint. It indicates the presence of lime or clay waste and the degree of combustion [22-27]. When stroked or manipulated between the fingertips, it displays a sleek texture [28-45].

In the manufacturing of cement by dry process. The processes are presented in the following figure:-


Lime stone
Jaw Crasher
Hammer Mill
Storage in silos
Clay
Grinders
Storage in silos
Raw Mixer
Nodulizer
Burring Rotary kilns
Formatten of Clinker
Clinker Crasher
Granting Mill
Gypsum 3 - 4 %
Storage in Silos
Weighing and package
Distribution

1) Large stones (up to 1.2 m) are loaded into the crusher's hopper from a massive dumper with a capacity of 4, 00,000 kg.

2) Large stones are reduced to smaller ones by use of the jaw crusher. The next step is to use a hammer to break the stones into even smaller bits. From the crusher, a succession of conveys-ours remove the little, crushed limestone, which is now about 75 mm in size, for stacking.

3) All of the quarry's argillaceous or clay elements are thrown into the crusher and piled on top of the limestone.

4) If the quarried materials are deficient in any of the following components, they are added separately: calcium carbonate, lime, alumina, ferrous oxide, and silica.

5) The storage hopper is emptied of the additive ingredient and crushed limestone. A conveyor carries the raw materials to the raw mill, where weigh feeders ensure an even distribution.

6) In the raw mill, the materials are ground to the required fineness. The raw mill's grinding produces a fine powder, which is then sent to the massive continuous blending and storage silo using an aero pole system that uses cyclones to gather the powder in the air.

7) Materials are transported to the storage silo from the blending process using just gravity, which helps to conserve electricity. The ingredients are pushed into the preheater by an aero pole.

8) The material is transferred to the rotary kiln from the base of the preheater. A rotating kiln made of steel tubes is used to conduct the burning process.

9) The revised slurry is introduced into the kiln through the top end. The kiln's bottom end is where the hot gasses or flames are pushed to exit. As the slurry slowly drains down the kiln, it evaporates at the area near the top, which is called the dry zone. The carbon dioxide in the slurry is evaporated in the next stage of the kiln as the temperature rises. At this point, the nodules, which are tiny lumps, begin to develop. In the end, these nodules make it to the burring zone, where temperatures range from 1400 to 1500 degrees Celsius, after slowly rolling down through zones of increasing temperature. Clinkers or raw cement, little hard greenish-blue balls, are created in the burring zone when nodules are transformed into the claimed product.

10) After the rotary kiln produces the desired clinkers, they are finely processed using ball mills and tube mills. A tiny amount of gypsum, around 3 to 4 percent, is added to manage the setting during grinding. Due to the fact that cement need meticulous packaging and storage protocols. Silos, which are concrete storage tanks, are used for this purpose.

System and Notations:

After carefully studying the working of a cement manufacturing plant, we have concluded that consists of following six sub- systems.

1. Sub- System R_1 (Jaw Crushers) :-

The mining, building, and demolition recycling sectors all make use of jaw crushers as their principal crushing machinery. Small pebbles, gravel, or rock dust can be contained with its help. The capacity of jaw crushers to process materials that are both hard and abrasive makes them indispensable in the aggregate industry.

2: Sub- System R_2 (Hammer Mill):-

A hammer mill is a type of grinding machine or mill that is used to share or crush materials into smaller pieces. It operate on the principle of rapid impact between hammers mounted on a rotor and the material fed into the mil hammer mill are widely used in various industries for size reduction of materials including agriculture , food processing , recycling and mining .

3. Sub- System R_3 (Raw Mixer):-

In a cement plants, the raw mixer (also known as a raw meal mixer or raw mix homogenizer) is a critical piece of equipment in the raw materials preparation process its primary function is to ensure the homogenization of the raw materials before they are fed into the kiln for clinker production. Achieving a consistent and uniform raw mix is assent at for producing high quality clinker, and ultimately, cement.

