IoT Driven Predictive Maintenance for Enhanced Reliability of Blowers in Wastewater Treatment

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Abstract— **The integration of IoT (Internet of Things) technology in industrial maintenance is transforming machine condition monitoring by enabling real time data acquisition and predictive maintenance. This work presents an IoT-based remote monitoring system for blowers in wastewater treatment plants, utilizing a Total Degradation Number (TDN) sensor for oil condition assessment, existing vibration sensors, and oil temperature monitoring.**

The system continuously tracks critical blower parameters, including the TDN to evaluate oil degradation, oil temperature, vibration levels, and operational runtime. By applying high-frequency AC waveforms, the TDN sensor accurately measures oil capacitance and conductance, deriving the TDN as a simplified index of oil health. Sensor data is seamlessly collected, transmitted to a cloud platform, and displayed on an intuitive dashboard that provides real-time visualization and automated alerts for abnormal conditions.

Field testing in an operational wastewater treatment facility demonstrates the system's effectiveness in early fault detection, reducing unexpected failures, and optimizing maintenance schedules. The proposed solution enhances equipment reliability, minimizes breakdowns, and extends machine lifespan. Future developments will explore the integration of machine learning algorithms to further refine predictive capabilities and improve overall system performance.

***Index terms*—IoT, IoT, Predictive Maintenance, Wastewater Treatment, Oil Quality, TDN, Vibration Monitoring.**

I. Introduction

Unprecedented innovations in Artificial Intelligence (AI), Machine Learning (ML), big data, robotics, communication, and cloud computing resulted in the fourth Industrial Revolution (IR 4.0). The salient feature of IR 4.0 is that machines exchange real-time data over the Internet without human intervention, creating the Internet of Things (IoT). Recent studies suggest that the adoption of IR 4.0 in the industrial process can significantly boost production. The mesmerizing emolument has resulted in a staggering 13.0% annual growth in IoT, reaching a count of around 18.8 billion in 2024. It is forecasted that IoT-connected devices will reach 40 billion by the end of this decade [1].

IoT adoption in industries resulted in supply-chain optimization, production-line automation, and downtime reduction due to Predictive Maintenance (PdM). Previously, maintenance was largely reactive-based and thus inefficient, leading to unforeseen stoppages in industrial processes. With the advent of the industrial Internet of Things (IoT), the scenario of industrial process monitoring has changed from offline sensing to real-time data collection through IoT and cloud-based data analysis, which opened a new era of Predictive Maintenance (PdM). Such IoT-based systems continuously monitor some of the key parameters, pinpoint an abnormal condition, and forecast failure even before it happens. All this can be done to minimize downtimes and optimize operational costs [1]. However, integration of IoT-based systems into existing complex industrial processes requires a significant cost in terms of sensors, networks, cloud-based services, and cyber security. Therefore, there is an urgent need to develop a cost-effective solution for small and medium industries.

The wastewater treatment industry is growing rapidly due to the recent surge in development around the world. The uninterrupted supply of water in densely populated urban areas demands minimum downtime of the water treatment plants. Blowers are vital mechanical components in wastewater treatment plants. They are mainly used for aeration i.e., to pump air into the water to help bacteria break down organic compounds and remove carbon dioxide, sludge treatment, or the overall effectiveness of the plant. Due to the presence of numerous varieties of chemicals and solid particles in the wastewater, the blower and overall water treatment plants are subjected to some very challenging operating conditions that could lead to equipment failures and costly downtime.

This paper outlines the architecture, implementation, and real-world testing of an IoT-based monitoring system designed for blowers in wastewater treatment plants. Oil quality is an important parameter for the assessment of the blower's health and maintenance needs [2]. Therefore, the system has a novel oil quality sensor retrofitted to measure the Total Degradation Number (TDN) instead of traditional oil condition monitoring, which uses using magnet to pick metal material. Furthermore, the availability of oil quality data is augmented with other essential blower parameters such as temperature, vibration, operating hours, etc. This IoT system gives a complete picture of the health of the blower and would thus enable the effective scheduling of maintenance proactively.

The rest of the paper is organized as follows. Section II reviews the blower's operation and its critical parameters.

