LOW VOLATILITY COMB POLYMER COMPOSITION FOR ENGINE OILS

The present invention is directed to viscosity index improvers comprising a polyalkyl (meth)acrylate copolymer in a low volatile carrier oil composition.

The need to reduce greenhouse gas emissions and improve fuel consumption of all vehicles in the transportation sector has become increasingly important in recent years due to the negative impact of these emissions on the environment and human health. Constant development and efforts are being taken to continuously improve energy consumption throughout the whole lifespan of products, including manufacturing, transport of products, use-phase and recyclability at or after end of life.

Lubricants are well known to have a positive impact on the fuel consumption of combustion engines, with low viscous lubricants being especially beneficial for fuel economy due to their minimized viscous drag, especially at low start-up temperatures. Overarching goal is to create a lubricant that only shows a minor change in viscosity over a broad range of temperatures. Sometimes such oils are called "flat-viscosity" oils. People skilled in the art are familiar with formulating such flat viscosity oils by using high quality base stocks of low viscosity, low volatility and high viscosity index (VI).

These low viscous base oils are then formulated with high performance viscosity modifiers in order to adjust the viscosity of the lubricant to certain limits.

Such a VI-improver needs to provide superior viscosity properties in the finished fluid, such as low KV40 and low HTHS100 for a given HTHS150 (e.g. for SAE 0W-20 a HTHS150 of min 2.6 mPas).

State of the art

Polyalkyl(meth)acrylate-based polymers are well known in the art to be efficient VI improvers.

US 5,565,130 discloses comb polymers and their use as viscosity index improvers. The working examples comprise 10-80 wt% (% by weight) of macromonomer and 20-90 wt% of C1-10 alkyl (meth)acrylates which show molecular weights Mw in the range of 119,000 g/mol to 325,000 g/mol. A polyalkyl (meth)acrylate copolymer in a composition with a low volatile carrier oil having a KV100 of 3.6 mm^2/s to 5.6 mm^2/s and the influence on the bulk viscosity is not disclosed therein.

WO 2007/003238 A1 describes oil-soluble comb polymers based on polyolefin-based macromonomers, especially polybutadiene-based methacrylic esters, and C1-C10 alkyl methacrylates. The working examples comprise 37.2-53.3 wt% of macromonomer, 12.3-61 wt% of C1-4 alkyl (meth)acrylates and 12-42.6 wt% of styrene. The weight-average molecular weight Mw of the working examples is in the range of 79,000 g/mol to 402,000 g/mol and D varies from 3.7 to 16.6.

The comb polymers can be used as an additive for lubricant oils to improve the viscosity index and shear stability. However, a polyalkyl (meth)acrylate copolymer in a composition with a low volatile carrier oil having a KV100 of 3.6 mm^2/s to 5.6 mm^2/s and the influence on the bulk viscosity is not disclosed therein.

US 2010/0190671 discloses the use of comb polymers based on polyolefin-based macromonomers, especially polybutadiene-based methacrylic esters, and C1-C10 alkyl methacrylates for improving the fuel consumption of motor vehicles. The weight-average molecular weight Mw of the working examples is in the range of 191,000 g/mol to 374,000 g/mol and D varies between 3.5 and 4.5. However, a polyalkyl (meth)acrylate copolymer in a composition with a low volatile carrier oil having a KV100 of 3.6 mm^2/s to 5.6 mm^2/s and the influence on the bulk viscosity is not disclosed therein.

WO 2018/041755 A1 is directed to selected comb polymers comprising specified amounts of macromonomer and alkyl acrylates. The presence of 0.5 wt% to 11 wt% of C4-18 alkyl acrylates have a positive impact on the Noack volatility of lubricating compositions comprising such comb polymers. However, a polyalkyl (meth)acrylate copolymer in a composition with a low volatile carrier oil having a KV100 of 3.6 mm^2/s to 5.6 mm^2/s and the influence on the bulk viscosity is not disclosed therein.

EP 3 839 017 A1 relates to polyalkyl(alk)acrylate comb polymers comprising at least 21 wt% of C12-24 alkyl (alk)acrylate ester monomers. However, a polyalkyl (meth)acrylate copolymer in a composition with a low volatile carrier oil having a KV100 of 3.6 mm^2/s to 5.6 mm^2/s and the influence on the bulk viscosity is not disclosed therein.

It was an object of the present invention to provide a VI improver polymer in the form of an additive composition with excellent handling properties and low dosage, in order to minimize transportation costs, transportation-related CO2-emissions and less or ideally no heating related cost and emissions for the VI improver additive during the manufacturing of the finished lubricant.