4. Sub- System R_3 (Clinker Section):-

The clinker section in cement plants is a crucial part of the cement manufacturing process. It involves the production of clinker, which is the intermediate product obtained by heating mixture of raw materials in a kiln. Clinker is then ground to produce cement. Below is an overview of the clinker section and its key components.

5. Sub-System R_4(Cement Mill):

The cement mill, also known as finish mill or cement grinding mill, is a critical piece of equipment in a cement plant. It is responsible for grinding clinker, along with additives like gypsum, into fine powder to produce cement. The cement mill is the final stage in the cement manufacturing process, where the product is prepared for packaging and distribution.

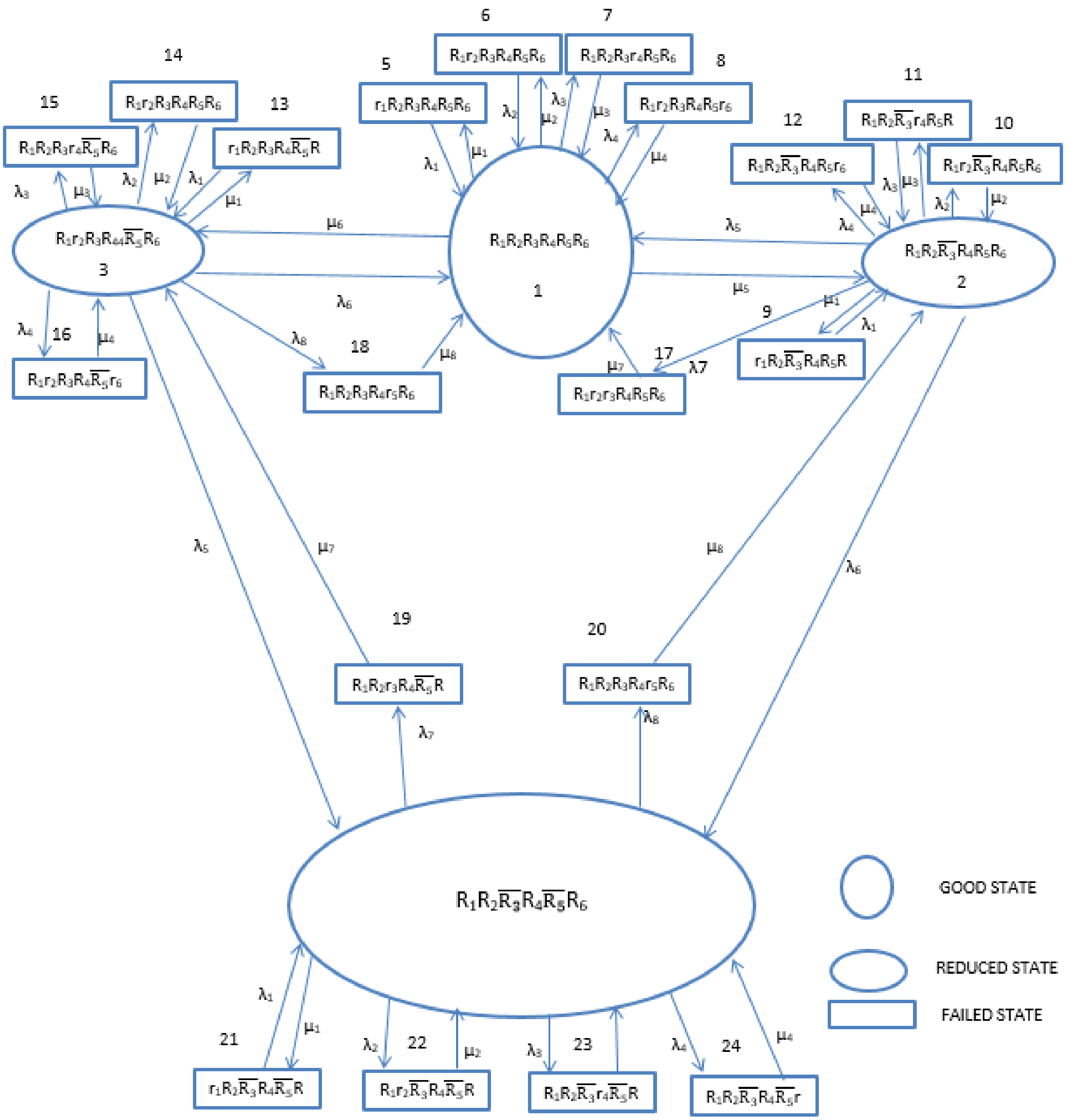
6. Sub-System R_6 (Packing): -

The packing section in cement in cement manufacturing is the final stage of the cement products process. It involves the packing of finished cement into bags to preparation for bulk shipment to customers. The section ensures that the cement is stored, handled, and transported efficiently while maintaining its quality.

Note:-

It is clear that

1. It is clear that R_1, R_2, R_3, R_4, R_5, and R_6 indicate favorable circumstances of the sub-systems
2. $\overline{R_3}$ and $\overline{R_5}$ show that subsystems R_3 and R_5 are operating in diminished levels.
