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Impact of Wind Speed on Vibration Levels in Water Cooling Systems

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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Short Communication

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ABSTRACT

This study explores the intricate relationship between wind speed and structural vibrations, with a particular focus on water cooling systems in oil plants. Water cooling is a vital process in the oil and gas industry, used to dissipate excess heat generated during operations such as refining and petrochemical production. The efficient functioning of these systems is crucial to prevent overheating, which can lead to equipment failure and operational inefficiencies. The research utilizes a comprehensive dataset collected over six months, comprising 8688 observations, to perform a regression analysis that quantifies the impact of wind speed on vibration levels. The findings indicate a significant positive correlation, suggesting that as wind speed increases, so does the vibration within the system. This correlation highlights the influence of wind-induced forces on structural dynamics, potentially exacerbating mechanical wear and risking structural integrity. By understanding these dynamics, engineers can design more robust and resilient cooling systems capable of withstanding external environmental factors like wind. The results of this study provide essential insights for improving the design and maintenance strategies of water cooling systems, ensuring their efficiency and reliability in oil plants, especially in wind-prone regions. To evaluate the system's condition, vibration levels are continuously monitored and analyzed using key criteria such as mechanical stability, vibration intensity, and the system's ability to maintain operational efficiency

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under varying wind conditions. These insights help identify critical points where vibrations could compromise the cooling system's performance. This methodology ensures a comprehensive assessment of how wind-induced forces affect system stability

Keywords: Wind speed; vibration; water cooling systems; oil plants; structural integrity; regression analysis.

1. INTRODUCTION

In the oil and gas industry, water cooling systems are indispensable for managing the excess heat generated during various industrial processes. These systems are critical for maintaining operational efficiency and ensuring the safety of equipment and personnel. Excess heat, if not properly managed, can lead to severe consequences, including equipment failure, reduced operational efficiency, and even hazardous situations. Therefore, understanding and optimizing the performance of water cooling systems is of paramount importance. Water cooling systems in industrial settings, particularly in oil plants, play a crucial role in maintaining thermal balance by dissipating the heat generated during refining, petrochemical production, and other processes. These systems operate by circulating water through heat exchangers, where the water absorbs heat from the machinery and processes before releasing it into the atmosphere, often through cooling towers [1]. The effectiveness of these systems is influenced by various factors, including the design and material of heat exchangers, the quality of the cooling water, and the environmental conditions in which they operate.

Extensive research has been conducted to explore the optimization of water cooling systems. Key areas of focus include the selection of materials for heat exchangers, which must be corrosion-resistant and capable of efficient heat transfer. The quality of cooling water is also critical; factors such as temperature, pH, and the presence of contaminants can significantly impact the system's efficiency [2-4]. Water treatment processes are often employed to maintain water quality, preventing scaling and corrosion that can reduce the efficiency of heat [5,6].

exchangers. Environmental factors play a crucial role in the performance of water cooling systems. Ambient temperature, humidity, and, notably, wind speed can affect the rate of heat dissipation. Wind speed, in particular, has been identified as a significant factor influencing the performance of cooling towers [7, 8]. Higher wind speeds can enhance the rate of evaporation, which can be beneficial for cooling efficiency. However, wind can also introduce complexities, such as altering airflow patterns around the cooling towers, which can lead to uneven cooling and reduced efficiency [9,10].

Another critical aspect of water cooling systems is the impact of mechanical vibrations. Vibrations can originate from several sources, including the operation of pumps, fans, and other mechanical components [11-14]. These vibrations can lead to mechanical wear and tear, increase maintenance costs, and potentially cause equipment failure if not properly managed. External factors like wind can exacerbate these vibrations, especially in structures exposed to strong winds [15]. The combination of mechanical and wind-induced vibrations can challenge the structural integrity of the cooling towers and associated infrastructure, making it essential to understand and mitigate these effects.

