WHITE PAPER

DEVELOPMENT TESTING OF ELECTRIC POWERTRAIN COOLING SYSTEMS AND FLUIDS

The science of EV fluids

CONTENTS

INTRODUCTION

The optimum architecture for an electric vehicle motor, transmission and power electronics is by no means decided. Innovations are abundant; increasing efficiency, reducing weight, eliminating expensive or difficult-to-source materials, improving refinement, enhancing manufacturability, optimising packaging and of course, managing costs.

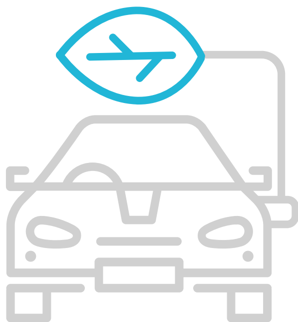
Just as with oils and coolants for internal combustion engines, there are effective products available off-the-shelf, ready to be specified. But is this the right direction to take? Internal Combustion Engine (ICE) powertrains have well over a century of development guiding their architectures, as do the fluids that lubricate and cool them. Electric vehicle powertrains are still evolving, very quickly, with fragmented technology roadmaps that generate a wide range of uniquely demanding conditions. An engineer who compromises an electric powertrain because it must work with an existing lubricant, usually based on a traditional Automatic Transmission Fluid (ATF), is compromising the efficiency of the vehicle and the competitive advantage that could have been delivered.

The science of EV fluids is therefore receiving considerable attention. It is now widely understood that a skilfully designed fluid, working in partnership with synergistically designed hardware, can enable a wide range of benefits across the powertrain, battery and charging systems. With improved fluids, designed as a key system component, many of the traditionally cautious approaches can be revisited. It is, however, a new field in which there are several possible technical directions and many unknowns, with no long-term fleet data to support decision-making.

The route to optimised designs must therefore begin with laboratory-based research and continue through test cell based powertrain validation. Only then can we progress to system designs that enable weight savings, packaging improvements, faster charging, extended range and much-needed cost reduction, all without compromising durability.

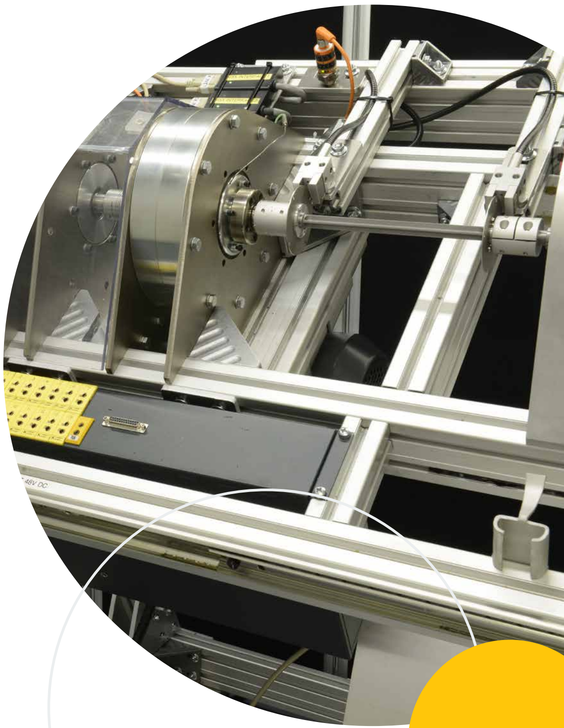
This white paper reviews the areas of design where robust testing and analysis can help optimise powertrain designs through more effective, more efficient lubrication and cooling. We reveal the major areas where test data is required to inform decision-making and consider how an improved understanding of the interactions between the fluid and the hardware is critical to our industry's ability to further improve almost every aspect of the technical performance of electric vehicle powertrains.

'A skillfully designed EV fluid can enable a wide range of benefits across the powertrain.'



POWERTRAIN

DESIGN TRENDS



An internal combustion engine may have many more moving parts than an electric powertrain, and it may stress its oil with combustion products and dilution by fuels, but it would be wrong to assume (as many do) that this makes the specification of EV fluids a simpler task.

The challenge begins with the variety of drive and motor architectures. At its simplest, these systems consist of a single drive unit replacing the ICE, and at its most complex, a motor for each wheel with planetary gears. For cost and packaging reasons, the majority of manufacturers are coalescing around a single motor architecture, often with the option to add an axle motor to provide a four-wheel drive capability.

To simplify this layout, second-generation electric powertrains combine the electric machine with the reduction gears in a single sealed unit to which the power electronics are attached to create a module known as an Electric Drive Unit (EDU). To manage temperatures within these more tightly integrated modules, the traditional indirect cooling system using water-glycol fluid is typically replaced by a hybrid cooling system in which cooling of the motor and gears is shared between the lubricant and a water-glycol loop with a liquid-to-air heat exchanger. The power electronics are typically still cooled indirectly by water-glycol, usually separately managed due to the substantially higher operating temperature. Even here, however, we are seeing fragmentation in approaches, with one of the most popular European electric vehicles already using a single water-glycol loop for indirect cooling of both the power electronics and the electric machine.

