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## Patent Public Search | Text View

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United States Patent Application Publication

20250263620

Kind Code

A1

Publication Date

August 21, 2025

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### LUBRICANT COMPOSITION COMPRISING TRACTION COEFFICIENT ADDITIVE

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#### Abstract

The present invention relates to a lubricant composition suitable for use in an electric vehicle. The lubricant composition comprises a traction coefficient additive and wherein the traction coefficient additive is an ester, said ester being the reaction product of at least one saturated branched-chain aliphatic monohydric alcohol having between 12 and 32 carbon atoms and at least one aliphatic carboxylic acid having between 6 and 32 carbon atoms. The lubricant composition as described herein provides an electric vehicle gear oil and imparts desirable coefficient of traction properties when in use.

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**Family ID:** 1000008578433

**Appl. No.:** 19/199188

**Filed:** May 05, 2025

#### Related U.S. Application Data

parent US continuation 18568037 20231207 PENDING WO continuation PCT/EP2022/065499  
20220608 child US 19199188

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#### Publication Classification

**Int. Cl.:** C10M129/70 (20060101); C10M169/04 (20060101); C10N20/00 (20060101);  
C10N20/02 (20060101); C10N40/04 (20060101)

**U.S. Cl.:**

## Background/Summary

### FIELD OF THE INVENTION

[0001] The present invention relates to a lubricant composition suitable for use in an electric vehicle comprising a traction coefficient additive. The lubricant composition as described herein provides utility inter alia in electric vehicle gear oil, and in particular electric vehicle transmission fluids, and provides improved coefficient of traction properties when in use.

### BACKGROUND

[0002] Electric vehicles are vehicles which are propelled using one or more electric motors. Electric vehicles may be fully electric (also known as pure-electric or all-electric vehicles) or hybrid in nature (in a hybrid electric vehicle propulsion may be achieved from an alternative means, such as hydrocarbon derived fuel some of the time). Electric vehicles also include range-extended electric vehicles where the vehicle is powered by an electric motor and a plug-in battery, but the vehicle also comprises an auxiliary combustion engine which is used only to supplement battery charging and not as a primary source of propulsion. The present invention is suitable for use in all of these types of electric vehicle.

[0003] Gear oils are a sub-class of lubricant, and typically comprise a lubricant base stock (or base oil) as their majority component. The choice of lubricant base stock utilised in a lubricant oil can have a major impact on properties such as oxidation and thermal stability, volatility, low temperature fluidity, solvency of additives, contaminants and degradation products, and traction. More especially, it is traditionally taught by industry that traction coefficient is an inherent property of the base stock fluid (i.e. based on chemical composition of the base oil) and that traction coefficient is not affected by additives. It is widely believed in industry that the viscosity of the base stock fluid determines a lubricants coefficient of traction in use.

[0004] The American Petroleum Institute (API) currently defines five groups of lubricant base stocks (API Publication 1509).

[0005] Groups I, II and III are mineral oils which are classified by the amount of saturates and sulphur they contain and by their viscosity indices. Table 1 below illustrates these API classifications for Groups I, II and III.

TABLE-US-00001 TABLE 1 Viscosity Group Saturates Sulphur Index (VI) I <90% >0.03% 80-120 II At least 90% Not more than 80-120 0.03% III At least 90% Not more than At least 120 0.03%

[0006] Group I base stocks are solvent refined mineral oils, which are the least expensive base stock to produce. They provide satisfactory oxidation stability, volatility, low temperature performance and traction properties and have particularly good solvency for additives and contaminants.

[0007] Group II base stocks are mostly hydroprocessed mineral oils, which typically provide improved volatility and oxidation stability as compared to Group I base stocks. The use of Group II stocks has grown to about 30% of the US market.

[0008] Group III (including Group III+) base stocks are severely hydroprocessed mineral oils or they can be produced via wax or paraffin isomerisation. They are known to have better oxidation stability and volatility than Group I and II base stocks but have a limited range of commercially available viscosities. Group III+ base stocks include those derived from GTL (gas-to-liquid) fuel streams.

[0009] Group IV base stocks differ from Groups I to III in that they are synthetic base stocks e.g., polyalphaolefins (PAOs). PAOs have good oxidative stability, volatility, and low pour points. Disadvantages include moderate solubility of polar additives, for example anti-wear additives.

[0010] Group V base stocks are all base stocks that are not included in Groups I to IV. Examples include alkyl naphthalenes, alkyl aromatics, vegetable oils, esters, polycarbonates, silicone oils and polyalkylene glycols.

[0011] The rapid move towards electrification of passenger vehicles has surpassed the understanding and specifications of current gear oil specifications of OEM's and regulators. Current generation hybrid and electric vehicles still use standard automatic transmission fluid (ATF) formulations which were not specifically designed for this application. Current gear oils are not fulfilling the dynamic requirements of OEM's, due to rapid advancements in electric vehicle technology, ATF base fluids, and ad-packs. Furthermore, because the electric motor in an EV is highly efficient, any losses in the gear lubricant in the EV's powertrain system can be quite large. Reduction in energy losses will provide improvements in the battery life at the EV in use, meaning that the EV requires less frequent charging as battery range is increased.

