Importance of copper corrosion in wet eMotor systems

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The heavy transportation industry is a large contributor to the overall level of CO_2 emissions. The EU states [1] that 25% of CO_2 emissions from the transportation sector is emitted from heavy vehicles, including trucks, buses and coaches. This corresponds to 6% of the total CO_2 emissions in the EU. Without further action it is assumed that this will increase by 9% between 2010 and 2030. As a result the EU has developed legislation for measurement, calculation and follow up of CO_2 emissions from heavy vehicles using a tool called VECTO. VECTO adds measured loss maps from engine, transmission, axles, tyres and air drag. Combined with reference drive cycles this allows for calculation of CO_2 emissions from the vehicle. The intention is to push the manufacturers to develop and produce more energy efficient vehicles. Based on this, the EU has also set targets for CO_2 reduction by 2025 of 15% and by 2030, 30%, using 2019 fleets as reference.

Meeting these targets is challenging OEMs who are having to adapt accordingly. Scania has decided to take this a step further in the Science Based Target Initiative. Its aims are to reduce the CO_2 emissions from its operations by 50% and the Wheel-to-Well CO_2 emission from the vehicles it produces by 20%. The 2025 targets are to be met and are in line with the 1.5°C target in the Paris Agreement on climate control (2015). The benefit of using wheel-to-well rather that tailpipe emissions, which is the case for VECTO, is that it drives the shift to a sustainable transport system in areas missed by VECTO, for example, that the use of biofuels can significantly reduce CO_2 emissions. Driver training is another area that can give lasting effects in fuel consumption reduction and thus CO_2 emissions by up to 10%. Scania is also including vehicles sold worldwide while VECTO only regulates those sold within the EU. To meet these stringent targets Scania is focusing on a number of activities one of which is electrification.

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In 2014 Scania launched the first hybrid electric vehicle (HEV), a bus intended for city operation. Since then plug in hybrid (PHEV) and battery electric vehicles (BEV), both trucks and buses are readily available in transport fleets. BEV trucks and buses offer quiet and emission free operation and are already a viable option for many transport operators today. With reductions in battery cost, size and weight, together with a growing network of charging points, market penetration of electrified vehicles has the potential to increase even further. From a vehicle designer's perspective the electrified drivetrain needs to be compact in order to fit batteries that for heavy vehicles are large enough to offer long range; additionally, for the HEV and PHEV case there needs to be space left to fit a combustion engine.

Direct cooling where copper winding of the eMotor is submerged in or sprayed with a liquid allows for compact design. eMotors in BEV operation typically operates at higher rpm than that of combustion engines, meaning that BEV drivelines often require reduction gears with single or multiple gears to select from. These gearboxes require lubrication to function properly. If the need for cooling of the electric machine and the need for lubrication of the gearbox can be combined into one oil system, the overall system can be designed in a compact manner. However, the requirements in an eMotor and in a gearbox are somewhat contradictory. The gearbox typically relies on the lubricant to reduce friction and wear in gears, bearings and other components subjected to sliding and/or rolling motion. The most important properties for eMotor cooling is the thermal properties and to prevent corrosion.

In order to prevent scuffing wear or seizure in gears and other components, EP additives are used [2]. These typically consist of chemically reactive sulphur [2]. They function by forming a chemically reacted low shear resistance layer in steel surfaces, this process has much in common with corrosion and is typically activated by the heat increase caused by local friction. When these types of reactive sulphur additives come into contact with copper, one common consequence is formation of copper sulphide.

This sulphur corrosion is detrimental to the copper windings in eMotors. As copper sulphide is conductive it means that if allowed to grow, copper sulphide can form contact bridges between electrical phases. This leads to a short circuit followed by sharp temperature increase resulting in electrical arcing and subsequent melting of components in the eMotor leading to a total breakdown and ultimately the eMotor will need to be replaced.

In order to avoid this problem in the future new methods to test corrosion of copper surfaces need to be developed and implemented.

New test methods for copper corrosion

Our first attempt to do this was to cut a piece of the copper winding and polish the ends. The piece is placed in a glass container together with the test oil so that one end of the piece sits below the oil surface and the other above. The intention is to test the corrosion properties both in the oil phase and in the vapour phase. The container is then placed in an oven with a controlled temperature and time. A schematic view of the test setup can be seen in Figure 2. After testing, visual inspection of the surfaces takes place specifically looking for presence of conductive layers. As copper sulphide is black and brittle it is easy to distinguish with the naked eye as exemplified by Figure 3.

