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Assessment of an Annual Maintenance Record of a Wastewater Treatment Plant in the Oil and Gas Industry

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Abstract:

Maintenance cost is a critical component in the operational sustainability of wastewater treatment plants (WWTPs), particularly within the oil and gas industry where complex effluent profiles and stringent environmental regulations demand robust treatment systems. This study assesses the maintenance cost drivers associated with WWTPs in oil and gas facilities, focusing on key parameters such as equipment reliability, spare parts usage, chemical usage, and sludge management. Pumps are the most frequently failing pieces of equipment and major contributors to downtime, experiencing breakdowns five times in the year and the failures are often related to motor issues, overheating, impeller damage, bearing failures, seals breakage etc. which represents 57% of the total downtime hours (37 hours). Root cause analysis shows that excessive vibrations contributed 14% of failures in the pumps which the highest failure contributor associated with the pumps. Findings suggest that proactive maintenance planning and technology-driven interventions can significantly reduce downtime, improve treatment efficiency, and ensure regulatory compliance. The study generates practical insights for engineers and facility managers aiming to enhance cost-effectiveness and operational resilience in industrial wastewater treatment systems.

Keywords — **Downtime, productivity, pumps, maintenance**

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I. INTRODUCTION

The oil and gas industry is one of the largest consumers of water and a major producer of wastewater, characterized by high levels of hydrocarbons, suspended solids, heavy metals, and other toxic substances. To mitigate the environmental impact of effluent discharge, wastewater treatment plants (WWTPs) are essential components of oil and gas processing facilities. However, maintaining the operational efficiency and regulatory compliance of these treatment plants requires substantial and continuous investment in maintenance. Maintenance costs can account for a significant portion of the total operational expenses due to the harsh operating conditions, complex treatment technologies, and the critical need to minimize unplanned downtime. Despite their importance, maintenance costs in WWTPs are often underestimated or poorly optimized, leading to inefficiencies and increased environmental risk. This study aims to assess the maintenance cost structure of WWTPs in the oil and gas sector, identify the key cost drivers, and propose strategies to improve cost-effectiveness without compromising treatment performance or regulatory standards. By doing so, it contributes to the broader goal of sustainable water management in an industry facing increasing environmental and economic pressures.

W.-K., & Yin, X. (2024) proposed a data-driven economic predictive control approach using the Koop man operator to enhance operational performance and reduce maintenance costs in water treatment processes. Betgeri, S. N et al. (2022) developed a K-Nearest Neighbours model to automate wastewater pipe condition rating, aiding in prioritizing maintenance and reducing costs. R., Molinos-Senante, M., et al. (2022) analyzed the efficiency of WWTPs, this study addressed the challenges in defining desirable outputs and their implications for maintenance cost assessments. Rathore, P., et al. (2022) conducted a life cycle cost analysis comparing various wastewater treatment technologies, finding that Up-flow Anaerobic Sludge Blanket (UASB) systems had the lowest maintenance costs. Han, M., et al. (2021) analyzed factors influencing energy performance in WWTPs, providing recommendations to reduce energy consumption and associated maintenance costs. Flores-Alsina, X., et al. (2021) assessed sludge management strategies in WWTPs using a plant-wide approach, highlighting their impact on maintenance frequency and operational costs. Parajes, E., & Román-Sánchez, I. M. (2021) used bibliometric analysis in their research work to highlight a growing interest in wastewater treatment costs, emphasizing the need for more focused research on maintenance expenses. Colacicco, A., & Zacchei, E. (2020) optimized energy consumption in oxidation tanks of urban WWTPs by integrating solar photovoltaic systems, leading to reduced maintenance costs. Tan, D. J. Y., & Law, A. W.-K. (2020) presented an economic perspective on predictive maintenance for filtration units, demonstrating potential cost savings through machine learning models and Monte Carlo simulations. Silva, C., & Rosa, M. J. (2020) by assessing 23 WWTPs, this case study identified key performance indicators affecting maintenance costs, such as sludge production and energy efficiency. Fitriani, H., et al. (2019) analyzed the economic viability of WWTPs by assessing users' ability and willingness to pay, highlighting the importance of aligning maintenance costs with community financial capacities. Filipe, J., et al. (2019) introduced a data-driven predictive control policy for wastewater pumping stations, achieving significant energy savings and reduced maintenance alarms. Di Fraia, S., et al. (2018) proposed a novel energy assessment methodology for urban WWTPs, focusing on improving energy efficiency and reducing maintenance-related costs. Chen, L., Hou, H., & Wang, J. (2013) developed a mathematical model to analyze operating costs in oxidation ditch processes. It identified power consumption and sludge disposal as primary cost drivers and suggested optimizing sludge retention time to reduce expenses.