Section III presents the methodology to monitor the parameters using IoT based system. Section IV presents a discussion of the test results. The final section provides a conclusion and discusses future work.

II. BLOWER OPERATION/BACKGROUND

Blower is a vital part of the wastewater treatment plant. It supplies airflow for aeration and biological processes. Its efficiency directly impacts plant's effectiveness, energy consumption, and overall operational costs. Moreover, blower's proper maintenance is essential to water quality and plant efficiency.

Blower performance in the treatment plant is mainly determined by vibration levels, oil condition, temperature, and running hours. Optimal values of these parameters need continuous monitoring and promptly maintenance. For instance, excessive vibration may indicate mechanical wear, misalignment, or bearing issues, while oil degradation can lead to overheating and increased friction, reducing efficiency and lifespan. Monitoring airflow and pressure is also crucial to ensure optimal aeration and prevent performance drops.

Continuous monitoring of these critical parameters can be achieved by integrating IoT-based remote monitoring that will facilitate early fault detection and predictive maintenance. The real-time monitoring of blower parameters enhances wastewater treatment efficiency.

III. METHODOLOGY

A comprehensive methodology to integrate the IoTs system into the blower is detailed in this section.

A. IoT System Architecture

The proposed modular IoT-based architecture enables real-time monitoring of blower parameters and provides data for scheduling predictive maintenance. As illustrated in Fig. 1, the architecture is organized into four main components: (i) sensors that measure the critical operational parameters, (ii) a microcontroller that converts these values into suitable digital formats, (iii) the communication layer that securely transmits data to the cloud, and (iv) the cloud platform itself, which handles data storage, visualization, and analytics to support operational insights and predictive maintenance decisions [3].

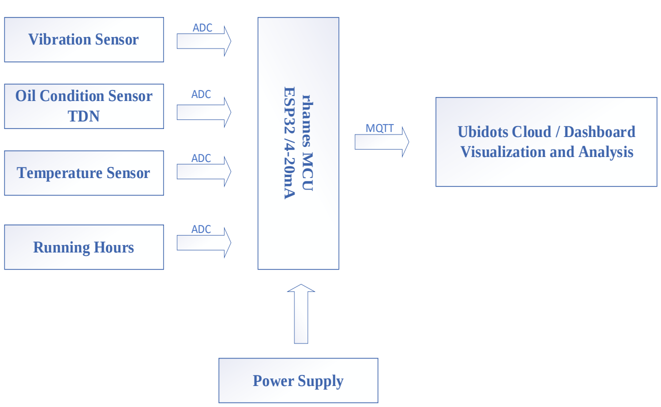


Figure 1. IoT system architecture for blower's predictive maintenance.

Several sensors (oil quality, temperature, and vibration) are attached to the blower to measure the parameters critical to operation accurately. The CPU core is an ESP32 microcontroller, the PCB custom design developed by the R&D department at rhames Ltd, specifically designed to support industrial protocols. It interfaces seamlessly with the 4–20 mA signals from the sensors and is programmed to publish data using the MQTT protocol. MQTT topics are structured by asset and parameter (e.g., /blower1/TDN), with QoS level 1 ensuring reliable message delivery. The system authenticates with the cloud broker using secure API tokens over TLS encryption, safeguarding data integrity and confidentiality.

The communication network is implemented through a GSM module, which serves as a robust gateway for transmitting data over cellular networks to the cloud platform. This choice of GSM over LPWAN technologies such as LoRa or Sigfox is driven by the need for higher bandwidth and widespread coverage, ensuring consistent multi-parameter data streaming even in remote industrial sites. The architecture also leverages Wi-Fi where strong plant infrastructure exists, providing flexible connectivity options that enhance system robustness against communication interruptions.

At the top layer, the cloud platform implemented using Ubidots acts as the central facilitator for storing, processing, and analyzing real-time data. It maintains a time series database with configurable retention policies and secure daily backups, supporting trend analysis and long-term asset management. The cloud also executes threshold comparisons on incoming data streams, triggering alerts when critical values are exceeded. This platform architecture sets the groundwork for future integration of machine learning models, such as time series forecasting and anomaly detection, to drive even more advanced predictive maintenance capabilities.

