

Lubricants for (Hybrid) Electric Transmissions

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ABSTRACT

In electric or hybrid electric transmissions, the transmission fluids can be in contact with the parts of the electric motors, for example, electrical windings in the stators in order to efficiently cool the electric motors and to insulate the electrical parts to prevent a short circuit of the electric motors. The transmission fluids must therefore have low electrical conductivities [1,2,3,4,5,6,7,8,9]. Transmission fluids contain dispersants, which can be reaction products of hydrocarbyl substituted carboxylic acids or anhydrides and amines. These dispersants can be further post-treated with boron and phosphorus compounds to improve friction and anti-wear properties. Certain dispersants, which have nitrogen content up to 10,000 ppm by weight, and boron plus phosphorus to nitrogen ((B+P)/N) weight ratios of from 0.1 to about 0.8 : 1.0, were found to be effective to provide low electrical conductivities less than 1,700 pS/m [10]. Metal detergents provide good anti-rust performance, but increase the finished fluid electrical conductivity. A balanced dispersant/detergent additive system was found to provide a good anti-rust performance and a low electrical conductivity. Through extensive fluid engineering, a (hybrid) electric transmission fluid consisting of such an optimized dispersant/detergent additive system has been developed, which shows low electrical conductivities at various temperatures even upon aging, in addition to all other critical features, for example excellent antiwear/extreme pressure performance and anti-oxidation durability.

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INTRODUCTION

A transmission system for a vehicle is suitably configured to deliver improved power transmitting efficiency, and improved fuel efficiency. A conventional transmission mechanism may be a manual transmission, an automated manual transmission, a conventional stepped automatic transmission, a continuously variable push-belt or chain type transmission, a wet or dry dual clutch transmission, or other type of vehicle transmission. Such transmissions are typically used with conventional gasoline or diesel engine systems.

By contrast, electric vehicles are equipped with electric motors, and hybrid electric vehicles may have electric motor(s) in combination with a combustion engine. The various economic and environmental implications of petroleum energy usage and emissions strongly support the need for continued development and advancement of electric or hybrid electric vehicles.

In an electric vehicle or a hybrid electric transmission, the transmission fluid may be in contact with parts of the electric motor or a similar fluid may be used for both the transmission and for cooling and lubricating the motor. For example, the lubricating and cooling fluid for the motor may be in contact with electrical windings in the stator, in order to efficiently

cool the electric motor and to insulate the electrical parts to prevent a short circuit of the electric motor. Accordingly, such fluid desirably has a relatively low electrical conductivity so that the electric motor can operate properly without short-circuiting.

With the current trend toward more energy efficient vehicles, it is desirable to provide a multipurpose or dual-purpose lubricating fluid that may be used to lubricate mechanical components as well as provide lubrication and cooling to electromechanical components in electric vehicles and/or hybrid electric vehicles [1,2,3,4,5,6,7,8,9]. Accordingly, it is desirable to provide a fluid that may meet electric motor oil requirements, such as lower electrical conductivity, cooling capability (high heat capacity, high thermal conductivity), and low Noack volatility, in addition to lubricity requirements for a transmission, such as a manual transmission, an automated manual transmission, a conventional stepped automatic transmission, a continuously variable push-belt or chain type transmission, a wet or dry dual clutch transmission.

Table 1. Composition of automatic transmission fluid

Component	wt % (Broad)	wt % (Typical)
Dispersant additive	0.5 – 20.0	1.0 – 15.0
Antioxidants	0 – 2.0	0.01 – 1.0
Metal detergents	0.0 – 10.0	0.01 – 2.0
Corrosion inhibitors	0 – 1.0	0 – 0.5
Extreme pressure/antiwear agents	0.01 – 1.0	0.1 – 0.9
Antifoaming agents	0 – 1.0	0.001 – 0.1
Pour point depressants	0 – 1.0	0 – 0.5
Friction modifiers	0 – 5.0	0.05 – 2.0
Demulsifiers	0 – 2.0	0 – 1.0
Base oils	Balance	Balance

