Electric Vehicles Grease technology:
A comprehensive study of greases used in EVs and hybrids and how they differ compared to greases used with conventional vehicles

Shah. R, Norman.D, Pokhriyal.N, Harinarain. H

Dr. Raj Shah: Koehler Instrument Company, Holtsville, NY, USA
Daisy-Ann Norman: Department of Chemical Engineering, Biotechnology and Materials, University of Stony Brook (SUNY), NY
Dr. Naveen Kumar Pokhriyal: Indian Oil Corporation, R & D center, Faridabad, India
Mr Ajay Kumar Harinarain: Indian Oil Corporation, R & D center, Faridabad, India

Corresponding Author: Dr. Raj Shah, rshah@koehlerinstrument.com

Keywords: Electric Vehicles (EVs), Hybrid Electric Vehicles (HEV), Hybrid Vehicles (HV), tribology, automobiles, greases, lubricants, Internal Combustion Engine (ICE) Vehicles.

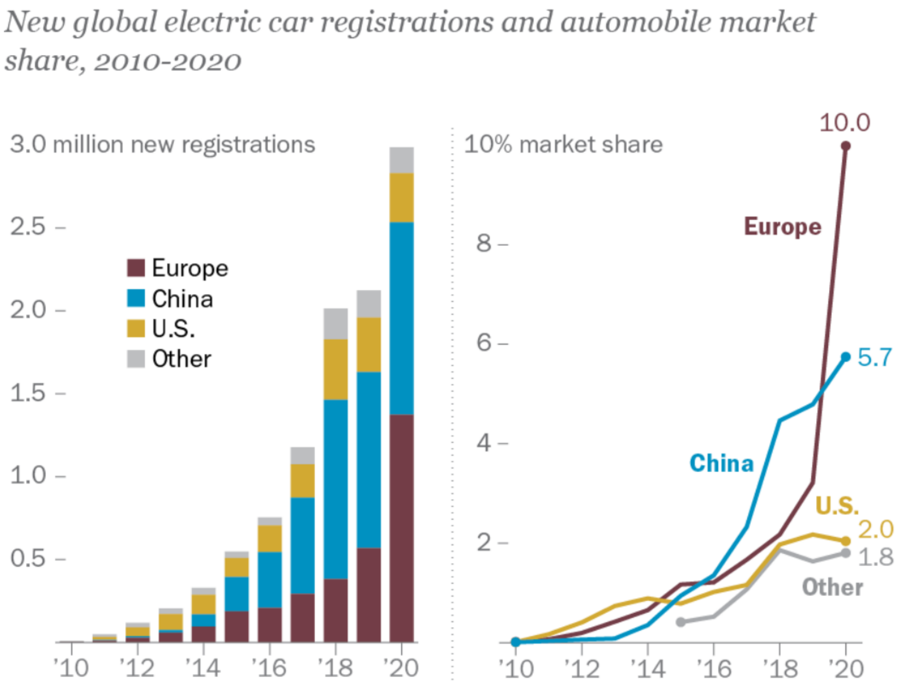
Abstract

Electric mobility with electric vehicles is in vogue across the world in view of environmental concerns being expressed. Passenger car manufacturers are making plans for their product mixes for the present for ICE vehicles and electric vehicles. Established car manufacturers are deploying significant research resources to compete with newcomers vying for a share of this pie. It is significant to note that research resources both from the hardware and software aspects in line with current industry 4.0 trends are being employed to make the product future ready in line with aspirations of the millennial generation which comprise a major segment of the customers. There is a shift from the engine powered mechanical powertrain components to a simpler electric motor-based drive and use of control technologies of electrification components in these advanced propulsion vehicles. This Industry 4.0 impact on worldwide development trends in automotive electrification designs has resulted in the development of novel propulsion systems such as hybrid electric vehicles (HEV) combining the two worlds and the and battery electric vehicles (EV).

Globally, electric car sales are gradually increasing in response to a push for a better environment and lower greenhouse gas emissions. The relevance of CO_2 emission reduction is being evaluated by the Environmental Protection Agency (EPA), and electric vehicle (EV) developments have been taking massive leaps in global interest. At this moment in history, the globe has been making progress toward creating a society that is green, eco-friendly, renewable, and long-lasting. As the automobile industry progresses toward a new era in which electric vehicles (EVs) will overshadow internal combustion engine (ICE) vehicles and presumably dominate the world's roads, a new set of lubricants and oils must be developed specifically to meet the performance requirements of the EVs electrical and gear components. With the shift towards using rotary machines like motors in these vehicles using rolling element bearings, the grease lubricants will come to play a significant role. The function of grease in rolling element bearings is to remain in contact with and lubricate bearing components without leaking out under the force of gravity, centrifugal action or being squeezed out under pressure. Greases will continue to play their unique role in retaining their properties under shear-at all temperatures it experiences during use. The role of grease lubrication in electric vehicles (EVs) and hybrid electric vehicles (HEVs) will be examined and compared in this paper to highlight how we as individuals and as a community benefit from safer car usage. This paper also seeks to contribute to a research study on the current state of crucial components utilized in passenger electric vehicles, as well as future and efficiency improvement trends. After a brief historical analysis, we gathered information on current demands and obstacles in electric and hybrid vehicles. The quality of lubricants was then compared, followed by the differences in performance between the vehicles in terms of frictional performance and thermal management.

1. Introduction

Lubricants of the future must be more ecologically friendly, perform better, and have a lower total life cycle cost (LCC) than lubricants currently in use. Considering the interest of future generations there is a need for sustainable development applying the principles of tribology conserving the finite resources available on planet Earth. The base fluids quality is key to synthesize these lubricants, and they can be split into three categories: physical, chemical, and film formation properties. One or more base fluids are used in the formulation of all liquid lubricants. The base fluid accounts for more than 95% of all lubricant formulations, based on a weighted average of all lubricants manufactured. However, the percentage of additives in a composition can range from 1% in very basic compressor oils to up to 30% in metalworking fluids and gear lubricants. Base fluids can be mineral, synthetic, or ester, and they're classed in a variety of ways [1]. Tribology is derived from the Greek word "tribos," which means "rubbing," although it was Peter Jost who coined the term in 1966 in the well-known Jost report. The science of tribology is about “wear, lubrication, and friction” [2]. In recent years, electric and hybrid vehicles have received significant. The intermittent on-and-off regulation of the internal combustion engine distinguishes conventional vehicles from electric/hybrid vehicles which run on electric motors. In addition to the fluidic performance that has been studied for decades this lubricant must incorporate new performance characteristics such as electrical (such as electrical conductivity and breakdown voltage) and thermal properties (thermal conductivity, specific heat, and others) [3]. Over the last few years, electric vehicles (EVs) powered by battery, fuel cell, or full cell hybrid systems have garnered considerable attention around the world as a viable solution for reducing greenhouse gas emissions and maintaining a clean and healthy environment by reducing the negative effects of internal combustion engines (ICEs) in the transportation and energy production sectors [4,5]. Compared to internal combustion engine vehicles (ICEVs), electric cars (EVs) require new components and energy infrastructure to run successfully, resulting in different manufacturing and maintenance infrastructure. In the case of battery powered EVs, for example, the cost of the battery accounts for 45.3 percent of the EV's total cost. As a result, the primary problem in the auto business is to build improved battery energy storage systems, which best complement the technology. Hydrogen fuel cells, hydrogen storage systems, supercapacitors, solar cells, automobile thermoelectric generators, regenerative braking systems, charging technology for energy storages, and other energy infrastructure components will also be required [6]. The growing interest in using electric vehicles (EVs) not only as passenger cars but also as heavy-duty vehicles and buses has opened opportunities for new developments and research in areas such as energy storage, hydrogen cells, electric motors (EMs), micro-electro-mechanical systems (MEMSs) and sensors, autonomous driving, thermal and electric efficiency improvement, and so on. The objective is to consolidate this technology as completely viable and efficient for the transportation sector, working in tandem with several multidisciplinary activities. EVs have a very high efficiency in terms of energy usage, but increasing it even further is a major challenge [7].