VI additives are typically viscous solutions of the respective VI improver polymer in a mineral oil. The solid polymer content in these concentrates range typically between 6 wt% and 20 wt%. Due to the viscous character of these additives, they need to be handled at elevated temperatures such as 60°C to 100°C.

Whether an additive can be handled easily on industrial scale can be assessed by its product viscosity (bulk viscosity) at 40°C (BV40). Good VI improver additive handling is given if the respective additive has a lower BV40 than 3000 mm^2/s. Of course, the handling viscosity can be easily adjusted by further diluting the VI improver additive concentrate, but dilutions below 20 wt% active ingredient should be avoided in order to keep transportation related costs and emissions at a minimum.

Additive concentrates of low viscosity are typically obtained by diluting the active ingredient with base oil. Lower contents of solids and lower base oil viscosities will typically result in lower viscosity of the

concentrate. However, it was surprisingly found that the use of higher viscous base oils and/or base oil blends as carrier, specifically the range for KV100 of 3.6 mm²/s to 5.6 mm²/s, result in lower bulk viscosity of the VI improver additive product at 40°C (BV40). Typically, only one given base oil is used to prepare an additive concentrate. However, depending on requirements, it is also possible and common practice to combine several base oils, sometimes from various base oil slates and even different API categories. In accordance with the present invention, it was found that it is beneficial to combine various mineral base oils and limit the amount of ester oil (for cost and performance reasons) to a maximum of 10 wt% with respect to the total amount of carrier oil.

It was surprisingly found that additives with higher carrier oil viscosity provided better handling characteristics.
This was unexpected because, typically, the viscosity of a polymer adds to the viscosity of a base oil. Therefore, solutions of said polymer in a low-viscous carrier oil at a given polymer load should result in lower viscosity, but the opposite was found.

Detailed description of the invention

A first object of the present invention is directed to a viscosity index improver, comprising:

(A) 20 wt% to 30 wt% of a polyalkyl(meth)acrylate copolymer, comprising the following monomers:
  (a) 10 wt% to 15 wt%, preferably 11 wt% to 13 wt%, of one or more polybutadiene-based macromonomer having a number-average molecular weight of 2,000 g/mol to 10,000 g/mol;
  (b) 85 wt% to 90 wt%, preferably 87 wt% to 89 wt%, of linear or branched C4-20 alkyl(meth)acrylates;
  (c) 0 wt% to 1 wt% of methyl (meth)acrylate; and
  (d) 0 wt% to 5 wt% of styrene,
  wherein the polyalkyl(meth)acrylate copolymer is characterized by an average carbon number of 4.5 to 5.5 and the average carbon number corresponds to the molar average of all carbon atoms present in the alkyl residues of the alkyl (meth)acrylates forming the polyalkyl(meth)acrylate copolymer; and
(B) 70 wt% to 80 wt% of a base oil having a KV100 of 3.6 mm²/s to 5.6 mm²/s.

The content of each component (A) and (B) is based on the total composition of the viscosity index improver.
In a particular embodiment, the proportions of components (A) and (B) add up to 100% by weight.

The content of each component (a), (b), (c) and (d) is based on the total composition of the polyalkyl(meth)acrylate copolymer.
In a particular embodiment, the proportions of components (a), (b), (c) and (d) add up to 100% by weight.

A further object of the present invention is directed to the viscosity index improver as mentioned further above, wherein the polyalkyl(meth)acrylate copolymer comprises the following monomers:

(a) 10 wt% to 15 wt%, preferably 11 wt% to 13 wt%, of one or more polybutadiene-based macromonomer having a number-average molecular weight of 2,000 g/mol to 10,000 g/mol;

(b1) 65 wt% to 75 wt% of butyl (meth)acrylate;

(b2) 10 wt% to 20 wt% of C10-20 alkyl (meth)acrylates;

(c) 0 wt% to 1 wt% of methyl (meth)acrylate; and

(d) 0 wt% to 5 wt% of styrene.

The content of each component (a), (b1), (b2), (c) and (d) is based on the total composition of the polyalkyl(meth)acrylate copolymer.
In a particular embodiment, the proportions of components (a), (b1), (b2), (c) and (d) add up to 100% by weight.

A polyalkyl(meth)acrylate copolymer in the context of this invention comprises a first polymer, which is also referred to as backbone or main chain, and a multitude of further polymers which are referred to as side chains and are bonded covalently to the backbone. In the present case, the backbone of the polyalkyl(meth)acrylate copolymer is formed by the interlinked unsaturated groups of the mentioned (meth)acrylates. The ester groups of the (meth)acrylic esters, the phenyl radicals of the styrene monomers and the substituents of the further free-radically polymerizable comonomers form the side chains of the polyalkyl(meth)acrylate copolymer.