Previous studies have highlighted the importance of accounting for these external factors when designing and maintaining water cooling systems. For instance, research has shown that wind-induced vibrations can significantly impact the thermal performance of cooling towers, leading to inefficiencies in heat dissipation. Additionally, the aerodynamic design of cooling towers can influence how wind affects the structure, with some designs being more prone to wind-induced vibrations than others [16, 17]. The existing body of research underscores the need for a comprehensive understanding of the interplay between wind speed, vibrations, and the overall performance of water cooling systems. By analyzing these factors, engineers can develop more robust designs that enhance system reliability and reduce the risk of operational disruptions [18]. The core target of this research is to establish the relationship between wind speed and vibration levels in industrial water cooling systems. This relationship is crucial for monitoring and detecting anomalies, such as seismic activities or mechanical malfunctions, which can significantly affect system performance. By understanding these dependencies, we aim to enhance the reliability and safety of water cooling systems, contributing to the development of an intelligent model for industrial facilities.

2. PROBLEM STATEMENT

Water cooling systems are essential for maintaining stability and safety in oil plants by dissipating the heat generated during industrial operations. Mechanical vibrations, originating from internal components like pumps and fans, or external factors such as wind speed, present a significant challenge to the reliability of these systems. In regions with high wind activity, wind-induced vibrations can amplify mechanical stresses, threatening the structural integrity of cooling towers. Although previous studies have investigated general environmental effects on cooling tower performance, there is a gap in detailed research quantifying how varying wind speeds specifically impact vibration levels. This study addresses this gap by analyzing the influence of wind speed on vibrations in water cooling systems, focusing on empirical data collected from oil plants exposed to harsh environmental conditions. Understanding these dynamics is crucial for developing resilient designs and effective maintenance strategies that can minimize the operational risks associated with excessive vibrations. In the oil and gas industry, uncontrolled vibrations can lead to significant operational disruptions, higher maintenance costs, and potentially hazardous failures. Ensuring the ability to predict and mitigate wind-induced vibrations is critical for maintaining reliable and efficient cooling systems, ultimately contributing to safer, more resilient infrastructure in extreme environments.

3. PROBLEM SOLVING

In analyzing the impact of various factors on the vibration levels in water cooling systems, we consider several key input variables and their corresponding outputs. The primary focus is on how these inputs contribute to the overall vibration observed in the system, particularly under the influence of wind speed and other environmental conditions.

3.1 Input Variables

- v- Motor's Rotating Frequency (Hz): The rotating frequency of motors within the water cooling system, measured in Hertz (Hz), is a crucial factor affecting vibrations. Motors drive essential components such as pumps and fans, which are vital for the operation of cooling towers. Variations in motor speed can lead to changes in mechanical stress and, consequently, the vibration levels. Monitoring the rotating frequency helps in identifying any irregularities or imbalances in the system.
- W- Wind Speed: Wind speed is a significant external factor that can induce additional forces on the cooling towers and associated infrastructure. These wind-induced forces can cause structural components to vibrate, leading to potential mechanical issues. Wind speed variations can affect the stability and efficiency of the cooling system, especially in regions prone to high winds.
- S- Seismic Activity (Force): While not typically a daily consideration, seismic activity can have a profound impact on structural integrity. For the purposes of this study, seismic activity is represented as an external force that could cause vibrations in the system. This force is crucial in understanding how sudden shifts or movements can influence the vibration levels within the cooling towers.
- E-Other Environmental Parameters: Other environmental factors, such as temperature, humidity, and atmospheric pressure, can also influence the vibration levels. These parameters can affect the physical properties of the materials used in the cooling system, as well as the efficiency of heat exchange processes.

3.2 Output Variable

- V-Vibration Levels: The primary output variable is the vibration level, measured in millimeters per second (mm/s). This measurement provides a quantitative assessment of the system's stability and integrity. Vibration data is collected through a network of vibrosensors placed strategically within the system. These sensors capture real-time data on the amplitude and frequency of vibrations, which are then analyzed to determine the impact of the input variables.