II. METHODOLOGY

2.1 Study Area

This study was conducted in Warri Refining and Petrochemical Company, in Ekpan-Effurun. The company is situated in the Ubeji community of Warri South Local Government Area, with a portion also extending into Ekpan community of Uvwie Local Government Delta State-Nigeria. The refinery's coordinates are 5◦32'N latitude and 5◦41'E longitude. Warri refinery and Petrochemical Company (WRPC) was established in 1978 with a refining nameplate capacity of 100,000 barrels per stream day plant and was debottlenecked to 125,000 barrels per stream day in 1987. The refinery is located at Ekpan, Warri, DeltaState, and it is operated by the Warri Refining & Petrochemicals Company (WRPC) Limited, an NNPC subsidiary. The refinery was installed as a complex conversion plant capable of producing Liquefied Petroleum Gas (LPG), Premium Motor Spirit (PMS), Dual Purpose Kerosene (DPK), Automotive Gas Oil (AGO), and Fuel Oil from a blend of Escravos and Ughelli crude oils'. WRPC has a petrochemical plant complex that produces Polyproylene, and carbon black from the propylene-rich feedstock and decants oil from the Fluid C2atalytic Cracking unit (FCCU).

Figure 2.1 Location map of Warri Refining and Petrochemical Company (WRPC)

At maximum design capacity, the refinery is configured to produce the petroleum products at the following rates:

TABLE I
PRODUCTS AT MAXIMUM DESIGN CAPACITY

DESIGN PARTICULARS	METRIC TON/DAY	LITRES
Fuel Gas	273.65	482,716.22
LPG	204.39	362,591.22
PMS	5,498.31	7.285,261.82
KERO	1,778.72	2,170,033.78
AGO	5,119.93	5,959,601.35
F.OIL	3,496.62	3,671,452.70FC

The primary processes are carried out at the Atmospheric Distillation Unit, the Vacuum Distillation Unit and the Gas Plant. The secondary process units are the Naphtha Hydro treating Unit, the Catalytic Reforming Unit, the Kerosene Hydro Treating Unit, the Fluid Catalytic Cracking Unit, the HF Alkylaion's Unit, Polypropylene and Carbon Black Plants.

2.1 Data Collection

Annual maintenance record of the company's wastewater treatment plant was obtained which entails maintenance operations that have been carried out in the plant. The following data was collected.

TABLE III
ANNUAL MAINTENANCE DATA

DATE	EQUIPMENT	MAINTENANCE TYPE	CAUSE OF FAILURE	REPAIR ACTION	DURATION (HRS)
10-01-22	Primary Settler Tank	Preventive Maintenance	Routine cleaning & inspection	Cleaning and sludge removal	4
03-02-22	Lift Pump	Breakdown Maintenance	Motor failure	Motor replacement	8
15-03-22	Clarifier Tank	Preventive Maintenance	Sludge accumulation	Tank cleaning and inspection	5
04-04-22	Aerator Blower	Breakdown Maintenance	Overheating due to clogged filter	Filter replacement & motor check	6
06-05-22	Sludge Dewatering	Preventive Maintenance	Filter maintenance	Filter replacement and cleaning	3
13-06-22	Filtration Feed Pump	Breakdown Maintenance	Impeller damage and bearing failure due to misalignment and cavitation	Impeller and bearing replacement & motor check	10
08-07-22	Primary Settler Tank	Breakdown Maintenance	Tank leakage	Welding & sealing	25
15-08-22	Clarifier Tank	Preventive Maintenance	Routine maintenance	Sludge removal & inspection	6
11-09-22	Transfer pump	Breakdown Maintenance	Motor fault (overload) due to flow blockage	Motor replacement	7
17-10-22	Sludge Dewat	Break down Maint	Sludge press malfun	Component replacem	8