B. Sensors Installation

The system incorporates several industrial grade sensors to monitor key parameters of blower operation. These sensors, including oil condition, oil temperature, and vibration, all provide a 4-20 mA output signal, which is directly interfaced with a custom designed circuit board compatible with the ESP32. The board is placed in the control panel, where the main PLC controller for the blower is located, and is protected from noise and environmental degradation through suitable insulation.

To monitor key operational parameters, sensors were retrofitted onto specific blowers within the wastewater treatment plant. The data generated by these sensors enable the identification of anomalies and deviations from expected operational conditions, facilitating the early detection of potential issues and minimizing the risk of unplanned shutdowns. Additionally, the sensors provide valuable insights into the overall operating environment.

These sensors serve as transducers, converting physical parameters into electrical signals. Depending on the sensor type, the physical parameters are represented in the electrical domain as voltage, current, or frequency. Following an in-depth evaluation of various sensor types and expert

consultations, it was decided to adopt an advanced oil condition monitoring solution, replacing traditional magnetic-based sensors. The selected sensor utilizes Total Degradation Number (TDN) technology, which evaluates oil health by measuring capacitance.
The oil condition sensor, produced by TanDelta, provides a 4-20 mA signal, which is mapped to a physical quantity using the following formula:

$$(mA-17)\times-100$$

where the resulting value represents oil quality.

The oil temperature sensor converts the 4-20 mA signal to a temperature range between -28°C and 130°C using a linear conversion formula. Similarly, the vibration sensor maps the 4-20 mA signal to a vibration level between 0 and 25 mm/s.

To further enhance the predictive maintenance strategy, additional sensors for monitoring oil temperature and vibration were integrated into the system. In total, three types of sensors were retrofitted to the blower system, as shown in Fig. 2, all of which output 4–20 mA signals:

- **Temperature Sensors**: These are installed to monitor the internal oil temperature within the blower system.
- **Vibration Sensors:** These sensors detect abnormal vibration levels, which could indicate mechanical issues such as bearing wear or imbalance.
- **Oil Condition Sensors:** These sensors assess oil quality and health, providing early warnings of contamination, oxidation, or degradation.

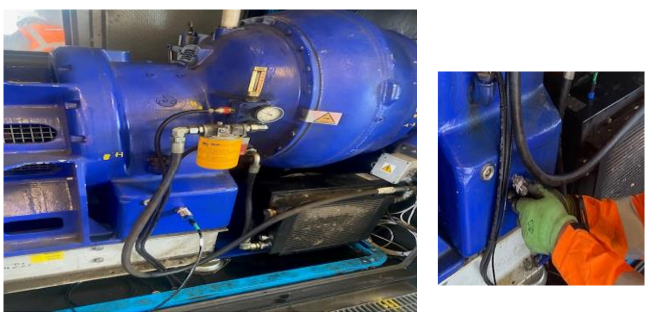


Figure 2. Blower unit with retrofitted sensor monitoring system i.e., Temperature, Vibration and Oil sensors installed.

Data from all sensors is sampled every 5 minutes, with the measurements transmitted to the central system for further analysis.

C. *Communication Layer*

The microcontroller is the core entity for adding the IoT based system of the blower in the wastewater management plant. A customized and efficient yet low-cost ESP32 microcontroller is used for this work. The microcontroller efficiently communicates sensor data to the cloud. The analogue interfaces (A0, …. A4) shown in Fig. 3 receive data from the sensors in analogue format and convert them to the corresponding digital values. The structured data is then forwarded to the cloud platform via the Global System for Mobile Communications (GSM) Module mounted on the CPU boards.