The relationship between these input variables and the resulting vibration levels is critical for understanding the dynamic behavior of the water cooling system. By analyzing this relationship, engineers can identify potential issues and implement strategies to mitigate excessive vibrations, ensuring the system operates efficiently and safely.

Vibration monitoring is a critical aspect of maintaining the operational health and safety of water cooling systems, particularly in oil plants where precision and reliability are paramount. This section delves into the types of vibrosensor used, their placement, and the data acquisition process, providing a comprehensive understanding of how vibrations are monitored and managed.

3.3 Types of Vibrosensors

- **Accelerometers:** Accelerometers are among the most commonly used sensors for vibration monitoring. These devices measure the acceleration of a vibrating object, which can be used to determine the frequency and amplitude of vibrations. Accelerometers are highly sensitive and can detect minute changes in vibration, making them ideal for monitoring the structural integrity of cooling towers and other components. They can be based on various technologies, including piezoelectric, capacitive, and microelectromechanical systems (MEMS).

- **Velocity Sensors:** Velocity sensors, also known as velocimeters, measure the velocity of a vibrating component. Unlike accelerometers, which measure acceleration, velocity sensors provide information on the speed of movement. This

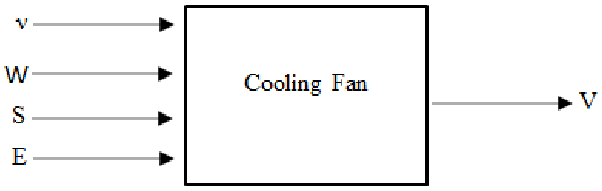

Fig.1. Input/Output parameters

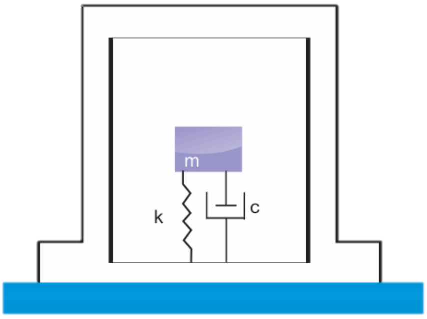

Fig. 2. Typical Capacitive Accelerometer

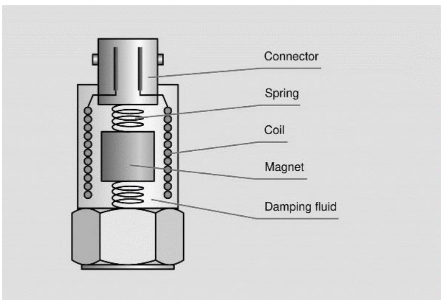

Fig. 3. Typical Inductive Velocity Sensor

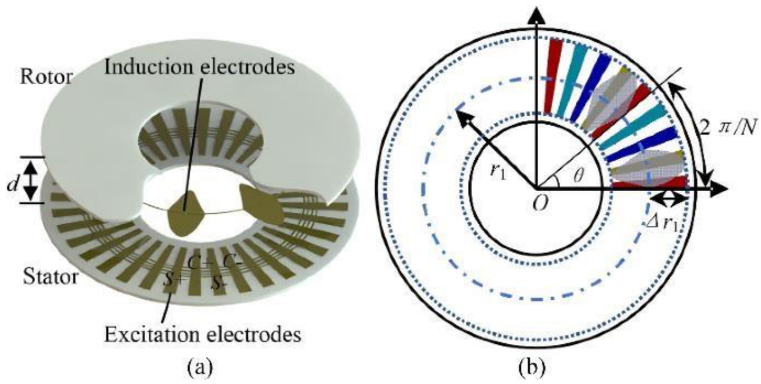

Fig. 4. Typical Displacment Sensor (Incremental Encoder)

data is crucial for understanding the energy and potential damage associated with vibrations. Velocity sensors are particularly useful for detecting low-frequency vibrations, which can be indicative of structural issues or mechanical wear.