The majority of these systems today operate at around 400 V with typical maximum motor speeds of around 15,000 RPM, but the drive to higher levels of efficiency is increasing both of these quickly and dramatically. 800 V systems are already in production and motor speeds will soon push beyond 20,000 RPM. Intertek is already supporting clients on speeds up to 25,000 rpm and has specified its latest test systems to accommodate E-Machines operating at up to 27,000 rpm. At these speeds, the test challenge isn't just about the physical test system: data capture at a meaningful resolution must also be carefully considered.

These technology paths, combined with the very substantial torque available from most electric traction motors, place considerable stress on the powertrain's gears and bearings (potentially clutches too, but most EVs don't have them). Higher shaft speeds also increase the Noise Vibration and Harshness (NVH) challenge, in which fluids also have a role in mitigation. While two-speed transmissions did initially look like they would be popular as a means of reducing energy consumption, these have so far been specified only on a few high-performance vehicle models.

To further reduce cost and complexity, third-generation EDUs may include the power electronics within the module, with a shared cooling loop. The cost, weight and packaging complexity of cooling circuits means that their integration into fewer loops is very attractive. Some vehicle manufacturers already employ the same coolant circuit for their batteries and electric machine, reducing costs and simplifying the hardware required to use excess motor heat to help bring batteries up to temperature more quickly.

DEVELOPMENT TESTING OF ELECTRIC POWERTRAIN COOLING SYSTEMS AND FLUIDS

A single fluid that can be employed to both cool and lubricate a highly integrated EDU is known as a monofluid. Today, these are typically derivations of traditional ATFs so there is clearly considerable scope for a new generation of fluid that is designed for this demanding application. Many fluid suppliers are making outstanding progress in this field, carefully balancing the range of thermal, dielectric and tribological properties to enable further improvements in hardware design. In many respects, it is this partnership between fluid design and hardware design that is most critical to understand, both for the fluid developer and for the powertrain engineer.

In parallel with these developments of the electric machine, power electronics are evolving at an equally rapid pace. In addition to higher voltages – Intertek is already able to accommodate up to 1,100 V - the use of high-speed switches within the power electronics is becoming an increasingly common route to increased efficiency. The performance of these typically silicon carbide devices is often restricted by an inability to remove heat sufficiently quickly. Even a modest improvement can create a virtuous circle of gains in powertrain efficiency, packaging and power density. To help solve this, whether standalone or as part of a highly integrated EDU, cooling systems may evolve from a traditional cold plate with indirect cooling, to direct cooling systems with bespoke, electrically insulating fluids.

To date, production implementation of novel EV fluids designed for these challenging technology paths has been limited by a combination of lack of development time (the pressing need for speed to market) and a pragmatic aversity to risk across new areas of technology. As we approach a new generation of electric powertrains designed with the benefit of volume production experience, we have an opportunity to develop and implement new fluids that enable significant improvements in cost and efficiency, not just through their own performance but also through the design improvements they enable across a highly integrated EDU, the battery and potentially also the charging system.

LUBRICANT REQUIREMENTS

One of the challenges with EV development is knowing which ICE powertrain expertise is transferable and which, if taken as the basis for EV development, will limit what can be achieved. The more we learn about EV fluids, the more we realise that there are so many additional requirements, and their formulations and their integration must be taken back to first principles.

As part of developing the necessary understandings, the breadth of data must be increased substantially beyond thermal performance, for example, to include copper wire corrosion testing, ultra-high-speed foaming testing, dielectric strength and breakdown, electrical conductance and impedance and many other areas not previously considered in detail. Here is a brief summary of some of the additional areas where EV powertrains place particularly stringent demands on their fluids, often causing conflicts between the possible mitigating strategies.

Viscosity Reduction

A detailed understanding of viscosity is essential because, in a simplified view, it enables the working clearances between surfaces that would otherwise destroy each other. We have seen the viscosity ratings of engine oils fall in recent years, driven by the need to reduce losses. It's a slow and cautious evolution because too great a reduction in viscosity can lead to localised failure of the oil film and hence to accelerated wear, surface fatigue and even catastrophic failure. Lower viscosity also requires reducing the gap between surfaces, which can cause more asperity contact and plastic deformation.

Later in this document, we will also look at the role of friction in determining pumping losses: another area where reducing viscosity brings energy savings, but at the expense of durability at the outsides of the performance envelope if the implications are not carefully understood.

Factors significantly affecting viscosity choices include speed and load, both of which reach new extremes in modern electric vehicle powertrains. In ICE applications, additive packs have been successfully employed to mitigate some of these issues, but the conditions and durability requirement imposed by EV applications imply a need for significant further research and validation.

Friction Reduction

Friction has been described as the major source of loss in an electric vehicle. Reducing friction will increase efficiency, which will increase range or reduce the demands on the battery and its specification. Reducing friction also reduces heat generation, so has a synergistic effect on system and fluid design and cost. Lower friction also reduces wear, which can cause durability and NVH issues as the vehicle ages.