The term "(meth)acrylate" refers to both, esters of acrylic acid and esters of methacrylic acid. Methacrylates are preferred over acrylates.

The polybutadiene-based macromonomer for use in accordance with the invention has a number-average molar mass M_n of 2,000 g/mol to 10,000 g/mol, preferably 4,000 g/mol to 6,000 g/mol, preferably 4,500 g/mol to 5,000 g/mol. Because of their high molar mass, the polybutadiene-based macromonomers can also be referred to as macromonomers in the context of this invention.

The number-average molar mass M_n is determined by size exclusion chromatography using commercially available polybutadiene standards. The determination is affected to DIN 55672-1 by gel permeation chromatography with THF as eluent.

Preferably, the polybutadiene-based macromonomer has a hydrogenation level of at least 99%. An alternative measure of the hydrogenation level which can be determined on the polyalkyl(meth)acrylate copolymer of the invention is the iodine number. The iodine number refers to the number of grams of iodine which can be added onto 100 g of polyalkyl(meth)acrylate copolymer. Preferably, the

polyalkyl(meth)acrylate copolymer of the invention has an iodine number of not more than 5 g of iodine per 100 g of polyalkyl(meth)acrylate copolymer. The iodine number is determined by the Wijs method according to DIN 53241-1:1995-05.

Preferred polybutadiene-based macromonomers can be obtained according to GB 2270317.

Preference is given to monohydroxylated hydrogenated polybutadienes. More preferably, the hydroxylated hydrogenated polybutadiene is a hydroxyethyl- or hydroxypropyl-terminated hydrogenated polybutadiene. Particular preference is given to hydroxypropyl-terminated polybutadienes.

These monohydroxylated hydrogenated polybutadienes can be prepared by first converting butadiene monomers by anionic polymerization to polybutadiene. Subsequently, by reaction of the polybutadiene monomers with ethylene oxide or propylene oxide, a hydroxy-functionalized polybutadiene can be prepared. This hydroxylated polybutadiene can be hydrogenated in the presence of a suitable transition metal catalyst.

The esters of (meth)acrylic acid for use in accordance with the invention and a hydroxylated hydrogenated polybutadiene described are also referred to as macromonomers in the context of this invention because of their high molar mass.

The macromonomers for use in accordance with the invention can be prepared by transesterification of alkyl (meth)acrylates. Reaction of the alkyl (meth)acrylate with the hydroxylated hydrogenated polybutadiene forms the ester of the invention. Preference is given to using methyl (meth)acrylate or ethyl (meth)acrylate as reactant.

This transesterification is widely known. For example, it is possible for this purpose to use a heterogeneous catalyst system, such as lithium hydroxide/calcium oxide mixture (LiOH/CaO), pure lithium hydroxide (LiOH), lithium methoxide (LiOMe) or sodium methoxide (NaOMe) or a homogeneous catalyst system such as isopropyl titanate ($Ti(OiPr)_4$) or dioctyltin oxide ($Sn(OCt)_2O$). The reaction is an equilibrium reaction. Therefore, the low molecular weight alcohol released is typically removed, for example by distillation.

In addition, the macromonomers can be obtained by a direct esterification proceeding, for example, from (meth)acrylic acid or (meth)acrylic anhydride, preferably under acidic catalysis by p-toluenesulfonic acid or methanesulfonic acid, or from free methacrylic acid by the DCC method (dicyclohexylcarbodiimide).

Furthermore, the present polybutadiene-based macromonomers can be converted to an ester by reaction with an acid chloride such as (meth)acryloyl chloride.

Preferably, in the above-detailed preparations of the esters of the invention, polymerization inhibitors are used, for example the 4-hydroxy-2,2,6,6-tetramethylpiperidinooxyl radical and/or hydroquinone monomethyl ether.