New global electric car registrations and automobile market share, 2010-2020

Note: Electric car totals include all-electric, plug-in hybrid and fuel cell vehicles. "Europe" includes the 27 nations in the EU, plus Iceland, Norway, Switzerland and the UK. "Other" includes Australia, Brazil, Canada, Chile, India, Indonesia, Japan, Malaysia, Mexico, New Zealand, South Africa, South Korea and Thailand.
Source: International Energy Agency, "Global EV Outlook 2021."

Figure 1. Global electric car registration over the past decade

2. Greases in Automotive Systems

The word grease comes from the Latin word *crassus*, which means fat. We can see where the name originates from (mutton fat, beef tallow); nonetheless, grease lube is not to be confused with fat for current applications. Grease was defined in 1916 as a solid to semi-fluid outcome of thickening agent dispersion in a liquid lubricant. In layman's terms, this means a lubricant made up of lubricating fluids (oils) that have been thickened using chemicals to achieve a semi-fluid to semi-solid consistency [8]. Lubricating grease is made up of three components, viz, oil, thickener (sometimes called soaps), and additives. The base oil and additive package are the most important components in grease formulations, and as such, they have a significant impact on the grease's performance. The lubricant is held in place by the thickener, which is commonly referred to as a sponge (base oil plus additives). The lubricating oil might be either petroleum or synthetic, and its viscosity can vary. Anti-wear and extreme pressure additives can also be added to grease formulations for specialized applications like high-speed bearings, extreme cold or heat, open gears, excessive loads, or high moisture conditions, to mention a few. Combining oil and thickeners allows for higher temperature ranges and moisture resistance. To make more complicated thickeners for specialized uses, thickeners can be mixed or compounded with additional ingredients. The amount and type of thickeners employed, as well as the viscosity of the lubricating oil utilized, will determine the thickness of the grease. The NLGI is the governing body that assigns grease ratings. Greases are evaluated on a scale of hardness from 000 to 6, with 000 being a thick liquid like pudding and 6 being a block like hard clay. Today, 000 grease lubricant is used to replace gear lubes in bearings and differentials, and number 6 grease is used where rubbing action is required to generate a light layer on the lubricated surface. NLGI #2 greases are commonly used in vehicle and truck applications for wheel bearings and chassis greases. NLGI #1 grease is preferred in extremely cold climates because it remains fluid at low temperature. Synthetic greases thickened with proper compounds can be used at temperatures ranging from minus 50°F (-45°C) to 500°F (260°C), but petroleum greases are limited to temperatures between 0°F (-17.78°C) and 300°F (148.89°C) [8,9]. In electric vehicles, the driving electric motor bearings and wheel bearings must be carefully targeted for performance improvements such as life and efficiency improvements. The tremendous torque in an EV's wheel bearings must be carefully managed. The grease utilized must be able to perform consistently across the temperature ranges such as exhibiting low temperature starting torque to low running torque in high-temperature environments [3]. Grease's job is to stay in contact with moving surfaces and lubricate them without leaking out due to gravity, centrifugal action, or being pushed out under pressure. It should be able to maintain its characteristics under shear forces at all temperatures encountered during operation.

2.1 Lubricants for EVs

Lubrication's primary goal is to reduce wear and heat emission between contacting surfaces in relative motion. While wear and heat cannot be totally avoided, they can be reduced to levels that are negligible or tolerable. Because friction causes heat and wear, lowering the coefficient of friction between the contacting surfaces can reduce both impacts. Lubricant is also used to minimize oxidation and prevent corrosion, as well as to provide insulation in transformers, transmit mechanical power in hydraulic fluid power applications, and seal against dust, dirt, and water. Grease is arguably the most popular boundary lubricant. Because greases have the most desirable features of a boundary lubricant, they are commonly used. They are not only easy to shear, but they also flow. Mineral oils are by far the most widely used base oils in industry. They are made of petroleum and are employed in applications with mild temperature requirements [15]. Mineral oils are commonly used in gears, bearings, motors, turbines, and other similar applications. Synthetic oils are mineral oil substitutes that have been created artificially. They were created with the goal of providing lubricants that outperform mineral oils. Temperatureresistant synthetic lubricants, for instance, are utilized in high-performance machinery that operates at high temperatures. There are other synthetic oils available for very low temperature applications [15,16].

Developing lubricants for electric vehicles in general may be challenging because there is lack of standardization in this industry, which may mean that each original equipment manufacturer has their own unique electric motor and design of associated drives, necessitating the development of a specific lubricant for their electric motors to meet their performance requirements. Besides since the EV technology is still in the nascent stage going through the iterative stages of development and improvements, EV may pose some challenging requirements for the lubricants in use that may still not have been fully addressed. This may be in stark contrast to the requirements posed for the ICE lubricants that has gone through several stages of improvements and refinements of the iterative process. Antiwear performance, friction reduction, efficiency, electrical compatibility and insulation, and electric motor and battery pack cooling are just a few of the critical characteristics that lubricants must meet. Coolants for the car battery, gear oils for differentials, chassis, gear reducer, and wheels, brake fluids, and grease for other EV components are all required lubricants. Apart from designing specific EV lubricants for performance, the developing lubricants must also be compatible with the electrical components of EVs, such as electric modules, cable insulations, sensors, and circuits. The heat generated by the electric motor must be isolated from the electric modules. When producing a suitable lubricant, a variety of cooling approaches and thermal management requirements must be considered. Mineral-based oils with various additives and synthetic-based oils are the most common lubricants nowadays due to their improved lubricity, thermal and oxidative stability. Aside from EVs, the growth of hybrid electric vehicles (HEV) necessitates the use of specialized lubricants. There are worries about heat and aging stability when using a smaller combustion engine alongside an electric motor. Strong insulating qualities are required to develop a viable lubricant. Various lubricant tests are carried out to guarantee that EV and HEV standards are met. Oil viscosity is determined by the application's load, speed, and operating temperature. While viscosity should be decreased to prevent friction loss, too low of a viscosity compromises durability and causes lubrication to leak out of the bearings [17].