[0012] Additionally, thermal management of parts in electric vehicles is gaining importance. In the battery of the vehicle thermal management is crucial to ensure safe running and use. There is currently a great amount of research being conducted looking into immersion cooled battery systems, which place the battery into direct contact with dielectric cooling fluids. Fluids with high thermal properties, for example heat capacity and thermal conductivity, are therefore required for this application. Cooling of electronic power systems, for example the electric motor and the transmission, are also required in order to keep them functioning effectively, without overheating. Removing excess heat from electronic systems also helps to reduce electrical resistance and therefore helps to improve engine efficiency. As such, the thermal properties of a lubricant composition suitable for use in an electric vehicle will differ greatly to those developed for use in automotive combustion engines.

[0013] As such, despite continuous development of lubricant technology for transmission and gearboxes in internal combustion, hybrid and electrical vehicles, there remains a need for lubricant oil formulations with improved energy efficiency over the lifetime of the lubricant oil. More especially there is a need for lubricant technology optimised and tailored to meet the requirements of electric vehicle gearboxes, which differ in their requirements to those of traditional combustion engines. As such, new base oils which offer high performance in electric engines (in particular low traction and high thermal conductivity) but are commercially viable for the electric vehicle passenger car market are still actively sought.

[0014] It is an object of the present invention to provide a lubricant composition, suitable for use in the gearbox of electric vehicles, which provides improved low traction and therefore energy losses are minimised. As well as providing low traction, the lubricant composition should have sufficient oxidative stability as well as having good low temperature properties and compatibility with materials such as elastomers and copper.

#### SUMMARY OF THE INVENTION

[0015] Accordingly, the present invention provides a lubricant composition suitable for use in an electric vehicle, comprising a traction coefficient additive and wherein the traction coefficient additive is an ester, said ester being the reaction product of [0016] i) at least one saturated branched-chain aliphatic monohydric alcohol having between 12 and 24 carbon atoms and, [0017] ii) at least one aliphatic carboxylic acid having between 6 and 24 carbon atoms.

[0018] The present invention also provides a method of reducing traction coefficient in a gearbox which comprises using a lubricating oil in accordance with the first aspect of the present invention.

[0019] The traction coefficient additive described herein may advantageously improve the performance of a gearbox to which the lubricant composition is applied by providing a reduced traction coefficient.

[0020] The traction coefficient additive described herein can be used as a traction coefficient reducing additive in a lubricant composition, and more especially in a gear oil for a gearbox, and in particular in a gear oil for a gearbox in an electric vehicle.

#### DETAILED DESCRIPTION OF THE INVENTION

[0021] It will be understood that any upper or lower quantity or range limit used herein may be independently combined.

[0022] It will be understood that, when describing the number of carbon atoms in a substituent group (e.g. 'C1 to C6'), the number refers to the total number of carbon atoms present in the substituent group, including any present in any branched groups. Additionally, when describing the number of carbon atoms in, for example fatty acids, this refers to the total number of carbon atoms including the one at the carboxylic acid, and any present in any branch groups.

[0023] As used in this specification in relation to the invention described and claimed, as required by the context, the term "wt %" indicates the percentage by weight of the component referred to as a percentage of the total weight of the lubricant composition. Where the context refers to a specific component, for example a Noack evaporation loss, the term "wt %" indicates the percentage by weight of the total weight of the component.

[0024] In accordance with the present invention there is provided a lubricant composition suitable for use in an electric vehicle, comprising a traction coefficient additive and wherein the traction coefficient additive is an ester, said ester being the reaction product of [0025] iii) at least one saturated branched-chain aliphatic monohydric alcohol having between 12 and 32 carbon atoms and, [0026] iv) at least one aliphatic carboxylic acid having between 6 and 32 carbon atoms.

[0027] Suitably, the aliphatic carboxylic acid may be saturated or unsaturated, linear, or branched. Preferably the aliphatic carboxylic acid is saturated, as this provides improved oxidative stability.

[0028] Desirably the carboxylic acid may be derived from vegetable fats and/or oils. As such, preferably the aliphatic carboxylic acid may be a fatty acid. The fatty acid may be saturated or unsaturated. The fatty acid may be linear or branched. Preferably the fatty acid is saturated. Naturally, fatty acids with even numbers of carbon in their fatty chain are more abundant in nature, and so are more readily and cheaply available, as such these forms of fatty acid may be preferred, and particularly those with C6, C8, C10, C12, C14, C16, C18 and C20 chain lengths. The fatty acid may be understood to contain a medium fatty acid chain, which preferably provides a fatty chain containing 6 to 18 carbons.

