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Adoption of Total Productive Maintenance System in Nigerian Agip Oil Company Ltd (Case Study: Kwale Gas Recycling Plant)

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Abstract
Consideration of drudgeries inherent in maintenance management system in Nigeria industries would eliminate the tedium associated in the system and improve equipment availability. Here an attempt was made to assess the equipment maintenance practice in NAOC-Kwale gas recycling plant, using Overall equipment effectiveness (OEE) as quantifiable performance indicator to determine the effectiveness and availability of various types of pumps and other installed equipment in the plant. Maintenance records of the pumps provided data for the computation. The availability, performance and quality rate of the pumps were used to assess the overall effectiveness of the various pumps. The OEE value of 5.3% obtained confirmed that the current maintenance strategy and policy of the company is very much below standard and unacceptable. Hence, it is evident that using TPM will avert unexpected system failure through early faults detection; provide safety operation, reliability and equipment durability.
Keywords: Adoption, Maintenance system, TPM, OEE, Reliability, Durability.
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1.0 Introduction

Maintenance management is responding to changing expectation as 'today's economic world is a world of growing expectation with increasingly numerous regulatory constraints, shifting technological paradigms and endless reorganizations, all of which must be dealt with urgently, it is easy to get best in delay. Just as most major corporations develop formal mission statement to help them maintain steady course through varying distractions, it is worth developing a mission statement to help maintenance do likewise [10].

[2], defined maintenance as any activity carried out on assets in order to ensure that the asset continues to perform intended functions. He further defined maintenance system or strategy as a long-term plan covering all aspects of maintenance management, and contains firm action plans for achieving a deserved future state for the maintenance function. It has been found that higher productivity maintenance contributes to better customer services, higher quality and on-time delivery [10]. This development therefore means that a quality maintenance program will play an increasingly central role in preserving all aspects on the physical, financial and competitive health of the sectors.

1.1 Problem discussion

Kwale Gas Recycling Plant is oil and gas production facility owned by NAOC, the facility is made up of old and new plants, the former is mainly oil production while the later is mainly gas production.

The importance of gas recycling cannot be over emphasized in considering the operation of the Nigerian Agip Oil Company Limited (NAOC) in this country. The productive pools of the Obiafu/Obrikom field considered for gas injections are four, named P, Q, S and T. To improve the recovery, a method of gas re-cycling is employed as shown in Figure 1. The gas produced from the oil zone is injected into the gas cap of the same pools and the gas zone is cycled to serve as a drive for additional recovery. The injection wells, duly located, are eight; six of them, formerly drilled as production wells, were re-completed for this purpose; two are new wells. The production wells are eighteen; expectedly other wells will be put on stream in the near future.