A traditional method of friction reduction is to specify a thinner oil – reducing viscosity – but there are limitations to how far viscosity can be reduced before the lubricating film becomes ineffective during the most demanding conditions. There are many proposals for mitigating friction without reducing viscosity, for example through the introduction of nanoparticles. These infiltrate the micro-roughness that remains on even the smoothest ground surfaces, depositing a thin wear-resistant layer that physically separates adjacent metal surfaces.

Because lubrication is a system whose performance is determined by the characteristics of the surfaces as well as by those of the lubricant, the hard surfaces have also received R&D attention with new techniques including laser surface texturing and plasma surface coating.

'New' is exciting, as innovation always is, but many engineers also regard it as a synonym for risk. Test systems must be carefully designed and test specifications agreed with the laboratory experts to ensure that each of these variables is considered. A test of friction reduction, for example, is valueless for an engineer if it doesn't also confirm a negligible increase in wear and fatigue under all appropriate operating conditions.

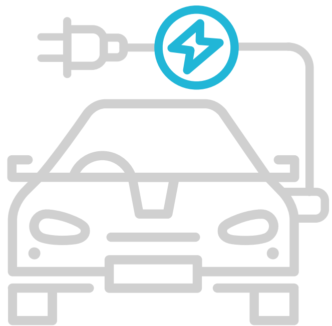
Electrical Characteristics

With EV motors typically operating at 400 to 800 Volts with 1,200 Volts on the horizon, the electrical characteristics of motor fluids are of paramount importance. Conductive bridging, for example, can occur between tightly spaced conductors such as motor windings. At high temperatures, this effect can be magnified by conductive deposits formed by the chemical reaction of copper with the fluid (both in fluid and vapour states). Testing for this potential failure mechanism is relatively simple but requires careful design of experiments and, of course, knowledge of the conditions in which it becomes an issue to ensure that testing is focussed on the most critical conditions.

A related area where it is important to consider the fluid and the hardware as a single system is associated with the high-speed switching of current, which may cause a build-up of static that can discharge through the bearings and gears: the system behaves like a capacitor with the lubricant as the dielectric. This can be prevented with physical modifications or made worse by failing to consider the scenario in hardware design. This condition is currently difficult to simulate in a digital model, making integration of this investigation within hardware and fluid development testing the most effective route to mitigation.

So important is this new field that at the 2022 Tribology and Lubrication for E-Mobility conference held by the Society of Tribologists and Lubrication Engineers (STLE), there was a call to establish a new area of expertise: 'electrotribology', the interaction between fluids and moving parts in an electrified environment. Intertek already has the capability to test with voltages up to 1,100 Volts with very high data collection rates, making it possible to design bespoke test systems to illuminate this vital new field.

'Brilliant powertrain engineering is at the heart of the most competitive vehicles.'



Materials Compatibility

Lubricating fluids circulate around copper windings, insulation, laminates and rare earth materials. For most of these, there is little compatibility research or in-service data gathered in the extreme conditions of a modern electric vehicle powertrain. It is also important to test as built, calling on expertise based on an understanding of possible issues. This is because, for example, microscopic imperfections in the protective coating surrounding the copper wires can lead to corrosion where the lubricant is in contact with the metal: perfect samples will fail to reveal the issues caused by production variability.

This is also an example of how important it is to understand the balance of properties and their interrelationships. Some lubricants, for example, use sulphur as an additive to reduce wear, but sulphur can be chemically active in contact with copper, a reaction that is exacerbated at high temperatures. While EV fluids may not suffer from the same contamination as ICE lubricants, they are not totally immune. The sulphides created in this reaction can form a sludge that impacts the performance of the fluid and of electrical components. It can reduce the ability of the fluid to remove heat and will physically impact the performance of components such as solenoids. There are also concerns about circuit-bridging dendrites of corroded copper residue.

Fluid developers have become adept at preventing copper corrosion, but as conditions continue to become more extreme, it is vital that testing continues to validate system performance within all likely scenarios.

A similar 'test as built' approach is necessary for areas such as surface texture, where prototype components may exhibit a different finish to production components, leading to unrepresentative test results. Intertek's test specialists can advise on how to accommodate these differences.

High Contact Pressures

One of the most demanding differences between an electric motor and an internal combustion engine is the former's ability to generate very high levels of torque from zero RPM. Clearly, this can create extreme contact loads and, if the vehicle has not been moving for long enough for the lubricant film to have diminished, there is a potential for metal-to-metal contact. Lubricants, therefore, need much improved anti-wear, anti-scuff and film retention capabilities.

A traditional solution is to increase the viscosity of the lubricant to slow down the dispersion of the fluid film. However, the molecules used in these Viscosity Index Improvers (VII) are extremely large. When the oil is hot they unfurl, making them susceptible to rupture by mechanical shearing, reducing the lubricant's viscosity over time. Understanding the potential for these relationships, where increasing one performance criteria may reduce another, is vital to effective test design.