3. λ_1,,λ_2, λ_3,λ_4, λ_5, λ_6, λ_7, and , λ_8 denotes consistent maintenance rates of sub-systems R_1, R_2, R_4, R_6, $\overline{R_3}$, $\overline{R_5}$.R_3, and R_5 respectively.
4. $f_r(t)$ = probability that the system is in r^{th} state at time t (where r=1,2,3,..., 24).
5. μ_1, μ_2, ..., μ_8 respectively indicate the fixed maintenance rates of sub-systems R_1, R_2, R_4,R_6, $\overline{R_3}$, $\overline{R_5}$,R_3,and R_5.
6. Small letters ε_1, ε_2, ε_3, ε_4, and ε_5 Specify the malfunctioning states of the corresponding subsystems, where s is the Laplace parameter.


$R_1R_2R_3R_4R_5R_6$
1
$R_1R_2\overline{R_3}R_4R_5R_6$
2
$R_1r_2R_3R_{44}\overline{R_5}R_6$
3
5
$r_1R_2R_3R_4R_5R_6$
6
$R_1r_2R_3R_4R_5R_6$
7
$R_1R_2R_3r_4R_5R_6$
8
$R_1r_2R_3R_4R_5r_6$
9
$r_1R_2\overline{R_3}R_4R_5R$
10
$R_1r_2\overline{R_3}R_4R_5R_6$
11
$R_1R_2\overline{R_3}r_4R_5R$
12
$R_1R_2\overline{R_3}R_4R_5r_6$
13
$r_1R_2R_3R_4\overline{R_5}R$
14
$R_1r_2R_3R_4R_5R_6$
15
$R_1R_2R_3r_4\overline{R_5}R_6$
16
$R_1r_2R_3R_4\overline{R_5}r_6$
17
$R_1r_2r_3R_4R_5R_6$
18
$R_1R_2R_3R_4r_5R_6$
19
$R_1R_2r_3R_4\overline{R_5}R$
20
$R_1R_2R_3R_4r_5R_6$
$R_1R_2\overline{R_3}R_4\overline{R_5}R_6$
21
$r_1R_2\overline{R_3}R_4\overline{R_5}R$
22
$R_1r_2\overline{R_3}R_4\overline{R_5}R$
23
$R_1R_2\overline{R_3}r_4\overline{R_5}R$
24
$R_1R_2\overline{R_3}R_4\overline{R_5}r$
GOOD STATE
REDUCED STATE
FAILED STATE

When the system is in its transitory state, the following first-order differential equations related to the transition diagram are obtained from probability considerations.