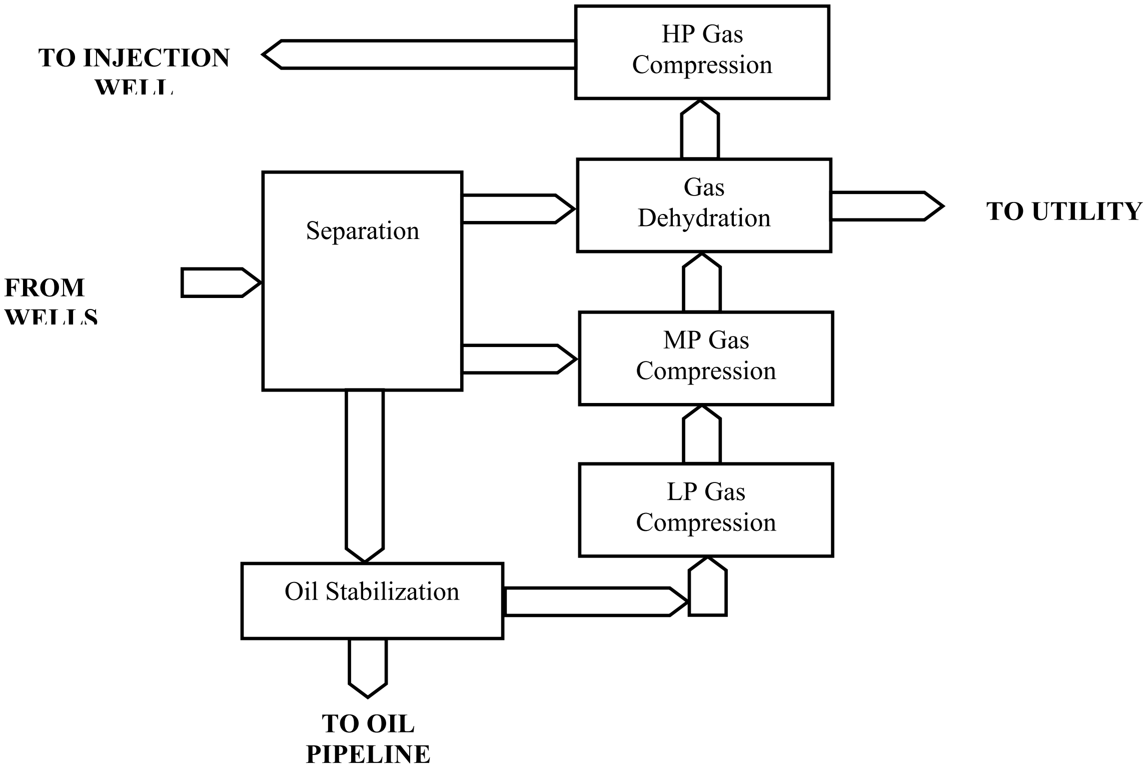


Figure 1: Gas recycling and utilization process

The crude produced is separated from gas, stabilized and sent to the oil pipeline system. The gas is conveyed to the dehydration unit and compressed to a pressure above the reservoir pressure, then re-injected into the reservoir.

Nigerian Agip Oil Company (NAOC) operates in the land and swamp of the Niger Delta with concessions lying within Bayelsa, Delta, Imo and Rivers States. NAOC's production asset includes eight (8) flow stations, two (2) gas plants and one (1) export terminal of 3,558,000 barrels storage capacity with 2 single point mooring-bouys for loading tankers. The flow stations and gas plants are connected to the Terminal in Brass through a 460km pipeline network, while an additional 180 km pipeline carries NGL and fuel gas to Eleme Petrochemical Company. Most of the flow stations are undergoing expansion and retrofit to take care of growth in operation, improved efficiencies (resulting from installation of latest technology) and are being adapted for gas utilization and flare down programmes.

NAOC, benefiting from more than 60 years of ENI-Agip composite experience in natural gas sector, pioneered the conservation and development of the nation's gas resources in Nigeria, when it built the first recycling plant at Akri-Oguta (in joint venture with Shell). In line with Government objective of promoting the use of this valuable resource, NAOC expanded the OBIAFU-OBRIKOM plant in 1994 to supply NGL feedstock and fuel gas to the NNPC's Eleme Petrochemical Plant (Indorama Eleme Petro-chemical Ltd) to produce polymers. In 1999 NAOC started supply of gas to Nigeria LNG Limited (NLNG) Bonny. NAOC was the only company ready to supply its full quota of gas when the third train of N-NLG start-up in November 2002. It is also working with other shareholders on actualization of trains IV and V and beyond.

NAOC has also completed construction of the first upstream IPP (450MW) in Kwale, Delta State in 2005.To further expand its activities in Nigeria, NAOC recently signed the Head of Agreement for the establishment of an LNG Project to be sited offshore Brass, Bayelsa State. A Memorandum of Understanding (MOU) for the feasibility of the LNG plant was signed with the Federal Government in September 2001. With the execution of these projects, which are part of a comprehensive Gas Master Plan (GMP), to gather and channel its associated gas for valorization and achieve zero gas flaring at all its sites.

These rapid growth and expansion produced surplus technical and managerial problems in the day-to-day running of the Gas plant. These problems have caused forced or emergency stoppages long or delayed downtime, high cost in the daily maintenance activity demands, the increasing environmental damage. Amongst all these problems, the gas plant must be maintained; therefore, there must be reduction in maintenance cost, prioritized maintenance action and raised reliability and availability. Thus, there must be reduction in maintenance cost, prioritize maintenance action and raise in reliability and availability. Also, to reduce these problems, a maintenance strategy must be adopted.

From records and information available at the gas plant, a review of the system management, maintenance planning and scheduling, leadership labour productivity, performance data, training, costs, materials management, logistic support, performance measures and technical documentation was carried out. A maintenance process that fully addresses the technical concerns of the sysytem must be adopted and the process must realize the value of integration, engineering, planning and quality, Webmasterlcep. Com, (1998). Such changes require a complete shift in the maintenance approach and TPM is such a process.

2.0 Literature review

The modem view of maintenance management is that it is all about preserving the functions of physical assets. In other words, carrying out tasks that serve the central purpose of ensuring that our equipment are capable of doing what the users want them to do when they want them to do it, [10]. Several works relating to maintenance management have been done in the past, which includes that of [8], who defined maintenance to mean ensuring that physical assets continue to do what their users want them to do. He went further to say that the major challenge facing maintenance people nowadays is not only in learning what the techniques are, but to decide which are worthwhile and which are not in their own organizations. This is because of the feeling that by making the right choices, it is possible to improve asset performance and at the same time contain and even reduce cost of maintenance, whereas if the wrong choices are made, new problems are created while existing problems are blown up and chain ripples.

