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Preventive Maintenance and Lubrication Performance Analysis of Gas Generators Used in CNG Refueling Stations: A Comprehensive Review Paper

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ABSTRACT

Gas generators used in compressed natural gas (CNG) refueling stations operate continuously under high load and severe environmental conditions. These operating conditions expose generator components to friction, wear, contamination, thermal stress, and lubrication degradation. Effective lubrication management and preventive maintenance are therefore essential for maintaining operational reliability, reducing downtime, and extending equipment life. This review paper presents a comprehensive analysis of lubrication performance and preventive maintenance strategies for gas generators used in CNG refueling stations. The study critically reviews previous research related to tribology, lubricant degradation, oil contamination, predictive maintenance, vibration monitoring, lubrication optimization, and condition monitoring techniques. The paper also discusses modern data-driven maintenance systems and intelligent lubrication management approaches. The findings indicate that proper lubrication analysis combined with predictive and preventive maintenance significantly improves generator efficiency, reliability, and operational safety.

KEYWORDS: Preventive maintenance, lubrication system, tribology, gas generator, predictive maintenance, oil degradation, condition monitoring, CNG refueling station.

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1. INTRODUCTION

Compressed natural gas (CNG) has emerged as one of the most widely adopted alternative fuels due to its environmental benefits and economic advantages. The growing use of CNG-powered vehicles has driven rapid expansion of CNG refueling stations worldwide, particularly in developing countries such as Bangladesh. Gas generators are commonly installed in these stations to supply electrical power for compressors, dispensers, lighting systems, and auxiliary equipment. These generators typically operate continuously under fluctuating load conditions, which imposes significant tribological and thermal stresses on engine components. As a result, lubrication and maintenance systems play a critical role in ensuring reliable and efficient operation [1].

Lubrication systems are essential for reducing friction, minimizing wear, dissipating heat, preventing corrosion, and enhancing overall engine performance. However, their effectiveness is often compromised by oil contamination, thermal degradation, oxidation, and inadequate maintenance practices. Previous studies have shown that poor lubrication management can lead to bearing failure, accelerated wear, increased fuel consumption, overheating, and unexpected system shutdowns [2], [3].

Predictive and condition-based maintenance approaches have been widely investigated to improve lubrication reliability in industrial engines. Techniques such as vibration monitoring, oil condition analysis, and sensor-based diagnostics have demonstrated strong potential in detecting early-stage faults and preventing catastrophic failures [1], [2].

This review paper critically examines previous research on lubrication performance and preventive maintenance strategies for gas generators used in CNG refueling stations, with a focus on improving operational reliability and extending equipment service life.

2. FUNDAMENTALS OF TRIBOLOGY AND LUBRICATION

Tribology refers to the science of friction, wear, and lubrication between interacting surfaces. Lubrication significantly reduces surface damage and energy loss in mechanical systems [10]. Lubrication systems operate under three primary lubrication regimes: 1. Boundary lubrication 2. Mixed lubrication 3. Hydrodynamic lubrication Gas generators used in CNG stations primarily operate under mixed and hydrodynamic lubrication conditions due to varying operating loads and temperatures [11].

3. OIL CARRYOVER AND CONTAMINATION ANALYSIS

Oil contamination is particularly significant in CNG refueling stations because compressors and generators operate continuously under high pressure conditions. Oil contamination is one of the major causes of lubrication-related failures in industrial generators. Arrhenius et al. investigated analytical methods for determining oil carryover from CNG and biomethane refueling stations. Their study focused on solvent-based analytical techniques for detecting compressor oil contamination [1].

The researchers concluded that oil carryover in CNG/biomethane refueling stations negatively affects generator and compressor performance by reducing operational efficiency, increasing mechanical wear, contaminating fuel quality, and accelerating lubrication degradation. The study emphasized that effective oil monitoring and contamination control are essential for improving equipment reliability, lubrication performance, and overall system efficiency [1].

The study highlighted that regular oil contamination monitoring, effective lubricant filtration systems, periodic oil analysis, and proper preventive maintenance scheduling are essential for maintaining lubrication quality, preventing equipment failure, reducing wear, and improving the reliability and efficiency of gas generators and CNG refueling station systems. Oil contamination is particularly significant in CNG refueling stations because compressors and generators operate continuously under high-pressure conditions [1].