[0029] Preferably the carboxylic acid is a monocarboxylic acid or dicarboxylic acid, such that said ester is a monoester or a diester, and most preferably carboxylic acid is a monocarboxylic acid, such that the ester is a monoester. Suitably, the carboxylic acid may be selected from one or more of the following: hexanoic acid, heptanoic acid, octanoic acid, decanoic acid, dodecanoic acid, myristic acid, stearic acid, behenic acid, hexenoic acid decenoic acid, linoleic acid, linolelaidic acid, palmitoleic acid, oleic acid, elaidic acid, erucic acid, nervonic acid, isohexanoic acid, 4-methylpentanoic acid, isooctanoic acid, 2-ethylhexanoic acid, isostearic acid, isobehenic acid, 2-ethyl-1-butanoic acid, 2-butyl-octanoic acid, 2-hexyl-decanoic acid, 2-octyldodecanoic acid, 2-decyltetradecanoic acid, adipic acid, suberic acid, azelaic acid, sebacic acid, phellogenic acid, cyclohexanedicarboxylic acid, fatty acids, tall-oil, reaction products with acrylic acid, and alkenylsuccinic acids.

[0030] Suitably, the at least one saturated branched-chain aliphatic monohydric alcohol having between 12 and 32 carbon atoms and may be obtained from any suitable source and typically may be selected from Guerbet alcohols, oxo alcohols, aldol condensation derived alcohols and mixtures thereof.

[0031] Preferably, the at least one saturated branched-chain aliphatic monohydric alcohol has between 12 and 32 carbon atoms, and more preferably between 12 and 24 carbon atoms, and most preferably between 12 and 20 carbon atoms. The preferred shorter chain lengths have a positive effect on the ester viscosity for the intended use. More especially, the at least one saturated

branched-chain aliphatic monohydric alcohol having between 12 and 32 carbon atoms is an alcohol branched at the  $\beta$  position on the main carbon chain. Preferably, such alcohols may be selected from, 2-butyloctanol, isomyristyl alcohol, 2-hexyldecanol, isostearyl alcohol, 2-octyldecanol-2-octadodecanol-1, 2-nonyltridecanol-1 and 2-1,2-heptylundecanol-1, decyltetradecanol-1 and mixtures of two or more such alcohols. Such alcohols are conveniently Guerbet alcohols, and preferably the alcohol may be selected from C12 Guerbet alcohol, C14 Guerbet alcohol, C16 Guerbet alcohol, C18 Guerbet alcohol, C20 Guerbet alcohol, and C24 Guerbet alcohol, or mixtures thereof. Use of the preferred Guerbet alcohols is believed to provide esters with unusually high thermal conductivity for their given viscosity, that is to say the thermal conductivity of the traction coefficient additive is surprising and renders the lubricant compositions of the present invention suitable for use in electric vehicles. It has also been found that the monoesters in accordance with the present invention in particular have low viscosity, low polarity and low volatility, while providing exceptionally low traction in comparison to other esters.

[0032] Suitably, the traction coefficient additive has a thermal conductivity of higher than 0.131 W/mK at 40° C., preferably 0.135 W/mK at 40° C., more preferably 0.141 W/mK at 40° C., and most preferably 0.151 W/mK at 40° C. Thermal conductivity is measured in accordance with the method described below, in relation to the Examples.

[0033] Preferably, said traction coefficient additive has a kinematic viscosity at 100° C. of not more than 8.0, preferably of not more than 6.0 cSt, and most preferably not more than 4.0 cSt, and in some particularly preferred embodiments said traction coefficient additive has a kinematic viscosity at 100° C. of not more than 3.3 cSt. Additionally, or alternatively, said traction coefficient additive has a kinematic viscosity at 40° C. of not more than 30 cSt, preferably of not more than 20 cSt, and most preferably not more than 10 cSt.

[0034] Preferably, said traction coefficient additive has a viscosity index of at least 130, preferably of at least 140.

[0035] Preferably, said traction coefficient additive has a pour point of not more than -30° C., more particularly of not more than -35° C. and especially not more than -40° C.

[0036] Preferably, said traction coefficient additive has a Noack evaporation loss at 250° C. of not more than 22 wt %, preferably of not more than 20 wt %, more preferably of not more than 18 wt %. Additionally, or alternatively, preferably said traction coefficient additive has a Noack evaporation loss at 200° C. of not more than 9 wt %, preferably of not more than 7 wt %, more preferably of not more than 5 wt %.

[0037] Preferably, said traction coefficient additive has a flash point of at least 200° C., more preferably at least 210° C. and more particularly at least 220° C.

[0038] Preferably, said traction coefficient additive has a non-polarity index (NPI), as described in EP-B-0792334, of at least 80, preferably of at least 90.

[0039] Preferably, said traction coefficient additive is stable when held at -20° C. for one week. This low temperature stability may be tested by storing approximately 30 ml of sample in a glass vial and placing the vial in a freezer unit at -20° C. for one week, checking the sample at regular intervals and noting any signs of crystal formation or gelling.

[0040] A further advantage of the traction coefficient additive of the present invention is that it has been found to have a minimal swell effect on FKM and/or HNBR elastomer, and so can be used at higher inclusion levels versus traditional lubricant additives. As such, in some, less preferred, embodiments the lubricant composition may consist solely of said traction coefficient additive. Alternatively, the lubricant composition may comprise a majority of said traction coefficient additive, such that the lubricant composition comprises more than 50 wt % of said traction coefficient additive. However, preferably, said lubricant composition comprises up to 50 wt % of said traction coefficient additive. Preferably, said lubricant composition comprises at least 3 wt %, more preferably at least 5 wt % of said traction coefficient additive. Said lubricant composition may comprise up to 45 wt %, more preferably up to 35 wt % and, more especially up to 25 wt % of

said traction coefficient additive. In one embodiment of the invention, said lubricant composition comprises between 3 wt % and 25 wt %, and preferably between 5 wt % and 20 wt % of said traction coefficient additive.