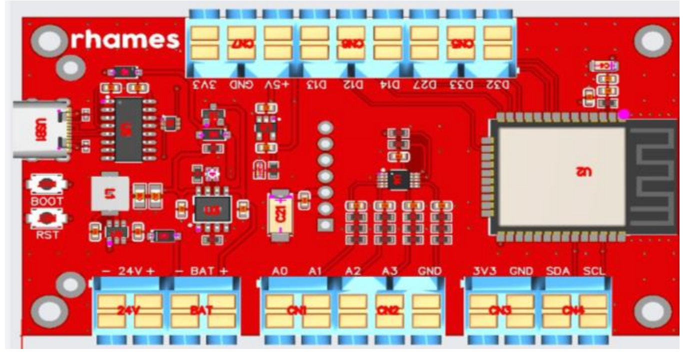


Figure 3. Custom-designed ESP32-based microcontroller board with industrial protocol interfaces for sensor integration and data processing.

D. *Sensor Integration and Data Acquisition*

A comprehensive discussion was conducted with blower operators and IoT experts from rhames Ltd. to identify the optimal solution for monitoring critical parameters and enhancing machine intelligence. A customized monitoring strategy for each blower in the wastewater treatment plant, incorporating specific sensor setups and data processing tailored to the operational requirements, i.e. oil condition, vibration, machine status, and running hours based on operation specific requirements. Furthermore, the sensor models are chosen by considering both accuracy and suitability for the rather harsh industrial environment. An in-house custom PCB was designed and developed to host the ESP32 based microcontroller board, as shown in Fig.3, which integrates industrial protocol interfaces for sensor connections and data processing. The microcontroller is programmed to perform data processing such as filtering, applying calibration factors, etc. Afterward, the data is shaped in the desired digital format. The GSM module transmits the data to the cloud setup, where further processing is carried out, such as data reprocessing, visualization, and analysis, to make decisions about predictive maintenance [4].

E. *Cloud Platform and Data Analysis*

The GSM module transmits the field sensor data to the cloud platform using Message Queuing Telemetry Transport (MQTT). The GSM module connects to Wi-Fi and authenticates with an API token. Sensor readings (Oil quality, Temperature, and Vibration) are transmitted along with the predefined variable labels to the cloud, where they can be monitored and analyzed in real-time. Initially, the data is stored securely in a time-series database at a designated location in the cloud. After initial preprocessing, the data is presented in a user-friendly dashboard developed using Ubidots Platform, as shown in Fig. 4.
Thresholds for TDN, vibration, and temperature are stored in the cloud dashboard, enabling dynamic comparisons with live data streams to trigger alerts.

Operators can monitor the blower's health in real time, as well as its operational status (On or Off) to create a clear view of the blower’s operation in the safe operation regions. When the margins are violated, alerts are created in the dashboard in accordance with the vibration ISO standard. The alerts are based on the criteria of excessive threshold (TDN values above 1100 and below 650) crossing, like highly degraded oil level, excessive rise in temperature, and vibration level beyond their normal values. Additionally, the dashboard shows the ON/OFF status of the blowers and the running period of the blowers. Furthermore, it also shows the trends in oil quality and vibrations of the blowers.

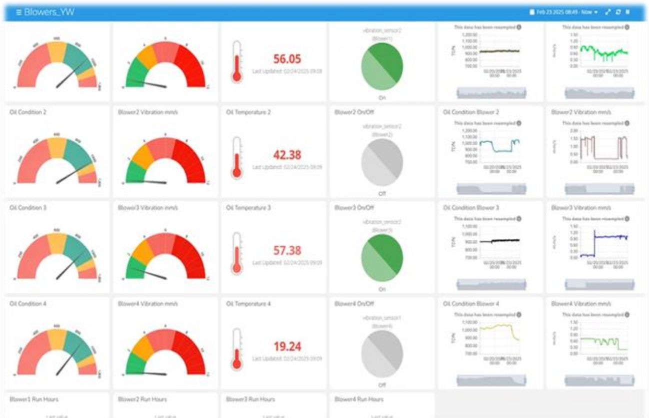


Figure 4. Dashboard to monitor blower's health in real time.

The trends in visualization help in performing predictive analysis, i.e., using data mining techniques, time series forecasting, and anomaly and deviation detection to forecast the need for predictive maintenance or the possible event of failure over time. Furthermore, it will automatically send alerts by text message and email to the operator and concerned officials. Moreover, the custom-designed setup generates weekly or monthly reports showing trends in vibration, oil quality, oil temperature, and machine status over the selected period, up to two years, and sends them directly to the relevant personnel.