4. LUBRICATING OIL DEGRADATION

Lubricating oil gradually degrades due to thermal stress, oxidation, and contamination. Thinprukgam et al. analyzed degradation factors of semi-synthetic lubricant oil in gasoline-CNG engines. The research identified that lubricating oil degradation in gasoline-CNG engines mainly occurs due to thermal oxidation, carbon deposit formation, fuel dilution, moisture contamination, and viscosity reduction. These degradation mechanisms reduce lubrication effectiveness, increase friction and wear, and negatively affect engine performance and reliability. The study showed that prolonged high-temperature operation significantly reduces lubricant effectiveness and accelerates wear [3].

Ratoi et al. studied the influence of organic friction modifiers on tribofilms formed in engine oils. Their findings demonstrated that friction modifiers significantly improve lubrication performance by reducing friction and wear between contacting surfaces. The additives help stabilize tribological surfaces, enhance protective oil film formation, and improve the overall efficiency and durability of engine components. These findings indicate that lubricant additives play a major role in maintaining generator reliability [6].

5. EFFECTS OF LUBRICANT CONTAMINANTS ON TRIBOLOGICAL PERFORMANCE

Ali et al. investigated the effects of lubricant contaminants during reciprocating sliding conditions. The study observed that contaminated lubricants degrade tribological performance by increasing surface roughness, wear rate, friction coefficient, and overall surface damage. This leads to reduced lubrication efficiency, faster component deterioration, and a higher risk of mechanical failure. The researchers concluded that contamination particles disrupt lubrication film stability and accelerate mechanical degradation [4].

The study recommended improving oil filtration systems, implementing scheduled oil replacement, conducting regular oil condition monitoring, and ensuring proper contamination control systems. These measures help maintain lubricant quality, reduce wear, and improve the reliability and lifespan of mechanical components. These recommendations are directly applicable to gas generators operating continuously in CNG refueling stations [4].

6. PREDICTIVE MAINTENANCE AND CONDITION MONITORING

Traditional maintenance methods are increasingly being replaced by predictive maintenance systems. Kumar and Singh identified that predictive maintenance of industrial gas engines relies on multiple monitoring techniques, including vibration analysis, thermal monitoring, oil condition analysis, acoustic emission monitoring, and sensor-based diagnostic systems. These methods help detect early signs of faults, improve reliability, and reduce unexpected equipment failures. Predictive maintenance helps identify faults before severe mechanical failure occurs [17]. Oliveira et al. proposed a vibration-based method for identifying lubrication conditions in hydrodynamic bearings. Their research demonstrated that rotor vibration responses can successfully detect lubrication deterioration [5].

Predictive maintenance provides several key advantages, including reduced downtime, early detection of faults, improved maintenance planning and scheduling, lower operational and repair costs, and enhanced overall system reliability and efficiency. These techniques are highly effective for continuously operating industrial gas generators.

7. PROACTIVE LUBRICATION MANAGEMENT

Pytel et al. [2] investigated proactive maintenance and data-driven optimization of mineral lubricating oil in gas engine cogeneration systems. The researchers developed intelligent maintenance systems that analyze oil viscosity, oil temperature, wear particle

concentration, and lubricant degradation trends. These parameters help assess lubricant condition in real time, enabling early fault detection, optimized maintenance scheduling, and improved engine reliability. Their findings showed that proactive lubrication management enhances system performance by improving operational reliability, extending lubricant service life, reducing maintenance costs, and increasing overall engine efficiency. The study emphasized the growing importance of intelligent maintenance systems in industrial applications.

8. LUBRICATION INJECTION AND FLOW CONTROL SYSTEMS

Dueholm et al. [7] investigated lubrication injection systems in large marine diesel engines using common rail lubrication technology. Their findings showed that proactive lubrication management enhances system performance by improving operational reliability, extending lubricant service life, reducing maintenance costs, and increasing overall engine efficiency. Although the study focused on marine engines, the lubrication control principles are applicable to gas generators used in CNG refueling stations. Advanced lubrication flow control systems may significantly improve lubrication performance and operational efficiency.

9. PREVENTIVE MAINTENANCE STRATEGIES

Preventive maintenance involves regular inspection and servicing before equipment failure occurs. Effective preventive maintenance significantly improves machinery reliability and operational safety [12,16]. Daily maintenance activities focus on ensuring safe and continuous operation of the system. These include checking the oil level, monitoring oil pressure, inspecting for any oil or fuel leakage, and observing abnormal noise or vibration. Regular execution of these tasks helps in early fault detection, prevents unexpected breakdowns, and ensures reliable generator performance. Weekly maintenance activities are performed to ensure the proper functioning of the lubrication and mechanical systems. These include cleaning or inspecting filters to prevent clogging, checking lubrication lines for blockage or leakage, and monitoring bearing temperature to detect early signs of overheating or wear. Regular weekly maintenance helps maintain system efficiency and prevents progressive damage [12,14].