Another example of these interdependencies can be found in high pressure contact patches subject to Elasto-hydrodynamic Lubrication (EHL). The majority of lubrication regimes work with Hydrodynamic Lubrication (HL) in which the surfaces do not distort. This is why it is possible to use coatings and other hard surface treatments within these conditions. If significant elastic deformation of the surfaces takes place, the shape and thickness of the lubricant film can be compromised. Designed with the correct lubricant, EHL is a perfectly legitimate design decision and can be used just as effectively to decrease friction and wear. When testing, it is essential that the hard surface replicates the deformation characteristics of the actual component, and that stress is applied over a representative curvature and pressure range.

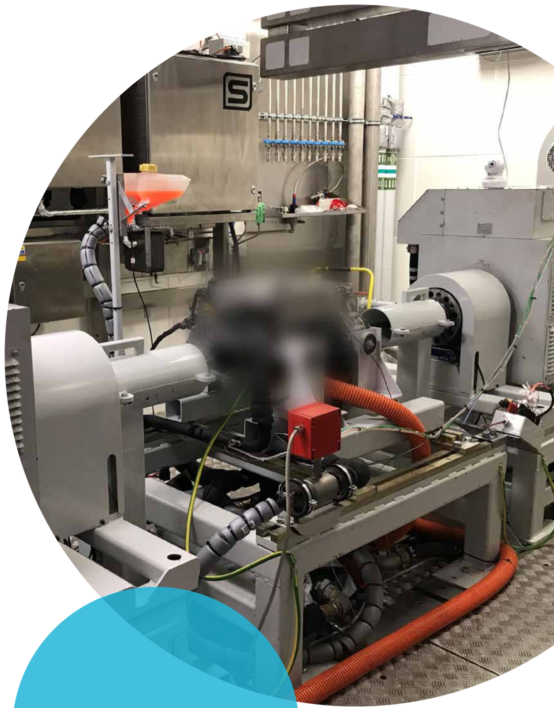
If this is not achieved, the performance of the lubricant film will be unrepresentative of in-service conditions. Intertek's test systems specialists can ask the difficult questions that help to ensure each test conducted at our laboratories is as representative as can realistically be achieved.

'Timescales are demanding, making fast, responsive development testing even more essential.'

TRIBOLOGICAL ANALYSIS

This is another area where perfection, or close to it, is possible, but at a cost that is far from realistic. The objective of decision-making is therefore to define the optimum compromises through an understanding of the many interlinked conditions and their mitigation techniques.

A high magnification view of gear and bearing surfaces will show that they are not perfectly smooth. This surface roughness, if well designed, can be a useful contribution to retaining lubricants, ensuring that the oil film is sufficiently thick to prevent the larger asperities from contacting each other. If the film becomes too thin, deformation and/or metal-to-metal contact can destroy the bearing. There are a number of mechanisms by which this may occur.



Abrasion

While abrasion is relatively easy to control, doing so requires a robust understanding of the specific conditions that may occur, even if only very briefly. Top of the list is the size of particle contamination as particles in the size range of the working clearance (between surfaces) create the greatest amount of abrasion. The population of small particles in a lubricant is usually much greater compared to large particles, so the reduction in working clearances necessary for the specification of lower-viscosity fluids places increased emphasis on preventing or capturing the smaller particles.

Testing, particularly for durability, must therefore be conducted with a realistic understanding of the likely particle profiles through the vehicle's life and with a production-realistic filtration system. Intertek's global network of oil analysis laboratories can help with this profiling while also supporting laboratory investigations. Degradation of the filtration system over time must also be considered. Effective lifetime filtration can reduce abrasion – and other types of wear – to an extent where even after many years of operation, the machining marks are still evident. Accurate and appropriate fluid analysis is one of the keys to illuminating these design decisions.

See also the sections on foam prevention additives and reducing pressure losses, both of which create opposing objectives in filter design.

Fatigue

Of all the tribological challenges, fatigue is one of the most critical because it can lead to sudden, unexpected failure. The challenge can be significantly more extreme than for ICE and continues to increase.

The relationship between fatigue and lubrication is complex and can be unexpected. For example, research has shown that fatigue may increase as viscosity falls. Another example is micro pitting, which can contribute to an increase in noise as the vehicle ages. Caused by rolling fatigue of the surface typically at high loads and temperatures, it can be difficult to see but is an essential area for examination during lubricant development or assessment. As with scuffing, its relationship with sliding velocity means the place to begin looking is at the bottom or top of the tooth profile. It has been suggested that micro pitting is more likely if the lubricant includes anti-scuffing additives, again indicating the importance of comprehensive testing.

Scuffing

This is one of the damaging consequences of highly localised heat in combination with high maximum sliding velocity and high contact stress. This causes the two surfaces to momentarily weld and then tear, creating the characteristic radial scratch lines. Several sources of heat and stress contribute to scuffing, including churning loss, expulsion of oil between meshing teeth and windage loss but because the main contributor is friction, the potential for very high surface speeds makes scuffing a particular challenge. To prevent scuffing, the fluid must both lubricate and cool, which means the characteristics must be chosen to ensure sufficient heat transfer to the fluid even during momentary contact with the gear surface.