- Displacement Sensors: Displacement sensors measure the actual physical displacement of a vibrating object. These sensors are essential for monitoring the relative movement between different parts of a system, such as between the base of a cooling tower and its structural frame. Displacement sensors can detect both static and dynamic displacements, providing valuable data on the long-term stability of the structure.

Strategic placement of vibrosensors is vital for capturing accurate and comprehensive data on the vibration levels within the system. Sensors are typically placed at critical points where vibrations are likely to be most pronounced, near motors, fans, and structural joints. Additionally, sensors are installed at different heights and locations on cooling towers to account for variations in vibration patterns caused by wind and other environmental factors. The placement strategy also involves redundancy, where multiple sensors are used to ensure data accuracy and reliability. This redundancy allows for cross-validation of data and helps in identifying sensor malfunctions or anomalies in the measurements.

The data acquisition process involves collecting and processing signals from the vibrosensors. This process is managed by a central data acquisition system (DAS), which aggregates the data from all sensors and processes it for further analysis. The DAS is responsible for filtering out noise and ensuring the integrity of the data collected. Key components of the data acquisition process include:

1. Sampling Rate: The sampling rate, or the frequency at which the vibration data of the cooling tower is collected from the sensors, is a crucial parameter. A higher sampling rate provides more detailed information about the vibration signals but also requires more storage and processing power. The choice of sampling rate depends on the expected frequency range of the vibrations and the level of detail required for the analysis.
2. Signal Conditioning: Signal conditioning involves amplifying and filtering the raw sensor signals to make them suitable for analysis. This process may include amplifying weak signals, filtering out unwanted noise, and converting the signals into a format that can be easily analyzed.
3. Data Logging and Storage: Once conditioned, the vibration data of the cooling tower is logged and stored for real-time monitoring and historical analysis. Data storage solutions must be robust enough to handle large volumes of data, especially when monitoring is conducted continuously over long periods.
4. Data Analysis: The collected data is analyzed using various techniques to identify patterns and anomalies. This analysis includes both time-domain and frequency- domain methods. In the time-domain, the focus is on identifying changes in the amplitude and duration of vibrations. In the frequency-domain, techniques such as Fast Fourier Transform (FFT) are used to decompose the vibration signals into their constituent frequencies,

helping to identify specific sources of vibration.

By employing a comprehensive vibration monitoring system with advanced vibrosensors and data acquisition techniques, engineers can gain deep insights into the operational health of water cooling systems. This system enables the early detection of potential issues, allowing for proactive maintenance and reducing the risk of catastrophic failures. Understanding the detailed characteristics of vibrations and their sources is essential for optimizing system performance and ensuring the longevity and safety of the infrastructure.

4. RESULTS

The primary objective of this analysis is to explore the relationship between wind speed and vibration levels in a water cooling system, focusing on how these vibrations are influenced under constant operational conditions. The dataset, collected over six months, comprises 8688 observations and includes key variables such as wind speed and vibration levels. During the entire measurement period, the motor's rotating frequency (Hz) remained constant, isolating wind speed as the primary variable influencing vibration levels.

The visual representation of the data includes Fig. 5. that illustrates the relationship between wind speed and vibration, measured over 30-minute intervals. The upper chart shows vibration levels, ranging from 5.8 to 7.5 mm/s, while the lower chart displays corresponding wind speeds, ranging from 0 to 40 km/h. Both charts are aligned on the same time scale, allowing for a direct comparison [18, 19]. The data reveals a noticeable correlation between increasing wind speed and elevated vibration levels, highlighting the significant impact of wind-induced forces on structural dynamics.