2.1 Modem approach to maintenance

A major revolution has taken place in the world of maintenance towards the latter part of the 20th century to escape the perceived 21st century idea of replacing traditional computer maintenance management systems (CMMS) with expensive integrated business solutions for the constant need to improve equipment uptime at lowest cost. So it became necessary for a radical change in the way in which maintenance is practiced [3].

The realisation that maintenance needs to be viewed as a center" and not as a "cost center" will serve as the main foundation improvement in productivity and equipment performance. Companies, which do not grasp this simple fact will not reap the benefits, but will have the production efficiency stagnate or fall, [11, 12]. At the very outset, it may be recognised that maintenance organisations adopt a proactive profit-focused approach to narrow the gap between manufacturing actual costs and ideal costs, waste, inefficiency and additional costs. A planned maintenance management system (PMMS) is the basic building block of all modem maintenance systems, including reliability centered maintenance (RCM) and total productive maintenance (TPM). The best approach to planned maintenance is to purchase a computerised maintenance system, though that is not in itself the final solution.

2.2 Reliability centered maintenance (RCM)

[14] suggests that a single maintenance policy however efficient it may be, cannot eliminate all breakdowns or restore the plant to its useful potentials. This gave birth to maintenance policy for corresponding items and modules of the system. The maintenance approach best suited to an item can be determined using the RCM methodology. It provides a structure for determining the maintenance requirement of a physical asset in its operatic context with primary objective of preserving system function cost effectively, [8]. Identification of system functions and functional failure as well as failure mode and effects analysis are important elements in RCM. The objectives of maintenance are defined by the functions and associated performance expectations of assets. The only occurrence that is likely to stop any asset performing by the standard required by its users, is some kind of failure. This suggests that maintenance achieves its objectives by adopting a suitable approach to management of failure. In order to achieve a blend of management tool, there is a need to identify when failure can occur. According to [10], RCM does this at two levels:

i. by identifying what circumstances resulted to a failed state; and
ii. by asking what events can cause the asset to get into the failure state.

The RCM process uses these categories as the basis of the new strategic framework for maintenance decision making, by forcing a structured review of the consequences of each failure modes in terms of the above categories, it integrates the operational, environmental and safety objectives of maintenance. According to [1], an effective use of resources can be achieved by using risk-based maintenance decisions to guideline were and when to perform maintenance. They maintained that the choice of risk analysis approach seems to have a major impact on the identification of risk sources, in terms of magnitude and location. [10] states that RCM uses function analysis in combination with risk analysis in prioritising maintenance action. Though RCM utilises the best of the several methods and disciplines, it cannot be used as a tool for deciding of the optional interval between two maintenance inspections, which in turn improves the system availability. Therefore, it has become essential for the companies to invest in new ideas and techniques to improve and cover all aspects of the maintenance requirements. Thus, the concept of total productive maintenance (TPM) came into existence.

2.3 Total Productive Maintenance (TPM)

TPM has become an industrial standard and it is an approach to optimise the effectiveness of production means in a structured manner. It is a maintenance methodology, which focuses on people and is an integral of total quality management (TQM). The methodology was developed in Japan's manufacturing industries, initially with the aim to eliminate production losses due to equipment breakdowns in just -in - time (JIT) production system. [3].

2.3.1 Concept

TPM is an effective process that has operators and maintenance staff working together as a team to reduce waste, minimise downtime, improve product quality, and equipment effectiveness, [7]. This is accomplished by focusing on those things that prevent a machine from running at optimal condition and by sharing responsibility of equipment upkeep.

According to [11, 12], TPM is concerned with the fundamental rethink of business process to achieve improvement in cost, quality, speed, e.t.c. It encourages radical changes such as flatter organisational structures (fewer managers, empowerment teams), multi-skilled workforce and rigorous reappraisal of the way things are done (often with the goal of simplification).

