Artificial intelligence and grease get engaged. Wedding scheduled for 2026

Dr. Raj Shah and Mr. William Chen

Introduction

The rise of artificial intelligence (AI) has revolutionized numerous industries by enhancing the way processes are developed, tested, and optimized. One such area is the grease industry, where lubricating greases play a crucial role in reducing friction and preventing machine wear under extreme conditions such as high loads, temperatures, or contaminant-heavy environments. While established methods like the Four-Ball Wear Test and Dropping Point Test are widely used and effective, they can be resource-intensive and may not fully address the complexities of modern grease formulations and the industry's evolving performance needs [1]. As the industry moves towards more advanced and environmentally friendly formulations, AI offers a promising solution for accelerating testing, formulation development, and product optimization.

Grease, a semi-solid lubricant, differs from traditional liquid lubricants by incorporating a thickening agent that helps it stay in place under varying conditions, making it ideal for applications where continuous lubrication is difficult. It is composed of a base oil, thickener, and various performance-enhancing additives. The unique properties of grease make it necessary in high-temperature, high-pressure, and high-stress industrial applications. However, these same properties make it more challenging to predict how greases will behave under varying conditions because the semi-solid structure can respond unpredictably to changes in temperature, pressure, and shear forces, affecting the distribution and flow of the lubricant. [2]. AI provides a new frontier in developing innovative greases with optimized performance by enabling more precise data analysis and real-time monitoring. Additionally, AI can help manufacturers design products that are more efficient, sustainable, and capable of performing under increasingly strict regulations, as well as enhancing data analysis and organization, to facilitate early detection of grease-related issues like degradation, contamination, and viscosity breakdown. These issues account for 66% of machine failures and repair costs, making proactive detection critical [3]. Major players in the industry, such as Shell and ExxonMobil, are already leveraging AI for more sophisticated predictive maintenance systems, which enable more accurate forecasting, reduce unexpected downtime, and enhance operational efficiency [4].

This paper provides a comprehensive overview of AI models, such as artificial neural networks (ANNs), convolutional neural networks (CNNs), and fuzzy logic, demonstrating how these techniques are transforming the grease industry. These AI models reduce the time and cost associated with traditional grease testing and development methods while enabling companies to create more sustainable, high-performance greases that meet evolving regulatory and operational requirements.

AI Models developed in Performance Predication of Grease

AI, particularly machine learning techniques like artificial neural networks (ANNs) and convolutional neural networks (CNNs), has become an essential tool for predicting grease performance. However, these AI systems often leverage foundational methods like design of experiments (DOE), statistical analysis, and mathematical modeling to enhance prediction accuracy and ensure reliable outcomes. For example, DOE frameworks are used to systematically plan and analyze experiments, allowing researchers to efficiently explore the relationships between multiple input factors such as base oil type, additive concentrations, operating conditions, and performance outputs like friction coefficients or thermal stability. Statistical methods, such as regression analysis and principal component analysis (PCA), play a crucial role in preprocessing experimental datasets for AI models, identifying key variables, and reducing dimensionality. Mathematical logic, such as optimization algorithms and non-linear equations, further supports AI by providing a structured framework for formulating grease behavior under varying conditions. These traditional tools are seamlessly integrated with AI techniques, enabling manufacturers to predict grease properties and optimize formulations more effectively.

ANNs, first utilized in 1998 for wear particle classification during ball-on-disc experiments [6,7], are now advanced tools in predicting key grease metrics such as wear resistance, friction coefficients, and thermal degradation. As shown in figure 1, ANNs consist of multiple layers, including input, hidden, and output layers [8]. These layers are connected by weighted nodes and biases, which enable the network to model complex, non-linear relationships between grease composition and key performance metrics, such as consistency, shear stability, wear resistance, and friction coefficients. They can identify non-linear relationships between input variables (such as base oil type, thickener structure, and additive concentrations) and output properties (such as thermal stability, oxidation resistance, and load-bearing capacity) [6,7]. This level of precision enables manufacturers to fine-tune grease formulations for specific industrial applications. A notable example is the use of ANNs to optimize grease formulations that incorporate advanced additives like graphene and carbon nanotubes [6]. These additives have shown tremendous potential in enhancing the performance of greases, particularly in reducing friction and improving wear resistance under extreme operating conditions. However, their behavior in grease formulations can be unpredictable due to the complexity of the interactions between the additives, thickeners, and base oils. AI models like ANNs can analyze vast amounts of data from experiments, simulations, and field tests, allowing manufacturers to predict how various concentrations of these additives will influence grease performance under different conditions.