[0041] Preferably, the lubricant composition comprises at least one base oil, and suitably the at least one base oil is selected from a Group I to Group IV base oil, or mixtures of two or more thereof. Preferably the lubricant composition comprises the at least one base oil as the majority component of the lubricant composition. One benefit of the present invention is that the traction coefficient additive has good compatibility with Group I to Group IV base oils, allowing flexibility in choice of base oil in the lubricant composition. However, for use in electrical vehicles lubricant compositions comprising at least one of Group III or Group IV base oils may be preferred. Examples of suitable Group III base oils include mineral oils, and examples of Group III+GTL base oils which are made by conversion of natural gas (ie, methane and higher alkanes) to synthesis gas (carbon monoxide and hydrogen) and then via oligomerisation (for example via the Fischer-Tropsch process) to higher molecular weight molecules that are hydrocracked to produce iso-paraffins in the required lubricant boiling/viscosity range. Examples of suitable Group IV base oils included poly- $\alpha$ -olefins (PAOs) derived from C<sub>8</sub> to C<sub>12</sub>  $\alpha$ -olefins and having kinematic viscosities in the range 2 cSt to 8 cSt at 100° C. Examples of PAOs include SpectraSyn MaX available from Exxon. Examples of Group V base oils include polyalkylene glycols (PAGs), alkyl benzenes and esters (it should be understood that in this case the Group V ester base oil is an ester other than said traction coefficient additive as described above.). Examples of esters include Priolube 3970™ a TMP nC<sub>8</sub>/nC<sub>10</sub> polyol ester.

[0042] In one embodiment of the invention, said lubricant composition consists essentially of said traction coefficient additive, and at least two base oils, said at least two base oils comprising at least one Group V base oil especially an ester.

[0043] In one embodiment, the lubricant composition is non-aqueous. However, it will be appreciated that components of the lubricant composition may contain small amounts of residual water (moisture) which may therefore be present in the lubricant composition. The lubricant composition may comprise less than 5% water by weight based on the total weight of the composition. More preferably, the lubricant composition is substantially water free, i.e. contains less than 2%, less than 1%, or preferably less than 0.5% water by weight based on the total weight of the composition. Preferably the lubricant composition is substantially anhydrous.

[0044] To further adapt the lubricant composition to its intended use, particularly for use as a gear oil, the composition may comprise one or more of the following additive types.

[0045] 1. Dispersants: for example, alkenyl succinimides, alkenyl succinate esters, alkenyl succinimides modified with other organic compounds, alkenyl succinimides modified by post-treatment with ethylene carbonate or boric acid, pentaerythritols, phenate-salicylates and their post-treated analogues, alkali metal or mixed alkali metal, alkaline earth metal borates, dispersions of hydrated alkali metal borates, dispersions of alkaline-earth metal borates, polyamide ashless dispersants and the like or mixtures of such dispersants.

[0046] 2. Antioxidants: Antioxidants reduce the tendency of mineral oils to deteriorate in service which deterioration is evidenced by the products of oxidation such as sludge and varnish-like deposits on the metal surfaces and by an increase in viscosity. Examples of anti-oxidants include phenol type (phenolic) oxidation inhibitors, such as 4,4'-methylene-bis(2,6-di-tert-butylphenol), 4,4'-bis(2,6-di-tert-butylphenol), 4,4'-bis(2-methyl-6-tert-butylphenol), 2,2'-methylene-bis(4-methyl-6-tert-butylphenol), 4,4'-butylidene-bis(3-methyl-6-tert-butylphenol), 4,4'-isopropylidene-bis(2,6-di-tert-butylphenol), 2,2'-methylene-bis(4-methyl-6-nonylphenol), 2,2'-isobutylidene-bis(4,6-dimethylphenol), 2,2'-methylene-bis(4-methyl-6-cyclohexylphenol), 2,6-di-tert-butyl-4-methylphenol, 2,6-di-tert-butyl-4-ethylphenol, 2,6-di-tert-butylphenol, 2,4-dimethyl-6-tert-butylphenol, 2,6-di-tert-butyl-4-dimethylamino-p-cresol, 2,6-di-tert-butyl-4-(N,N'-dimethylamino-methylphenol), 4,4'-thiobis(2-methyl-6-tert-butylphenol), 2,2'-thiobis(4-methyl-6-tert-butylphenol), bis(3-methyl-

4-hydroxy-5-tert-butylbenzyl)-sulfide, and bis(3,5-di-tert-butyl-4-hydroxybenzyl). Other types of oxidation inhibitors include alkylated diphenylamines (e.g., Irganox L-57 ex. BASF, metal dithiocarbamate (e.g., zinc dithiocarbamate), and methylenebis(dibutyldithiocarbamate).

[0047] 3. Anti-wear agents: As their name implies, these agents reduce wear of moving metallic parts. Examples of such agents include phosphates, phosphites, carbamates, esters, sulfur containing compounds, and molybdenum complexes.

