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Original Article

Performance of Electromechanical Equipment Under Various Maintenance Strategies. A Case Study in Sasol Synfuels Catalyst Preparation Unit

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Abstract *- The subject of maintenance optimisation is not new, and many researchers have explored it. However, it is seen that one optimisation solution cannot be used in all industries. However, Turnaround management is the most used strategy in the petrochemical industries. Equipment downtime remains the biggest challenge; thus, the purpose of the study was to understand the different maintenance practices and how they impact the production use of the electromechanical equipment in Sasol Synfuels Catalyst Preparation. A case study having 5 electromechanical equipment, namely the Arc furnace, casting machine, Conveyor belt, Ball mill, and Kiln, was analysed to determine the overall performance of electromechanical equipment by analysing the current maintenance strategy applied in the identified electromechanical equipment. Both qualitative and quantitative methods were applied. From the results, it is observed that all the types of equipment identified apply on average above 50% condition-based maintenance. The fixed time maintenance strategy followed with a 30% ranking, then the operate to failure maintenance strategy with a 13% ranking, and lastly corrective maintenance with 7%.*

Keywords *- Equipment performance, Maintenance strategy, Condition-Based Maintenance, Fixed maintenance, Operation to failure.*

1. Case Study- Introduction

A petrochemical plant consists of an oil refinery and chemical processing units that utilize refinery products to produce various useful materials, such as raw materials for rubber, paints, paper, Polyvinyl Chloride (PVC), resins, plastics, textiles, fertilizers, and more. (OLUWASINA, 2011).

Maintenance is the combination of technical and administrative activities necessary to maintain equipment, installations, and other physical assets in optimal operating condition or restore them to that state. (MBOHWA, 2016). Various maintenance approaches, often referred to as strategies or philosophies, are currently available for use across all production methods. (MUNGANI, 2013).

Reliability-Centered Maintenance (RCM), for example, originated in the aviation industry and emphasizes equipment reliability. (MUNGANI, 2013). The effect of maintenance on these variables has prompted increased attention to the maintenance area as an integral part of productivity improvement. (OLUWASINA, 2011).

Several different maintenance approaches, better known as strategies, are available for application in all production methods. (MINGANI, 2013). They consist of reactive repairs and replacement activities employed through failures, as well as planned and predictive tasks such as preventive replacements, inspections, scheduled repairs, etc. (WAKIRU, 2018).

In general, the maintenance of any system is classified under two maintenance approaches: failure-based maintenance (i.e., Corrective Maintenance (CM)) and life-based maintenance (i.e., regular Preventive Maintenance (PM)) (DHINGRA T, 2014). For a more comprehensive approach, the following approaches have been developed, as stated by MUNGANI (2013):

Operate To Failure (OTF) – equipment is run until a failure occurs, when a replacement is usually performed. This tactic is often the cheapest since the full design life of the component is utilised. However, it is not good practice when the consequence of failure is severe, such as loss of life or a major release of harmful substances.

- Time-Based Maintenance (TBM) – replacement or cleaning is performed at a predetermined time or usage intervals. This tactic is often used for simple components that exhibit a definite wear-out failure mode with a narrow failure distribution. A drawback is that only part of the useful life of components is utilised.

- Condition-Based Maintenance (CBM) – some parameter that indicates the condition of the equipment is measured continuously or periodically, and replacement is performed when the condition is no longer acceptable.

- Fault-Finding Maintenance (FFM) – periodic checks are performed to determine whether the backup equipment, redundant equipment, or protective equipment is still fully functional. If not, repair or replacement is performed.

1.1. Risk-Based Maintenance (RBM)

In recent years, the process and power plant industries have used a wide range of methods to assess risks and safety hazards. (CHEMWENO, 2018). CHEMWENO's (2018) study explains that in the maintenance decision-making activities, risk assessments are performed to identify, analyze, evaluate, and mitigate failure risks in assets.

SHAFIEE's (2017) study of maintenance optimization defines RBM's aim as reducing the overall risks associated with unexpected failures. The author studied the behaviors of wind turbines.

Among the commonly used methods in this context are Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), and Bayesian Network (BN) (CHEMWENO, 2018). These methods will be elaborated further in the subsequent sections.

Despite the implementation of the best maintenance approaches/concepts/strategies, maintenance managers face equipment failures and plant shutdowns, which lead to the stoppage of operation/production.

Therefore, there is an immense requirement to study the formulation and selection of maintenance strategies and their impact. (DHINGRA T, 2014) Thus, the purpose of this article is to.

The objective of this study is to analyze the current maintenance strategies applied to the identified electromechanical equipment in the catalyst preparation unit at Sasol Synfuels.

The study aims to identify the overall performance of electromechanical equipment to optimise the maintenance strategies employed.

2. Methodology

A case study on Maintenance strategies employed on electromechanical equipment in Sasol Synfuels Catalyst Preparation Unit

The case study is mainly focused on electromechanical equipment utilised in the Sasol Synfuels catalyst preparation unit, which consists of:

1. Arc furnace
2. Casting Machine
3. Conveyor belt
4. Ball mill
5. Kiln

The Sasol Synfuels catalyst preparation unit consists of a Kiln (X04KN-101A and B), which uses the RMS (raw mill scale) fed by the conveyor belts (X04CV-101A and B) to burn the RMS and produce OMS (Oxidized Mill Scale). The OMS is then stored in the Bin. From the Bin using conveyor belts, the OMS is fed into the Arc furnace (X04AF-141A and B), which uses Electrodes to burn the product with promoters so that it melts the OMS into a molten catalyst.

The catalyst is fed into the crusher to crush the cooled catalyst into small quantities using jaws, using the casting machine (X04CM-141) with spraying water coolers. The catalyst is fed into the storage Hopper manually from the crusher, whereby conveyor belts are utilized to transport the catalyst into the rotating Ball mill (X04GM-141).

The analysis contains both east and west units. The eastern unit consists of two arc furnaces, conveyor belts, and kilns, all running concurrently, making a total of 8 equipment. The western unit consists of 5 electromechanical equipment, thus making 13 pieces of equipment.

Meridium software was used to analyze the current maintenance strategy applied to the equipment. This software is used primarily in Sasol to populate the FMEA for each piece of equipment. Thus, the preceding three steps were taken to obtain a database of the different maintenance strategies applied to the Electromechanical equipment.

Step 1: The identification of the technical equipment is made using the mechanical flow diagram unit U004- Western side, as illustrated in Figure 1. After the technical identification of the equipment is obtained, the equipment number is then placed in Meridium software.

Using the technical identification. The equipment strategy can be obtained through searching on the technical ID tab, using the technical identification (Figure 1).