The C4-20 alkyl (meth)acrylates for use in accordance with the invention are esters of (meth)acrylic acid and straight chain or branched alcohols having 4 to 20 carbon atoms. The term "C4-20 alkyl methacrylates" encompasses individual (meth)acrylic esters with an alcohol of a particular length, and likewise mixtures of (meth)acrylic esters with alcohols of different lengths.
Suitable C4-20 alkyl (meth)acrylates include, for example, *n*-butyl (meth)acrylate, *iso*-butyl (meth)acrylate, *tert*-butyl (meth)acrylate, pentyl (meth)acrylate, hexyl (meth)acrylate, heptyl (meth)acrylate, octyl (meth)acrylate, ethylhexyl (meth)acrylate, nonyl (meth)acrylate, decyl (meth)acrylate, iso-decyl (meth)acrylate, 2-butyldecyl (meth)acrylate, undecyl (meth)acrylate, 5-methylundecyl (meth)acrylate, dodecyl (meth)acrylate, 2-methyldodecyl (meth)acrylate, tridecyl (meth)acrylate, 5-methyltridecyl (meth)acrylate, tetradecyl (meth)acrylate, pentadecyl (meth)acrylate, hexadecyl (meth)acrylate, 2-butyloctyl (meth)acrylate, 2-hexyloctyl (meth)acrylate, 2-hexyldecyl (meth)acrylate, 2-octyldecyl (meth)acrylate, undecyl (meth)acrylate, 5-methylundecyl (meth)acrylate, dodecyl (meth)acrylate, 2-methyldodecyl (meth)acrylate, 2-hexyldodecyl (meth)acrylate, 2-octyldodecyl (meth)acrylate, 2-methylhexadecyl (meth)acrylate, 2-dodecylhexadecyl (meth)acrylate, heptadecyl (meth)acrylate, 5-isopropylheptadecyl (meth)acrylate, 5-ethyloctadecyl (meth)acrylate, octadecyl (meth)acrylate, 2-decyloctadecyl (meth)acrylate, nonadecyl (meth)acrylate, and eicosyl (meth)acrylate. Preferred are C10-15 alkyl (meth)acrylates.

The C10-20 alkyl (meth)acrylates for use in accordance with the invention are esters of (meth)acrylic acid and straight chain or branched alcohols having 10 to 20 carbon atoms. The term "C10-20 alkyl methacrylates" encompasses individual (meth)acrylic esters with an alcohol of a particular length, and likewise mixtures of (meth)acrylic esters with alcohols of different lengths.
Suitable C10-20 alkyl (meth)acrylates include, for example, decyl (meth)acrylate, iso-decyl (meth)acrylate, 2-butyldecyl (meth)acrylate, undecyl (meth)acrylate, 5-methylundecyl (meth)acrylate, dodecyl (meth)acrylate, 2-methyldodecyl (meth)acrylate, tridecyl (meth)acrylate, 5-methyltridecyl (meth)acrylate, tetradecyl (meth)acrylate, pentadecyl (meth)acrylate, hexadecyl (meth)acrylate, 2-butyloctyl (meth)acrylate, 2-hexyloctyl (meth)acrylate, 2-hexyldecyl (meth)acrylate, 2-octyldecyl (meth)acrylate, undecyl (meth)acrylate, 5-methylundecyl (meth)acrylate, dodecyl (meth)acrylate, 2-methyldodecyl (meth)acrylate, 2-hexyldodecyl (meth)acrylate, 2-octyldodecyl (meth)acrylate, 2-methylhexadecyl (meth)acrylate, 2-dodecylhexadecyl (meth)acrylate, heptadecyl (meth)acrylate, 5-isopropylheptadecyl (meth)acrylate, 5-ethyloctadecyl (meth)acrylate, octadecyl (meth)acrylate, 2-decyloctadecyl (meth)acrylate, nonadecyl (meth)acrylate, and eicosyl (meth)acrylate. Preferred are C10-15 alkyl (meth)acrylates.

The C10-15 alkyl methacrylates for use in accordance with the invention are esters of methacrylic acid and alcohols having 10 to 15 carbon atoms. The term "C10-15 alkyl methacrylates" encompasses individual methacrylic esters with an alcohol of a particular length, and likewise mixtures of methacrylic esters with alcohols of different lengths.

The suitable C10-15 alkyl methacrylates include, for example, decyl methacrylate, undecyl methacrylate, 5-methylundecyl methacrylate, dodecyl methacrylate, 2-methyldodecyl methacrylate, tridecyl methacrylate, 5-methyltridecyl methacrylate, tetradecyl methacrylate and/or pentadecyl methacrylate.

Particularly preferred C10-15 alkyl methacrylates are methacrylic esters of a linear C12-14 alcohol mixture (C12-14 alkyl methacrylate).

The alkyl (meth)acrylates used to prepare the polyalkyl (meth)acrylate copolymers are characterized by an average carbon number of 4.5 to 5.5.
The average carbon number corresponds to the molar average of all carbon atoms present in the alkyl residue of each alkyl (meth)acrylate forming the polyalkyl(meth)acrylate copolymer and was calculated based on the total composition of the polyalkyl(meth)acrylate copolymer, i.e. by calculating the molar average of all carbon atoms present in the alkyl residues of the alkyl (meth)acrylates.