2.2 Viscosity

The internal friction within a liquid is measured by viscosity, which is the way molecules interact to prevent motion. It is an important lubricant quality since it affects the oil's capacity to build a lubricating film or reduce friction. The absolute viscosity of a Newtonian liquid is defined as the ratio of the applied shear stress to the resulting shear rate. The viscosity index (VI) is the most often used approach for assessing the fluctuation of viscosity with temperature between different oils using dimensionless values. The sample's kinematic viscosity is tested at two temperatures (40°C and 100°C), and the results are compared to an empirical reference scale. Using a high VI base oil gives the best combination of efficiency at low to moderate temperatures while maintaining good high temperature wear protection [18]. With respect to the greases, the base oil viscosity is generally decided based on the speeds of operation of the end application – rolling element bearings and gear boxes.

3. Lithium Grease

Lithium grease is the most widely used lubricating grease in the world, accounting for 75% of all lubricating applications across all industries. It is commonly utilized as a lubricant in wheel bearing and chassis applications in the automotive industry for the ICE applications. It has good water resistance as well as a high temperature tolerance. Because of this dual capability, it has mainly superseded sodium and calcium-based greases. Lithium grease inherently offers a high level of metal adhesion. This means that once it's on, it won't come off. This feature offers a lot of advantages, such as reducing the need for reapplication and saving time. It's a non-corrosive grease, which means it would not damage the parts or machinery applied upon. It is a chemically stable compound that does not react with the substances with which it comes into contact. It is designed for usage to sustain high loads in the end application bearing and gear contacts. The inherent physical characteristics of Lithium greases of excellent shear stability ensures that it maintains it structure under heavy loads in the end application and does not soften and flow out like a sodium or a calcium grease would. Lithium greases can work at high temperatures of up to 200° C to a good extent which means that it is able to maintain a film at high flash temperatures generated momentarily in the contact zones. These properties make it the grease of choice in the auto sector with its inherent shear stability and high temperature properties. The maximum temperatures in automotive applications do not exceed 120° Celsius which is just perfect for a lithium grease. These properties of lithium greases ensure that it can meet the long-life requirements when used in an automotive wheel bearing. The grease properties for life and performance can be further boosted using suitable antioxidants and EP/AW additives. Lithium-based greases offer better water resistance which may offer some advantages in wheel bearing applications prone to some water ingress [19].

4. Grease in EVs and HVs

As the industry swings away from internal combustion engines (ICEs) and toward electrification, electric vehicles (EVs) are emerging as the future of transportation [21,22]. Although electric vehicles (EVs) are more energy efficient than internal combustion engines (ICEs), energy losses in electric motors (EMs) would be still quite significant with room for reduction [23,24]. Friction in bearings is the primary source of mechanical losses in EMs [23,25,26]. Looking at life performance, premature bearing defects are said to account for 40–60% of early EM failures, with insufficient lubrication [27] accounting for most failures [23,28]. Because grease lubrication is used in 80–90% of rolling bearings, poor grease lubrication is the most common cause of EM bearing failure [29,30,31]. Exposure to electrical conditions, such as those present in EVs, is another driver of premature bearing failure that reduces EM life [24]. Because of fundamental variations between the environment and operating circumstances in EVs and those encountered by greases in standard ICEVs, such as speed, temperature, and materials, formulating greases for EV applications may be a challenging task. The electrified environment of operation of the vehicle may also be challenging. There are two major areas where grease is used as a lubricant in battery electric vehicles– in electric motor support bearings and the wheel bearings. The Wheel Bearings are grease lubricated and use tapered roller bearings. It has been found that BEVs operate under higher loads in terms of Gross Axle weight rating (GAWR) due to the heavier battery pack mounted on the chassis of the vehicles. Therefore, greases with higher load carrying capacity (Higher EP) and higher base oil viscosities may be required [61]. Greases with higher concentrations of non-conventional EP/AW additives [64] may be necessary. The higher loads may translate into higher operating temperatures in the bearings which may necessitate more antioxidants in the grease. Assessment of the simulated grease life in the bearings can be carried out using laboratory bench tests like FAG FE9 test or the SKF ROF+ test before extended field trials are run for validation [60].

In terms, greases used in industrial EMs is subjected to similar circumstances [32]. To begin with, EMs in industrial applications and electric vehicles (EVs) work at significantly much higher speeds [22,23]. The design of lubricant as well as the bearing may be different especially for the Electric motor bearings operating at nd_m factors approaching 1,000,000 (say 20000 rpm and a bearing mean diameter of 40-50 mm). This would necessitate laboratory studies with special equipment such as ROF+ which tends to only reach laboratory simulations of nd_m around 800,000 [60]. Grease lubrication being extremely speed-dependent can exhibit inverse Stribeck behavior, with reduced friction at low speeds, however higher speed behavior may be dependent on how it is formulated. It may require special formulations to meet the performance levels of friction and life at such special conditions. At low ratios, i.e., small film thickness to effective surface roughness ratios [22], this departure from lubricating oil behavior is most noticeable. Furthermore, friction is dictated only by the grease thickener at low speeds or nominal boundary conditions, and it is lower than that predicted for base oil [22,24,25]. Grease lubrication in EMs is further hampered by high temperatures. Although a slight increase in temperature might promote grease bleed and so resupply lubrication to the bearing contact track, excessive temperatures can also create severe working conditions. High rotor speeds generate heat, and certain EMs may operate at temperatures as high as 150 °C or even 180 °C. As a result of EM operating environments, greases used in EM bearings may face thermal degradation in the form of oxidation and diminished lubricating capacities [32] leading to even failures as experienced in conventional electrical equipment [63].

Another issue with grease lubrication of EMs for EVs is that bearing materials may differ from those used in conventional motors. Many EM bearings feature ceramic components that act as insulators to reduce stray current problems. Stray current can harm both the bearing and the grease, as well as generate heat, which can cause localized melting of metal surfaces, pitting, and embrittlement of materials [33,34]. Furthermore, electrically conductive grease can magnify these effects and hasten bearing degradation [34]. Grease deterioration is also caused by current discharge due to heat oxidation and evaporation of the base oil and additives, resulting in grease becoming rigid [33]. Grease in EVs is influential in understanding the environment and vehicles.

4.1 Grease formulation

One area where electrification is changing things, according to Sharbel Luzuriaga, energy project manager for the Kline Group's Energy Practice Market Research Division, is the operating circumstances under which greases perform. The use of high operating temperatures and voltages is a major concern. As current density rise, the chance of stray currents pitting bearings rises as well. Typical electric motor speeds, which are currently at 15,000 rpm, are expected to approach 20,000 rpm in the near future, he adds. Conventional greases will still be viable for mechanical components that operate in much the same way they always did, such as windshield wipers, door hinges, and window winder mechanisms, according to STLE member Gareth Fish, Technical Fellow at the Lubrizol Corp., Wickliffe, Ohio. OEMs (original equipment manufacturers) may be changing the balance away from greases with a longer life to greases with improved energy efficiency, according to Fish. Quality base fluids (usually synthetic base oils) and additives that prevent wear, fretting, and oxidation are required for long-life greases. Friction-reducing additives are required in energy-efficient greases, which is especially critical for tapered bearings, where sliding can diminish efficiency. Grease additive concentrations are projected to rise overall as a result of all of these factors, according to Fish. The type of thickener used in a grease recipe also affects efficiency. A thicker grease may better separate solid surfaces, but it may also result in increased churning losses, which increases friction. According to Fish, the qualities of the grease during the running-in period have an impact on efficiency and wear.