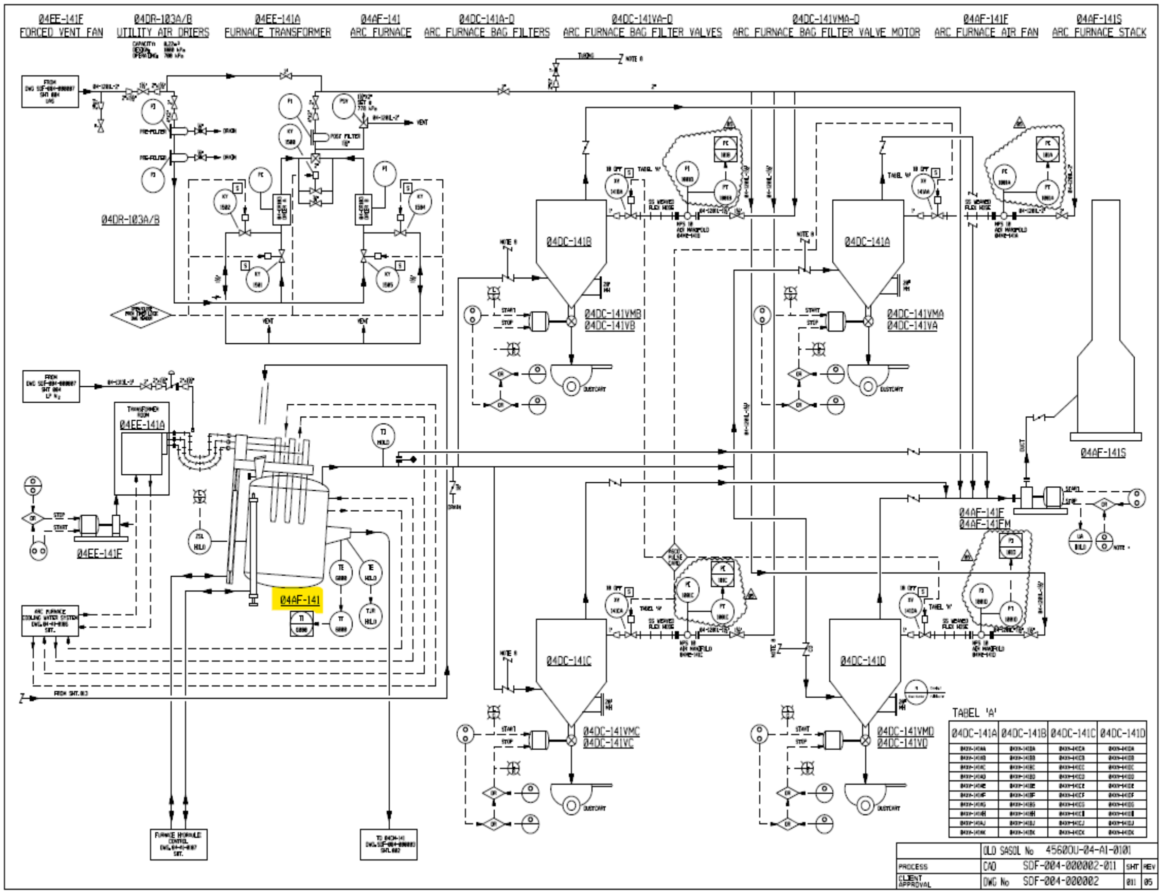

Fig. 1 Mechanical flow diagram from SAP drawn for catalyst preparation unit (U004- Western side)

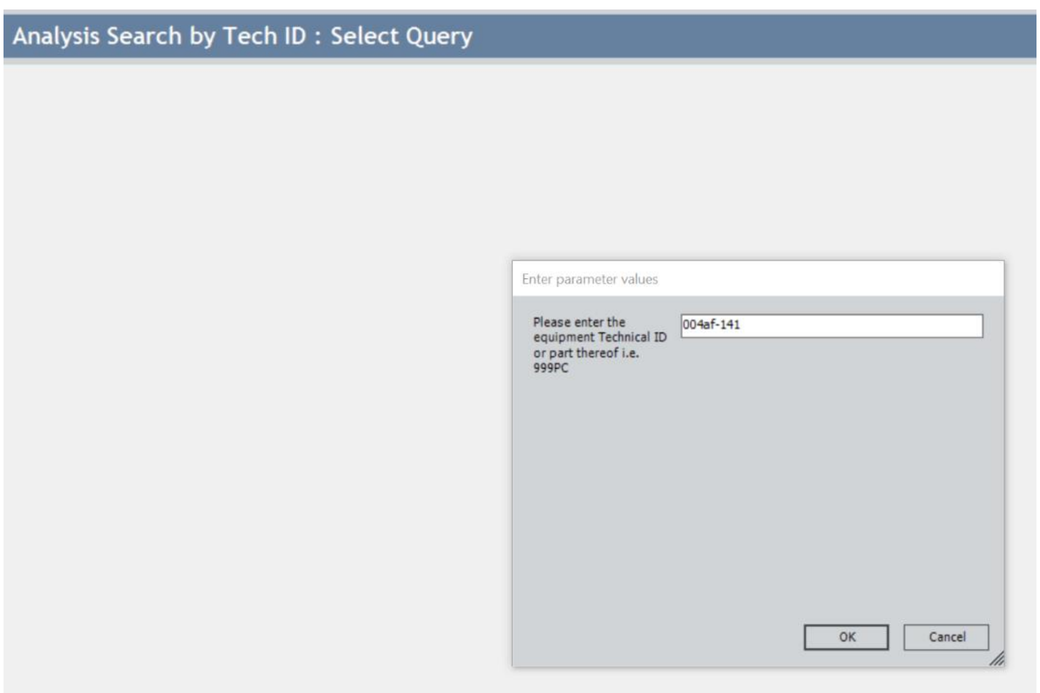

Fig. 2 Analysis search by tech ID in Meridium software

Step 2: Extract the FMEA from the Meridium software populated by the subject matters of the equipment, as in Figures 2 and 3. The FMEA is the tool utilized to perform the different maintenance strategies applied to the equipment within specified time frames. Figure 4 shows an example of the different maintenance strategies used on one of the electromechanical equipment, the arc furnace. The maintenance strategies applied are Condition-Based Maintenance (CBM), Fixed Time Maintenance (FTM), and Operate To Failure maintenance (OTF). The FMEA used to analyze these different maintenance strategies is the latest, dating from January 2019 to November 2021. Maintenance strategies applied to other electromechanical equipment studied in this work are illustrated in Appendix 1.