COOLANT REQUIREMENTS

The ability to remove heat quickly is particularly important for the efficiency and durability of an electric machine. The strength of magnets, for example, can be reduced by excessive temperatures. Motors without permanent magnets must also be temperature controlled to improve performance and reduce the risk of overheating neighbouring components.

While normal operating conditions are handled relatively easily, the immense current flows created by spikes in power demand can create temperature spikes, often localised (a hotspot), that stress fluids far outside their normal working envelopes. Excessive temperature will reduce viscosity, creating the potential for metal-to-metal contact and may cause varnishing and carbon deposits that close the working gap and change the tribological properties of the surfaces. As we have discussed in a preceding section, hotspots can also 'crack' the lubricant's molecules, leading to a permanent and severe loss of viscosity that will affect the entire system.

Failure to understand hotspots can create what has been called a 'thermal circle of despair' in which heat reduces lubricant viscosity, which increases wear and friction causing more heat, and so on. Intertek is experienced in working with clients to define instrumentation solutions and inspection methods to assess thermal stability and wear.

Even normal operation is becoming more demanding. For example, higher motor speeds generate higher bearing temperatures, so the impact of the potential doubling of shaft speeds must be thoughtfully investigated. We see, therefore, that optimisation of the fluid specification must consider the hardware geometry and performance, so true system optimisation can only be accomplished by development, test and validation of both fluid and hardware together. For highly specific areas of investigation, this may require a bespoke rig, which Intertek is able to design and build cost-effectively in-house.

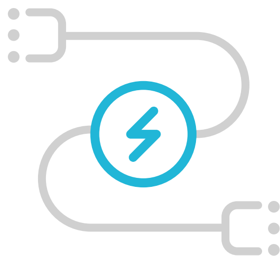
Battery Integration

In today's production vehicles, batteries are usually cooled either by air or indirectly using a water-glycol mix. We have already discussed the reasons for the trend towards sharing a cooling circuit between the motor, the transmission and the battery. While this paper will not consider the science of battery cooling, the integration trend may necessitate its requirements to be considered during fluid development.

Keeping batteries cool is one of the key requirements for reducing charge times as well as maintaining the battery's durability. As we move towards very high-speed charging and EVs offering astonishing levels of performance (driving very high current demand), the ability to manage spikes in heat generation becomes increasingly vital both for safety and to protect battery life. For this reason, it is possible that battery cooling will move from indirect to direct (immersion), in which the cells are surrounded by a dielectric cooling fluid. Specialists in the field have stated that the method is many times more effective than indirect cooling but also brings the substantial challenge of electrical isolation. Direct cooling, therefore, requires a new generation of EV thermal fluids the requirements for which can be summarised as:

- Excellent thermal properties already discussed including high heat capacity
- Lower viscosity levels than conventional dielectric cooling fluids
- Strong electrical insulation with a high flash point to prevent electrical breakdowns and ignition
- Oxidation resistance to help the fluid maintain performance over its lifetime

'Failure to understand hotspots can create a thermal circle of despair.'



DEVELOPMENT TESTING OF ELECTRIC POWERTRAIN COOLING SYSTEMS AND FLUIDS

As previously stated, while there are many synergies to be developed from integrating the cooling loops of the battery and the EDU, there are also many challenges relating to both. For example, the different optimum temperature regimes of each system and the impact of very high heat generation from the battery on the stability of EDU cooling and vice versa. Should this technology direction become a priority, accommodating both sets of requirements in a single fluid will require significant research and development if the resulting specification is not to compromise hardware performance.

Fluid performance is also affected by coolant volume, which must therefore also be considered in test design as the volume of fluid affects the degree of contamination and, in some instances, degradation. Volume is determined more by the size of batteries and the large surface area of the cooling plates than by the need to increase flow to accelerate heat removal.

Power Electronics

A similar trajectory is apparent in the cooling of power electronics. We have already discussed the relevance of the move to wide band gap switching technologies such as SiC. While all switches perform at their best when heat can be removed quickly, research suggests that significant additional performance could be extracted from SiC switches if cooling can be improved.

Electronics have traditionally been cooled indirectly, via a base plate. However, this requires an electrical insulator between the coolant and the electronics, which can increase thermal resistance. Direct cooling is clearly a sensible design objective, but places considerable additional strains on the fluid, most notably around its dielectric properties but also materials compatibility and degradation due to hotspots.

Testing fluids for power electronics, therefore, requires precise emulation of the battery capability and characteristics and of the demands placed on the electronics by the drive cycle. Intertek's new emulator the first in the UK to be built around high-speed SiC MOSFET switches, allowing precise emulation of the battery in the most demanding conditions, with faster response and less current ripple than conventional emulators and an ability to supply current at a uniquely representative rate of >1 MW/ms.