The grease flows around the rolling element as it passes through a polyurea-thickened grease with a "rice pudding"-type thickening microstructure, and energy losses are minimal. To allow the rolling element to travel through a grease with a solid soap structure, it must be shearsoftened (see figure 2). As a result, soap-thickened greases are less efficient than greases thickened with urea. Although a low coefficient of friction is advantageous in general, employing a grease with a low coefficient of friction in systems that are prone to sliding might result in skidding and bearing failure.

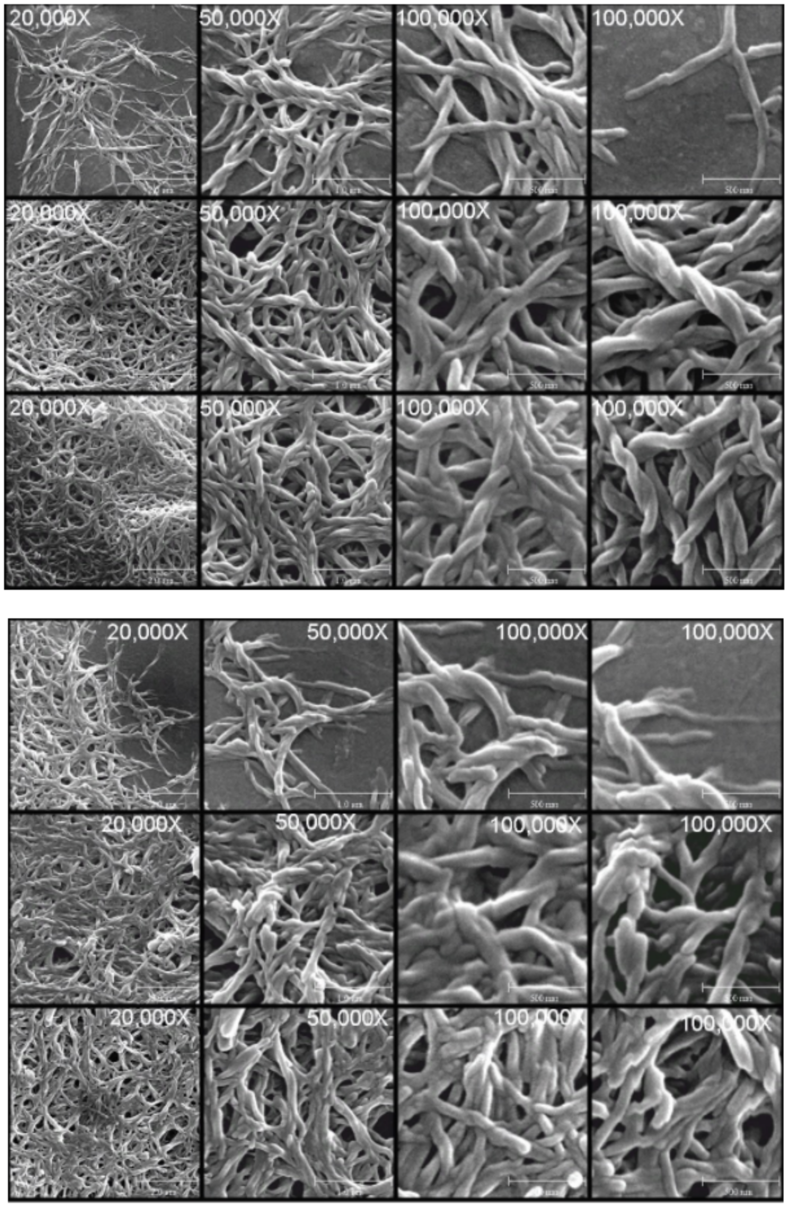


Figure 2. Lithium and lithium complex grease thickeners have fibrous microstructures. *Figure courtesy of STLE [62].*

Although many mechanical components in EVs do not necessitate changes in grease compositions, the increased manufacturing of EVs and the associated demand for lithium batteries may necessitate a different type of adjustment. In order to prepare for anticipated lithium price rises or shortages, several grease makers are looking for alternatives to lithium-based thickeners [62],[66].

Grease formulas for electric vehicles are only one of the numerous developments shaking up the industry today, but getting the formulations right is critical to a vehicle's overall performance. Even with small amounts of grease in each part and fill-for-life parts that don't need to be replenished, small increases in lithium prices can add up to a major concern for large OEMs, according to STLE member Paul Shiller, owner of the tribological research consultancy AARDCO LLC in Youngstown, Ohio. Polyurea-thickened greases are quieter to run and bleed less than lithium greases, according to Shiller. Another possible option, calcium sulfonate greases, have intrinsic antiwear qualities that lithium greases lack, reducing or eliminating the need for additional antiwear additives, he says. Lithium complex greases are common in North America, according to Fish. However, polyurea-thickened greases, which are also popular with Korean carmakers, are used in around 80% of Japanese passenger automobiles. Non-lithium greases may become increasingly common in Europe as the EU considers designating some lithium salts (including those used in grease manufacture) as dangerous to fertility and fetal development [62],[67]. Environmentally aware chemicals and friction reduction to promote energy efficiency may be the key motivations for change in grease formulas of all sorts, according to Shiller. However, because EVs are quieter than ICE cars, there is a movement to replace lithium stearate with polymeric thickeners in "quieter" greases (i.e. greases that minimize noise, vibration, and harshness [NVH]). Carlevaris claims that combining the correct mechanical component designs with the right grease will lessen the "hooting" noise (a constant, low-frequency sound) made by electric motors at low temperatures due to periodic pulsing in the grease. BSR noise is more noticeable in EVs than in ICE automobiles, according to Kumar, since it is not masked by noise from other sources. By lowering friction, grease formulas that are ideally suited to the size and speed of the components they lubricate can minimize noise levels. Kumar notes that polyurea thickeners are particularly effective in noise reduction because they are thixotropic, meaning they become less viscous while under stress. The softening of these greases is caused by moving bearings, which reduces vibrations and noise. Another advantage of polyurea thickeners, according to him, is that they withstand oxidation better than greases containing metal ions like lithium thickeners. Piet Lugt, an STLE member and senior scientist at SKF Research and Technology Development in Houten, the Netherlands, and professor of tribology-based maintenance at the University of Twente in the Netherlands, adds that the right match between components and greases not only extends component life but also increases grease life. Hybrid bearings, for example, that combine ceramic rolling components with steel cages and raceways, can extend grease life, he claims. [62],[63]. The larger initial investment in hybrid bearings, according to Carlevaris, pays off in the long term. Low friction and extended grease life in terms of parasitic current control. Because of the stress that batteries exert on wheel bearings, battery weight remains a problem in all EVs, according to Fish. For bearing greases, this involves a trade-off between load-bearing capacity and speed (which is related to grease viscosity). The load-carrying capacity of a grease is increased by using viscous base oils and adding more extreme pressure (EP) and antiwear additives. Bearings that are subjected to higher loads heat up faster, necessitating the use of antioxidants to extend the grease's life. After bearings are first loaded, there is a churning or running-in period of one to 24 hours, followed by a bleed phase, according to Lugt. The grease migrates between the bearing's balls during the first running-in phase [57]. However, he says, if the grease remains in place during operation, it increases drag. To guarantee effective clearing and channeling performance, the grease's churning qualities must be optimized. Chemical compatibility difficulties in EV greases are different from those in ICE cars. Grease and oil formulas must not contain additives that encourage yellow-metal corrosion due to the presence of copper wiring in EVs. Any grease that leaks from the bearing might end up on the motor windings, where it could corrode the copper or the insulating coating that surrounds the wires, according to Fish. Chemical compatibility with polymer vehicle components may compel a switch from mineral oil-based greases to wholly synthetic base oils such as PAOs, according to Fish. To lessen the danger of seal failure, the formulation should be balanced with another base oil component (e.g., esters or alkylated naphthalenes) because PAOs can cause seal materials to shrink. Not only must base oils not pull components out of polymer parts, causing the polymers to become brittle, but lubricant additives must not seep into polymers, causing them to swell, according to Shiller [62].