	ering	enance	ction	ent & adjustment	
21-11-22	Primary Settler Tank	Preventive Maintenance	Routine cleaning	Sludge removal and system check	5
14-12-22	Sludge pump	Breakdown Maintenance	Housing (volute) damage due to the formation of vapour bubbles caused by vapour pressure of the sludge	Impeller, bearing and seals replacement & Reshaping and smoothening the internal surface of the volute	6
30-12-22	Chemical Dosing Pump	Preventive Maintenance	Calibration and inspection	Dosing system calibration	4
TOTAL					**90**

Key Performance Indicators (KPIs):
- Average Downtime per Month: 7.5 hours
- Number of Breakdown Events: 7
- Preventive Maintenance Frequency: 70% of maintenance activities are preventive.
- Failure Rate: 3.5 failures per quarter.

III. RESULTS AND DISCUSSION

3.1 Root Cause Analysis

Failure cause analysis, also known as Root Cause Analysis (RCA) is a structured method employed to identify the underlying causes of machinery failures. From figure 4.30 below, it depicts that excessive vibrations contributed the highest percentage (i.e 14%) of the downtime failures. This gives rise to the need of optimizing vibration parameters so as to drastically reduce the failure of the plant.

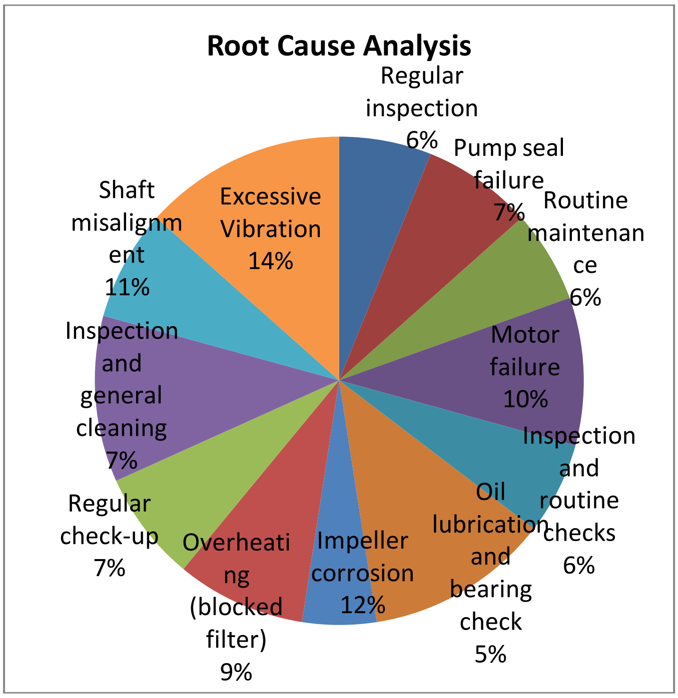

Figure 3.1 Failure cause analysis (FCA)

3.2 Breakdown vs. Preventive Maintenance:

Preventive maintenance comprises of all recorded actions, indicating that the refinery is proactive in maintaining the equipment and averting major failures. However, the breakdown maintenance (7 breakdowns in total) indicates that certain equipment, particularly the aerators and dosing pumps, may have inherent issues or insufficient predictive maintenance. The total downtime from breakdown maintenance is 53 hours, which affects the plant's overall efficiency and performance.