$\frac{df_1(t)}{dt}+(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)f_1(t)=\mu_1 f_5(t)+\mu_2 f_6(t)+\mu_3 f_7(t)+\mu_4 f_8(t)+\mu_5 f_2(t)+\mu_6 f_3(t)+\mu_8 f_{18}(t)+\mu_7 f_{17}(t)$ ... (1)

$\frac{df_2(t)}{dt}+(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_6+\lambda_7+\mu_5)f_2(t)=\mu_1 f_9(t)+\mu_2 f_{10}(t)+\mu_3 f_{11}(t)+\mu_4 f_{12}(t)+\mu_8 f_{20}(t)+\mu_5 f_1(t)$ ... (2)

$\frac{df_3(t)}{dt}+(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5+\lambda_8+\mu_6)f_3(t)=\mu_1 f_{13}(t)+\mu_2 f_{14}(t)+\mu_3 f_{15}(t)+\mu_4 f_{16}(t)+\mu_7 f_{19}(t)+\lambda_6 f_1(t)$ ... (3)

$\frac{df_4(t)}{dt}+(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_7+\lambda_8)f_4(t)=\mu_1 f_{21}(t)+\mu_2 f_{22}(t)+\mu_3 f_{23}(t)+\mu_4 f_{24}(t)+\lambda_5 f_3(t)+\lambda_6 f_2(t)$ ... (4)

$\frac{df_5(t)}{dt}+\mu_1 f_5(t)=\lambda_1 f_1(t)$ ... (5)

$\frac{df_6(t)}{dt}+\mu_2 f_6(t)=\lambda_2 f_1(t)$ ... (6)

$\frac{df_7(t)}{dt}+\mu_3 f_7(t)=\lambda_3 f_1(t)$ ... (7)

$\frac{df_8(t)}{dt}+\mu_4 f_8(t)=\lambda_4 f_1(t)$ ... (8)

$\frac{df_9(t)}{dt}+\mu_1 f_9(t)=\lambda_1 f_2(t)$ ... (9)

$\frac{df_{10}(t)}{dt}+\mu_2 f_{10}(t)=\lambda_2 f_2(t)$ ... (10)

$\frac{df_{11}(t)}{dt}+\mu_3 f_{11}(t)=\lambda_3 f_2(t)$ ... (11)

$\frac{df_{12}(t)}{dt}+\mu_4 f_{12}(t)=\lambda_4 f_2(t)$ ... (12)

$\frac{df_{13}(t)}{dt}+\mu_1 f_{13}(t)=\lambda_1 f_3(t)$ ... (13)

$\frac{df_{14}(t)}{dt}+\mu_2 f_{14}(t)=\lambda_2 f_3(t)$ ... (14)

$\frac{df_{15}(t)}{dt}+\mu_3 f_{15}(t)=\lambda_3 f_3(t)$ ... (15)

$\frac{df_{16}(t)}{dt}+\mu_4 f_{16}(t)=\lambda_4 f_3(t)$ ... (16)

$\frac{df_{17}(t)}{dt}+\mu_7 f_{17}(t)=\lambda_7 f_2(t)$ ... (17)

$\frac{df_{18}(t)}{dt}+\mu_8 f_{18}(t)=\lambda_8 f_3(t)$ ... (18)

$\frac{df_{19}(t)}{dt}+\mu_7 f_{19}(t)=\lambda_7 f_4(t)$ ... (19)

$\frac{df_{20}(t)}{dt}+\mu_8 f_{20}(t)=\lambda_8 f_4(t)$ ... (20)

$\frac{df_{21}(t)}{dt}+\mu_1 f_{21}(t)=\lambda_1 f_4(t)$ ... (21)

$\frac{df_{22}(t)}{dt}+\mu_2 f_{22}(t)=\lambda_2 f_4(t)$ ... (22)

$\frac{df_{23}(t)}{dt}+\mu_3 f_{23}(t)= \lambda_3 f_4(t)$ ... (23)

$\frac{df_{24}(t)}{dt}+\mu_4 f_{24}(t)= \lambda_4 f_4(t)$ ... (24)

With boundaries $f_1(0)=1$ and 0,otherwise ... (25)

Now, taking the Laplace transforms of equations the (2) and solving recursively,

we get.