IV. Results and Discussion

After a successful proof of concept, the developed IoT-based system was subjected to field testing by retrofitting it into several blowers in a wastewater treatment plant. The sensors retrofitting needed a few modifications to the already running blower units. After that, all sensors were precisely calibrated according to the operational parameters of the blowers. The microcontroller was programmed to cover the full scale of each sensor, and a third-party evaluator verified the system's overall functionality. The blower's manual and operator jointly decided that a test running period of six months would be sufficient to evaluate its usefulness. Therefore, we started collecting data in real-time, and so far the system functioned as desired in the harsh industrial environment.

During the test period, the IoT-based system detected maintenance needs before failure, especially oil degradation assessment. For instance, by TDN tracking, the testing team changed the oil in time, hence eliminating mechanical problems that surfaced due to lubrication failure. Furthermore, the accurate monitoring of the installed vibration sensors enabled the IoT-based system to monitor the mechanical stability of the blowers during the test period. Over the testing period, the system detected no abnormal vibration levels in the blowers, indicating potential mechanical stability.

Compared to traditional manual inspections and periodic sampling (5 min), the proposed system offers continuous oversight and immediate notifications. This reduces unplanned downtime and extends equipment life, underlining its advantage over conventional approaches.

A. *Dashboard Analysis*

The dashboard developed for this IoT-based monitoring system played a crucial role in visualizing the key health indicators of the blowers. It provided real-time plots and summaries of critical parameters, including oil quality (TDN), vibration levels, oil temperature, and blower running hours. These visualizations enabled operators and maintenance teams to easily monitor machine status, identify deviations from normal operating ranges, and respond proactively to maintain system reliability.

Over the test period, the dashboard helped the team observe stable trends across the monitored parameters, confirming that all blowers operated within safe limits. In one instance, by analyzing long term vibration patterns, the team identified slight increases under specific operational conditions, prompting minor adjustments to blower settings to minimize mechanical stress. This demonstrated how the dashboard not only supported daily monitoring but also informed small operational optimizations to enhance equipment lifespan.

Once familiar with the dashboard interface, the operators could efficiently assess the condition of both the blower systems and the sensor network itself. This clear, combined visualization significantly improved situational awareness and simplified maintenance planning.

Fig. 5 illustrates maintenance personnel interacting with the installed system during its evaluation in a live industrial setting, underscoring the practical application of the developed monitoring solution.

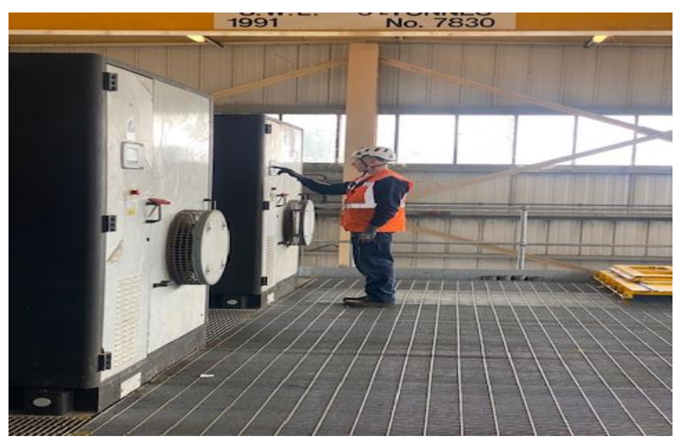


Figure 5. Maintenance technician performing system inspection

B. Vibration Sensor Analysis

Vibration sensors are a critical part of the IoT-based system integrated into the blowers of the wastewater treatment plant. Any deviation in the real-time data of the sensors indicated the blower's imbalance, misalignment in the blower's moving parts, or internal wearing out, such as bearing degradation or friction among moving parts. The real-time data installed on the four blowers of the wastewater treatment plant is shown in Fig. 6. During the test period, the IoT-based system detected no abnormal vibration signatures in the blowers as potential indicators of the mechanical stability of the system. However, the vibration amplitude of Blower-2 indicated variation in the vibration. However, the amplitude of the vibration was below the threshold indicated by the vibration standards ISO 10816. Therefore, the system did not generate any alarm to the testing and maintenance team.