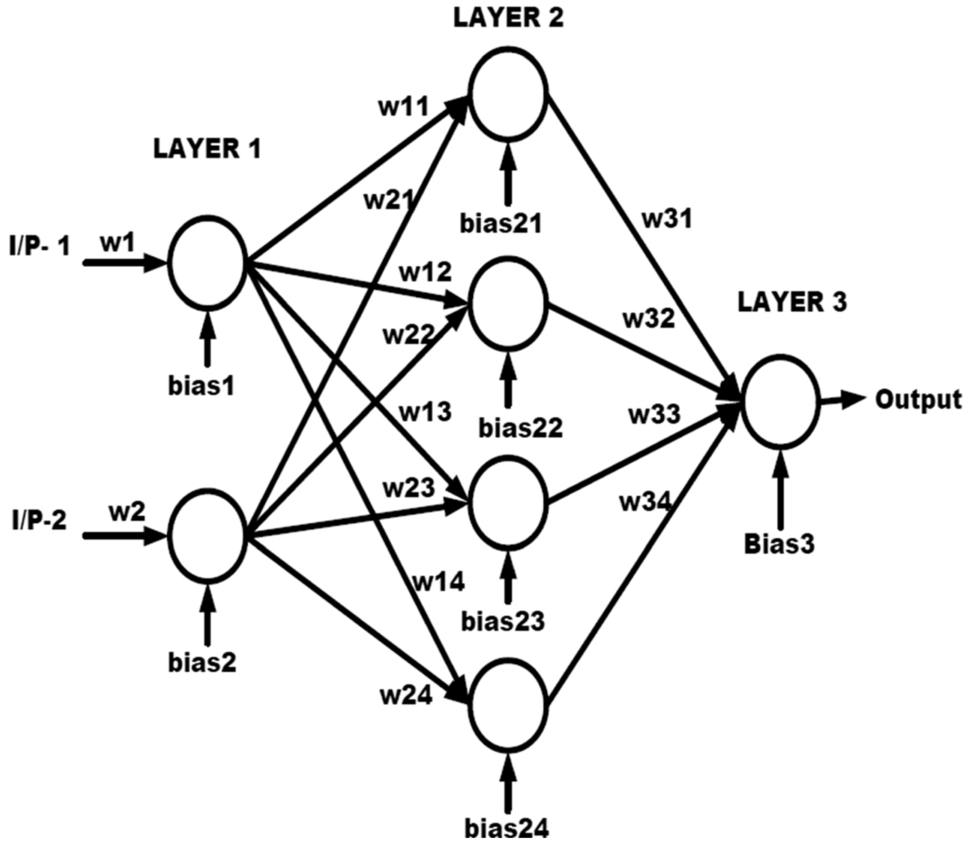

Figure 1: Feed forward ANN architecture [8]

In a notable study, Rosenkranz et al. demonstrated how ANNs, coupled with genetic algorithms, could optimize vegetable oil-based greases containing carbon nanotubes, reducing the friction coefficient (COF) by 50% [4]. The ANN was trained using a dataset that included experimental results for various grease formulations, where input parameters such as the concentration of carbon nanotubes, type of vegetable oil, thickener content, and operating conditions like temperature and load were fed into the model. The genetic algorithm was employed to search for the optimal combination of these parameters by continuously generating new grease formulations and evaluating their performance based on the COF. Through this repetitive process, the ANN learned to predict COF accurately by adjusting its internal weights and thresholds, while the genetic algorithm fine-tuned the input variables, eventually identifying the formulation that provided the most significant reduction in friction. This AI approach significantly reduced development time compared to traditional methods, which would have required extensive trial-and-error experimentation. The combination of ANNs with genetic algorithms allows grease manufacturers to explore a wide range of formulation options quickly and efficiently, ensuring the best possible performance with minimal resource expenditure.