[0048] 4. Emulsifiers: for example, linear alcohol ethoxylates.

[0049] 5. Demulsifiers: for example, addition products of alkylphenol and ethylene oxide, polyoxyethylene alkyl ethers, and polyoxyethylene sorbitan esters.

[0050] 6. Extreme pressure agents (EP agents): for example, zinc dialkyldithiophosphate (primary alkyl, secondary alkyl, and aryl type), sulfurized oils, diphenyl sulfide, methyl trichlorostearate, chlorinated naphthalene, fluoroalkylpolysiloxane, and lead naphthenate. A preferred EP agent is zinc dialkyl dithiophosphate (ZnDTP), e.g. as one of the co-additive components for an anti-wear hydraulic fluid composition.

[0051] 7. Multifunctional additives: for example, sulfurized oxymolybdenum dithiocarbamate, sulfurized oxymolybdenum organo phosphorodithioate, oxymolybdenum monoglycehd, oxymolybdenum diethylate amide, amine-molybdenum complex compound, and sulfur-containing molybdenum complex compound.

[0052] 8. Viscosity index improvers: for example, polymethacrylate polymers, ethylene-propylene copolymers, styrene-isoprene copolymers, hydrogenated styrene-isoprene copolymers, polyisobutylene, and dispersant type viscosity index improvers.

[0053] 9. Pour point depressants: for example, polymethacrylate polymers. Although it is a benefit of the present invention that pour point of the compound of formula (I) is suitable for use as a gearbox oil, embodiments utilising the relatively longer chain linear molecules may benefit from the addition of pour point depressant. Additionally, the presence of some alternative additives may adversely affect the formulation pour point making the addition of a pour point depressant attractive.

[0054] 10. Foam inhibitors: for example, alkyl methacrylate polymers and dimethyl silicone polymers.

[0055] 11. Friction modifiers: which may include amides, amines and partial fatty acid esters of polyhydric alcohols and include for example glycerol mono oleate, oleyl amide and alternative friction modifiers available from Croda under the "Perfad" tradename, or available from Nouryon under the "Ethomeen" tradename.

[0056] Suitably, the lubricant composition may comprise at least 0.5 wt. % of one or more additive types, preferably at least 1 wt. %, more preferably at least 5 wt. % based on the total weight of the formulation. The lubricant composition may comprise up to 30 wt. % of one or more additive types, preferably up to 20 wt. %, more preferably up to 10 wt. % based on the total weight of the formulation.

[0057] Other additives may also be present in the lubricant composition of known functionality at levels between 0.01 to 30 wt. %, more preferably between 0.01 to 20 wt. % more especially between 0.01 to 10 wt. % based on the total weight of the lubricant composition. These can include detergents, corrosion inhibitors, rust inhibitors, and mixtures thereof. Corrosion inhibitors include sarcosine derivatives, for example Crodasinic O available from Croda Europe Ltd. Ashless detergents include carboxylic dispersants, amine dispersants, Mannich dispersants and polymeric dispersants. Ash-containing dispersants include neutral and basic alkaline earth metal salts of an acidic organic compound. Additives may have more than one functionality in a single material.

[0058] The additive or additives may be available in the form of a commercially available additive pack. Such additive packs vary in composition depending on the required use of the additive pack. A skilled person may select a suitable commercially available additive pack for a gear oil. An example of a particularly suitable additive pack for the gear oil is Evogen 5201 ex. Lubrizol, USA

which is designed specifically for use in electric vehicles.

[0059] The lubricant composition preferably comprises at least 0.05 wt. %, more preferably at least 0.5 wt. %, particularly at least 1 wt. %, and especially at least 1.5 wt. % of further additive(s) (additive pack) based upon the total weight of the lubricant composition. The lubricant composition preferably comprises up to 15 wt. %, more preferably up to 10 wt. %, particularly up to 4 wt. %, and especially up to 2.5 wt. % of further additive(s) (additive pack) based upon the total weight of the lubricant composition.

[0060] Notwithstanding the examples given above, to render the lubricant composition suitable for use in an electric vehicle, the selection of any additive(s) should take into account copper compatibility (because of the requirements of the electric motor), as well as provide or exhibit low (but not necessarily zero) electrical conductivity; not all additives commonly utilised for combustion engine automotive engines will be suitable for use in electric vehicle power train fluids.

[0061] The lubricant composition may have a kinematic viscosity according to an ISO grade. An ISO grade specifies the mid-point kinematic viscosity of a sample at 40° C. in cSt (mm<sup>2</sup>/s). For example, ISO 100 has a viscosity of 100±10 cSt and ISO 1000 has a viscosity of 1000±100 cSt. The lubricant composition preferably has a viscosity in the range from ISO 10 to ISO 1500, more preferably ISO 68 to ISO 680.