System Implications

It is clear that when evaluating thermal performance, the fluid and the mechanical components should be treated (except in very specific areas of development) as a system through which we must understand the heat flows and hotspots, especially through the most extreme elements of the drive cycle. Intertek can help the client understand their real-world system operating conditions and develop solutions to simulate this accurately in the test environment.

COMBINED COOLING & LUBRICATION

With the transmission now usually integrated with the electric machine, the fluid must also accommodate the cooling and lubrication requirements of the rotating parts and of the gear tooth surfaces. As motor speed and torque increase, this becomes increasingly demanding, both for wear prevention and for the mitigation of NVH issues that are particularly prominent when there is no engine noise to mask them.

Testing must also deliver a thorough understanding of low temperature characteristics, for example to ensure that the fluid is still able to flow through the system at the required rate with minimum pumping losses. Low-viscosity fluids are clearly part of the solution and are generally more effective at heat transfer, but they can bring detrimental impacts to both friction and wear. For lubricants with an oil (hydrocarbon) base, thermal conductivity and density fall with temperature so the implications of this characteristic must be understood.

Investigation of energy losses in the EV fluids system is a useful example of the skill required from the test engineers, not just in the development of a bespoke, high-precision test system that accommodates the requirements, but also in understanding how to specify the test conditions and parameters to accurately reflect real-world usage. On a previous project, Intertek found there was no third-party instrumentation available to meet the particularly challenging measurement requirements, and instead developed a bespoke test system, using a custom twist beam sensor to provide torque measurement to +/- 0.001 Nm. To ensure correlation with real-world usage, Intertek has also developed a bespoke oil conditioning system and a novel technique for heating the stator that contributes to making this a unique test capability.

Physical Properties

With motor speeds now pushing beyond 20,000 RPM, fluids operate in a very demanding environment, especially when lubricating and cooling reduction gears. None of the specified properties will be effectively deployed if the fluid suffers from foaming or a host of other conditions that can, and must, be prevented. Conditions such as foaming and cavitation can be difficult to simulate with digital tools, making them important considerations in the design of physical test programmes.

We have already discussed the importance of reducing the energy wasted in pumping losses. Churning losses must be added to this area of development and taken together with an understanding of the hardware and its impact on fluid performance. While designing the fluid to reduce these losses, the impact on other issues such as cavitation must be considered. Foam inhibitors can work well, but if their solubility isn't correctly specified they can be trapped in the increasingly fine filtration systems required for these tribologically very demanding systems. It has been noted that this is an area where new test processes, to mimic the conditions in EDUs, would be beneficial: hence Intertek's commitment to building custom laboratory systems to help its' clients investigate both specific and system interactions.

Fluid Durability

The elimination of the contamination issues faced by lubricants in ICE applications suggests an EV system could be sealed for life – as most designs are currently intended – but while there may be no combustion products or dilution by fuels, there are still many factors that will lead to degradation of fluid performance over time. We have already looked at several of these, including tribological debris (eg from abrasion) and the products of corrosion and high voltages.

One way of mitigating additive degradation is to increase the volume of fluids in the sump, but this carries cost, weight and packaging penalties. Another would be to initiate an additive top-up regime. The optimum strategy is to increase our understanding of additive performance and degradation so that blends can be created that can be truly sealed for life.

Both gear oils and coolants for EVs require a significant amount of additive chemistry – said by some to be greater than for ICE vehicles – and combining these functions more than doubles the complexity of finding the optimum combinations. The understanding of what causes additive degradation is still evolving, with a lack of in-service data making rigorous, well-designed laboratory testing even more vital.

'Heat flow analysis may look simple, but these are highly complex systems with many variables.'

Cost

Fluid choice has a surprisingly significant impact on total cost because of its influence on system design. Improved thermal properties, for example, can reduce the size and weight of cooling loops and simplify packaging. Improved electrical properties can reduce the need for other mitigation. When designing or specifying an EV fluid, it is important that these system impacts are fully understood.

Environmental Performance

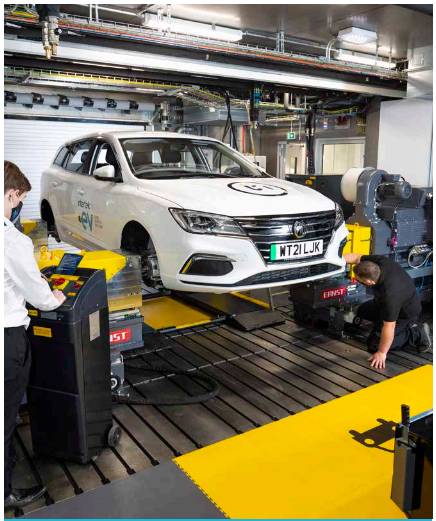
Cooling has an important role to play in the ability to reduce our dependency on expensive materials and those that may have unstable or questionable origins. This can be achieved through materials substitution, such as finding alternatives to the heavy rare earth metals that are added to improve the temperature resistance of neodymium, and through efficiency improvements that reduce the requirement for these materials. As is demonstrated in this white paper, efficiency improvement and rigorous thermal management are closely linked. For example, improving thermal conductivity from the electric machine to the fluid allows a higher continuous power rating, which can be employed to reduce the use of many of the materials in the stator and the rotor.