$f_2(s) = \delta_1 f_1(s)$ ... (26)

$f_3(s) = \delta_2 f_1(s)$ ... (27)

$f_4(s) = \delta_3 f_1(s)$ ... (28)

$f_5(s) = \phi_1 f_1(s)$ ... (29)

$f_6(s) = \phi_2 f_1(s)$ ... (30)

$f_7(s) = \phi_3 f_1(s)$ ... (31)

$f_8(s) = \phi_4 f_1(s)$ ... (32)

$f_9(s) = \phi_1 \delta_1 f_1(s)$ ... (33)

$f_{10}(s) = \phi_2 \delta_1 f_1(s)$ ... (34)

$f_{11}(s) = \phi_3 \delta_1 f_1(s)$ ... (35)

$f_{12}(s) = \phi_4 \delta_1 f_1(s)$ ... (36)

$f_{13}(s) = \phi_1 \delta_2 f_1(s)$ ... (37)

$f_{14}(s) = \phi_2 \delta_2 f_1(s)$ ... (38)

$f_{15}(s) = \phi_3 \delta_2 f_1(s)$ ... (39)

$f_{16}(s) = \phi_4 \delta_2 f_1(s)$ ... (40)

$f_{17}(s) = \phi_7 \delta_1 f_1(s)$ ... (41)

$f_{18}(s) = \phi_8 \delta_2 f_1(s)$ ... (42)

$f_{19}(s) = \phi_7 \delta_3 f_1(s)$ ... (43)

$f_{20}(s) = \phi_8 \delta_3 f_1(s)$ ... (44)

$f_{21}(s) = \phi_1 \delta_3 f_1(s)$ ... (45)

$_{22}(s) = \phi_2 \delta_3 f_1(s)$ ... (46)

$f_{23}(s) = \phi_3 \delta_3 f_1(s)$ ... (47)

$f_{24}(s) = \phi_4 \delta_3 f_1(s)$ ... (48)

It is clear that

$\phi_1 = \frac{\lambda_1}{s+\mu_1}$ ... (49)

$\phi_2 = \frac{\lambda_2}{s+\mu_2}$ ... (50)

$\phi_3 = \frac{\lambda_3}{s+\mu_3}$ ... (51)

$\phi_4 = \frac{\lambda_4}{s+\mu_4}$ ... (52)

$\phi_7 = \frac{\lambda_7}{s+\mu_7}$ ... (53)

$\phi_8 = \frac{\lambda_8}{s+\mu_8}$ ... (54)

$\psi_1 = \frac{\lambda_7\mu_7}{s+\mu_7}$ ... (55)

$\psi_2 = \frac{\lambda_8\mu_8}{s+\mu_8}$ ... (56)

$v_1 = \frac{(v+\alpha_4)}{(v+\alpha_2)(v+\alpha_4)-\psi_2\lambda_6}$ ... (57)

$v_2 = \frac{(v+\alpha_4)}{(v+\alpha_2)(v+\alpha_4)-\psi_2\lambda_6}$ ... (58)

$v_3 = \frac{(v+\alpha_4)\lambda_6}{(v+\alpha_3)(v+\alpha_4)-\psi_1\lambda_5}$ ... (59)

$v_4 = \frac{\psi_1\,\lambda_5}{(v+\alpha_3)(v+\alpha_4)-\psi_1\lambda_5}$ ... (60)

$\delta_1 = \frac{v_1+v_2+v_3}{1-v_2v_4}$ ... (61)

$\delta_2 = \frac{v_1+v_3+v_4}{1-v_2v_4}$ ... (62)

$\sigma_3 = \frac{\lambda_5(v_1+v_3+v_4)+\lambda_6(v_1+v_2+v_3)}{(v+\alpha_4)1-v_2v_4}$ ... (63)

Also taking Laplace transform of equation (1) and using equation (25), We get

$f_1(s)=[(v+\alpha_1)-\sigma_1(\mu_5+\psi_1)-\sigma_2(\mu_6+\psi_2)]^{-1}$ ... (64)

Laplace transforms of the reliability function for the system is given by

$R(s)=f_1(s)+f_2(s)+f_3(s)+f_4(s)$

$=(1+\sigma_1+\sigma_2+\sigma_3)f_1(s)$ ... (65)

Where $f_1(s)$ is given by equation (64) the inversion of R(s) gives the reliability function R(t).