Monthly maintenance activities are essential for maintaining lubrication quality and overall machine health. These include replacing lubricating oil and filters to ensure clean and effective lubrication, inspecting seals to prevent leakage, and checking bearings for wear or damage. Regular monthly servicing helps maintain engine efficiency, reduce wear, and improve system reliability [14,16].

Annual maintenance activities involve a comprehensive inspection and servicing of the entire generator system. This includes a complete generator inspection to assess overall condition, a lubrication system overhaul to restore optimal oil circulation and performance, and performance testing to evaluate efficiency, reliability, and operational stability. Annual maintenance ensures long-term durability and prevents major failures [12,16]. Systematic maintenance significantly reduces breakdown frequency and maintenance cost.

10. RELIABILITY ASSESSMENT OF GAS GENERATORS

Ahmed and Rahman [19] investigated reliability assessment of gas generators operating continuously in industrial environments. Their study showed that lubrication quality is a critical factor in determining generator reliability. Poor or degraded oil increases the probability of system failure, while effective preventive maintenance enhances operational stability. In addition, continuous condition monitoring helps reduce downtime by detecting faults early and enabling timely maintenance actions. Reliability-centered maintenance is therefore essential for industrial generator systems [19, 21, 22].

11. LUBRICATION OIL ANALYSIS FOR PREDICTIVE MAINTENANCE

Patel and Shah [18] studied lubrication oil analysis for predictive maintenance in power generation systems. Their research identified key oil analysis parameters used to evaluate lubricant condition, including viscosity, acid number, water contamination level, metal wear particles, and oxidation level. Monitoring these parameters helps detect oil degradation, identify internal wear, and support predictive maintenance decisions to improve equipment reliability. Oil analysis helps identify early signs of mechanical and lubrication-related problems, including bearing wear, lubricant degradation, contamination, and other internal mechanical abnormalities. This enables timely maintenance actions, reduces the risk of unexpected failures, and improves overall system reliability. Regular oil analysis therefore supports predictive maintenance and improves generator reliability [18].

12. PERFORMANCE EVALUATION OF LUBRICATION SYSTEMS

Bose and Chatterjee [20] evaluated lubrication systems in stationary gas engines. Their study showed that effective lubrication systems play a vital role in improving engine performance by reducing frictional losses, enhancing thermal stability, increasing overall engine efficiency, and minimizing mechanical wear. This leads to improved reliability, longer equipment life, and lower maintenance requirements. The researchers concluded that lubrication system performance directly affects operational reliability and fuel efficiency [20].

13. OPTIMIZATION OF CNG REFUELING STATION OPERATION

Özcan and Kılıç [8] developed a dynamic model for CNG refueling station optimization using multi-objective optimization techniques. The study demonstrated that operational optimization improves system performance by reducing thermal stress, minimizing mechanical loading, enhancing energy efficiency, and increasing overall equipment reliability. This results in smoother operation, lower maintenance requirements, and improved long-term system stability. Optimized operating conditions indirectly improve lubrication performance and maintenance efficiency [8].

14. DISCUSSION

The reviewed literature demonstrates that lubrication management and preventive maintenance are highly interconnected in industrial gas generators. Oil contamination significantly accelerates component wear, while lubricant degradation reduces lubrication effectiveness [1,3,4]. Predictive maintenance enhances early fault detection, and vibration monitoring is effective in identifying lubrication-related issues [5]. Intelligent lubrication monitoring systems improve maintenance planning and decision-making, while preventive maintenance practices significantly reduce operational downtime and improve system reliability [12]. Modern maintenance systems increasingly rely on advanced technologies such as IoT sensors, data analytics, AI-based diagnostic systems, and intelligent lubrication monitoring systems for real-time condition assessment [2,17].

15. CONCLUSION

This review paper analyzed previous studies related to preventive maintenance and lubrication performance analysis of gas generators used in CNG refueling stations. The literature confirms that effective lubrication management significantly reduces friction, wear, contamination effects, and thermal stress [1–6]. Preventive maintenance techniques such as oil analysis, vibration monitoring, predictive diagnostics, lubrication optimization, and condition monitoring significantly improve operational reliability and reduce maintenance costs [5,17,18]. The integration of intelligent monitoring technologies and data-driven maintenance systems offers significant potential for improving future industrial gas generator performance [2].

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