Key summary statistics for wind speed and vibration are as follows:

- Mean Wind Speed: 19.10 km/h
- Mean Vibration Level: 0.66 mm/s
- Median Wind Speed: 19.0 km/h
- Median Vibration Level: 0.66 mm/s
- Standard Deviation of Wind Speed: 11.42 km/h
- Standard Deviation of Vibration Level: 0.24 mm/s

Sample data points to illustrate the dataset:

Regression Model Description:

The study uses a regression model to analyze the impact of wind speed on vibration. The model is represented by the equation:

$$V = \beta_0 + \beta_1 W + \varepsilon$$

Where:

V is the vibration.
W is the wind speed.
β_0 is the intercept term.

β_1 is the regression coefficient representing the effect of wind speed on vibration.
ε is the error term.

4.1 Variables

Dependent Variable (V): Vibration. Independent Variable (W): Wind speed.

4.2 Rationale

The selection of wind speed as an independent variable is based on its hypothesized impact on vibration. Wind speed variations can influence the vibration levels in the system, thereby affecting overall performance.

4.3 Model Assumptions

The regression analysis is based on the following assumptions:

1. Linearity: The relationship between wind speed and vibration is linear.
2. Independence: The observations are independent of each other.
3. Homoscedasticity: The variance of the error terms is constant across all levels of wind speed.
4. Normality: The error terms are normally distributed.

4.4 Analysis Results

- The regression analysis indicates a significant relationship between wind speed and vibration. Below are the detailed regression statistics:

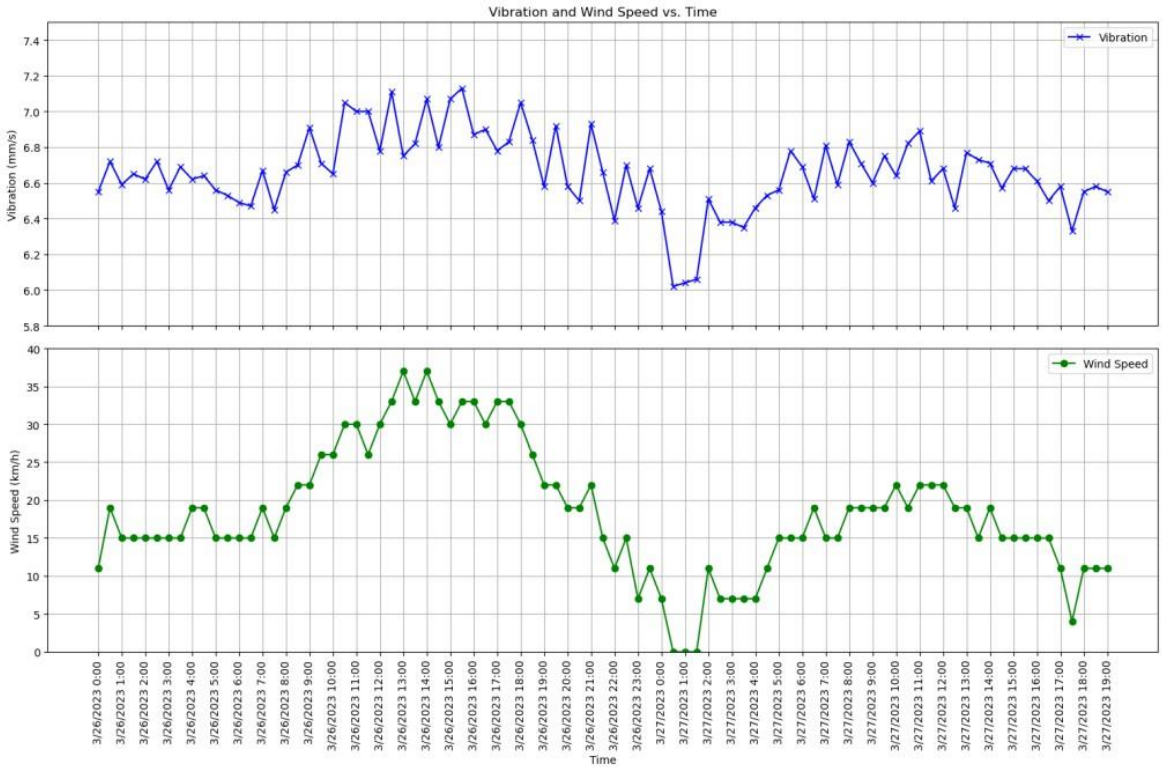

Fig. 5. Visual Analysis

Table 1. Sample Data points

Observation	Wind Speed (km/h)	Vibration (mm/s)
1	11	6.55
2	19	6.72
3	15	6.59
4	33	6.90
5	30	6.78
6	33	6.83
7	30	7.05
8	26	6.84
9	22	6.58
10	22	6.92

Table 2. Detailed regression statistics

Regression Statistics	Value
Multiple R	0.874036
R Square	0.763940
Adjusted R Square	0.763913
Standard Error	0.122874
Observations	8688

Table 3. ANOVA

df	SS	MS	F	Significance F
Regression	1	424.402102	424.402102	28109.68431
Residual	8686	131.1418733	0.015098074	
Total	8687	555.5439752		

Table 4. Coefficients

Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	6.278300083	0.00256877	2444.087843	0	6.273264684	6.283335482	6.273264684
X Variable 1	0.019354447	0.000115439	167.6594295	0	0.019128159	0.019580735	0.019128159

The R-squared value of 0.76394 indicates that approximately 76.39% of the variability in vibration is explained by wind speed. The positive coefficient for wind speed (0.019354447) suggests that an increase in wind speed is associated with an increase in vibration. The p-value for the wind speed coefficient is 0, indicating a highly significant relationship between wind speed and vibration levels.

5. DISCUSSION

The analysis confirms a strong correlation between wind speed and vibration levels in the water cooling system, as indicated by the regression model results. The R-squared value of 0.76394 suggests that wind speed accounts for approximately 76% of the variability in vibration levels. This finding demonstrates the significant role wind-induced forces play in influencing mechanical stability. In practical terms, the increase in vibration levels as wind speeds rise presents a critical challenge for maintaining the structural integrity and operational efficiency of the cooling system. These vibrations, if left unmanaged, could lead to increased mechanical wear, higher maintenance costs, and potential equipment failure. Implementing design modifications to counteract wind-induced forces, such as aerodynamic improvements or damping mechanisms, could help minimize these effects and improve system resilience. The study’s findings emphasize the need for real-time monitoring of environmental conditions to predict and manage wind-induced vibrations. This approach would allow for more adaptive maintenance strategies and enhanced reliability in regions prone to high winds. Further research could explore optimizing these systems for other environmental factors like temperature and humidity.

6. CONCLUSION

This study examined the impact of wind speed on vibration levels in water cooling systems, with a focus on maintaining a constant motor's rotating frequency. Over six months and 8688 observations, regression analysis revealed a strong positive correlation between wind speed and vibrations, indicating that as wind speed increases, vibration intensity also rises. This finding highlights the significant role of wind-induced forces in affecting the structural dynamics of these systems, especially in industrial settings like oil plants. The study's controlled conditions allowed for isolating wind speed as a primary factor influencing vibrations, explaining approximately 76.39% of the variability. These insights are crucial for engineers and designers, as understanding this relationship can lead to the development of more resilient and efficient systems, reducing maintenance costs and preventing potential failures. The research suggests that incorporating wind speed considerations into the design and maintenance phases is essential, particularly in areas prone to high winds. Additionally, the study emphasizes the need for further exploration of other environmental factors like

temperature and humidity, which could also impact vibration levels. Overall, the findings provide valuable guidance for optimizing the performance and durability of water cooling systems, ensuring their reliability in challenging environmental conditions.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1. OpenAI's Chat GPT-3