Fuzzy logic is another AI tool gaining popularity in the grease industry, particularly for applications where uncertainty and non-linear behavior are significant [6,7]. Grease formulations are notoriously difficult to model due to their complex behavior under different conditions, such as shear thinning, thermal degradation, or contamination [7]. Fuzzy logic systems can analyze data from multiple sources, including real-time sensor inputs, laboratory experiments, and field data, to provide accurate predictions about grease behavior under specific operating conditions. Unlike binary logic systems, which classify results as either true or false, fuzzy logic operates with degrees of truth, allowing it to handle the imprecision inherent in grease formulation. This makes fuzzy logic particularly well-suited to predicting how greases will respond to variable conditions, such as fluctuating temperatures or loads. In contrast to ANNs, which require large datasets to learn patterns and provide highly accurate predictions, fuzzy logic can make decisions based on smaller amounts of data and expert-driven rules, making it particularly useful in situations where data is sparse or uncertain [17]. For example, while ANNs are highly effective for tasks such as predicting the friction coefficient of greases by learning from experimental data, they may struggle in situations where inputs are not well-defined or where real-time adaptability is crucial. Traditional methods, such as regression models, also fall short when dealing with imprecise inputs, as they rely on fixed mathematical relationships rather than adaptive reasoning. By integrating fuzzy logic with ANNs, grease manufacturers can develop hybrid models that combine the quantitative precision of ANNs with the qualitative flexibility of fuzzy logic. These hybrid models can offer more accurate predictions about grease performance, helping manufacturers design products that perform reliably across a wide range of conditions [9].

While ANNs and fuzzy logic are primarily used for performance prediction, CNNs are increasingly being used for real-time monitoring of grease-lubricated systems. CNNs, as illustrated in figure 2, are particularly well-suited to analyzing complex sensor data, such as vibration patterns, temperature fluctuations, or pressure variations, to detect signs of grease degradation or contamination [10]. This data can be used to predict when grease needs to be reapplied or when machinery is at risk of failure due to insufficient lubrication. For example, Hassan et al. developed a CNN-based real-time monitoring system that detects contamination accumulation in grease-lubricated bearings. The model continuously analyzed images from machine-environment interactions, detecting signs of grease degradation and enabling timely intervention [10]. By identifying potential issues before they lead to machinery failure, such systems reduce downtime, improve operational efficiency, and extend the lifespan of critical equipment.

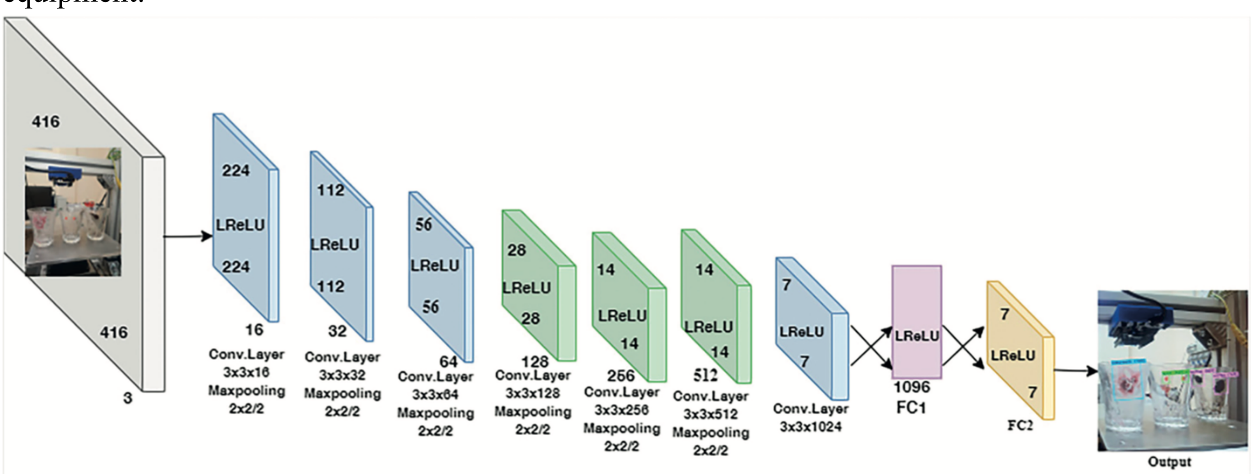

Figure 2: Architecture of a CNN model [10]