[0062] The present invention also provides a gear oil comprising said lubricant composition as described above. The gear oil can be considered to be a lubricant fluid and may have utility in other areas as a lubricant even where thermal conductivity and traction are not of importance. The gear oil formulation may be suitable for use as an industrial, automotive and/or marine gear oil for use in any type of transmission system. However, the gear oil suitably provides a gearbox oil, and more especially an integrated gearbox oil suitable for use in an electric vehicle; this is because the lubricant composition as described above provides advantageous thermal conductivity properties and desirable traction properties when in use. Additionally, provision of good thermal properties in gear oil may enhance the longevity of the engine life.

[0063] It is also envisaged that the base oil may find utility as a heat transfer fluid. Such a heat transfer fluid can provide a means of removing heat from a system. Such systems requiring, or benefiting from, use of heat transfer fluid may be mechanical or electrical systems. The present base oils may be well suited to use as heat transfer fluids in electrical systems, and more especially they may be well suited to use as heat transfer fluids in electric vehicles.

[0064] In accordance with an alternative embodiment of the present invention there is provided a method of improving energy efficiency in an electric vehicle, the method comprising using a lubricant composition in accordance with the first aspect of the invention in the electric vehicle's powertrain. The lubricant composition may be used in various systems within the power train such as axels, differentials, transmissions, battery pack and power electronics. The lubricant composition possesses suitable properties for use in the electric vehicle power train, including traction, thermal, conductivity and viscosity properties which have been optimised for use in electric vehicles. In a further alternative, there is provided a method of improving heat removal from an electric vehicle power train, the method comprising using a base oil in accordance with the first aspect of the present invention in the electric vehicle's powertrain.

[0065] Additionally, or alternatively, there is provided a method of improving energy efficiency in an electric vehicle, the method comprising using a lubricant composition in accordance with an aspect of the present invention in the electric vehicle's gearbox. More especially, the method of improving energy efficiency of the electric vehicle comprises the step of providing the lubricant composition in an integrated gearbox. Accordingly, there is provided use of a lubricant composition, as described herein in an electric vehicle powertrain, and more especially use in an electric vehicle integrated gearbox. More especially, the lubricant composition or gear oil may be used in systems within the power train such as axels, differentials, transmissions, battery pack and



power electronics.

[0066] Lubricant compositions according to the present invention include those suitable for use in an electrical vehicle power train. More especially, the lubricant composition is a gear oil suitable for use in gear systems with are both integrated and not integrated into the electric motor. Such systems include axels, differentials, and transmissions. It should be noted that electric vehicles may be provided with 2 or more electric motors.

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## Description

[0067] The present invention will now be described with reference to the following examples and accompanying Figures in which,

[0068] FIG. 1. shows MTM coefficient of traction data for experimental samples and commercial samples at 40° C.,

[0069] FIG. 2. shows MTM coefficient of traction data for experimental samples and commercial samples at 60° C.,

[0070] FIG. 3. shows MTM coefficient of traction data for experimental samples and commercial samples at 75° C.,

[0071] FIG. 4. shows MTM coefficient of traction data for experimental samples and commercial samples at 100° C.,

[0072] FIG. 5. shows MTM coefficient of traction data for experimental samples and commercial samples at 120° C.

### Materials

[0073] The following materials are utilised in the present examples: [0074] A Group III Base Oil-Yubase 4. ex. SK Lubricants [0075] A Group IV Base Oil-SpectraSyn PAO 4 ex. Exxon Mobil.

[0076] A commercially available low viscosity traditional automotive friction modifier additive—Priolube 3959 ex. Croda.

[0077] The invention will now be further illustrated with reference to the following Examples.

### 1. Examples

[0078] Samples in accordance with the present invention, are detailed in Table 1, below. The method of producing the sample materials is by a conventional esterification method as known to the skilled person. The alcohol in each of the ester example samples is provided by a Guerbet alcohol, available under the ISOFOL trade name from Sasol.

TABLE-US-00002 TABLE 1 Sample Composition Chemistry Type IP-731-89 Isofol 16 isostearate Monoester IP-731-90 Isofol 16 heptanoate Monoester IP-731-84 Isofol 12 stearate Monoester IP-731-78 Isofol 12 di-sebacate Diester DE11845 Isofol 20 isostearate Monoester DE10766 Isofol 20 heptanoate Monoester

### 2. Testing

[0079] The following tests were used to evaluate the properties of the example base oils:

[0080] 2.1 Oxidative stability was measured using an Anton Paar RapidOxy machine. 4 grams of sample is placed in a pressure vessel and charged with oxygen at 700 kPa before being heated to 140° C. The time taken for the pressure to drop by 10% is measured as the Oxidative Induction Time (OIT). This provides a relative measure of the resistance of the samples tested to oxidative decomposition, the longer the OIT the more oxidatively stable the sample is.

[0081] 2.2 Kinematic viscosity (KV) was measured at 100° C. and 40° C. using an Anton Paar SVM Viscometer. The viscosity index (VI) of the materials tested is also provided. The higher the VI value the more stable a material is over a range of temperatures. 2.3 Thermal conductivity was measured using a Thermtest THW-L2, which is based upon the hot wire transient method. Ten data points were collected at temperatures of 40° C. and 80° C. to create a reliable average, with 5 minutes between each data point to allow the fluid to settle. The test power was set such that the

output power measured was 70-90 mW and gave a temperature rise of ~3° C., the test time was set to 1 second.