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Sukhov EA, Gurfinkel LM, Popov YuG. Abstracts of Papers, Conference and Meeting on Hydraulic Engineering. Leningrad: Energoatomizdat;1985.
2. Agayev FH, Mehdiyeva AM, Gafarov GA, Bakhshaliyeva SV, Shirinzade NV. Development of the functional safety system in primary oil refining Nafta- Gaz. Oil and Gas Institute – National Research Institute. Poland.
   Available: https://www.inig.pl/en/nafta-gaz-en/available-articles
   ISSN 0867-8871
3. Available:https://www.vibrosystm.com/en/library/
4. Available:https://wilcoxon.com/resources/applications-and-case-studies/
5. Kim S, Chen J, Yang X. Vibration Analysis of Cooling Systems in Harsh Environments. Journal of Applied Mechanics. 2021;90(1):334-348.
   DOI:10.1115/1.4049712
6. Singh K, Ahmed M. Optimization of cooling systems for wind- induced vibration mitigation. International journal of energy research. 2022;46(11):9074-9083.
   DOI:10.1002/er.7642.
7. Gladkov VA, Aref'ev YuI, Ponomarenko VS. Mechanical-Draft Cooling Towers. Moscow: Stroiizdat; 1976.
8. Ponomarenko VS, Aref'ev YuI. Cooling towers of power manufactures: Handbook. Moscow: Energoatomizdat; 1988.
9. Johnson P, Taylor R. Impact of environmental factors on cooling system efficiency. Journal of Mechanical Engineering Science. 2022;68(3):456-472.
   DOI:10.1177/0954406221992035.
10. Wang L, Zhao Y, Liu H. Wind-Induced Vibrations in Industrial Structures: A Review. Energy Procedia. 2023;144:102-110.
    DOI:10.1016/j.egypro.2023.02.027.
11. Li T, Zhang Y, Huang X. Analysis of wind speed effects on cooling tower performance. Journal of Environmental Engineering, 2023149(5), 401-412.
    DOI:10.1061/(ASCE)EE.1943-7870.0002039
12. Patel A, Verma P. Real-Time monitoring of cooling tower vibrations in oil plants. Journal of Process Mechanical Engineering, 202267(8), 2331-2345.
    DOI:10.1177/09544089211047852.
13. García E, Martínez J. Advanced vibration control techniques in industrial cooling systems. Journal of control and automation systems. 2023;18(2):129-140.
    DOI:10.1007/s12555-022-01594-8.
14. Ranjan R, Chakraborty S. Wind-Induced vibrations and structural integrity in cooling systems. Energy Reports. 2021; 7:1730-1741.
    DOI:10.1016/j.egyr.2021.04.012.
15. Talosh-Teoresku A. Abstracts of papers, conference and meetings on hydraulic engineering. Main trends of investigation improvements and power modules. St. Petersburg: VNIIG im. B.E. Vedeneeva; 1992.
16. Hill GB, Pring EJ, Osborn PD. Cooling Towers: principles and practice. London: Butterworth-Heinemann; 1990.
17. Yusifov Sİ, Mayilov RA, Mehdiyeva AM, Mehdizade EK. Advanced Information-Measuring System for the Improvement of the Quality Indicators of Metrological Characteristics. E3S Web of Conferences (Environment, Energy and Earth Sciences). 2024; 474:02003.
    Available:https://doi.org/10.1051/e3sconf/202447402003
    ISSN: 2267-1242.
18. Agayev FH, Mehdiyeva AM, Ibrahimova AE. Advance technologies to eliminate environmental problems of oil and gas

processing. 2nd international conference on emerging applications of material science and technology (ICEAMST 2024), Bengaluru, India. Advances in Science, Technology & Innovation (Springer Book Series). 2024;3-4

19. Kalatuzov VA. Hydromechanics. Moscow: Izd. MGTU im. N.E.Baumana; 2002.

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