Several industries are already adopting AI models for both performance prediction and real-time monitoring. For example, Axel Christiernsson International AB, a leading European grease manufacturer, is at the forefront of integrating AI into their grease production and performance monitoring systems [11]. The company aims to harness AI to deliver customized lubrication solutions tailored to specific machinery needs, optimizing the performance and longevity of both the grease and the equipment. AI allows them to enhance operational efficiency by accurately predicting when lubrication is needed, reducing friction losses, and preventing premature machinery wear. One of the key benefits highlighted by their Product Manager, Mikael Kruse, is that AI helps improve a company's Total Cost of Ownership (TCO) by providing more effective, tailor-made grease solutions that minimize the risk of machinery failure. As AI technologies continue to advance, Axel Christiernsson expects AI to play an even more integral role in providing precise, automated maintenance predictions, ultimately reducing downtime and enhancing productivity. AI models are now able to predict potential machinery failures with accuracy rates as high as 92%, transforming the way grease manufacturers optimize equipment performance [12].

AI in Sustainability and Regulatory Compliance

As environmental regulations tighten and industry moves toward more sustainable practices, the development of environmentally acceptable greases has become a priority for grease manufacturers. These greases incorporate biodegradable additives and are designed to minimize leakage and environmental impact [13]. AI plays a critical role in developing greener formulations by enabling manufacturers to strike a balance between performance, regulatory compliance, and broader sustainability goals. These goals encompass reducing environmental impact through lower emissions, minimizing resource consumption during production, and enhancing biodegradability or recyclability of products. By analyzing complex datasets, AI supports decision-making across the entire product lifecycle, ensuring that formulations not only perform effectively but also align with global environmental standards and long-term sustainability objectives.

AI models, such as ANNs and fuzzy logic systems, can analyze how various biodegradable base oils and thickeners interact under operational stresses, allowing manufacturers to design greases that perform well under stringent environmental regulations. This capability is particularly important in industries like marine, construction, and agriculture, where grease leakage can have significant environmental consequences [13]. AI helps optimize formulations that meet regulatory standards without compromising on performance, ensuring that greases are both effective and eco-friendly. In response to stricter regulations on emissions and waste management, the grease industry is increasingly moving towards AI-based testing to meet these standards. AI systems can predict how a grease will perform in accordance with industry standards, such as those established by the American Petroleum Institute (API) and the

European Automobile Manufacturers' Association (ACEA). However, these systems are not typically focused on environmental certifications like Blue Angel, Nordic Swan, EU Ecolabel, EcoLogo, or US EPA VGP/VIDA, which are key drivers in promoting environmentally acceptable lubricants and greases. These AI-driven systems analyze various factors, including viscosity, contamination, and thermal stability, to ensure that greases meet stringent performance and environmental regulations before physical testing occurs. For instance, the API focuses on specifications for motor oils and lubricants that ensure performance in extreme conditions, while ACEA prioritizes durability and environmental performance in Europe, including reducing emissions and improving fuel efficiency [14]. AI predictions enable manufacturers to adjust formulations during development, ensuring they meet regulatory standards before physical testing. By simulating performance and compliance outcomes, AI minimizes the need for trial-and-error, saving time and resources while improving formulation efficiency.

The global push for net-zero emissions is also accelerating the demand for sustainable greases. For example, as illustrated in figure 3, the European Union aims to ban the sale of internal combustion engine (ICE) vehicles by 2035 as part of its plan to reach net-zero emissions by 2050. Similarly, California's Air Resources Board (CARB) has implemented regulations that will require 100% of new vehicles sold to be zero-emissions by 2035 [13]. These regulatory trends underscore the need for high-performance, eco-friendly greases that not only meet emissions standards but also maintain efficiency across various industries. In the United States, the Environmental Protection Agency (EPA) has introduced stricter emissions guidelines for 2027-2032 model-year vehicles, further reinforcing the importance of sustainable lubrication solutions [15]. Together, these efforts signal a new era in sustainability where ongoing improvements in grease formulations are essential. For EALs, manufacturers will need to entirely rethink formulations, using AI to achieve the delicate balance between sustainability and performance, ensuring that greases meet regulatory expectations while remaining effective in demanding operational environments [13,15]