Technical ID	Functional Location ID	FMEA Analysis ID	FMEA Report	Analysis Short Description	Unit	Discipline
004AF-141	SP004-0303-AF-141	X04AF-141	X04AF-141	ARC FURNACE ANALYSIS	X04	M
004AF-141-DM	SP004-0303-MO-AF-141-DM	Furnace equipments	Furnace equipments	Maintenance of furnace electrical motor	004	E
004AF-141-ELECTRODE LIFTING LUG		X04 LIFTING LUGS	X04 LIFTING LUGS	LIFTING LUG ANALYSIS	X04	M
004AF-141-F	SP004-0305-FA-AF-141-F	X04AF-141-F	X04AF-141-F	ARC FURNACE DUST EXTRACTION FAN	X04	M
004AF-141-FM	SP004-0305-MO-AF-141FM	X04MO-525 Motor with pulley	X04MO-525 Motor with pulley	525V Motor with pulley	X04	E
004AF-141-FM-MCC	SP004-0305-EF-AF-141-FM	525V MCC	525V MCC	525 V Feeder (MCC) analysis	X04	E
004AF-141-HM	SP004-0302-MO-AF-141-HM	Furnace equipments	Furnace equipments	Maintenance of furnace electrical motor	004	E
004AF-141-KR01M	SP004-0302-MO-KR-01M	Furnace equipments	Furnace equipments	Maintenance of furnace electrical motor	004	E
004AF-141-LAUNDER LIFTING LUGS		X04 LIFTING LUGS	X04 LIFTING LUGS	LIFTING LUG ANALYSIS	X04	M
004AF-141-PX01AM	SP004-0302-MO-PX-01AM	Furnace equipments	Furnace equipments	Maintenance of furnace electrical motor	004	E
004AF-141-PX01BM	SP004-0302-MO-PX-01BM	Furnace equipments	Furnace equipments	Maintenance of furnace electrical motor	004	E
004AF-141-PX04A1M	SP004-0302-MO-PX-04A1M	Furnace equipments	Furnace equipments	Maintenance of furnace electrical motor	004	E
004AF-141-PX04B1M	SP004-0302-MO-PX-04B1M	Furnace equipments	Furnace equipments	Maintenance of furnace electrical motor	004	E
004AF-141-PX05M	SP004-0302-MO-PX-05M	Furnace equipments	Furnace equipments	Maintenance of furnace electrical motor	004	E
004AF-141-PX08M	SP004-0302-MO-PX-08M	Furnace equipments	Furnace equipments	Maintenance of furnace electrical motor	004	E
004AF-141-ROOF LIFTING LUGS		X04 LIFTING LUGS	X04 LIFTING LUGS	LIFTING LUG ANALYSIS	X04	M
004AF-141-S	SP004-0305-SK-AF-141-S	X04AF-141-S	X04AF-141-S	ARC FURNACE STACK	X04	M
004AF-141-SF1M	SP004-0302-MO-AF-141-SF1M	X04MO-525V Motor (<30kW)	X04MO-525V Motor (<30kW)	525 V Motor (<30kW) analysis	X04	E
004AF-141-SF1M-MCC	SP004-0302-EF-AF-141-SF1M	525V MCC	525V MCC	525 V Feeder (MCC) analysis	X04	E
004AF-141-SF2M	SP004-0302-MO-AF-141-SF2M	X04MO-525V Motor (<30kW)	X04MO-525V Motor (<30kW)	525 V Motor (<30kW) analysis	X04	E
004AF-141-TS1M	SP004-0302-MO-AF-141-TS1M	X04MO-525V Motor (<30kW)	X04MO-525V Motor (<30kW)	525 V Motor (<30kW) analysis	X04	E
004AF-141-TS1M-MCC	SP004-0302-EF-AF-141-TS1M	525V MCC	525V MCC	525 V Feeder (MCC) analysis	X04	E
004AF-141A	SP004-0302-HT-AF-141A	X04HT-Heater	X04HT-Heater	X04 Heaters	X04	E
004AF-141A-SP01A	SP004-0302-VA-AF-141A-SP01A	X04AF-141 Proportional valve system	X04AF-141 Proportional valve system	X04 Proportional Valves	X04	E
004AF-141A-SP01B	SP004-0302-VA-AF-141A-SP01B	X04AF-141 Proportional valve system	X04AF-141 Proportional valve system	X04 Proportional Valves	X04	E
004AF-141A-SP01C	SP004-0302-VA-AF-141A-SP01C	X04AF-141 Proportional valve system	X04AF-141 Proportional valve system	X04 Proportional Valves	X04	E
004AF-141A-SP01D	SP004-0302-VA-AF-141A-SP01D	X04AF-141 Proportional valve system	X04AF-141 Proportional valve system	X04 Proportional Valves	X04	E
004AF-141AEE	SP004-0303-TR-AF-141AEE	X04AF-141-TR Arc Furnace Transformer	X04AF-141-TR Arc Furnace Transformer	33KV / 220V Arc furnace Transformer	X04	E
004AF-141AEE-MCC	SP004-0303-EF-AF-141AEE	004AF-141AEE-MMC	004AF-141AEE-MMC	ARC FURNANCE TRANSFOMER FEEDER	004	E
004AF-141ATR	SP004-0303-EE-AF-141ATR	X04AF-141	X04AF-141	X04 Arc furnace analysis	X04	E

Fig. 3 Different equipment registered under the technical ID in Meridium software

1 of 1 100% Find | Next

FMEA Report

sasol reaching new frontiers

Unit/Area: X04 Discipline: M Report Date: 28/07/2021

Analysis ID:	X04AF-141		Revision Number:	10
Analysis Description:	ARC FURNACE ANALYSIS		Approval Status:	Approved

Technical ID	Functional Location ID	Technical ID	Functional Location ID
004AF-141	SP004-0303-AF-141	204AF-141A	SP204-0303-AF-141A
204AF-141B	SP204-0303-AF-141B		

FM ID	Component	Symptom	Cause	Strat Type	Action	Freq.	Freq. Unit	Res	Trigger Action	Primaryor Secondary Action
01	BRIDGE	CRACKS OF STRUCTURAL WELDS	HEAT SHIELD FAILURE	CBM	SANDBLAST IDENTIFIED AREAS, MPI ON IDENTIFIED AREAS	48	Mont hs	CO N	CRACKS AND OTHER DEFECTS FOUND	REPAIR
02	HEAT SHIELD	BROKEN	MECHANICAL DAMAGE	CBM	VISUALLY INSPECT HEAT SHIELD AND BRACKETS FOR DAMAGE	1	Mont hs	FIT	DAMAGE FOUND	REPLACE HEAT SHIELD OR REPAIR BRACKETS
03	PIVOT BEARING ASSEMBLY	SEIZE	LACK OF LUBRICATION	FTM	GREASE PIVOT BEARING ASSEMBLIES.	1	Mont hs	FIT		
04	TILTING CYLINDER PIVOT POINTS	SEIZE	LACK OF LUBRICATION	FTM	GREASE TILTING CYLINDER PIVOT POINTS.	1	Mont hs	FIT		
05	TILTING CYLINDER SHAFT SEALS	FAILURE	SERVICE LIFE	CBM	VISUALLY INSPECT SHAFT SEALS FOR ANY LEAKS.	14	Days	FIT	ANY LEAKS DETECTED.	EVALUATE LEAK AND REPAIR IF NECESSARY
06	TILTING CYLINDER PISTON ROD	DAMAGED SURFACE COATING	SERVICE LIFE	CBM	VISUALLY INSPECT FOR COAT FAILURE	1	Mont hs	FIT	COAT FAILURE DETECTED	REMOVE CYLINDER AND SEND OUT FOR OVERHAUL
07	PEDESTAL BEARING ASSEMBLY	SEIZE	LACK OF LUBRICATION	FTM	GREASE FOUNDATION PEDESTAL BEARING ASSEMBLY.	1	Mont hs	FIT		
08	ELECTRODE GUIDE COLUMN ROLLERS	SEIZE/STICKY	MISALIGNMENT	CBM	CLEAN AND INSPECT ROLLERS & ADJUST CLEARANCE IF NECESSARY.	1	Mont hs	FIT	DEVIATIONS FOUND	ADJUST CLEARANCE
09	ELECTRODE GUIDE	SEIZE/STICKY	ACCUMULATIO N OF CATALYST	FTM	CLEAN ROLLERS OF ALL DUST	1	Mont	PR		

Fig. 4 Arc furnace FMEA report from the Meridium software

Step 3: The data obtained was then used to prepopulate an Excel spreadsheet, where the data was analyzed according to the different maintenance strategies and intervals applied (See Appendix 1). A table was created by filtering the different maintenance intervals of the different strategies applied within that specific time frame. Using Formula 1, the total percentage of maintenance strategy per interval was tabulated.

$$\text{Total maintenance (\%)} = \left(\frac{number\ of\ (CBM, FTM, OTF) maintenace\ strategy\ applied}{Total\ number\ of\ maintenace\ tasks}\right) \times 100 \quad (1)$$

Each step had to be repeated for each equipment data extraction.

3. Results and Discussion

The paper dealt with the current maintenance strategies applied in the identified electromechanical equipment in the catalyst preparation unit at Sasol Synfuels. The focus was to identify the overall performance of electromechanical equipment in order to optimise the maintenance strategies employed. Using qualitative and quantitative methods, a Sasol SAP system software was used to extract the data inputs and identify the performance of each equipment maintenance FEA model.