But it is difficult to find Laplace inverse since expressions for probability transforms are in very much complicated form and complexity increases with the increase in number of equations. To overcome this difficulty equations (1) to (64) with initial condition (25) have been solved numerically wing Runga-Kutta fourth order method. The numerical integration is performed with t = 0.005 assuming as one day, there for to get the reliability up to 360 days we will have to perform 72000 iteration with the Runga-Kutta fourth order method. The reliability function of the system R(t) is computed by

$R(t)=f_1(t)+f_2(t)+f_3(t)+f_4(t)$ ... (66)

The reliability of the system, as defined in equation (66) has been computed for various values of the repair and failure rates. It may be mentioned here that these values combinations are not exhaustive and we have only considered the main sub-systems in the numerical study.

Steady State:-

In process industries, management is interested in long run availability. As such, steady state probabilities are required to calculate long run. Availability that can be calculated by considering the fact that,

$\frac{d}{dt} \rightarrow$ 0 as t$\rightarrow \infty$

We have used f_1, f_2, f_3… f_{24} for denoting steady state probabilities equations (1) to equations (24) can be given as:

$(\lambda_{1,}+\lambda_2+\lambda_3+\lambda_4+\lambda_5+\lambda_{6,})f_1= \mu_1 f_5+\mu_2 f_6+\mu_3 f_7+\mu_4 f_8+\mu_5 f_2+\mu_6 f_3+\mu_8 f_{18}+\mu_7 f_{17}$ … (67)

$(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_6+\lambda_7+\mu_5)f_2 = \mu_1 f_9+\mu_2 f_{10}+\mu_3 f_{11}+\mu_4 f_{12}+\mu_8 f_{20}+\lambda_5 f_1$ … (68)

$(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5+\lambda_8+\mu_6)f_3 = \mu_1 f_{13}+\mu_2 f_{14}+\mu_3 f_{15}+\mu_4 f_{16}+\mu_7 f_{19}+\lambda_6 f_1$ … (69)

$(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_7+\lambda_8)f_4 = \mu_1 f_{21}+\mu_2 f_{22}+\mu_3 f_{33}+\mu_4 f_{24}+\lambda_5 f_3+\lambda_6 f_2$ … (70)

$\mu_1 f_5 = \lambda_1 f_1$ … (71)

$\mu_2 f_6 = \lambda_2 f_1$ … (72)

$\mu_3 f_7 = \lambda_3 f_1$ … (73)

$\mu_4 f_8 = \lambda_4 f_1$ … (74)

$\mu_1 f_9 = \lambda_1 f_2$ … (75)

$\mu_2 f_{10} = \lambda_2 f_2$ … (76)

$\mu_3 f_{11} = \lambda_3 f_2$ … (77)

$\mu_4 f_{12} = \lambda_4 f_2$ … (78)

$\mu_1 f_{13} = \lambda_1 f_3$ … (79)

$\mu_2 f_{14} = \lambda_2 f_3$ … (80)

$\mu_3 f_{15} = \lambda_3 f_3$ … (81)

$\mu_4 f_{16} = \lambda_3 f_3$ … (82)

$\mu_7 f_{17} = \lambda_7 f_2$ … (83)

$\mu_8 f_{18} = \lambda_8 f_3$ … (84)

$\mu_7 f_{19} = \lambda_7 f_4$ … (85)

$\mu_8 f_{20} = \lambda_8 f_4$ … (86)

$\mu_1 f_{21} = \lambda_1 f_4$ … (87)

$\mu_2 f_{22} = \lambda_2 f_4$ … (88)

$\mu_3 f_{23} = \lambda_3 f_4$ … (89)

$\mu_4 f_{24} = \lambda_4 f_4$ … (90)

Solving these equations recursively, we get

$f_2=G_3f_1$ … (91)

$f_3=(G_3G_3+G_1)f_1$ … (92)

$f_4=G_4f_1$ … (93)

$f_5=\frac{\lambda_1}{\mu_1}f_1$ … (94)

$f_6=\frac{\lambda_2}{\mu_2}f_1$ … (95)