2.3.2 Six major losses

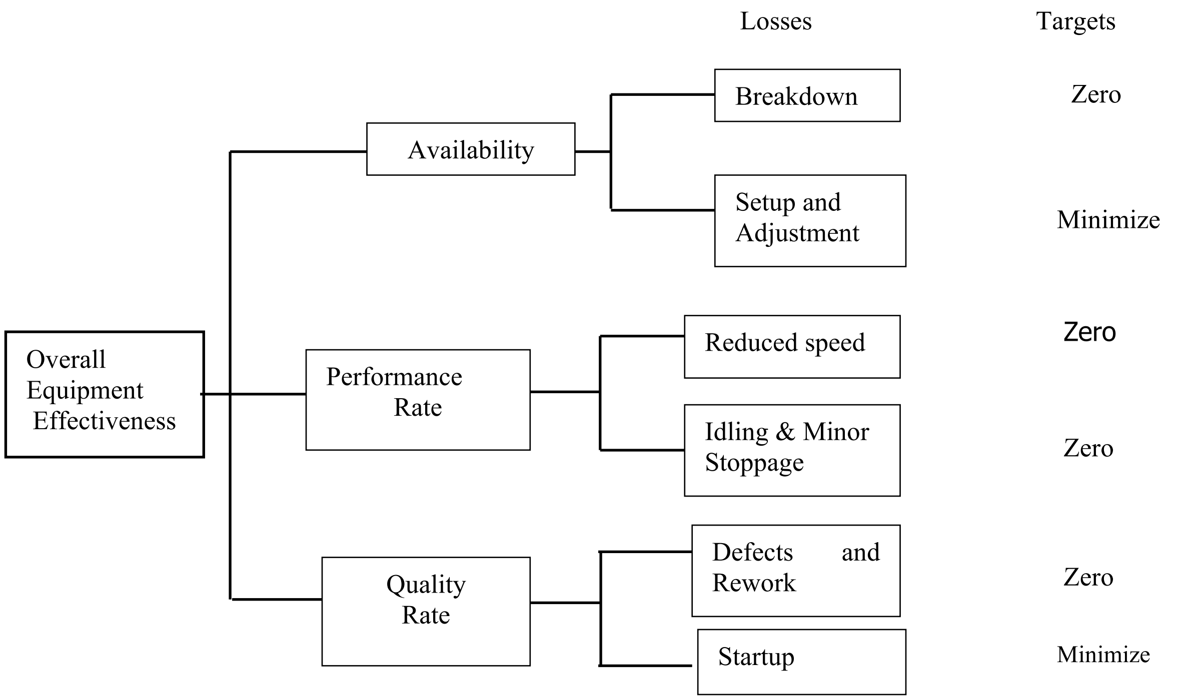
One of the major goals of TPM and OEE programmes is to reduce and/or eliminate what are called the six major losses- the most common causes of efficiency loss in production. The Table 1 lists the six major losses, and shows how they relate to the OEE loss categories.

Table 1: the six major losses:

Six major losses	OEE category	Comment
Breakdowns	Down time loss	There is flexibility on where to set the threshold between a breakdown (Down Time Loss) and a small stop (Speed Loss).
Setup and adjustments	Down time loss	Includes tool changeovers.
Small stops/idling	Speed loss	Typically only includes stops that are under five minutes, and that do require maintenance personnel.
Reduced speed	Speed loss	Anything that keeps the process from running at its theoretical maximum speed (Minimum cycle time)
Rejects during startup	Quality loss	During warm-up, startup or other early production.
Rejects during production	Quality loss	During steady-state production.

Source: [13]

Figure 2: Six major losses and related OEE category)



Source: [13]

2.3.3 World-class status with best practices in TPM

Terms like best practices, benchmarking and world class continue to be the innovating feature of modern business world. But what are best practices? How does an industry begin to benchmark other companies to help them achieve best practices within the organization? How does an industry come to know that they have achieved world-class status? A definition of best practice adapted to the maintenance process reads: "maintenance practices that enable a company achieve competitive advantage over its competitors in the maintenance processes"[9].

Specifically, benchmarking is the practice of measuring performance against a standard. An individual company can set the standard. Based on competitions, performance or on comparable industry data. Benchmarking is used by industries to learn about practice that have been proven to lead to superior performance and then adopt it, not their own organization processes.

Benchmarking is performed after an internal audit is conducted. There are some companies that have successfully implemented TPM. They include Ford, Eastman, Kodak and Xerox etc. A manufacturer reported that the time required for die changes on a forming press went from several hours down to minutes; most of these companies that have implemented TPM have tremendously increased in productivity while reducing in downtime. [3] benchmarked the characteristics of world's best power station versus those for Afam Thermal-Power Station (ATPS) and pointed out the following weaknesses (i.e. opportunities for improvement) in the existing maintenance-scheme at ATPS;

A poor performance rate of <38% compared to >98% for world's best; availability of <40% whereas world's best is >98% and quality rate of <30% where the world's best is >99%; this indicates a poor utilization of available resources.