Figure 6. Vibration measurements of the four blowers during test period

C. Temperature Monitoring

The oil temperature is a good indicator of the blower's overall internal condition and mechanical health in industrial processes. Any increase in mechanical friction or deterioration in oil quality can raise the internal oil temperature. In this work, integrated oil/temperature sensors were retrofitted to each blower unit to provide comprehensive and continuous monitoring of the internal oil temperature at the wastewater treatment plant. The oil temperature was monitored on an hourly basis, as shown in Fig. 7, and no significant temperature variations were observed during the test period. This real-time oil temperature monitoring confirmed that the blowers remained within defined safety limits, ensuring effective lubrication and stable mechanical operation.

D. Oil Condition Monitoring: TDN Analysis

A key feature of the implemented IoT-based system is its ability to monitor oil quality in real time using Total Degradation Number (TDN) measurements. TDN serves as a combined indicator that reflects important aspects of oil health, such as contamination levels, viscosity changes, and chemical stability. For these blower units, maintaining TDN values between 650 and 1100 is essential to ensure proper lubrication and protect mechanical components from accelerated wear or overheating.

Fig. 7. Presents the trends of TDN and oil temperature for the four monitored blowers, providing insight into how oil condition responds to operational cycles. **Note that the** sampling period differs slightly between machines, which may influence the density and continuity of data points shown.

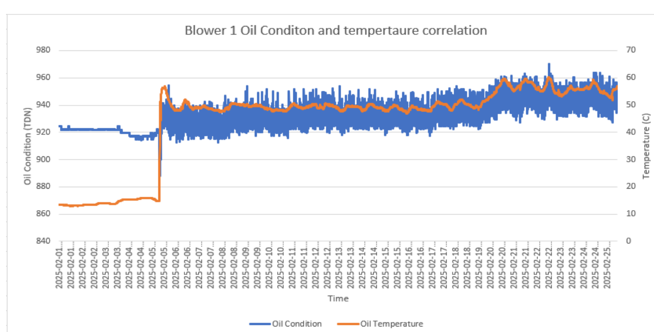
Blower 1 demonstrates stable performance, with TDN consistently within the safe range. The plot reveals a clear relationship between operational state and oil temperature, when the blower is active, the oil temperature rises, and the TDN curve tracks this thermal pattern, reflecting expected physicochemical responses under heat. When the blower cycles off, temperatures drop, the TDN remains securely within operational limits, confirming that the oil continues to provide effective lubrication.

Blower 2 shows a similar dynamic, with TDN closely following the oil temperature profile. Notably, when oil temperature drops to around 20°C indicative of machine downtime TDN also dips slightly, likely due to changes in oil conductivity and measurement sensitivity at lower temperatures. Throughout the operational cycles, TDN values remain well within the acceptable range, suggesting healthy oil condition despite these minor fluctuations.

Blower 3 maintains both TDN and temperature in a remarkably steady state across the observed timeframe. The TDN remains consistently centered within the optimal band, showing minimal variation even during operational or cooling phases. This stability suggests that Blower 3 operates under particularly uniform load conditions, with less thermal or mechanical stress, and its oil system exhibits excellent resilience and quality retention.

Blower 4 also maintains stable TDN values within the desired range, with occasional temperature drops below 20°C clearly corresponding to blower shutdowns. Importantly, these shutdowns do not precipitate any concerning declines in oil quality. The TDN profile remains flat and healthy, reinforcing confidence in both the lubrication system and the blower's mechanical integrity.

Overall, these results underscore the strength of the implemented monitoring strategy. Continuous tracking of TDN alongside temperature not only provides immediate assurance of oil health but also enables early detection of potential issues well before reaching critical failure points. Such predictive insights, derived from simple but powerful trend correlations, enhance maintenance planning, reduce unexpected failures, and contribute to the overall operational efficiency of wastewater treatment systems.