$f_7=\frac{\lambda_3}{\mu_3}f_1$ ... (96)

$f_8=\frac{\lambda_4}{\mu_4}f_1$ ... (97)

$f_9=\frac{\lambda_1}{\mu_1}G_3f_1$ ... (98)

$f_{10}=\frac{\lambda_2}{\mu_2}G_3f_1$ ... (99)

$f_{11}=\frac{\lambda_3}{\mu_3}G_3f_1$ ... (100)

$f_{12}=\frac{\lambda_4}{\mu_4}G_3f_1$ ... (101)

$f_{13}=\frac{\lambda_1}{\mu_1}(G_2G_3+G_1)f_1$ ... (102)

$f_{14}=\frac{\lambda_2}{\mu_2}(G_2G_3+G_1)f_1$ ... (103)

$f_{15}=\frac{\lambda_3}{\mu_3}(G_2G_3+G_1)f_1$ ... (104)

$f_{16}=\frac{\lambda_4}{\mu_4}(G_2G_3+G_1)f_1$ ... (105)

$f_{17}=\frac{\lambda_7}{\mu_7}G_3f_1$ ... (106)

$f_{18}=\frac{\lambda_8}{\mu_8}(G_2+G_3+G_1)G_4f_1$ ... (107)

$f_{19}=\frac{\lambda_7}{\mu_8}G_4f_1$ ... (108)

$f_{20}=\frac{\lambda_8}{\mu_8}G_4f_1$ ... (109)

$f_{21}=\frac{\lambda_1}{\mu_1}G_4f_1$ ... (110)

$f_{22}=\frac{\lambda_2}{\mu_2}G_4f_1$ ... (111)

$f_{23}=\frac{\lambda_3}{\mu_3}G_4f_1$ ... (112)

$f_{24}=\frac{\lambda_4}{\mu_4}G_4f_1$ ... (113)

Where

$G_1=\frac{\lambda_6\lambda_7+\lambda_6\lambda_8}{[(\lambda_7+\lambda_8)(\lambda_5+\lambda_8+\mu_6)-\lambda_5\lambda_7]}$ ... (114)

$G_2=\frac{\lambda_6\lambda_7}{[(\lambda_7+\lambda_8)(\lambda_5+\lambda_8+\mu_6)-\lambda_5\lambda_7]}$ ... (115)

$G_3=\frac{\lambda_5\lambda_7+\lambda_5\lambda_8+G_1\lambda_5\lambda_8}{[(\lambda_7+\lambda_8)(\lambda_6+\lambda_7+\mu_5)-\lambda_6\lambda_8]-\lambda_5\lambda_8\lambda_2}$ ... (116)

$G_4=\frac{\lambda_5(G_2G_3+G_1)+\lambda_6G_3}{\lambda_7+\lambda_8}$ ... (117)

Now, using the normalizing condition

$f_1+f_2+f_3+\ldots+f_{24}=1$ ... (118)

$f_1=[(1+\frac{\lambda 1}{\mu 1}+\frac{\lambda 2}{\mu 1}+\frac{\lambda 3}{\mu 3}+\frac{\lambda 4}{\mu 4})(1+G_1+G_3+G_4+G_2G_3)+\frac{\lambda 7}{\mu 7}(G_7+G_4)+\frac{\lambda 8}{\mu 8}(G_1+G_2G_3+G_4)]^{-1}$ ... (119)

$A(\infty)=f_1+f_2+f_3+f_4$

$= [1+G_1+G_2+G_3+G_4+G_2G_3] f_1$ ... (120)

Effect of Failure Rate of Clinker Section (λ_3) on the Reliability of the System:-

We have now calculated the reliability of the system by varying the failure rate of clinker section. The values of the different parameters is taken as: λ_1=0.03, λ_2=0.03, λ_4=0.07, λ_5=0.03, λ_6=0.03, λ_7=0.003, λ_8=0.003,μ_1=6.0,μ_2,μ_3,μ_4,μ_5,μ_6=,μ_7=0.30,μ_8=0.30 and λ_3 is varied from 0.01 to 0.05 with an increment of 0.01. in table 1, shows the result of this study. It can be noticed that reliability and MTBF is days of the system decreases by approximately 0.8% with the increase of failure rate of clinker section from 0.01 to 0.05 and the reliability decreases by approximately 0.02% with the increase in time from 30 to 360 days