3.0 Behavioral models

The overall performance of a production system is determined by the quantitative and qualitative properties of the system. These properties are found in all the different components of the system, also in the organisation or structure of the system. The relation between the qualitative properties of the most important sub-systems of a production system are duly explained as follows:

i. Overall system performance: the total production result over a long period of time, in principle, the lifetime of the system, it can also include the economical result.

ii. Capability performance: the average production result per unit time, normally related to the rated capacity, if a plant is operated at 100% capacity and the product is 100% perfect in quality the capability performance is 100%.

iii. Availability performance: the part of the total calendar time the equipment is in economic production condition. If the condition does not permit production at full rate capacity and with the product quality at the specified level the equipment has one or more failure and needs maintenance. When waiting for maintenance or under maintenance the equipment is not available for production;

iv. Operation performance: the ability of the operating system to utilise the equipment capacity and availability. Production planning and control, the personnel, the safety payment motivation, etc, have influence on the operation performance;

v. Capacity performance: the ability of the equipment to produce at the rate capacity with specified product quality;

vi. Reliability performance: the ability of the equipment to perform the expected function when operated. If the function obtained does not meet the specification, the equipment has a failure and needs maintenance. Normally measured in probability of function, R, or mean time between failure, (MTBF), or failure rate, X, which is 1/MTBF, Reliability (t)=(I*t)= e-t/M1HF), t= specified period of failure - free operation;

vii. Maintainability performance: the properties determining the time to repair measured in mean time to repair, MTTR, which has little to do with the performance of the maintenance resources but more dependent on the design and installation of the equipment; and

viii. Maintainability M (t) = e-t/MTTR = e-t μ/im = e-mt where t = restoration time or duration of outage.

Support performance: the ability of the logistics support system, or maintenance to provide support to the equipment when maintenance is required. Depends on the organisation of maintenance and the resources, the personnel, tools, skill, spares, etc, the performance is measured in mean waiting time, MWT or mean logistic down time, (MLDT).

The availability performance (A) can be calculated in two ways; the theoretically correct method is to use calendar time 100%. It is mostly used for systems that are supposed to work round the clock, such as some process industries, etc.

3.1 Overall equipment effectiveness (OEE)

Equipment performance and reliability have become major concerns as business reorganize, down size, and

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aggressively pursue "Lean" principles. In order to streamline the Nigerian industries there are some salient causes of actions: Firstly, to find out why the equipment are not doing what they ought to do every time. Secondly, find the causes of poor performance and, thirdly, to find what should be focused on.

Measuring and improving equipment performance is presently a typical issue in facilities, manufacturing and processing plants. The basic measure associated with TPM has been OEE. It incorporates three basic indicators of equipment performance and reliability.

- availability or uptime (down time: planned or unplanned);
- performance efficiency (actual vs. design capacity); and
- rate of quality output (yield).

some loses involved in OEE includes:

Availability losses: where breakdowns and changeovers indicate situation where the line is not running, whereas it should, performance losses: where speed loses and small stops/empty positions indicate the line is running, but not producing outputs.

There are also losses due to start-ups. These losses lead to the OEE indicator, which shows how efficient the process is:

OEE = Availability	x	Performance efficiency	x	Quality Rate output
• Breakdown • Setup & adjustment		• Idling and minor Stoppage loss • Reduced		• Quality defect • Rework

$$Availability = \frac{Operating\ time}{Planned\ production\ time} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Availability takes into account downtime losses. It is the amount of time the equipment actually was running as a proportion of time it could have been running.

$$Performance = \frac{Actual\ output\ of\ equipment}{Ideal\ output\ of\ equipment} \quad \ldots\ldots\ldots\ldots\ (2)$$

The equipment performance is the actual output of the equipment as a percentage (%) of the theoretical output running at its rated speed and actual run time. Performance rate measure speed loss.

$$Quality\ rate = \frac{Good\ product}{Total\ product} \quad \ldots\ldots\ldots\ldots\ldots\ (3)$$

The quality takes into account quality loss.

OEE = Availability x Performance rate x Quality rate …………… (4)

where,

Availability = Percent of scheduled production or calendar hours (24/7/365) that equipment is available for production. It measures the percent of time that the equipment can be used, usually total hours of (24-7-365) divided by the equipment uptime (actual production).

Performance = Percent of parts produced per time frame, it is the percentage of available time that the equipment is producing product at its theoretical speed for individual products. It measures speed losses.

Quality Rate = Percent of good products produced out of total parts produced per time frame.

The *OEE* percentage is obtained by multiplication of the three ratios: availability, performance rate and quality rate. Overall equipment effectiveness can be used to save companies from making inappropriate purchases, and help them to focus on improving the performance of machinery and plant equipment they already own, OEE is used to find the greatest areas of improvement, so you start with the area that will provide the greatest return on asset. The OEE format will show how improvement in changeovers, quality and machine reliability will affect the bottom line.

As there is striving towards world-class productivity in the facility, this simple formula will make an excellent benchmark tool. The derived OEE percentage is easy to understand, and displaying this simple number where all facility personnel can view it makes for a great motivational technique by giving your employees an easy way to see how they are doing in overall equipment utilisation, production speed, and quality.