4.2 Difference In Greases for EVs and Conventional Vehicles

Internal combustion engines (ICE) fuel conventional cars, which are also known as internal combustion engine vehicles (ICEVs). If an electric motor or several electric motors are used to drive the wheels of a vehicle, it is referred to as an electric vehicle (EV). In addition, if a vehicle's wheels are propelled by both an electric motor and an internal combustion engine (ICE), the vehicle is called a hybrid electric vehicle (HEV) [44]. The entire concept of a prime mover is being redefined in electric vehicles. A battery powers an electric motor (or motors) that drives the wheels, rather than an engine that is lubricated with oil and transfers power to a transmission and then to the wheels. Engineers must select (or develop) gear oils, coolants, and greases with new parameters in mind while constructing EVs. The most significant differences from traditional vehicles in terms of lubrication can be found in three areas: noise, efficiency, and the presence of electrical current and electromagnetic fields from electric modules, sensors, and circuits. Thermal transmission, sealing, and material compatibility are all factors to consider [35].

4.2.1 Noise

Noise is at the top of STLE (Society of Tribologists and Lubricant Engineers) member Chad Chichester's list of EV challenges for lubricant engineers, according to the application engineer at Molykote Lubricants in Midland, Mich. "While conventional automobiles are becoming increasingly quieter, the omnipresent hum of the internal combustion engine continues to disguise noise, vibration, and harshness (NVH) as well as buzz, squeak, and rattle (BSR)," he explains. NVH/BSR concerns aren't only annoyances for the occupants; they also affect quality perception. More importantly, noise has the potential to interfere with sensors that are increasingly used in vehicle safety and guiding." Vehicles will be safer and more pleasurable if lubricants that decrease or eliminate noise are used [35].

4.2.2 Energy Efficiency

Range anxiety—the dread of being stranded out of range of a charging station—is one of the most significant barriers to the widespread adoption of electric vehicles. People may not be ready to give up the 300- to 400-mile ranges they are used to in a conventional vehicle without recharging infrastructure, according to Chichester. By making vehicles lighter and minimizing friction in all components, automotive experts are continuously looking for methods to improve efficiency—and, as a result, range [35]. The thickness of the lubricating film can be linked to energy efficiency. Thinner lubricants lower viscous friction, which allows for higher energy conservation. Grease, on the other hand, will lower the thickness of the lubricating film at high temperatures, posing new issues for wear prevention of sliding surfaces. Where wear is a problem, a thinner lubricating coating will be closer to the mixed and boundary lubrication regimes. Finding a balance between the capacity to maintain a complete film lubrication regime and the wear protection provided by thinner lubricating films is a critical turning point in improving energy efficiency when employing low-viscosity lubricants or grease [36].

4.2.3 Electrified Conditions (electromagnetic fields, electromagnetic fields, circuits, sensors)

Dr. Kuldeep K. Mistry, a product development specialist at The Timken Co. in North Canton, Ohio, notes that the development of electric vehicles will have a global impact on the selection and development of gear oils, coolants, and greases, as they will encounter electric modules, sensors, and circuits and be affected by electrical current and electromagnetic fields. Even in traditional automobiles, the number of electrical connections is likely to treble in the next five years, according to Chichester. Corrosion and material compatibility will be one of the most important life-limiting factors in this scenario. Although grease lubricants will keep moisture from reaching the surfaces, preventing rust, electromagnetic fields will provide a new difficulty.

The amount of energy transferred is determined by the intensity of the field, its oscillation frequency, and the material's dielectric characteristics. The faster a thing absorbs energy, the faster it will become heated. As the frequency of the electromagnetic field rises, the object will become hotter. The temperature will rise if the rate of temperature diffusion is slower than the pace at which the electromagnetic field loses its energy [36,37]. Electric motors emit electromagnetic fields, which can cause greases to degrade prematurely. The electrical discharge and free radicals react with the oxygen in greases, producing hydrogen peroxide and continuing the free radical chain reaction. This causes the oxidation of basic oils and thickeners, resulting in lubricity loss. Furthermore, components within the grease will begin to separate, and the temperature impacts of the electrical discharge will cause specific parts of the grease to evaporate, resulting in grease failure [37,38].

5. Grease demands and challenges in EVs

Tesla Motors' entry and rapid expansion have wreaked havoc on the automotive sector. This has recently become the most valuable automotive manufacturer in North America by market capitalization (45). Though this achievement has been dismissed as an overreaction by the market, investors and its own CEO, Elon Musk, the fact remains that Tesla Motors has become a major player in the automotive industry and is now the pre-eminent battery electric vehicle manufacturer in the world. The battery is the primary energy source in electric vehicles, providing electric power to electric motor drives and other equipment such as lighting. A system schematic of EVs is illustrated in figure 3 [44].

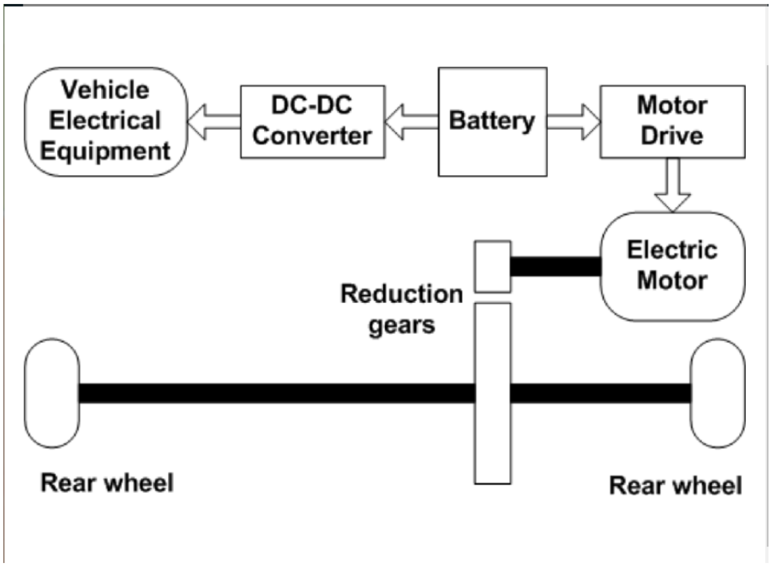


Figure 3. System schematic of EVs [44].