In this section, the generated results are presented and discussed.

3.1. Status of Maintenance Strategy Employed

The following figure (Figures 5-10) shows the percentage of maintenance utilized by Condition-Based Maintenance (CBM), Fixed Time Maintenance (FTM), and Operate To Failure maintenance (OTF). For each electromechanical equipment used, based on the frequency of the maintenance tasks in the Catalyst preparation unit. Note that the FMEA is created generally to cover both the east and west of the same equipment. Thus, as in Appendix 1, the FMEA report uses conventional X04 to present both 204 and 004 units. The Task sheets used to analyze these different maintenance strategies date from January 2019 to November 2021.

3.2. Arc Furnace Applied Maintenance Strategy

The arc furnace results are presented in Table 1. The table illustrates the types of maintenance strategies employed compared to the maintenance intervals employed. The results were further analysed through the graphical presentation in Figure 5. It is crucial to note that the strategies employed are for both Western and Eastern unit arc furnaces.

Table 1. Arc furnace maintenance strategy was applied per maintenance task interval

Maintenance Intervals	Maintenance Interval in months	Condition Based Maintenance (CBM)	Fixed Time Maintenance (FTM)	Operate To Failure (OTF)	Total maintenance tasks	Condition Based Maintenance (CBM) %	Fixed Time Maintenance (FTM) %	Operate To Failure (OTF)%
7 days	0.25	1	0	0	1	100.00	0.00	0.00
14 days	0.5	5	1	0	6	83.33	16.67	0.00
1 month	1	9	4	0	13	69.23	30.77	0.00
1 year	12	2	3	0	5	40.00	60.00	0.00
2 years	24	1	0	0	1	100.00	0.00	0.00
4 years	48	6	1	0	7	85.71	14.29	0.00
The average percentage of the maintenance strategy applied						79.71	20.29	0.00

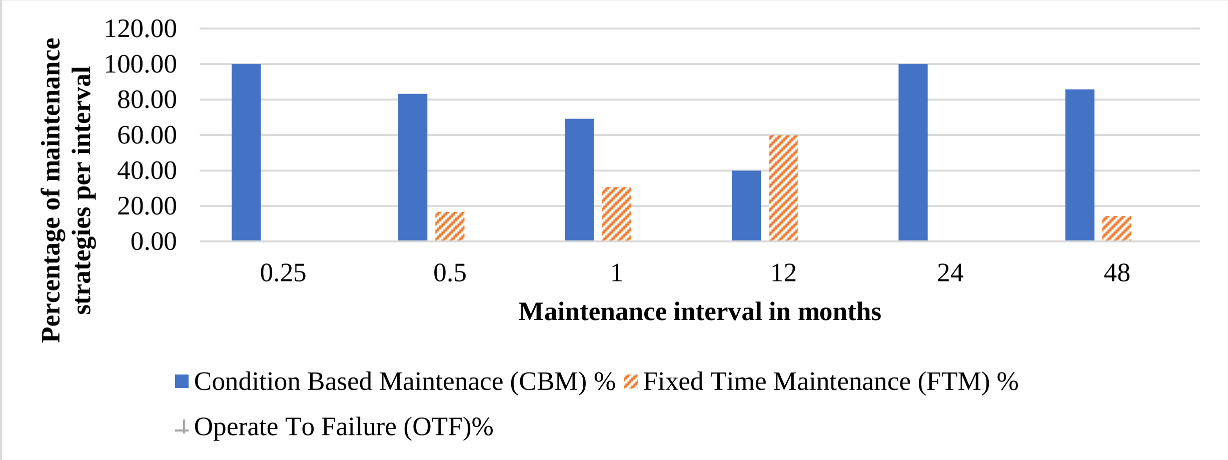

Fig. 5 Arc furnace maintenance strategy percentage per maintenance task interval

From the results obtained in Figure 5, it can be seen that every week, only a condition-based strategy is applied, but as the maintenance interval reaches a year, a higher volume of fixed-time maintenance is employed. From the FMEA in Appendix 1, many of the tasks are mainly associated with the cooling water line, which supplies water to the equipment. At a two-year frequency, the inspections are condition-based and focus on the equipment. The average condition-based maintenance used in 4 years is 80%, and Fixed-time maintenance is 20%. There are no operate-to-failure tasks applied to the equipment. The FMEA for the equipment is obscure in such a way that it incorporates exterior elements, leading to the equipment's failure to be inspected, but not solely the equipment components.

3.3. Casting Machine Applied Maintenance Strategy

The results were further analysed through the graphical presentation in Figure 6. The casting machine results are presented in Table 2, which illustrates the types of maintenance strategies employed compared to the maintenance intervals employed. The strategies employed are for both Western and Eastern unit casting machines, similar to the arc furnace.

Table 2. Casting machine maintenance strategy applied per maintenance task interval

Maintenance Intervals	Maintenance Interval in months	Condition Based Maintenance (CBM)	Fixed Time Maintenance (FTM)	Operate To Failure (OTF)	Total maintenance tasks	Condition Based Maintenance (CBM) %	Fixed Time Maintenance (FTM) %	Operate To Failure (OTF)%
7 days	0.25	0	2	0	2	0	100	0
14 days	0.5	3	4	0	7	42.86	57.14	0
1 month	1	2	0	0	2	100	0	0
6 months	6	18	2	0	20	90	10	0
1year	12	4	0	0	4	100	0	0
The average percentage of the maintenance strategy applied						66.57	33.43	0

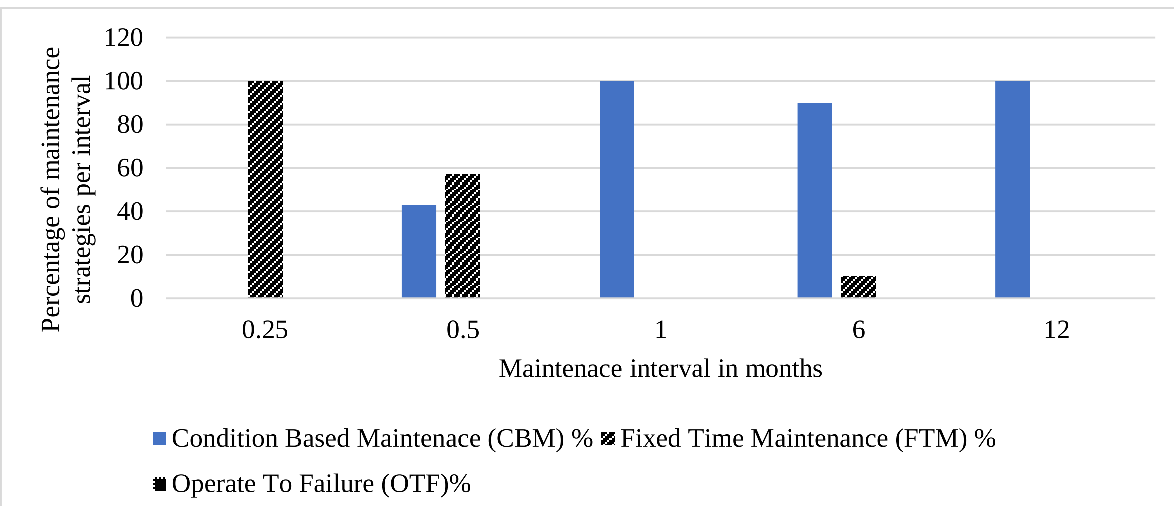

Fig. 6 Casting machine maintenance strategy percentage per maintenance task interval

On the casting machine, FMEA and results obtained in Figure 6, it is noted that fixed-time maintenance is applied every week, consisting of cleaning the pins and rollers of the machine. However, as the maintenance interval reaches a month onwards, a higher volume of condition-based maintenance is employed. From the FMEA in Appendix 1, all the tasks mainly focus on equipment components such as the drive system. The maximum maintenance interval or task is 1 year, the average condition-based maintenance used within the year is 67%, and Fixed-time maintenance is 33%. There are no operate-to-failure tasks applied to the equipment. The FMEA is populated in such a way that it directly addresses the equipment components' failures and maintains action thereon.