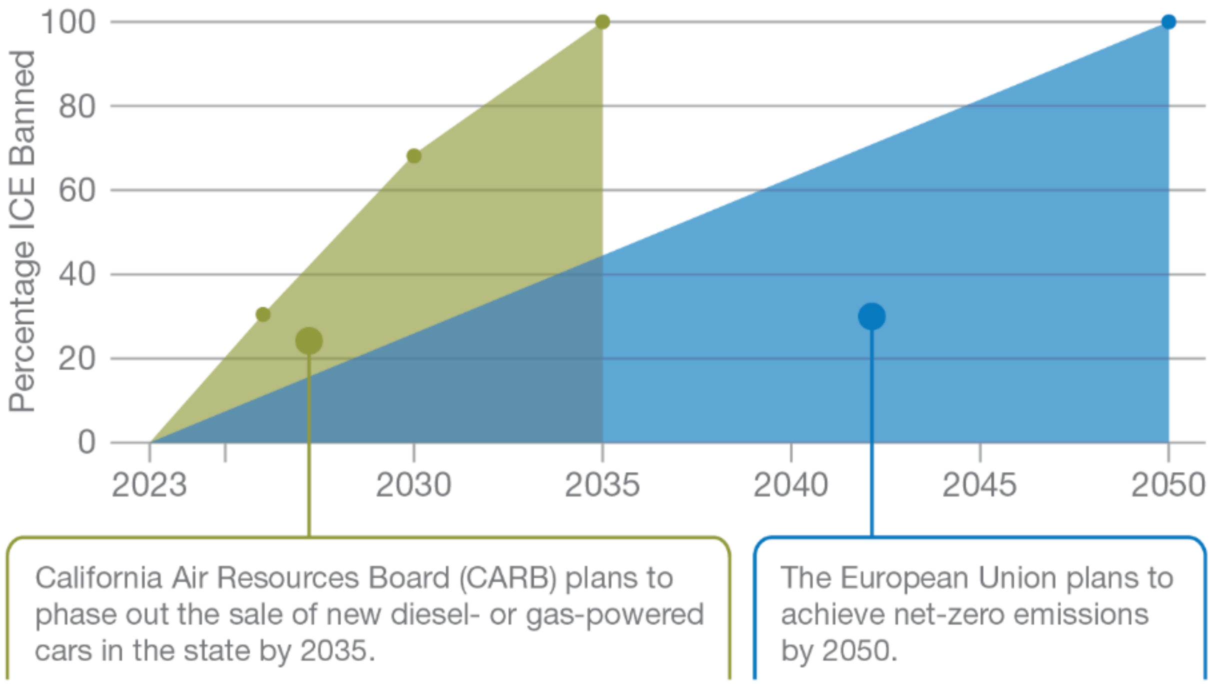

Figure 3: Government plans to achieve net zero emission by phasing out internal combustion engine [13].

Applications of AI in Grease Testing and Real-Time Monitoring

AI models are transforming the way grease formulations are tested and simulated. Rather than relying solely on physical trials, manufacturers are using AI-driven simulations to predict how grease will perform under various operational conditions. These models, based on real-time sensor data or historical performance data, enable more efficient experimentation. The integration of AI-based simulations allows companies to speed up their research and development cycles significantly. By simulating performance in extreme conditions, such as high temperatures or heavy loads, potential issues can be identified and mitigated before physical testing begins. This approach enables the rapid development of products tailored to specific industrial applications, reducing both costs and time-to-market.

In addition to aiding grease formulation, AI plays a crucial role in real-time monitoring of grease-lubricated systems. Traditional maintenance strategies typically rely on predefined schedules or periodic inspections to determine when machinery requires lubrication. This can lead to inefficiencies, as equipment may be either over-lubricated or under-lubricated, resulting in reduced machine lifespan and potential downtime. AI systems, particularly CNNs and machine learning models, analyze sensor data—capturing metrics like temperature, load, and vibration—to predict when grease is needed [16]. These systems can automatically detect signs of contamination or wear and recommend corrective actions before failure occurs.