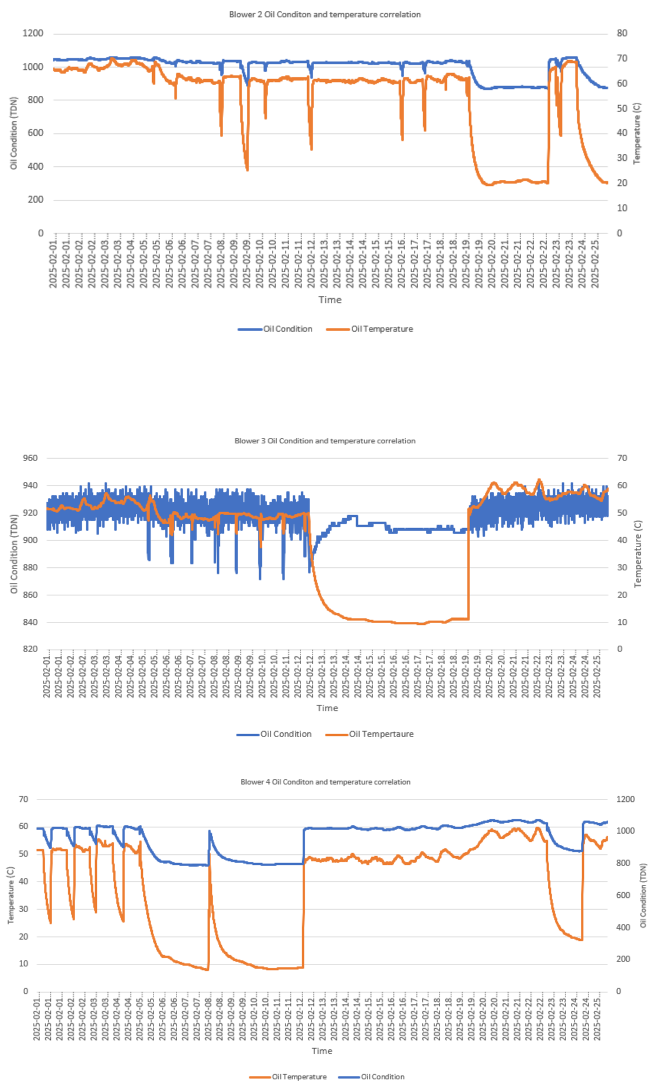


Fig. 7. Correlation between oil degradation (TDN) and temperature measurements of the four blowers showing cyclic patterns of operation

E. Operational Effectiveness and Predictive Maintenance

IoT devices are retrofitted to four blowers of the wastewater treatment plant; their data is stored in the cloud, and real-time values of the critical parameter are presented at the dashboard in Fig. 4. Vibration analysis of all four blowers is shown in Fig. 6. Finally, the oil condition and temperature analysis are presented in Fig. 7. A brief overview of the measurements for the four blowers suggests that all the data provided by the sensors suggest that the blowers are operating in good conditions and are in good health. Sensor data demonstrates high consistency and reliability, reflecting the robustness of the IoT based monitoring solution. Importantly, the system remains under continuous observation to support ongoing performance assessment and to facilitate a predictive maintenance strategy, ensuring early detection of any potential issues and minimizing unplanned downtime.

V. CONCLUSION

IoT based system in this paper for the blower of wastewater treatment plant provided real-time data visualization through an intuitive dashboard. The system generated automated alerts via email and SMS when key parameters exceeded predefined thresholds. Furthermore, the system assisted in performing proactive maintenance to minimize unplanned downtime, optimize performance, and extend equipment lifespan.

While this work primarily focused on the system's architecture, deployment, and field validation, future enhancements will expand its capabilities by integrating additional process parameters and leveraging advanced analytics. In particular, the incorporation of Artificial Intelligence (AI) and Machine Learning (ML) techniques will enable sophisticated predictive analytics, such as anomaly detection based on vibration and TDN patterns, and time-series forecasting to refine maintenance scheduling. This next phase aims to move beyond simple threshold based alerts toward predictive, data driven insights that can further strengthen maintenance strategies and overall operational efficiency.

Finally, this research highlights the potential of IoT-based solutions in transforming wastewater treatment, paving the way for smarter, more resilient, and cost-effective asset management practices.

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