Tesla wheels contain typical roller bearings packed in mild oil and are operated by greased drive axles (front half-axles have greased universal joints), according to Dan Colestock, an Electrical Engineering Consultant. The axles' integrated 11:1 reduction gear connect directly to the oil-filled traction motor drive units. Each driving unit has an external oil filter starting with the Tesla Model 3 like any other high-quality car, the door hinges, latches, and handles, frunk/trunk hinges and latches, windows, and seat slides all require regular maintenance. The charging hatch motor, windshield wiper motors, washer fluid pump, cooling system pump, and interior fan motor are all lubricated on a continuous basis. Tesla brakes use DOT3 brake fluid, which is hygroscopic, meaning it accumulates moisture and needs to be refilled every 24 months. Aside from that, the Model 3 only needs to be serviced every 48 months or 50000 miles (excluding tire rotation, wiper blades and washer fluid). Because they lack gasoline engines, other BEVs should have similar lubrication requirements. Although the trend has been towards using relatively thin 0W-20 oil for crankcase lubrication (instead of 10W-30 or 10W-40) to increase engine economy, PHEV vehicles with gasoline or diesel engines have lubrication requirements equal to regular ICE vehicles [55].

Experts have reported hybrid vehicles, battery electric vehicles, fuel cell vehicles and ICE vehicles as the future of cars on the road. Sharbel Luzuriaga and his team recently published a study covering the forecast for the passenger car motor oil (PCMO) market to 2040.

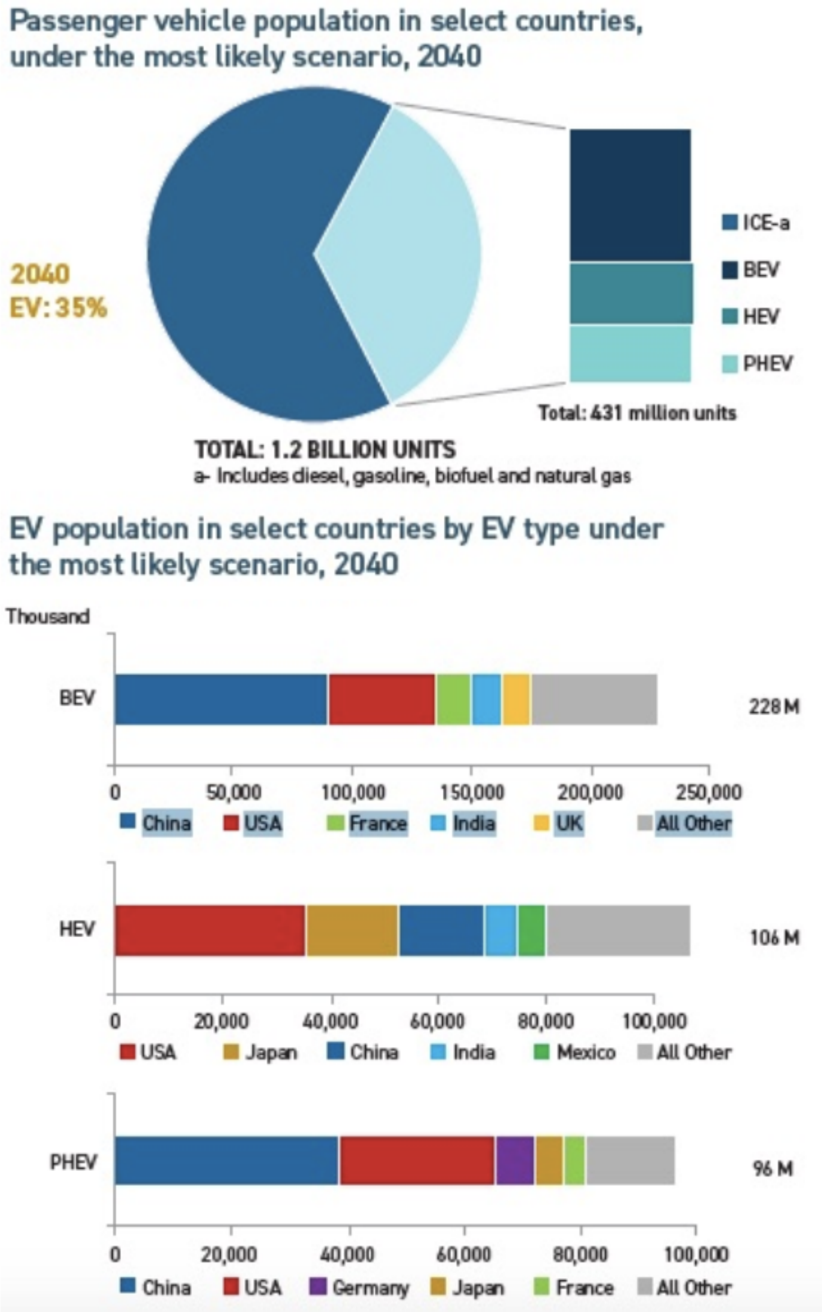


Figure 4. Internal combustion engine vehicles, battery electric vehicles, hybrids and plug-in hybrids will likely share the roads for the next two decades. *Figure courtesy of The Kline Group.* [62].

Despite recent market disruptions caused by car battery and semiconductor chip shortages [62], [59], Luzuriaga forecasts a double-digit reduction in global ICE vehicle demand in 2020, accompanied by a comparable growth in EV demand, fueled in part by substantial government incentives. According to him, China and the European Union (EU) have the most demand for passenger electric vehicles, with Japan and the United States also emerging as important participants. Germany, France, and the United Kingdom are the European countries with the highest EV demand, with Germany intending to be carbon neutral by 2050. Due to social pressure and trade unions, the European Commission has recommended a ban on ICE vehicles by 2035. Despite its commitment to the shift to electric vehicles, the Chinese government has witnessed some waning support, owing in part due to COVID-19. However, the country remains a significant market, he says. The United States is trailing behind the other big players in terms of demand—China has 500,000 electric vehicle charging stations, while the United States has just approximately 50,000 (mostly in California). However, he believes that demand in the United States will expand, especially given the present administration's focus on infrastructure development.

Although passenger cars now dominate the BEV industry, light- to medium-weight commercial on-road vehicles are in high demand. Because batteries capable of managing these loads take up too much space at today's power densities, heavy-duty vehicles still require alternative sources of power, according to Luzuriaga. Alternate-fuel internal combustion engines, hybrid designs, liquefied natural gas (LNG), and other kinds of hydrogen fuel continue to be better possibilities for these cars. Vehicles used off-road for mining or construction in environmentally sensitive regions are an exception, he says. Companies can keep their own onsite chargers for these cars, but power density is still an issue.