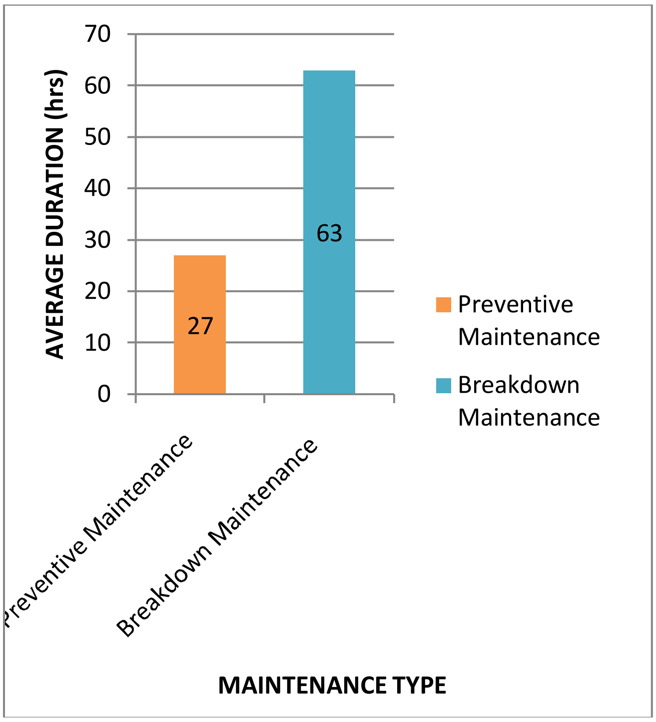

Figure 3.2 Comparison of preventive and breakdown maintenance durations (hours)

3.3 Downtime vs. Productivity

The average downtime per month is 7.5 hours, which may not seem excessive but can accumulate over time, leading to potential delays in effluent processing and environmental compliance issues. *Pumps failures are the primary contributor to downtime.* If more attention is given to preventive maintenance and monitoring of the pump systems, significant downtime could be reduced.

3.4 Suggested Measures

a. Improve Preventive Maintenance

1. Pump Systems: Given that these systems account for a significant number of breakdowns, it would be beneficial to implement more frequent monitoring, vibration analysis, flow characteristics analysis and motor inspections to predict and detect potential issues before they lead to failure.
2. Primary Settler Tank: The tank leakage could potentially have been avoided with corrosion monitoring and early detection of stress points. Consider adding pressure sensors or conducting more regular stress testing of critical components.

b. Predictive Maintenance Techniques

To reduce the breakdown maintenance, consider integrating predictive maintenance tools such as vibration analysis, thermal imaging, and condition monitoring for high-risk equipment like the aerators, pumps, and tanks. A predictive maintenance approach could detect issues such as motor wear or electrical faults before they cause failures, helping reduce downtime and costly repairs.

c. Cost Control Measures:

The high repair costs for breakdowns, especially motor replacements for the aerators, suggest the need for more comprehensive spare parts management to ensure that critical parts are always available when needed, minimizing downtime. Training for operators and maintenance staff should be prioritized to ensure early detection of faults and better operational efficiency, which can reduce costly failures.

d. Downtime Reduction:

1. To improve the refinery's overall efficiency, focus on reducing unplanned downtime, especially from the Pumps and Primary Settler Tank.
2. Implementing condition-based monitoring for the aerators could help address issues proactively and prevent the need for emergency repairs.
3. The refinery could also consider investing in redundant systems for critical components to minimize the impact of any downtime.

e. Environmental and Regulatory Compliance:

Maintaining compliance with environmental regulations is critical, especially when dealing with wastewater treatment systems.

Ensuring continuous monitoring and maintenance of equipment like chemical dosing pumps and sludge dewatering systems will help avoid system failures that could result in regulatory violations or environmental risks.

DISCUSSION

Pumps are the most frequently failing pieces of equipment, experiencing breakdowns five times in the year. The failures are often related to motor issues, overheating, impeller damage, bearing failures, seals breakage etc. It represents 57% of the total downtime hours (37 hours). Primary Settler Tank and Clarifier Tank experience a moderate number of failures, but their issues are generally less frequent, and maintenance is often preventive (e.g., cleaning and sludge removal). The Primary Settler Tank had a major failure in June, involving a 12-hour downtime due to tank leakage, which is costly and disruptive.

IV. CONCLUSION

Based on the assessment carried out, it is clear that while the refinery is largely proactive in its maintenance practices, certain critical equipment such as Pumps, Aerator Blower and Primary Settler Tank still experience frequent failures. The refinery should focus on improving the predictive maintenance strategies for these units, along with investing in enhanced diagnostic tools and operator training. Additionally, better spare parts management and the introduction of condition monitoring can help reduce breakdown maintenance and its associated costs, thereby improving both system reliability and operational efficiency in the long run.

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