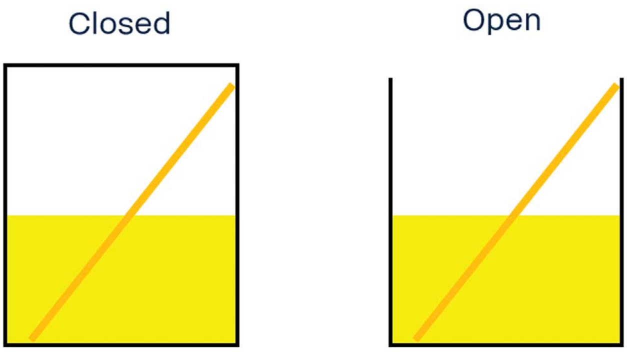

Figure 2: *Schematic view of the test setup for the corrosion test with eMotor copper windings. The test setup can be run either with or without closed container, in general closed system appears to be more severe. Variation of test temperature and time is also recommended to mimic the conditions of the specific system*

Figure 3: *Results from copper corrosion test run at 150°C in closed vessel, to the left an eFluid, to the right the same eFluid but with 10% axle oil added to it. On top row from the part or the piece exposed to the vapour phase and the bottom row exposed to the oil phase*

In order to further develop our test capability to also get quantitative test data, another test setup was installed, the basic principle behind the test was to monitor the change in electrical resistance in a thin copper wire. Should corrosion take place the wire gets thinner and the resistance increases. The copper wire is wound up on a plastic holder and placed in a glass beaker at elevated temperature. The test setup has two different electrical circuits, one in the oil phase and one in the vapour phase [3]. By using this method the corrosion rate as a function of time can be quantified, Figure 4.

Results from the two test setups show that there are significant differences in corrosion performance in some common transmission and axle lubricants. Furthermore, there is a difference between the oil and the vapour phase indicating that either the vapour contains material that is more corrosive or that the corrosion inhibitors are more effective in the oil phase. This is not easily distinguishable using the corrosion test shown in Figure 2. Scania has some experience from field issues where non recommended oils have been used and often the most severe corrosion damage occurs above the oil surface, indicating that the vapour phase is more severe than the oil phase for lubricants containing sulphur based EP-type components.

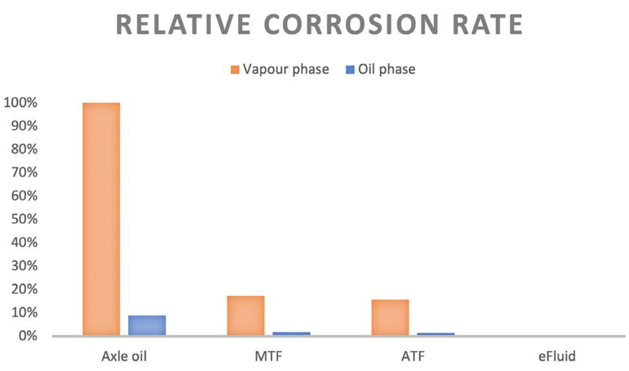

Figure 4: *Corrosion rate relative to that of axle oil in the vapour phase for some commonly used fluids. In comparison the corrosion rate for the eFluid is almost zero*

Concluding remarks

In general, it seems that the corrosion properties in the vapour phase are more severe than that in the oil phase for lubricants containing sulphur-based EP-type components.

Results from the corrosion testing indicates that there is a connection between the scuffing performance in the sense that products like axle oils in general have very high scuffing protection performance, but are also very corrosive towards copper, while fluids having lower scuffing performance are less corrosive towards copper. There seems to be a compromise between EP scuffing protection and copper corrosion protection and in order to overcome the conflict between scuffing and corrosion and have good properties in both areas new chemistries are required, described in Figure 5 as dedicated eFluid. This could be either new additives for scuffing protection and/or new corrosion inhibitors that are active both in the oil and vapour phase.
If there is a possibility to minimise the amount of corrosive material released from the oil to the vapour phase during elevated temperatures it is likely to be beneficial for the corrosion rate in the vapour phase.

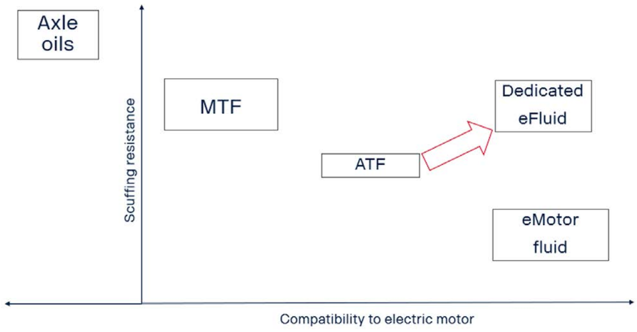

Figure 5: *Schematic view of the trade-off between scuffing performance vs copper corrosion here expressed as compatibility to electric machine. As the amount and reactivity of the EP additives decreases the compatibility towards the eMotor increase. For oil systems that are used both for lubrication of a transmission and for cooling of an eMotor there is a need for both high scuffing resistance and good compatibility towards the electric motor, here displayed as dedicated eFluid*

This article puts focus mainly on the importance of copper corrosion in combination with scuffing wear protection. However, there are many other aspects that needs to be considered when developing lubricants for a system with both wet eMotor and transmission, including thermal conductivity and capability, air entrainment, foaming, surface fatigue protection, emulsifying/demulsifying properties, seal material compatibility.

References

[1] Regulation (EU) 2019/1242

[2] Lubricant Additives - Chemistry and Applications. Rudnick. L. R. ISBN: 0-8274-0857-1

[3] Understanding Vapour and Solution Phase Corrosion of Lubricants Used in Electrified Transmissions," SAE Technical Paper 2020-01-0561, 2020, doi: 10.4271/2020-01-0561, Hunt G Prengaman. C.

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