3.4. Conveyor Belt Applied Maintenance Strategy

Table 3 indicates the conveyor belt maintenance strategies employed compared to the maintenance intervals employed. The results were further analysed through the graphical presentation as per Figure 7. Both western and eastern unit conveyor belts are incorporated in the FMEA maintenance strategies employed.

Table 3. Conveyor belt maintenance strategy applied per maintenance task interval

Maintenance Intervals	Maintenance Interval in months	Condition Based Maintenance (CBM)	Fixed Time Maintenance (FTM)	Operate To Failure (OTF)	Total maintenance tasks	Condition Based Maintenance (CBM) %	Fixed Time Maintenance (FTM) %	Operate To Failure (OTF)%
14 days	0.5	5	4	0	9	55.55556	44.44444	0
28 days	1	4	0	0	4	100	0	0
1 year	12	5	1	0	6	83.33333	16.66667	0
2 years	24	1	1	0	2	50	50	0
3 years	36	0	1	0	1	0	100	0
The average percentage of the maintenance strategy applied						57.78	42.22	0

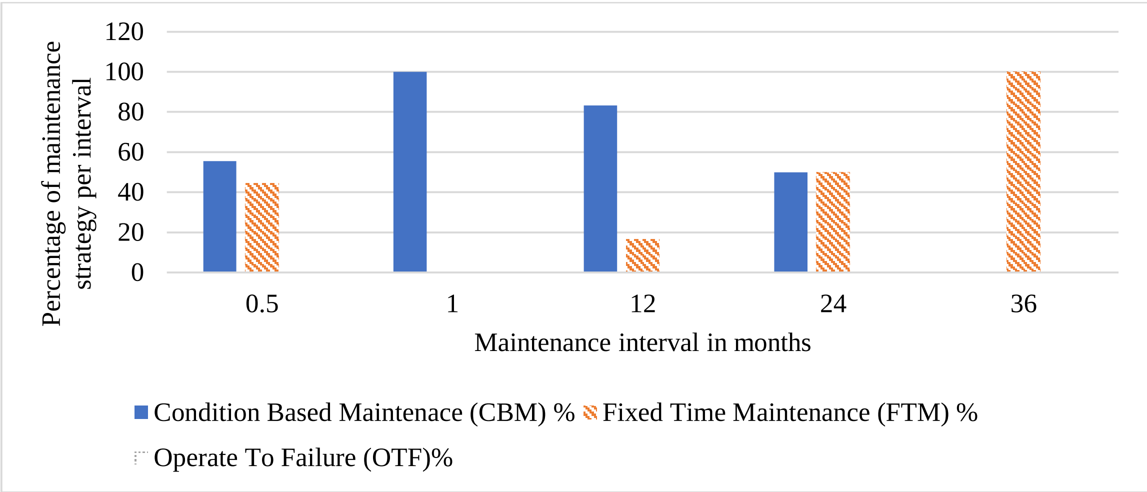

Fig. 7 Conveyer belt maintenance strategy percentage per maintenance task interval

Like the Arc furnace FMEA, the Conveyor belt utilizes more condition-based maintenance for the first maintenance interval. However, unlike the arc furnace and casting machine, the lowest or first maintenance interval is two weeks, focusing on different inspection techniques on idler rollers, belts, and belt splices. More condition-based strategy is applied in the next month and a 1-year maintenance interval. However, as the maintenance interval reaches 2 and 3 years, a higher volume of fixed-time maintenance is employed. Likewise, to the casting machine, FMEA in Appendix 1, all the tasks are mainly focused on the equipment components, such as the gearbox, pulleys, etc. The maximum maintenance interval or task is 3 years. The average condition-based maintenance used within the 3 years is 58%, and Fixed-time maintenance is 43%. There are no operate-to-failure tasks applied to the equipment.

3.5. Ball Mill Applied Maintenance Strategy

Table 4 indicates the ball mill maintenance strategies employed compared to the maintenance intervals employed. Similarly, to arc furnaces, conveyor belts, and casting machines, the strategies employed are for both Western and Eastern unit ball mills. Figure 8 represents the graphical representation of the results analysed in Table 4.

Table 4. Ball mill maintenance strategy applied per maintenance task interval

Maintenance Intervals	Maintenance Interval in months	Condition Based Maintenance (CBM)	Fixed Time Maintenance (FTM)	Operate To Failure (OTF)	Total maintenance tasks	Condition Based Maintenance (CBM) %	Fixed Time Maintenance (FTM) %	Operate To Failure (OTF)%
14 days	0.5	4	1	0	5	80	20	0
1 month	1	3	0	0	3	100	0	0
3 months	3	0	1	0	1	0	100	0
8 months	8	10	2	0	12	83.33333	16.66667	0
18 months	18	7	3	0	10	70	30	0
The average percentage of the maintenance strategy applied						66.67	33.33	0

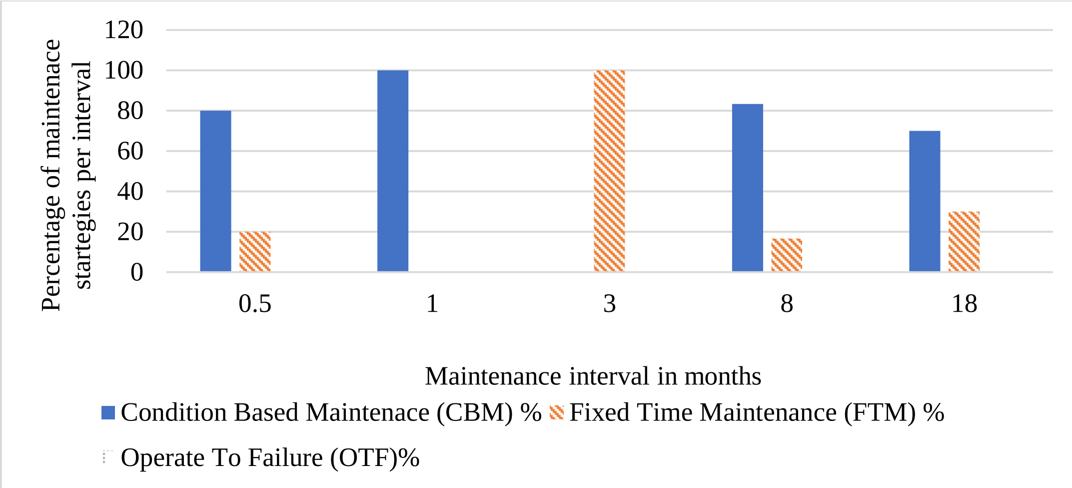

Fig. 8 Ball mill maintenance strategy percentage per maintenance task interval

In contrast to the Arc furnace and Conveyor belt, the Ball mill utilizes more condition-based maintenance for the first maintenance interval. Just like the casting machine, the first maintenance interval is two weeks, focusing on different inspection techniques on the gears and bearings. However, unlike the equipment reviewed, the maintenance strategy does not have a pattern. The 1-month maintenance interval focuses solely on condition-based strategies, while the 3-month interval focuses on fixed-time maintenance and torquing of liner plates. A more condition-based strategy is then applied at the next 8-month and 18-month maintenance intervals. Likewise, for the casting machine and conveyor belt, FMEA in Appendix 1, all the tasks are mainly focused on the equipment components, such as the bearings, liner plates, etc. The maximum maintenance interval or task is 18 months. The average condition-based maintenance used within the 18 months is 67%, and Fixed-time maintenance is 33%. There are no operate-to-failure tasks applied to the equipment.