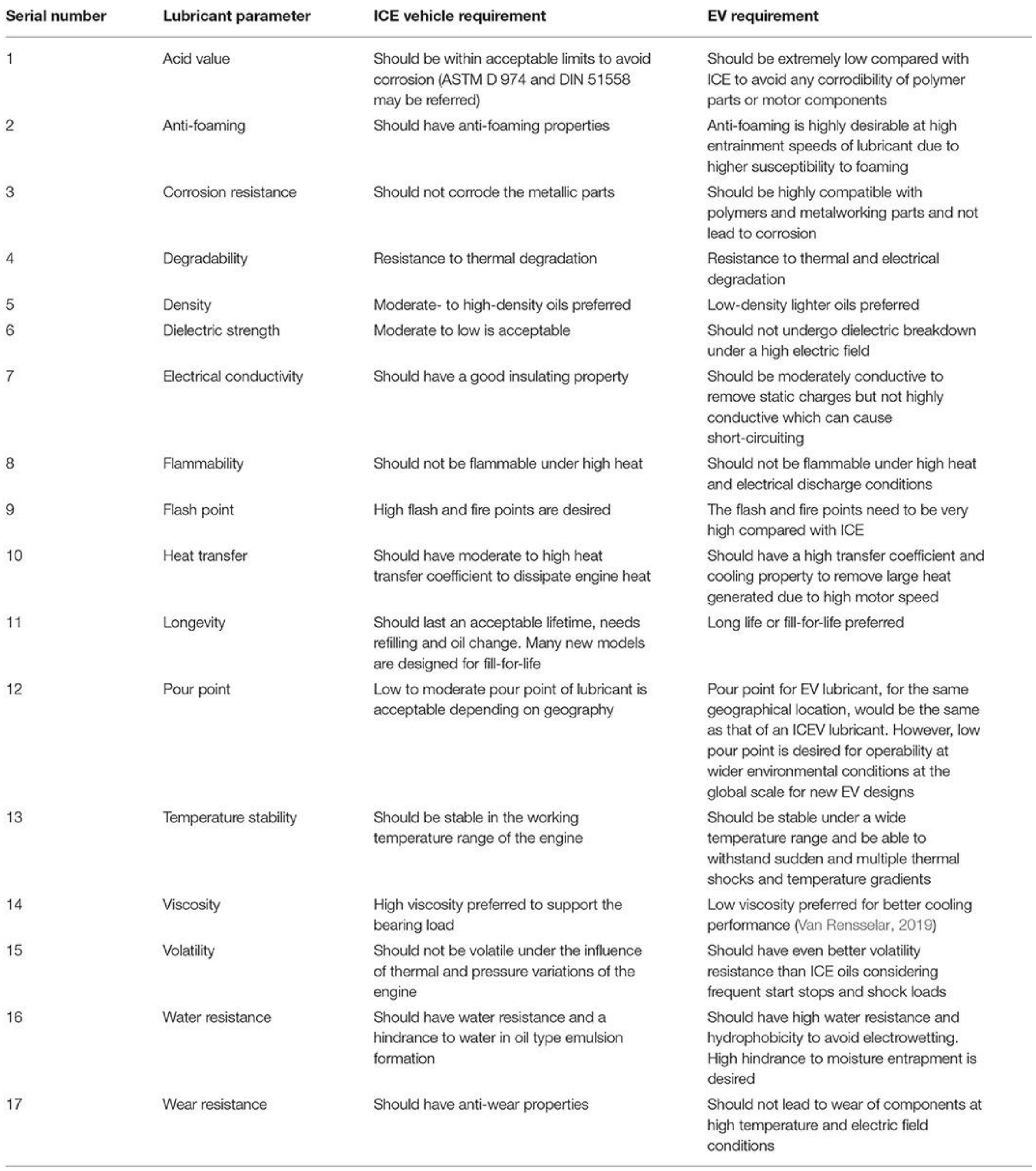
According to Luzuriaga, demand for a variety of base oils, additives, and finished lubricant products for all these types of vehicles will continue. Despite the fact that most grease-lubricated parts on conventional cars are filled for life, a typical EV or ICE vehicle has at least 25 grease points and they don't all utilize the same grease compositions. He anticipates that original equipment manufacturers (OEMs) will continue to need a wide range of greases, each tailored to meet the unique requirements of each application.

EV greases now account for a relatively tiny percentage of the entire grease market volume, according to Kumar, and the EV market is dominated by passenger automobiles. He says that 60 percent of all greases are used in industrial applications, such as industrial vehicles. However, the automotive sector (all sorts of vehicles) accounts for almost one-third of the grease industry, and this segment is likely to increase rapidly in the future years. [58].

6. Future Developments in EVs

According to Grand View Research, a market research firm based in India and the United States, demand for electric vehicles will continue to rise steadily in the coming decade, owing to factors such as fuel savings, government incentives for green vehicles and other products, and increased consumer awareness of the impact of fossil fuel use on climate change. Vehicle engineers are confronted with a slew of new difficulties unique to the bearings of the new electric standard because of this fundamental shift in priorities from consumers and regulators. From engine hardware to chassis, the push for vehicle electrification has transformed conventional thinking about several of the most important substances in motor engineering. Even everyday items like grease must evolve to meet the demands of an electrified future.

Grease is an essential component in the operation of 80 percent of the world's motor bearings. Grease differs from liquid lubricants like motor oils chemically due to the presence of thickening agent particles—usually a form of soap complex— that are spread throughout the oil phase to generate a solid or semi-solid substance. Additives that impart qualities to the dispersion are frequently used to improve load-carrying capacity, corrosion resistance, and wear resistance. Dr. Kuldeep Mistry even explains that "Every grease is a unique recipe." The grease's primary lubricating role is performed by basic oils that are tailored for certain settings, while the thickening "acts like a sponge to store and appropriately release the oil" over a long period of time, according to Mistry. He goes on to say that the presence of the thickening explains why grease lasts longer than oil alone—it "tends to remain put within the bearing and requires less maintenance" than liquid lubricants. Because of this diversity, there is a grease for every bearing and every situation, if engineers know what they're looking for [39]. To ensure that criteria are met, various ASTM standard lubrication tests are carried out. Oil viscosity is determined by the application's load, speed, and operating temperature [35]. While viscosity should be decreased to prevent friction loss, too low a viscosity compromises durability and allows lubrication to leak out of bearings. When exposed to severe temperatures, this brings oxidation qualities and a dropping point into play. Oxidation, aided by spark discharges, degrades the oil, and increases the likelihood of sludge accumulation, which impairs the motor's temperature regulation. Additives are used to change these qualities, although some of them can be counterproductive and reduce the grease's life duration. Finally, to avoid electrical losses in the system, the lubricant must retain electrical qualities such as volume resistivity, dissipation factor, and dielectric strength [35]. Overall, the lubricant must be designed to meet all these criteria.