For example, in one study by Holzer et al., AI models were used to differentiate normal versus abnormal soot accumulation rates in greases [9]. Their models improved the precision of maintenance alerts by a factor of 3.9, reducing unnecessary interventions and extending equipment life by ensuring lubrication is applied only when required. This improvement allowed industries to reduce unnecessary interventions and extend equipment life by ensuring lubrication is applied only when needed. The AI models achieved this by analyzing historical data from 7,683 assets and using machine learning to distinguish between typical soot buildup and abnormal spikes that could indicate mechanical issues, such as injector problems [9].

The AI's ability to track multiple variables—such as wear metal concentrations and contaminant levels—simultaneously resulted in a 4.5-fold increase in critical alerts with a 30-day lead time. This predictive maintenance capability not only eliminated many false positives that traditional statistical-based alerts often triggered but also provided more reliable recommendations for maintenance scheduling. As a result, industries could significantly reduce downtime and streamline operations by avoiding manual inspections and optimizing the timing of interventions.

Conclusion

Artificial Intelligence is reshaping the grease industry by optimizing formulations, enhancing performance prediction, and enabling real-time monitoring. As the industry moves towards sustainability with the development of environmentally acceptable greases, AI plays a pivotal role in balancing performance with eco-friendly practices. The integration of AI-driven models like ANNs, CNNs, and fuzzy logic reduces the reliance on labor-intensive testing methods and accelerates the discovery of high-performance greases that comply with regulatory standards.

In terms of the future, the development of hybrid AI models that merge machine learning with physical chemistry principles will further improve the reliability and performance of greases under extreme conditions. The grease industry is assured to benefit from these innovations, leading to more efficient, sustainable, and cost-effective products that meet the evolving needs of industrial applications. However, to fully realize AI's potential in the grease industry, collaboration between academia and industry stakeholders is essential Continued investment in research and development, coupled with the establishment of industry standards for AI integration, will ensure that these technologies are applied effectively and in a responsible manner, ensuring data privacy, avoiding biases in algorithms, and supporting sustainable practices. This will not only enhance the performance and sustainability of grease formulations but also create innovation and competitiveness in the global market.

About the Authors

Dr. Raj Shah is a Director at Koehler Instrument Company in New York, where he has worked for the last 30 years. He is an elected Fellow by his peers at IChemE, AOCS, CMI, STLE, AIC, NLGI, INSTMC, Institute of Physics, The Energy Institute and The Royal Society of Chemistry. An ASTM Eagle award recipient, Dr. Shah recently coedited the bestseller, "Fuels and Lubricants handbook", details of which are available at ASTM's Long Awaited Fuels and Lubricants Handbook 2nd Edition Now Available. https://bit.ly/3u2e6GY

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He earned his doctorate in Chemical Engineering from The Pennsylvania State University and is a Fellow from The Chartered Management Institute, London. Dr. Shah is also a Chartered Scientist with the Science Council, a Chartered Petroleum Engineer with the Energy Institute and a Chartered Engineer with the Engineering council, UK. Dr. Shah was recently granted the honorific of "Eminent engineer" with Tau beta Pi, the largest engineering society in the USA. He is on the Advisory board of directors at Farmingdale university (Mechanical Technology), Auburn Univ (Tribology), SUNY, Farmingdale, (Engineering Management) and State university of NY, Stony Brook (Chemical engineering/ Material Science and engineering). An Adjunct Professor at the State University of New York, Stony Brook, in the Department of Material Science and Chemical Engineering, Raj also has over 675 publications and has been active in the energy industry for over 3 decades. More information on Raj can be found at https://bit.ly/3QvfaLX

Contact: rshah@koehlerinstrument.com

Mr. William Chen is a senior studying Chemical Engineering At State University of NY, Stony Brook, set to graduate in May 2025. He is active with the American Institute of Chemical Engineers Chapter at SUNY, demonstrating his commitment to both cultural and professional development within her field of study and is part of a thriving internship Program at Koehler Instrument company, Holtsville, NY

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