3.2 World class OEE

In practice, the generally accepted "world-class" goals for each factor are quite different from each other, as shown in the Table 2:

Table 2: World class OEE

OEE factor	World class
Availability	90.0%
Performance	95.0%
quality	99.0%
Overall OEE	85.0%

Studies indicate that the worldwide average OEE rate in most industries is 60%. As can be seen from the table 2, a world class OEE is considered to be 85% and above. Clearly, there is room for improvement in most industries.

4.0 Discussion and data analysis

Data collection is an integral part of any predictive maintenance programme. Pumps that operate with low cavitation levels can maximise the productive capacity of the equipment and the lifespan of its components, saving both time and money. There are two basic assignment worksheets; which enable operators and maintenance staff in the plant to attend to daily units serviceable points. The operator/maintainer is expected to visit the unit site according to the programme daily to collect useful data as per equipment/machine performance.

Companies without a predictive maintenance programme can encourage various forms of pump damages that range from minor pitting to catastrophic failure. A failure can be linked to pumped fluid characteristics, energy levels or the duration of cavitation. The impeller is the most commonly damaged component of the pump. Specifically, the leading face of the non-pressure side of the impeller endures the bulk of cavitation damage. During cavitation, tiny bubbles form and rapidly collapse in the pumped fluid. On the vanes or impeller blades is where the bubbles will normally begin to collapse or implode and release energy to the vane or blade removing particles of the metals. The overall result will be rough, pockmarked surface. Pumps are devices for lifting or transferring a liquid, Fluids can be made to move through conduits or channels by various means, such as: gravity, displacement, transfer of mechanical energy; and transfer of energy from one fluid to another.

Pumps come in many different sizes, have different flow rates, pump different liquids and otherwise operate under different conditions. In industrial operations, we need to transfer various types of fluids or liquids both horizontally and vertically; in this case we must use special devices i.e. pumps. The classification of pumps is shown in Figure 3.

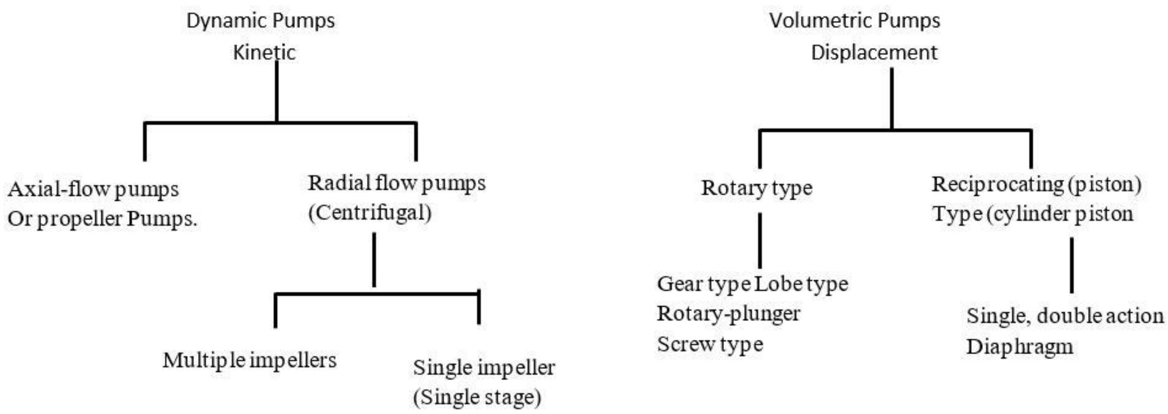

Figure 3: Classification of pumps

Data collected from case study plant (NAOC-Kwale Gas Recycling Plant) on condition of working units for the years (2017-2018) have been tabulated as raw data shown in Table 3 and the failure analysis of the plant units for calculation of OEE as shown in Table 4. The data presented in Table 4 was recorded from the maintenance planning and execution of daily work activities and were obtained for a One (1) year period. This period was chosen in order to examine the trend in failure intervention calls in the gas recycling plant.

Table 3: NAOC-Kwale Gas Recycling Plant Raw Technical Data

Plant units location	Installed capacity	Working capacity	Observation period	Number of failures	Remarks
4100 Del. Pumps l and 2	175.6m3/h	88m3/h	8760 hours	10	No spare part
4200 Glycol pumps	3.5m3/h	1.75m3/h	8760 hours	8	No spare part
5600 Diesel pumps PI and P2	15m3/h	2.5m3/h	8760 hours	12	No spare part
6100 Booster pumps	185 m3/h	93 m3/h	8760 hours	10	No spare part
7100 Condensate pumps	5m3/h	3.0m3/h	8760 hours	12	No spare part
8200 Auto clave pumps land 2	30m3/h	18m3/h	8760 hours	11	Running Ok
8200 Fire pumps 1 and 2	200m3/h	110 m3/h	8760 hours	10	Running Ok
Residential Water treatment pumps	3.5m3/h	2.0m3/h	8760 hours	15	Running Ok
Total	617.60	318.25			