[0082] 2.4 Pour point testing was performed on an ISL Mini Pour Point 5Gs to determine the minimum temperature at which the substance will still flow which is correlated to ASTM D97 and D2500.

[0083] 2.5 Traction was measured using a mini traction machine (MTM), tests were performed on a PCS MTM 1. All pieces required to set up the MTM, and standard test specimens supplied by PCS (as detailed in Table 2, below), were sonicated 3 times in heptane for 15 minutes using Camsonix C940 ultrasonic bath with heptane drained and then refreshed after each sonication. All pieces were dried using nitrogen before assembly in the MTM. The test profile goes from 0-100% slide to roll ratio (SRR) at 16N, taking 41 data points at a given temperature to create a traction curve. This is repeated at 40° C., 60° C., 75° C., 100° C. and 120° C. to show performance across a wide range of temperatures. The test parameters are detailed in Table 3 below.

[0084] 2.6 NOACK volatility at 250° C. is measured in accordance with standard test method ASTM D5800. Since electric vehicles do not operate at such high temperatures, a modified test, based on ASTM D5800 but at a temperature at 200° C. Is also performed, to provide a NOACK volatility at 200° C. measurement.

[0085] 2.7 Hydrolytic stability as measured over 15 days (RR1006).

[0086] 250 g of oil and 25 g of water are mixed in a conical flask and fitted with a water trap (airlock). This is placed in an oven at 90 C for 15 days with acid value being tested once every several days.

[0087] 2.8 Seal swell test. Seals of differing material are subject to submersion in a sample to be tested for 2 weeks at 100° C.

TABLE-US-00003 TABLE 2 MTM Specimen Parameters. Disc Ball Diameter (mm) 46 ¾ inch Roughness <0.01 µmRa — Steel AISI 52100 AISI 52100 Hardness 720-780 Hv

TABLE-US-00004 TABLE 3 MTM Testing Parameters. Parameter Rubbing step Temperature (° C.) 40, 60, 75, 100, 120 Ball load (N) 16 Rolling speed (mms.sup.-1) 2200 SRR % 0-100

### 3. Test Data

[0088] The sample materials as detailed in Table 1, and the commercially available base oils from Group III and Group IV as detailed above, were subject to the tests outlined in Section 2, above.

TABLE-US-00005 TABLE 4 Example Sample physical properties in comparison to Group III and IV base oils. Thermal Thermal KV Pour conductivity conductivity KV@40° C./ @100° C./ point/ @ @ Material Composition cSt cSt VI ° C. 40° C. 80° C. Group III Yubase 4 19.3 4.2 122 -15 0.131 0.126 Base Oil Group IV SpectraSyn 18.6 4.1 122 -75 0.136 0.130 Base Oil PAO 4 731-89 Isofol 16 21.0 4.7 148 -57 0.141 0.135 Isostearate 731-90 Isofol 16 6.8 2.2 140 -87 0.133 0.126 Heptanoate 731-84 Isofol 12 14.3 3.7 154 0 0.146 0.139 stearate 731-78 Isofol 12 di- 21.9 4.8 146 -78 0.143 0.137 sebacate DE11845 Isofol 20 25.3 5.5 157 -48 0.145 0.138 isostearate DE10766 Isofol 20 9.6 2.9 158 -35 0.139 0.13 heptanoate

[0089] The example Samples of the present invention have physical properties which render them useful as additives for use in lubricant compositions for use in electrical vehicles. In particular, the balance between Kinematic Viscosity (KV) and thermal conductivity is particularly desirable for use in the power train of electrical vehicles. More especially, the sample denoted as DE10766 provides a material particularly suited for use in electrical vehicles, as it has a low kinematic viscosity material of just 2.9 cSt at 100° C., an excellent viscosity index (VI) and very low NOACK for its viscosity (NOACK data is provided in Table 5, below). The pour point of DE10766 is also acceptable for use in electric vehicle lubricant applications.

TABLE-US-00006 TABLE 5 DE10766 NOACK Data NOACK @250° C. % loss 17.5 NOACK @200° C. % loss 2

[0090] Sample DE10766 was further tested to consider its electrical breakdown voltage, which is an important consideration for fluids suitable for use in electrical vehicles. The Electrical

breakdown voltage value was lower than expected.

TABLE-US-00007 TABLE 6 DE10766 0 days AV 5 days AV 8 days AV 15 days AV mg KOH/g mg KOH/g mg KOH/g mg KOH/g DE10766 0.06 0.06 0.15 0.38

[0091] The hydrolytic stability of Sample DE10766 is excellent and varied by just 0.38 AV units over 15 days; this is surprising for a mono ester, and it believed that the use of the Guerbet alcohol offers some resistance to hydrolysis, although the reason for this is not yet understood.

[0092] Compatibility with engine seals is another important feature of any additive to be used in an electrical vehicle power train. Sample DE10766 was also tested to access seal swell over a two-week time period. Generally, low viscosity materials are highly polar and will swell elastomers significantly. As a comparative additive, Priolube 3959 (a commercially available lubricant additive diester of with a KV at 100° C. of 2.5 cSt) was also tested. A small amount of seal swell is desirable and so the results for DE10766 are desirable where as Priolube 3959 swells elastomers to a greater, undesirable, extent. A result of 1% swell in FKM means that despite its low viscosity, DE10766 can be used at high treat rates.