Automatic transmission fluids may contain dispersants, antioxidants, metal detergents, corrosion inhibitors, extreme pressure/antiwear agents, antifoaming agents, pour point depressants, friction modifiers, demulsifiers, and base oils (Table 1). To keep the transmission clean and to provide desired friction characteristics, a large quantity of dispersants, typically, 1.0 to 15.0 wt% in the finished fluid formulation, is included [11]. For the (hybrid) electric transmission application, we have extensively studied the dispersant effects on electrical conductivity of finished fluids, and hence we have developed a new dispersant additive for such application. The dispersant includes a reaction product of a hydrocarbyl substituted carboxylic acid or anhydride and an amine. The reaction product has a nitrogen content up to 10,000 ppm by weight, and a boron plus phosphorus to nitrogen ((B+P)/N) weight ratio of from 0:1 to about 0.8:1. The dispersant additive composition is effective to provide an electrical conductivity to a lubricant composition of less than about 1700 pS/m [10].

In addition to dispersant additive, metal detergents also show significant effects on electrical conductivity of finished fluids, *i.e.*, the electrical conductivity increases with adding more metal detergents. Such detergents are required to be present due to their ability to keep the transmission clean, to tune the friction characteristics, to provide wear protection, and to neutralize acidic by-products generated by oxidative reactions [11]. Moreover, metal detergents enable the fluid to provide suitable anti-rust performance. Accordingly, there is a tension between providing lower amounts of detergent in order to achieve suitable electrical conductivity for the fluid and higher amounts of detergent required to provide suitable anti-rust performance.

Through extensive fluid engineering, a (hybrid) electric transmission fluid (HEVTF) consisting of such a dispersant additive and an optimized metal detergent has been developed, which shows low electrical conductivities at various temperatures and less electrical conductivity change

upon aging, in addition to all other critical features, for example, excellent antiwear/extreme pressure performance and anti-oxidation durability.

This paper reports the new dispersant additive, the optimized dispersant/metal detergent system, and the properties of the newly developed HEVTF, particularly the low and stable electrical conductivities even upon aging.

NEW DISPERSANT ADDITIVE

The dispersant additive is a reaction product of a hydrocarbyl-dicarboxylic acid or anhydride and a polyamine. The hydrocarbyl moiety of the hydrocarbyl-dicarboxylic acid or anhydride may be derived from butene polymers, for example polyisobutylene. The average number molecular weight of the polyalkenyl substituent may vary over a wide range, for example from about 500 to about 5000, as determined by gel permeation chromatography (GPC) as described above.

A mole ratio of dicarboxylic acid or succinic anhydride to hydrocarbyl moiety in a reaction mixture used to make the hydrocarbyl-dicarboxylic acid or anhydride may vary widely. Accordingly, the mole ratio may vary from about 5:1 to about 1:5. In this study, the molar ratio of anhydride to hydrocarbyl moiety (SA/PIB) is from about 1:1 to less than about 1.6:1.

Some of the dispersants were further post-treated with boron and/or phosphorus compounds to tune their properties including dispersancy and electrical conductivity.

Table 2. Dispersants tested in this study

Dispersant No.	SA/PIB wt. ratio	Phosphorus (ppm by wt.)	Boron (ppm by wt.)	Nitrogen (ppm by wt.)	(B+P)/N ratio
1	1.15	0	0	7270	0
2	1.15	384	28	7590	0.054
3	1.15	0	39	7650	0.005
4	1.15	450	0	7530	0.060
5	1.15	0	232	7260	0.032
6	1.15	1597	0	7290	0.219
7	1.15	1650	207	7400	0.251
8	1.15	1721	293	7140	0.282
9	1.15	3410	1786	7060	0.736
10	1.6	0	0	10100	0
11	1.15	0	0	20530	0
12	1.15	8088	0	18340	0.441
13	1.15	8060	3720	15500	0.76
14	1.15	0	8707	16490	0.528
15	1.15	6553	10173	16760	0.998
16	N/A	1402	730	2400	0.888

Table 2 shows all 16 dispersants tested in this study. The dispersants are identified by SA/PIB molar ratios, phosphorus / boron / nitrogen content, and (B+P)/N weight