Days	**0.01**	**0.02**	**0.03**	**0.04**	**0.05**
30	0.978454	0.976464	0.974481	0.972507	0.970541
60	0.978417	0.976426	0.974444	0.972471	0.970505
90	0.978385	0.976396	0.974414	0.972440	0.970474
120	0.978359	0.976370	0.974388	0.972414	0.970449
150	0.978338	0.976348	0.974366	0.972393	0.970427
180	0.978320	0.976330	0.974348	0.972375	0.970409
210	0.978304	0.976315	0.974333	0.972369	0.970394
240	0.978292	0.976302	0.974321	0.972347	0.970382
270	0.978281	0.976292	0.974310	0.972337	0.970371
300	0.978272	0.976283	0.974301	0.972328	0.970363
330	0.978265	0.976275	0.974294	0.972321	0.970355
360	0.978259	0.976269	0.974288	0.972315	0.970349
MTBF	**352.416**	**351.852**	**351.033**	**350.336**	**349.649**

Table 1

The repair rate of the clinker section in a cement plant has a significant Impact on the overall efficiency, productivity, and cost effectiveness of the plant. The clinker section, which includes the kiln, preheater, and cooler, is the heart of the cement production process. Hence one the key effects of the repair rate on the critical section.

The impact on system dependability of the repair rate of the clinker section: -

We have now taken into account how the clinker section repair rate affects the system's dependability. We have taken into account five tiers of (m3) = 4.5, 4.6, 4.7, 4.9 and other parameters are taken as (lamda3) = 0.03, (lamda2) =0.03, (lamda4) =0.07, (lamda5) =0.03, (lamda6) =0.03, (lamda7) = 0.03, (lamda8) = 0.03, (m1)= 6.0, (M2)=6.0, (M4)= 12.0, (M5)= 24.0, (M6)= 24.0, (M7)= 0.30, (M8)= 0.30 . The reliability of the system is computed for above parameter and results are shown in table (2). It can be noted from this table that reliability and MTBF in days of the system increases by approximately 0.05% with the increase in repair rate of clinker section and decreases by approximately 0.02% with the increase in time from 30 to 360 days.

Table 2

Conclusion: -

The repair rate of the clinker section in a cement plant has a profound impact on various aspects of the plant`s operation. A low repair rate, achieved through regular maintenance and timely interventions, is essential for ensuring high production efficient, controlling operational costs, extending equipment longevity, reducing energy

μ_3 → **Days ↓**	**4.5**	**4.6**	**4.7**	**4.8**	**4.9**
30	0.974085	0.974223	0.974355	0.974481	0.974602
60	0.974049	0.974186	0.974318	0.974444	0.974566
90	0.974018	0.974156	0.974287	0.974414	0.974535
120	0.973992	0.974130	0.974262	0.974388	0.974509
150	0.973971	0.974108	0.974240	0.974366	0.974487
180	0.973953	0.974091	0.974221	0.974349	0.974469
210	0.973938	0.974075	0.974207	0.974333	0.974454
240	0.973925	0.974063	0.974194	0.974321	0.974442
270	0.973914	0.974052	0.974184	0.974310	0.974431
300	0.973906	0.974043	0.974175	0.974301	0.974422
330	0.973898	0.974036	0.974168	0.974294	0.974415
360	0.973893	0.974030	0.974162	0.974287	0.974409
MTBF	**350.888**	**350.937**	**350.983**	**351.027**	**351.069**

consumption, maintaining product quality, ensuring safety and minimizing environmental impact. Conversely, a high repair rate can lend to increased downtime, higher costs, and potential safety and environmental issues. Therefore, investing in preventive maintenance and efficient repair Strategies is crucial for the optimal performance of a cement plant.

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