We must also consider what happens to the lubricants at the end of their life. The intention may be that Electric Drive Units are sealed for life, but when that life ends, the vehicle manufacturer is responsible for their safe disposal. There is already significant research around the reconditioning and reuse of synthetic and oil-based lubricants enabled by their degradation being largely a consequence of contamination (less of a problem in electric powertrains) and failing additives. An alternative is bio-lubricants, which offer accelerated biodegradability but as less is known about their long-term performance in such demanding applications, require substantial testing and development.

DIGITAL TOOLS

Having assessed the complexity of EV fluid design, and the necessary consideration of the hardware systems the fluid will protect, it will inevitably be concluded that simulation provides an excellent tool for the initial phase of design and validation. The challenge, however, is that simulations require robust calibration using proven data, and with the development of EV fluids, there is insufficient data to create a truly representative full-system model.

One of the objectives of physical testing must therefore be to generate the data needed to improve the fidelity of the simulations. Frequently, the marginal cost of increasing the range of data delivered by a test programme is extremely attractive. This paper has already noted Intertek's capability in very high-resolution data collection and expertise in non-contact sensing. This is an area in which our engineers can contribute valuable programme extensions that will save time and money throughout the system design and development.



OUR INDUSTRY-LEADING CAPABILITIES

The new Centre of Excellence is a hub through which a wide range of complementary specialists is accessed to quickly deliver the complete range of technical insights needed by powertrain engineers with deadlines that cannot be missed.

Intertek's global network of specialists has assessed more than 20,000 batteries for performance, durability, and safety. They analyse more than 1,000 oil samples a year, dismantle transmissions and axles to study wear, and operate a network of impressive Non-Destructive Testing Laboratories and the world's largest network of EMC test laboratories. Corrosion, materials, vibration, dust intrusion, salt spray and a host of other complementary techniques can be accessed in all major markets, together with laboratories for EV charging and electrical safety.

And the investments in future mobility technology continue, with the recent opening of a brand-new 500-acre facility for the development of autonomous and connected vehicles including heavy-duty trucks, ready for the next generation of new automotive technologies.

CONCLUSION

We have seen that the considerable number, and complexity of factors affecting the specification of EV fluids and their interactions requires great depth of expertise in many specialist areas. While the programme lead may have this expertise within the team, or certainly within the suppliers' teams, an overview knowledge is necessary to guide the design of the research and development testing that informs key decisions. As a world-class specialist in the research and development testing of electric vehicle powertrains, Intertek is making considerable investments in this important new area, helping our clients accelerate their programmes and make more informed design decisions.

Meeting these diverse requirements is driving an entirely new approach to fluid formulation. Even the choice of base stock is still being debated with each realistic option excelling in key areas while introducing compromises in others. It will also require a rigorous approach to testing that takes informed decisions about the number of interdependent parameters to be assessed and calls on statistical analysis to create insights quickly and at an affordable cost. The importance of extending test design to allow continuous improvement in digital tools should also be accommodated within test programmes to extend their benefit and enable further acceleration in timescales and cost reduction.

Building on this capability, the future will bring a new generation of fluids developed specifically to meet the challenges of electric vehicle powertrains. Most importantly, they will enable useful system cost reductions alongside performance improvement across the powertrain, power electronics, battery, and charging.

With the insights provided by robust, carefully designed test programmes, it will be possible to define the optimum balance of properties against cost and durability and to use these properties to enable improvements across almost every aspect of system design.

INTERTEK'S GLOBAL ELECTRIC VEHICLE CENTRE OF EXCELLENCE

As a company that believes in the importance of data, Intertek has put considerable time into researching the requirements for its Global EV Centre of Excellence, located in Milton Keynes, UK. As the world's most comprehensive testing and certification partner, with more than twenty years' experience working with vehicle manufacturers and technology suppliers on EV programmes, Intertek has brought considerable expertise to the design of this facility. It also called on the vision and experience of electrification specialists throughout our client businesses to ensure that the new laboratories will accommodate the fast-changing requirements of this demanding sector.

Intertek's UK facilities encompass 32 test cells, covering ten different major techniques and a range of subsidiary techniques for the test and development of E-Machines (at up to 27,000 RPM), power electronics (up to 1,100 V), integrated axle modules and on-board vehicle electrical systems. Flexible test programmes provide insights at component, system and systems integration levels. Complementing the component and systems laboratories, there is a four-wheel drive full-vehicle climatic test chamber that is believed to be the first independently available facility of its type in Europe. Further development is planned, adding additional facilities for EV system testing.