Serial number	Lubricant parameter	ICE vehicle requirement	EV requirement
1	Acid value	Should be within acceptable limits to avoid corrosion (ASTM D 974 and DIN 51558 may be referred)	Should be extremely low compared with ICE to avoid any corrodibility of polymer parts or motor components
2	Anti-foaming	Should have anti-foaming properties	Anti-foaming is highly desirable at high entrainment speeds of lubricant due to higher susceptibility to foaming
3	Corrosion resistance	Should not corrode the metallic parts	Should be highly compatible with polymers and metalworking parts and not lead to corrosion
4	Degradability	Resistance to thermal degradation	Resistance to thermal and electrical degradation
5	Density	Moderate- to high-density oils preferred	Low-density lighter oils preferred
6	Dielectric strength	Moderate to low is acceptable	Should not undergo dielectric breakdown under a high electric field
7	Electrical conductivity	Should have a good insulating property	Should be moderately conductive to remove static charges but not highly conductive which can cause short-circuiting
8	Flammability	Should not be flammable under high heat	Should not be flammable under high heat and electrical discharge conditions
9	Flash point	High flash and fire points are desired	The flash and fire points need to be very high compared with ICE
10	Heat transfer	Should have moderate to high heat transfer coefficient to dissipate engine heat	Should have a high transfer coefficient and cooling property to remove large heat generated due to high motor speed
11	Longevity	Should last an acceptable lifetime, needs refilling and oil change. Many new models are designed for fill-for-life	Long life or fill-for-life preferred
12	Pour point	Low to moderate pour point of lubricant is acceptable depending on geography	Pour point for EV lubricant, for the same geographical location, would be the same as that of an ICEV lubricant. However, low pour point is desired for operability at wider environmental conditions at the global scale for new EV designs
13	Temperature stability	Should be stable in the working temperature range of the engine	Should be stable under a wide temperature range and be able to withstand sudden and multiple thermal shocks and temperature gradients
14	Viscosity	High viscosity preferred to support the bearing load	Low viscosity preferred for better cooling performance (Van Rensselar, 2019)
15	Volatility	Should not be volatile under the influence of thermal and pressure variations of the engine	Should have even better volatility resistance than ICE oils considering frequent start stops and shock loads
16	Water resistance	Should have water resistance and a hindrance to water in oil type emulsion formation	Should have high water resistance and hydrophobicity to avoid electrowetting. High hindrance to moisture entrapment is desired
17	Wear resistance	Should have anti-wear properties	Should not lead to wear of components at high temperature and electric field conditions

Figure 5. Desired lubricant properties in electric vehicles (EVs)/hybrid vehicles (HVs) compared with in internal combustion engine vehicles (ICEVs). [3, 40,41] To what does the “location” column refer?

7. Conclusion

In cars, lubricants play a crucial role. Recent advancements in lubrication have been reported in fields including bio-lubricants, mineral oil-based lubricants, and others. Synthetic base oils and thickeners have exhibited improved lubricity, longer service life, and low friction torque in grease applications. Lithium grease has been demonstrated to have good adhesion, non-corrosiveness, and moisture resistance, making it suitable for a variety of applications. Polyurea grease, on the other hand, has proven to be advantageous in wetter settings and applications requiring a longer grease life. Dedicated EV lubricants with new test methods are becoming more common as electrified powertrains become more mainstream. However, these new lubricants and testing procedures are still in the early phases of research, posing potential hurdles. Dedicated lubricants will be challenged as lithium greases continue to increase at a steady rate. Lithium for grease competes with the other types of grease that are unavoidably required by batteries. Electrified engine lubricants are becoming more of a reality, thanks to rising optimism and a strong push for environmentally friendly lubricants. Vehicle emission rules are being enforced, and there is a greater focus on the environment, which has necessitated modifications in vehicle design. The global adoption of electric vehicles is likely to increase market value in the future years. Diverse EV designs, such as HEVs, BEV’s as well as different firms, such as Tesla and Nissan, indicate the keen drive for people to move to electric vehicles from their conventional gasoline vehicles. To suit the new designs of EVs, lubrication changes are required as stated in this paper. For lubricants, batteries, and electric motors in place of a traditional internal combustion engine are unique. Today's greases may be unsuitable for application in the fields of electricity, heat, and noise reduction. To generate better-performing greases for these vehicles, additives and alterations in base oils must be used. Grease with these modifications is likely to become more popular in the market, with individuals and businesses purchasing them for their high efficiency and performance.

Authors

Dr. Raj Shah is a Director at Koehler Instrument Company in New York, where he has worked for the last 25 years. He is an elected Fellow by his peers at IChemE, 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 - Jul 15 2020 - David Phillips - Petro Industry News Articles - Petro Online (petro-online.com)

A Ph.D in Chemical Engineering from The Penn State University and 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 honourific 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), The Pennsylvania State university (SEDTAPP), Auburn Univ (Tribology) and Stony Brook University (Chemical engineering/ Material Science and engineering).
An adjunct professor at the Dept. of Material Science and Chemical Engineering at State University of New York, Stony Brook, Raj has over 450 publications and has been active in the petroleum field for 3 decades. More information on Raj can be found at

Koehler Instrument Company's Director elected as a Fellow at the International Institute of Physics Petro Online (petro-online.com)

Ms. Daisy- Ann Norman is a student of Chemical engineering at State University of New York, where Dr. Raj Shah is the chair of the external advisory board of directors. She is also a part of a growing internship program at Koehler Instrument company, in Holtsville, NY which encourages students to learn more about the world of petroleum and petrochemical engineering.

Dr. Naveen Kumar Pokhriyal obtained Ph. D. degree in Chemistry from M. S. University of Vadodara, Gujarat, India. He is currently working as Deputy General Manager (Grease) at Indian Oil Corp Ltd, R&D Centre, Faridabad and is a board member and Treasurer of National Lubricating Grease Institute (NLGI) – India Chapter. His research interests include development of novel greases for industrial, automotive and defence segments and novel analytical techniques for grease analysis. He has nearly two decades of experience in lubricants especially in greases, metalworking and rheology. He has 41 research publications and 12 patents to his credit. He is also a member of Indian Society of Analytical Scientists (ISAS), Tribology Society of India (TSI) and Society of Automotive Engineers (SAE) INDIA.

Mr Ajay Kumar Harinarain currently working as Chief General Manager (LT- Industrial) at Indian Oil Corp Ltd, R&D Centre, Faridabad. He has a Masters in Technology in Industrial Tribology from Indian Institute of Technology(IIT), Madras, Chennai India and an Executive MBA from SP Jain Institute for Management and Research(SPJIMR), Mumbai, India. He is the Secretary of Tribology Society of India. His research interests include Tribotesting, development of new Tribotesting methodologies for screening of lubricant for their field performance and condition monitoring of field machinery and lubricants. He has over three decades of experience in lubricants in Tribology and product development. He has over 50 research publications and 8 patents to his credit. He is a member of Tribology Society of India and the Society of Tribologists and Lubrication Engineers (STLE).

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