Table 4: NAOC-Kwale Gas Recycling Plant Technical Data Analysis 2017-2018

S/N	Plant unit location	System failures period	System repairs period	No. of failures	Total downtime Per period
1.	4100 Delivery pumps 1 and 2	5/10/05 – 27/08/06	10/10/05 - 02/09/06	10	888 hrs
2.	4200 Glycol pumps 3 and 4	21/04/05 - 05/10/06	21/04/05 - 15/10/06	8	1758.45 hrs
3.	5600 Diesel pumps 1 and 2	27/02/05 - 09/09/06	10/03/05 - 16/09/06	12	2760.35 hrs
4.	6100 Booster pumps 1 and 2	03/03/05 - 23/09/06	04/03/05 - 23/09/06	10	2977.25 hrs
5.	7100 Condensate pumps 1 and 2	09/04/05 - 05/09/06	09/04/05 - 15/09/06	12	1109.61 hrs
6.	8200 Autocleave pumps 1 and 2	23/02/05 - 16/04/06	23/02/06 - 21/04/05	11	1181.55 hrs
7.	8200 fire pumps 1 and 2	25/02/05 - 23/04/06	30/02/05 - 26/04/06	10	2060.05 hrs
8.	R/A water treatment pumps 1 and 2	24/04/05 - 09/10/06	28/04/05 - 14/10/06	15	1900 hrs

Thus, carriyg out individual analysis of pumps shown in Table 4 will provide separate results of work perfomance as following:

1. *For 4100 Delivery pumps 1 and 2*

   Planned production time = 8760 hrs
   Total down time = 888 hrs
   Operating time = Planned production time - Total down time
   = 8760 - 888 = 7872hrs

   $$Availability = \frac{operating\ time}{Planned\ production\ time} = \frac{7872}{8760} = 0.8986 \times 100 = 89.9\%$$

   From Table 4.1
   Actual output of pump = 88 m^3/h
   Ideal output of pump = 175.6m^3/h

   $$Performance = \frac{Actual\ output\ of\ pump}{Ideal\ output\ of\ pump} = \frac{88m3/h}{175.6m3/h} \times 100\% = 50\%$$

2. *For 4200 Glycol pumps 3 and 4*

   Planned production time = 8760 hrs
   Total downtime = 1758.45 hrs
   Operating time = Planned production time -Total down time
   = 8760 - 1758.45 = 7001.55hrs

   $$Availability = \frac{operating\ time}{Planned\ production\ time} = \frac{7001.55}{8760} = 0.7993 \times 100 = 79.9\%$$

   From Table 1:

Actual output of pump = 1.75 m3/h
Ideal output of pump = 3.5 m3/h

$$Performance = \frac{Actual\ output\ of\ pump}{Ideal\ output\ of\ pump} = \frac{1.75\ m3/h}{3.5\ m3/h} = 0.5 \times 100 = 50\%$$

3. *For 5600 Diesel pumps 1 and 2*
Planned production time = 8760 hrs
Total down time = 2760.35 hrs
Operating time = Planned production time - Total down time
= 8760 - 2760.35 = 5999.65 hrs

$$Availability = \frac{operating\ time}{Planned\ production\ time} = = \frac{5999.65}{8760} = 0.6849 \times 100 = 68.5\%$$

From Table 1:
Actual output of pump = 2.5m ^{3}/h
Ideal output of pump = 15m^3/h

$$Performance = \frac{Actual\ output\ of\ pump}{Ideal\ output\ of\ pump} = \frac{2.5\ m3/h}{15\ m3/h} = 0.1666 = 0.17 \times 100 = 17\%$$

4. *For 6100 Booster pumps 1 and 2*
Planned production time = 8760 hrs.
Total down time = 2977.25hrs
Operating time = Planned production time - Total downtime
= 8760 - 2977.25 = 5782.75 hrs

$$Availability = \frac{operating\ time}{Planned\ production\ time} = = \frac{5782.75}{8760} = 0.55027 \times 100 = 66\%$$

From Table 1:
Actual output of pump = 93m^3/h
Ideal output of pump = 185m^3/h

$$Performance = \frac{Actual\ output\ of\ pump}{Ideal\ output\ of\ pump} = \frac{93\ m3/h}{185\ m3/h} = 0.5027 \times 100 = 50.3\%$$

5. *For 7100 Condensate pumps 1 and 2*
Planned production time = 8760hrs.
Total downtime = 1109.61hrs.
Operating time = Planned production time - Total downtime
= 8760-1109.61hrs = 7650.39 hrs

$$Availability = \frac{operating\ time}{Planned\ production\ time} = = \frac{7650.39}{8760} = 0.8733 \times 100 = 87.3\%$$