Fast and Flexible

The ability to deliver high-quality insights that accurately reflect real-world usage is partnered with a focus on accelerating the development process. The Centre of Excellence is structured for remote set-up so test cells can achieve very fast turnaround, combined with a high level of automation to allow safe 24/7 operation. Because electrification technology is evolving so quickly, with many questions as yet undefined, there is a substantial in-house design and build capability so that rigs can be quickly modified, or all new rigs designed and built, to allow new areas of investigation.

Every test cell and laboratory is designed to accommodate the specific requirements of these new technologies. Electrical noise has received particular attention as Intertek's experience suggests it is an area that can have a significant effect on the results, yet is often given insufficient consideration. New systems have also been developed to ensure environmental correlation, for example, a bespoke climatic soak system that can bring a test system down to -40°C quickly and cost-effectively before the test piece is moved to a cell.

Real World Correlation Built on Experience

However, as well-planned as a test laboratory may be, its results will only be as good as the understanding of real-world usage against which it correlates its procedures. The differences between how conventional and battery electric vehicles are driven can be surprisingly significant, requiring a fresh look at drive cycles.

An example is the application of the motor's often generous torque, which is typically available from zero RPM and could be applied after a considerable time standing. How often will this event occur? What will the pattern of torque transients be when there is no powertrain noise to deter aggressive acceleration?

One of Intertek's specialist groups is researching this question, developing a substantial database of real-world EV drive cycles. Their results show some surprising differences between EV and ICE driving characteristics: knowledge that is helping to ensure the results we deliver are tightly correlated with real-world usage.

'The differences between ICE and BEV drivecycles can be surprisingly critical.'

THE INTERTEK ADVANTAGE

One of the challenges with the development of any new technology is the range of expertise required to make it ready for the starting grid. In a relatively new field such as electric motorsport, some of these requirements may be unscheduled, required to answer questions revealed by testing but without time in an already hard-pressed programme.

With more than 1,000 laboratories and offices worldwide, Intertek can provide a complete, end-to-end test programme that can adapt quickly to developing requirements.

Recognising the quality of Intertek's capability, the UK government's South East Midlands Local Enterprise Partnership (SEMLEP) provided funding to support the development of our Global EV Centre of Excellence for the testing of automotive electric propulsion systems.

To learn more about solving the test and development challenges of electric and hybrid vehicles, visit our website: intertek.com/automotive/electric-vehicle-centre-of-excellence/

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IATF16949, SOCIAL & SUSTAINABILITY

With our services in the field of auditing and certification of management systems (for example ISO 9001, 14001, 18001, 27001, 50001, IATF 16949, IFS, HACCP, BRC, SMETA, supplier audits, etc.), we help you to continually improve your company.

ELECTRIC VEHICLES, BATTERIES & EVSE

As a world leader in the testing and certification of electric propulsion systems, batteries and charging systems, our global network of experts can help you to bring your products faster to these rapidly growing markets, utilising our state-of-the-art Electric Vehicle Centre of Excellence based in the UK.

ASSURANCE & GLOBAL MARKET ACCESS (GMA) SERVICES

We can support manufacturers at the early stages of design and development within a product's journey to market, from ensuring the required testing protocols and certifications are achieved to supporting with market regulations, safety testing requirements, design verification planning, and global market access.

ENGINES & HYBRIDS

Our testing services for internal combustion engines and hybrids help to develop optimal products, and we offer a variety of options for products used in passenger cars, trucks and high-performance engines sectors for gasoline, diesel and alternative fuels.

ELECTRICAL COMPONENTS & SYSTEMS

Ensure that your systems and components are compliant with SAE, OEM, E/e-Mark, EMC and other related national and regulatory standards.

ENVIRONMENTAL SIMULATION TESTING

The range of simulated and accelerated environmental testing options we offer brings your automotive products an assurance that they are ready to weather any environmental challenges that may come, rain or shine, fog or humidity, mechanical vibration & shock, or even freezing temperatures and corrosive salt.

VEHICLE TESTING SERVICES

Our in-lab, closed course (track), and on-road fleet testing solutions provide Total Quality Assurance for both passenger and heavy-duty vehicles. We offer mileage accumulation programs virtually anywhere on the planet in any climate, or dedicated time on a closed-course, proving grounds.

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We are a leader in additive, lubricant, and engine oil testing for standardized gasoline and diesel engines, engine endurance and durability testing, fuel additive & alternative fuel testing, and sealed housing for evaporative emission determination (SHED) fuel system services testing. We provide testing services for American Petroleum Institute (API) and Coordinating European Council (CEC) compliance, as well as bespoke testing solutions.

EV FLUIDS

We support energy companies develop their EV Fluid products with assurance and testing services across our global network of experts. Our testing services cover e-Motors, Electric Drive Units (EDU), and battery systems.

Find out how we can help you:
intertek.com/automotive/

Intertek is a leading Total Quality Assurance provider to industries worldwide. Our network of more than 1,000 laboratories and offices in more than 100 countries, delivers innovative and bespoke Assurance, Testing, Inspection and Certification solutions for our customers' operations and supply chains. Intertek Total Quality Assurance expertise, delivered consistently with precision, pace and passion, enabling our customers to power ahead safely.

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