3.6. Kiln Applied Maintenance Strategy

The Kiln results are presented in Table 5, which illustrates the maintenance strategies employed compared to the maintenance intervals employed. Figure 9 represents the graphical presentation obtained. The strategies employed are for both the western and eastern unit kilns.

Table 5. Kiln maintenance strategy applied per maintenance task interval

Maintenance Intervals	Maintenance Interval in months	Condition Based Maintenance (CBM)	Fixed Time Maintenanc e (FTM)	Operate To Failure (OTF)	Total maintenanc e tasks	Condition Based Maintenance (CBM) %	Fixed Time Maintenance (FTM) %	Operate To Failure (OTF)%
7 days	0.25	5	1	0	6	83.33	16.67	0
14 days	0.5	0	3	0	3	0	100	0
1 month	1	2	0	0	2	100	0	0
3 months	3	3	0	0	3	100	0	0
7 months	7	10	0	0	10	100	0	0
1 year	12	9	1	0	10	90	10	0
4 years	48	9	0	0	9	100	0	0
The average percentage of the maintenance strategy applied						81.90	18.1	

The Kiln, similarly to the Ball Mill, Arc furnace, and Conveyor belt, employs more condition-based maintenance for the first maintenance interval. Just as in the Arc furnace, the first maintenance interval is weekly, focusing on condition monitoring techniques on the gears and rollers. However, the most frequent maintenance strategy employed every two weeks is fixed-time maintenance, like the casting machine. There is an increase from the 1-month maintenance interval to condition-based maintenance until the last 4-year maintenance interval. The arc furnace and the Kiln have the highest maintenance cycle; however, like the ball mill, conveyor belt, and casting machine, FMEA in Appendix 1, all the tasks mainly focus on the equipment components, such as the drive system, shell, etc. The average condition-based maintenance used within the 4-year maintenance interval is 82%, and Fixed-time maintenance is 18%. There are no operate-to-failure tasks applied to the equipment.

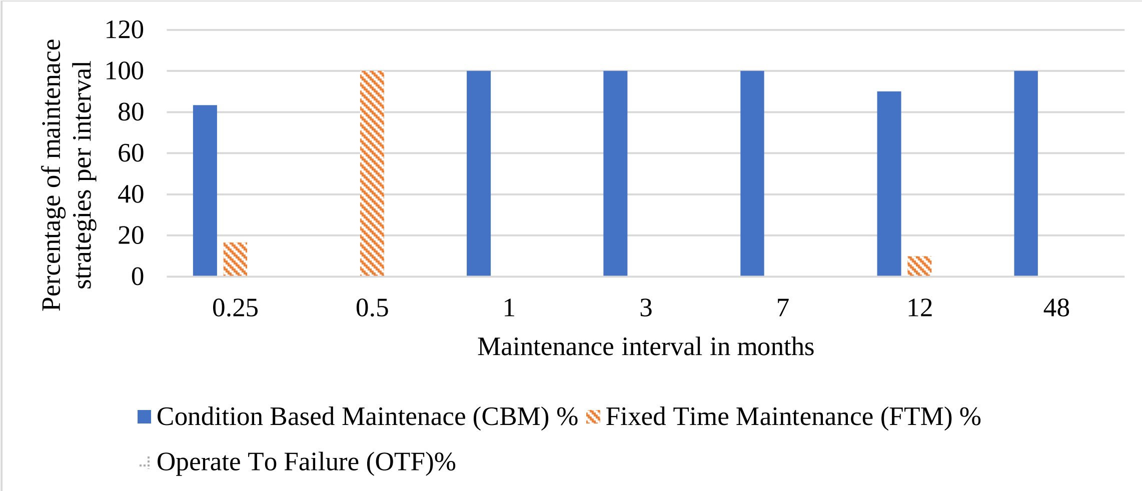

Fig. 9 Maintenance strategy percentage per maintenance task interval

4. General Discussion of Results

SHAFIEE's (2017) study further explains how an effective maintenance strategy aims to reduce the frequency of asset downtime and avoid such interruptions. More so, how over-maintenance can increase maintenance costs, and subsequently, less maintenance may bring undesirable failures and interruptions. Thus, integration of an optimal maintenance strategy is important.

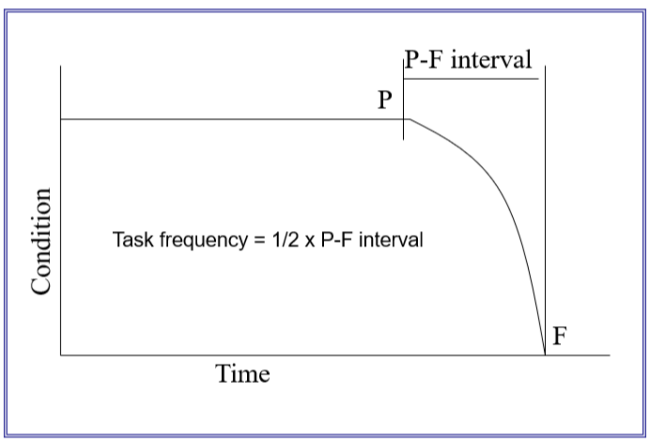

Fig. 10 Failure characteristics of equipment to apply CBM (SWART, 2015)

According to ABEDINI (2016), a Condition monitoring maintenance strategy is a form of preventive maintenance technique that entails performance, parameter monitoring, and subsequent actions. This strategy aims to monitor the equipment behavior using techniques to prevent a breakdown from occurring; however, the action to apply and the interval are solely dependent on the end user. According to SASOL's EMS process, the CBM strategy can only be applied to equipment in which the condition versus time graph can be plotted, and the P-F interval can be obtained, as shown in Figure 10. The P-F curve illustrates how a failure starts and deteriorates to the point at which it can be detected (the potential failure point "P"). If the failure is not detected and corrected, it continues to deteriorate at an accelerated rate until it reaches the point of functional failure ('F') (JOSHI, 2004). The frequency at which maintenance is applied to equipment is thus dependent on the P-F interval, as the basic measurement is half of the P-F interval.

This structure shows the prediction method to obtain the frequency of the maintenance strategy, but the actual how-to depends on the individuals who partake in the Equipment Maintenance Strategy review. That is the reason that, though over 50% of the condition monitoring maintenance strategy is applied, breakdown still occurs. One, therefore, could argue that the technique and correct use of tools could also be investigated for each equipment.

The monitored data of equipment parameters are used to inform the engineers of the situation, allowing maintenance to be performed before a breakdown occurs. CBM is often designed for rotating and reciprocating machines; however, limitations and deficiencies in data coverage and quality reduce the effectiveness and accuracy of the condition-based maintenance strategy (PARIAZAR, 2008).