TABLE-US-00008 TABLE 7 Seal Swell Data for DE10766 as compared to Priolube 3959 (an alternative ester). HNBR FKM DE10766 7% 1% Priolube 3959 37% 16%

[0093] At 40° C., all of the Samples tested had significantly lower traction than both the Group III and Group IV base oils, this trend continued at 60° C. and 75° C., however at 100° C. the Sample denoted as 731-90 started to exhibit high coefficient of traction at low slide to roll ratios. It is thought that the very low viscosity of the 731-90 sample is the reason for this (KV at 100° C. of 2.2 cSt) and that the sample is unable to sustain a lubricant film under the low slide roll ratio conditions. At 120° C. the Sample denoted as 731-84 also shows an increase in coefficient of traction; the reason for this is unknown as the Sample 731-84 has a viscosity higher than DE10766 which is able to maintain low traction levels even at high temperatures and the expectation would be that the higher viscosity material would perform better. However, in any case, since the operating temperature in an electric vehicle are typically lower than 100° C. all the example Samples prepared herewith are believed to have utility for use in an electric vehicle power train. More especially, DE10766 looks to be an excellent choice for use in reduction of traction in electric vehicles. It is low viscosity, low polarity and has excellent thermal properties, low traction properties and elastomer compatibility. Additionally, the other example Samples tested herein show that the Isofol 12 and Isofol 16 containing Samples give desirably very low traction.

## Claims

**1-29.** (canceled)

**30.** A method of lubricating a gear box of an electric vehicle, comprising the step of lubricating the gear box with a gear oil including a base oil and a traction coefficient additive present in the gear oil in an amount effective to reduce a traction coefficient characteristic of the gear oil, wherein the traction coefficient additive comprises an ester, said ester being the reaction product of at least one saturated aliphatic carboxylic acid have 6 to 32 carbon atoms and a saturated, branched-chain, aliphatic monohydric alcohol having 12 to 24 carbon atoms.

**31.** The method of claim 30, wherein the base oil comprises a mixture of two or more base oils selected from at least two different groups among Group I, Group II, Group III, and Group IV base oils.

**32.** The method of claim 30, wherein the saturated, branched-chain, aliphatic monohydric alcohol is a Guerbet alcohol.

**33.** The method of claim 30, wherein the saturated, branched-chain, aliphatic monohydric alcohol is selected from the group consisting of a C12 Guerbet alcohol, a C14 Guerbet alcohol, a C16 Guerbet alcohol, a C18 Guerbet alcohol, a C20 Guerbet alcohol, and a C24 Guerbet alcohol

**34.** The method of claim 30, wherein the saturated, branched-chain, aliphatic monohydric alcohol

comprises a main carbon chain that is branched at the beta carbon position of the main carbon chain.

35. The method of claim 30, wherein the saturated, branched-chain, aliphatic monohydric alcohol is 2-octyldodecanol.
  36. The method of claim 30, wherein the saturated, branched-chain, aliphatic monohydric alcohol is 2-butyloctanol.
  37. The method of claim 30, wherein the saturated, branched-chain, aliphatic monohydric alcohol is
  38. The method of claim 30, wherein the saturated aliphatic carboxylic acid is linear.
  39. The method of claim 30, wherein the saturated aliphatic carboxylic acid is branched.
  40. The method of claim 30, wherein the ester is a heptanoate ester.
  41. The method of claim 30, wherein the ester is a stearate ester.
  42. The method of claim 30, wherein the ester is a di-sebacate ester.
  43. The method of claim 30, wherein the ester is an isostearate ester.
  44. The method of claim 30, wherein the ester is 2-octyldodecyl isooctadecanoate.
  45. The method of claim 30, wherein the ester is 2-hexyldecyl heptanoate.
  46. The method of claim 30, wherein the ester is 2-butyloctyl octadecenoate.
  47. The method of claim 30, wherein the ester is bis(2-butyloctyl) decanedioate.
  48. The method of claim 30, wherein the ester is 2-octyldodecyl isooctadecanoate.
  49. The method of claim 30, wherein the ester is 2-octyldodecyl heptanoate.
  50. The method of claim 30, wherein the gear oil includes 3 wt % to 25 wt % of the traction coefficient additive.
  51. The method of claim 30, wherein the gear oil includes up to 50 wt % of the traction coefficient additive.
  52. The method of claim 30, wherein the gear oil includes up to 35 wt % of the traction coefficient additive.
  53. The method of claim 30, wherein the gear oil includes at least 3 wt % of the traction coefficient additive.
  54. An electric vehicle comprising a gear box lubricated with a gear oil including a base oil and a traction coefficient additive present in the gear oil in an amount effective to reduce a traction coefficient characteristic of the gear oil, wherein the traction coefficient additive comprises an ester, said ester being the reaction product of at least one saturated aliphatic carboxylic acid have 6 to 32 carbon atoms and a saturated, branched-chain, aliphatic monohydric alcohol having 12 to 24 carbon atoms.
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