From Table 1:
Actual output of pump = 3.0m^3/h
Ideal output of pump = 5.0 m^3/h

$$Performance = \frac{Actual\ output\ of\ pump}{Ideal\ output\ of\ pump} = \frac{3.0m3/h}{5.0m3/h} = 0.6 \times 100 = 60\%$$

6. *8200 Auto-clave pumps 1 and 2*
Planned production time = 8760 hrs
Total downtime = 1181.55 hrs
Operating time = Planned production time - Total down time
= 8760-1181.55 = 7578.45 hrs

$$Availability = \frac{operating\ time}{Planned\ production\ time} == \frac{1181.55}{8760}$$ = 0.8651x 100 = 86.5%

From Table 1:
Actual output of pump = 18m^3/h
Ideal output of pump = 30m^3/h

$$Performance = \frac{Actual\ output\ of\ pump}{Ideal\ output\ of\ pump} = \frac{18m3/h}{30m3/h}$$ = 0.6 x 100 = 60%

7. *For 8200 fire pumps 1 and 2*

Planned production time = 8760 hrs
Total downtime = 2060.05 hrs
Operating time = Planned production time - Total down time
= 8760-2060.05 = 6699.95 hrs

$$Availability = \frac{operating\ time}{Planned\ production\ time} = \frac{2060.05}{8760}$$ = 0.7648 x 100 = 76.5%

From Table 1:
Actual output of pump = 110 m3/h
Ideal output of Pump = 200 m3/h

$$Performance = \frac{Actual\ output\ of\ pump}{Ideal\ output\ of\ pump} = \frac{110m3/h}{200m3/h}$$ = 0.55 x 100 = 55%

8. *For Res. water treatment auto-clave pumps 1 and 2*
Planned production time = 8760hrs
Total downtime = 1900 hrs
Operating time = Planned production time - Total downtime
= 8760 – 1900 = 6860.08 hrs

$$Availability = \frac{operating\ time}{Planned\ production\ time} == \frac{6860}{8760}$$ = 0.7831x 100 = 78.3%

From Table 1:
Actual output of pump = 2.0m^3/h
Ideal output of pump = 3.5m^3/h

$$Performance = \frac{Actual\ output\ of\ pump}{Ideal\ output\ of\ pump} = \frac{2.0m3/h}{3.5m3/h}$$ = 0.5714 x 100 = 57.1%

4.1 Calculation of system O.E.E.

From data Table 1:

Annual output capacity for 1 year = 318.25 m^3/h
Total installed capacity for 1 year = 617.60 m^3/h

1. $$System\ quality\ rate = \frac{Annual\ output\ capacity}{Total\ installed\ capacity} = \frac{308.25\ m3/h}{617.60\ m3/h}$$ = 0.5241 x 100 = 52%
2. System Availability = Product of individual pumps availability:

= 0.899 x 0.799 x 0.685 x 0.660 x 0.873 x 0.865 x 0.7648 x 0.783
= 0.1469 = 14.69 x 100 = 15%

3. System performance = Average sum of individual pumps performances:
= 0.5 + 0.5 +1.7 + 0.50 + 0.60 + 0.60 + 0.55 + 0.57

= 5.52/8 = 0.69x100 = 69%

4. OEE of system = System Availability x System performance x Overall System Quality.

$$= 0.1469 \times 690 \times 0.52 = 0.0527 \text{ OEE} = 0.0527 \times 100 = 5.27 \approx 5.3\%$$

5.0 Conclusion

In developing an effective maintenance management system for NAOC-Kwale Gas Recycling Plant necessary for global competition, which traces the various roles played by the maintenance dimensions by first self auditing and benchmarking before implementation. From the analysis undertaken, the poor OEE rating is a reflection of how equipment are loaded or doing what they are supposed to do. In this case, low quantifiable performance indicator show that Kwale gas recycling plant maintenance management scheme is not effective. This means there is opportunity to increase capacity and productivity to large reasonable percentage.

Individual equipment problems affect the entire system and hence the equipment effectiveness of the gas plant under these circumstances, the availability of the process becomes the product of the individual's availability, [6]. TPM therefore, if implemented in NAOC, will improve the OEE by providing a structure to quantify losses or downtime, and by subsequently giving priority to important ones. With competition in industry at all time high, TPM may be the only thing that stands between success and total failure for the NAOC-Kwale Gas Recycling Plant. It has been proven to be a programme that works. Based on the results obtained, the following weaknesses (though opportunities for improvement) were found:

- a poor OEE rating which indicates that the maintenance management system is suffering;
- there are written maintenance policies, which are not followed to the letter, and most of the descriptions require review;
- organisational charts are not current and not complete; and
- there is no reliablity engineer for planning the work orders, in order to decide what resources, materials and equipment necessary for the department, etc.

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