5. Conclusion

From the presented results, the most commonly used maintenance is condition-based maintenance, followed by fixed-time maintenance, and lastly, operation or run to failure, as there are no records of the OTF strategy applied. The Kiln shows the highest condition-based maintenance employed in the specific interval of 4 years, whilst the conveyor belt is the least averaged condition-based strategy employed at a maximum maintenance frequency of 3 years. The most frequently inspected equipment is the arc furnace, casting machine, and Kiln, as they have the least maintenance interval of 7 days. The equipment with the highest maintenance interval of 4 years is both the arc furnace and the Kiln. The Ball mill has the highest average fixed time maintenance strategy within the maintenance interval of 18 months. The question remains, based on the results obtained and analysed.

If a high quantity of inspections is performed, why do breakdowns still occur? Is the method of inspection correct, or is there over-maintenance occurring? This study was conducted to obtain the average maintenance approach applied to electromechanical equipment in the Sasol unit. From the results, it is observed that all the types of equipment identified apply on average above 50% condition-based maintenance. This is followed by a fixed-time maintenance strategy with a 30% ranking, then operates to failure of 13% and lastly corrective maintenance with 7%.

It can be concluded that it is not only how often a certain maintenance strategy is applied, but also the other aspects that should be investigated, rather than how the maintenance strategy is applied.

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Appendix 1

FMEA Report

sasol reaching new frontiers

Unit/Area: X04 Discipline: M Report Date: 06/02/2020

Analysis ID:	X04AF-141		Revision Number:	8
Analysis Description:	ARC FURNACE ANALYSIS		Approval Status:	Approved

Technical ID	Functional Location ID	Technical ID	Functional Location ID
004AF-141	SP004-0303-AF-141	204AF-141A	SP204-0303-AF-141A
204AF-141B	SP204-0303-AF-141B		

FM ID	Component	Symptom	Cause	Strat Type	Action	Freq.	Freq. Unit	Res	Trigger Action	Primaryor Secondary Action
01	BRIDGE	CRACKS OF STRUCTURAL WELDS	HEAT SHIELD FAILURE	CBM	SANDBLAST IDENTIFIED AREAS, MPI ON IDENTIFIED AREAS	48	Months	CON	CRACKS AND OTHER DEFECTS FOUND	REPAIR
02	HEAT SHIELD	BROKEN	MECHANICAL DAMAGE	CBM	VISUALLY INSPECT HEAT SHIELD AND BRACKETS FOR DAMAGE	1	Months	FIT	DAMAGE FOUND	REPLACE HEAT SHIELD OR REPAIR BRACKETS
03	PIVOT BEARING ASSEMBLY	SEIZE	LACK OF LUBRICATION	FTM	GREASE PIVOT BEARING ASSEMBLIES.	1	Months	FIT		
04	TILTING CYLINDER PIVOT POINTS	SEIZE	LACK OF LUBRICATION	FTM	GREASE TILTING CYLINDER PIVOT POINTS.	1	Months	FIT		
05	TILTING CYLINDER SHAFT SEALS	FAILURE	SERVICE LIFE	CBM	VISUALLY INSPECT SHAFT SEALS FOR ANY LEAKS.	14	Days	FIT	ANY LEAKS DETECTED.	EVALUATE LEAK AND REPAIR IF NECESSARY
06	TILTING CYLINDER PISTON ROD	DAMAGED SURFACE COATING	SERVICE LIFE	CBM	VISUALLY INSPECT FOR COAT FAILURE	1	Months	FIT	COAT FAILURE DETECTED	REMOVE CYLINDER AND SEND OUT FOR OVERHAUL
07	PEDESTAL BEARING ASSEMBLY	SEIZE	LACK OF LUBRICATION	FTM	GREASE FOUNDATION PEDESTAL BEARING ASSEMBLY.	1	Months	FIT		
08	ELECTRODE GUIDE COLUMN ROLLERS	SEIZE/STICKY	MISALIGNMENT	CBM	CLEAN AND INSPECT ROLLERS & ADJUST CLEARANCE IF NECESSARY.	1	Months	FIT	DEVIATIONS FOUND	ADJUST CLEARANCE

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Fig. 11 X04 Arc-Furnace FMEA

FMEA Report

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Unit/Area: X04 Discipline: M Report Date: 06/02/2020

Analysis ID:	X04CM-141		Revision Number:	4
Analysis Description:	CASTING MACHINE		Approval Status:	Approved

Technical ID	Functional Location ID	Technical ID	Functional Location ID
004CM-141	SP004-0306-CM-141	204CM-141	SP204-0306-CM-141

FM ID	Component	Symptom	Cause	Strat Type	Action	Freq.	Freq. Unit	Res	Trigger Action	Primaryor Secondary Action
01	IDLER ROLLER STRUCTURE	METAL LOSS ON ROLLER	ACCUMULATION OF CATALYST & WATER	FTM	WASH & CLEAN SECTION BETWEEN ROLLERS OF STRUCTURE WITH UTILITY WATER.	7	Days	PRD		
02	IDLER ROLLER STRUCTURE	WALL LOSS	CORROSION	CBM	DO VISUAL INSPECTION	182	Days	FIT	ANY CORROSION DETECTED.	EVALUATE & REPAIR IF NECESSARY AT FIRST OPPORTUNITY
03	IDLER ROLLER STRUCTURE	CRACKS	FATIGUE	CBM	DO VISUAL INSPECTION ON THE STRUCTURE FOR ANY CRACKS.	182	Days	FIT	CRACKS FOUND	REPAIR
04	IDLER ROLLER STRUCTURE	DEFORMATION	HIGH TEMPERATURE EXPOSURE	CBM	DO VISUAL INSPECTION ON STRUCTURE.	182	Days	FIT	ANY DEFORMATION DETECTED.	REPAIR / REPLACE SECTION OF STRUCTURE IF NECESSARY
05	SUPPORT FRAMES	WALL LOSS	CORROSION	CBM	DO VISUAL INSPECTION OF SUPPORT FRAMES AND INSPECT ALL BOLTS	182	Days	FIT	ANY CORROSION DETECTED	REPAIR
06	SUPPORT FRAMES	BROKEN / LOOSE BOLTS	VIBRATION	CBM	DO VISUAL INSPECTION OF ALL SUPPORT FRAME TO STRUCTURE & FOUNDATION BOLTS.	182	Days	FIT	ANY DAMAGED / LOOSE BOLTS DETECTED.	REPLACE AND / OR TIGHTEN ALL BROKEN / LOOSE BOLTS
07	SKID PLATE	SPALLING REFRACTORY	HEAT / MECHANICAL DAMAGE	CBM	DO VISUAL INSPECTION FOR EXCESSIVE WEAR	182	Days	FIT	WEAR OR DEFECTS FOUND	REPLACE DEFFECTED BRICKS

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Fig. 12 X04 casting machine FMEA

FMEA Report

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Unit/Area: X04 Discipline: M Report Date: 06/02/2020

Analysis ID:	X04CV-101		Revision Number:	7
Analysis Description:	KILN RMS FEED CONVEYOR ANALYSIS		Approval Status:	Approved

Technical ID	Functional Location ID	Technical ID	Functional Location ID
004CV-101	SP004-0102-CV-101	204CV-101	SP204-0102-CV-101
204CV-201B	SP204-0102-CV-201B		

FM ID	Component	Symptom	Cause	Strat Type	Action	Freq.	Freq. Unit	Res	Trigger Action	Primaryor Secondary Action
01	BELT SPLICE	SEPERATION OF SPLICE JOINT	HIGH TEMP OR WORKMANSHIP OR OVERLOADING	CBM	INSPECT SPLICE LISTENING FOR A 'SLAPPING' NOISE	14	Days	FIT	LOOSE SPLICE	STOP AND REPAIR SPLICE
02	BELT	MISALIGNMENT OF BELT	STRETCHED BELT	OTF	INSPECT FOR MISALIGNMENT			FIT	MISALIGNMENT FOUND	PERFORM ALIGNMENT AT THE TAIL PULLEY
03	GEARBOX	INTERNAL GEAR FAILURE	OIL SEAL FAILURE (LACK OF OIL)	CBM	INSPECT GEARBOX FOR OIL LEAKS	28	Days	FIT	LEAKS DETECTED	REPLACE GEARBOX OR OIL SEAL
04	GEARBOX	INTERNAL GEAR FAILURE	SERVICE LIFE	FTM	DRAIN AND REPLACE OIL USE HEMAT 320	364	Days	FIT		
05	GEARBOX COUPLING	SHEARED RUBBER AND BROKEN BOLTS	SERVICE LIFE	CBM	DO A VISUAL INSPECTION ON COUPLING	364	Days	FIT	SHEARED RUBBER, MISSING BOLTS	REPLACE RUBBER AND ALIGN AND REPLACE BOLTS
06	DRIVE PULLEY	PULLEY RUBBER WORN AWAY	BELT SLIP ON PULLEY	OTF	STOP BELT AND INSPECT PULLEY LINING			FIT	WORN LINING FOUND	REPLACE LINING
07	DRIVE PULLEY	BEARING NOISY	LACK OF LUBRICATION	FTM	GREASE BEARING.	14	Days	FIT		
08	DRIVE PULLEY	BEARING HOT	TOO MUCH LUBRICATION OR WEAR	OTF	MEASURE BEARING TEMP WITH HEAT GUN. MAX TEMP APPROX 40 DEG C			FIT	TEMP ABOVE 40 DEG C	CHECK ALIGNMENT, ALIGN IF REQUIRED OR REPLACE

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Fig. 13 X04 conveyer belt FMEA

FMEA Report

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Unit/Area: X04 Discipline: M Report Date: 06/02/2020

Analysis ID:	X04GM-141		Revision Number:	15
Analysis Description:	BALL MILL		Approval Status:	Approved

Technical ID	Functional Location ID	Technical ID	Functional Location ID
004GM-141	SP004-0402-GM-141	204GM-141	SP204-0402-GM-141

FM ID	Component	Symptom	Cause	Strat Type	Action	Freq.	Freq. Unit	Res	Trigger Action	Primaryor Secondary Action
01	LINER PLATES	WALL LOSS	WEAR	FTM	OPEN BALL MILL, EMPTY ALL BALLS & REPLACE CIRCUMFERENTIAL LINER PLATES, END PLATES AS PER GO PROCEDURE	18	Month s	FIT		
02	LINER PLATE BOLTS	BREAK	WEAR	FTM	REPLACE ALL BOLTS	546	Days	FIT		
03	LOBSTER ASSEMBLY	WALL LOSS	EROSION	CBM	CARRY OUT INTERNAL VISUAL INSPECTION FOR WEAR AND FUNCTIONALITY OF FLAP VALVE	252	Days	FIT	DEVIATIONS FOUND	REPAIR OR REPLACE
04	INTERNAL SHELL	CRACKS	FATIGUE	CBM	CARRY OUT MT ON IDENTIFIED INTERNAL WELDS	546	Days	ZIN	ANY CRACKS FOUND	REPAIR
05	SCROLL (INLET AND OUTLET)	WEAR	EROSION	CBM	VISUALLY INSPECT FOR WEAR AND ANY OTHER DEFECTS	252	Days	FIT	WEAR OR DEFECTS FOUND	REPAIR OR REPLACE SCROLL
06	INLET & OUTLET JOURNAL	BEARING SURFACE DAMAGED	LACK OF LUBRICATION	FTM	REPLACE THE OIL	546	Days	FIT		
07	JOURNAL OIL SEAL	WALL LOSS	WEAR	CBM	VISUALLY INSPECT FOR LEAKS	28	Days	FIT	ANY LEAKS DETECTED	REPLACE SEALS
08	INLET & OUTLET JOURNAL	JOURNAL OUTER SURFACE GROOVED	CATALYST DUST BETWEEN OIL SEAL & JOURNAL	CBM	REMOVE TOP COVER AND INSPECT JOURNAL SURFACE GROOVE	252	Days	FIT	ANY GROOVE DETECTED	CONSULT THE MECHANICAL ENGINEERING & FOREMAN
09	IN-& OUTLET WHITE METAL BEARINGS	BEARING SURFACE DAMAGED	LACK OF LUBRICATION	CBM	INSPECT OIL LEVELS	14	Days	FIT	LOW LEVELS FOUND	TOP UP LEVEL

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Fig. 14 X04 ball mill FMEA

FMEA Report

sasol
reaching new frontiers

Unit/Area: X04 Discipline: M Report Date: 06/02/2020

Analysis ID:	X04KN-101		Revision Number:	8
Analysis Description:	ROTARY KILN ANALYSIS		Approval Status:	Approved

Technical ID	Functional Location ID	Technical ID	Functional Location ID
004KN-101-R1	SP004-0201-KN-101	204KN-101A	SP204-0201-KN-101A
204KN-101B	SP204-0201-KN-101B		

FM ID	Component	Symptom	Cause	Strat Type	Action	Freq.	Freq. Unit	Res	Trigger Action	Primaryor Secondary Action
01	SHELL EXTERNAL	EXTERNAL CRACKS OF COMPENSATION PADS TO SHELL & TO WEDGES ATTACHMENT WELDS ON IN- & OUTLET RIDING RINGS	FATIGUE	CBM	DO VISUAL INSPECTION ON COMPENSATION PADS TO SHELL & TO WEDGES ATTACHMENT WELDS ON IN- & OUTLET RIDING RINGS.	12	Months	FIT	ANY CRACKS DETECTED.	EVALUATE & REPAIR CRACKS IF NECESSARY.
03	SHELL INTERNAL	INTERNAL DAMAGE	MECH. DAMAGE CAUSED BY JACK HAMMERS	CBM	DO VISUAL INSPECTION OF INTERNAL OF SHELL WHEN REFRACTORY IS REPLACED	1456	Days	FIT	ANY CRACKS DETECTED.	EVALUATE & REPAIR DAMAGE IF NECESSARY.
04	SHELL EXTERNAL	CRACKS	FATIGUE	CBM	DO VISUAL INSPECTION OF GIRTH GEAR Z-PLATES TO SHELL ATTACHMENT WELDS.	182	Days	FIT	ANY CRACKS DETECTED.	REPAIR ALL CRACKS.
05	SHELL EXTERNAL	HOT SPOT	SPALLED / DAMAGED REFRACTORY	CBM	DO THERMOVISION SCAN. (MAX. SHELL TEMP. = 350 DEG. C.)	182	Days	FIT	ANY HOT SPOTS DETECTED.	EVALUATE RESULTS AND IF TEMP. EXCEEDS 370 Deg C, REPAIR / REPLACE REFRACTORY
06	LIFTING LUGS	CRACKS	FATIGUE OR SHOCK LOADING	CBM	INSPECT FOR CRACKS (MPI / DYE PEN)	364	Days	ZIN	ANY CRACKS FOUND	REPAIR AS PER RECOMMENDATION

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Fig. 15 X04 Kiln FMEA