The weight-average molecular weight of the polyalkyl(meth)acrylate copolymers according to the present invention is preferably in the range of 100,000 g/mol to 1,000,000 g/mol, more preferably in the range of 200,000 g/mol to 800,000 g/mol, more preferably in the range of 300,000 g/mol to 700,000 g/mol.

The number-average molecular weight of the polyalkyl(meth)acrylate copolymers according to the present invention is preferably in the range of 50,000 g/mol to 250,000 g/mol, more preferably in the range of 60,000 g/mol to 220,000 g/mol, more preferably in the range of 80,00 g/mol to 200,000 g/mol.

Preferably, the polyalkyl (meth)acrylate copolymers according to the present invention have a polydispersity index (D) M_w/M_n in the range of 2 to 6, more preferably in the range of 3 to 6.
M_w and M_n are determined by size exclusion chromatography (SEC) using commercially available polymethylmethacrylate standards. The determination is effected by gel permeation chromatography (GPC) with RI (refractive index) detector in tetrahydrofuran at 40°C using a polymethyl methacrylate (PMMA) calibration.

A further object is directed to the viscosity index improver as mentioned further above, wherein the polyalkyl(meth)acrylate copolymer is selected from the group consisting of:

Polymer A, consisting of 11.0 wt% of polybutadiene-based macromonomer (MM), 73.93 wt% of nBMA, 13.35 wt% of LMA, 0.25 wt% of MMA and 1.47 wt% of styrene and having an average carbon number of 4.73;

Polymer B, consisting of 11.5 wt% of polybutadiene-based macromonomer (MM), 70.0 wt% of nBMA, 16.0 wt% of LMA, 2.0 wt% of SMA, 0.25 wt% of MMA and 0.25 wt% of styrene and having an average carbon number of 5.05,

Polymer C, consisting of 11.5 wt% of polybutadiene-based macromonomer (MM), 68.0 wt% of nBMA, 18.0 wt% of LMA, 2.0 wt% of SMA, 0.25 wt% of MMA and 0.25 wt% of styrene and having an average carbon number of 5.19;

Polymer D, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 74.6 wt% of nBMA, 11.7 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene and having an average carbon number of 4.64;

Polymer E, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.1 wt% of nBMA, 13.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene and having an average carbon number of 4.73;

Polymer F, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene and having an average carbon number of 4.84;

Polymer G, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 69.1 wt% of nBMA, 17.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene and having an average carbon number of 4.98;

Polymer H, consisting of 15.0 wt% of polybutadiene-based macromonomer (MM), 65.6 wt% of nBMA, 19.0 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene and having an average carbon number of 5.13;

Polymer I, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 74.8 wt% of nBMA, 12.8 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene and having an average carbon number of 4.70;

Polymer J, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.9 wt% of nBMA, 13.7 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene and having an average carbon number of 4.76; and

Polymer K, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene and having an average carbon number of 4.86;

wherein the alkyl (meth)acrylate copolymers have a weight-average molecular weight M_w of 200,000 g/mol to 800,000 g/mol.

A further object is directed to the viscosity index improver as mentioned further above, wherein the polyalkyl(meth)acrylate copolymer is selected from the group consisting of:

Polymer A, consisting of 11.0 wt% of polybutadiene-based macromonomer (MM), 73.93 wt% of nBMA, 13.35 wt% of LMA, 0.25 wt% of MMA and 1.47 wt% of styrene and having an average carbon number of 4.73;

Polymer B, consisting of 11.5 wt% of polybutadiene-based macromonomer (MM), 70.0 wt% of nBMA, 16.0 wt% of LMA, 2.0 wt% of SMA, 0.25 wt% of MMA and 0.25 wt% of styrene and having an average carbon number of 5.05,

Polymer C, consisting of 11.5 wt% of polybutadiene-based macromonomer (MM), 68.0 wt% of nBMA, 18.0 wt% of LMA, 2.0 wt% of SMA, 0.25 wt% of MMA and 0.25 wt% of styrene and having an average carbon number of 5.19;

Polymer D, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 74.6 wt% of nBMA, 11.7 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene and having an average carbon number of 4.64;

Polymer E, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.1 wt% of nBMA, 13.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene and having an average carbon number of 4.73;

Polymer F, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene and having an average carbon number of 4.84;

Polymer G, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 69.1 wt% of nBMA, 17.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene and having an average carbon number of 4.98; and

Polymer H, consisting of 15.0 wt% of polybutadiene-based macromonomer (MM), 65.6 wt% of nBMA, 19.0 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene and having an average carbon number of 5.13;

wherein the alkyl (meth)acrylate copolymers have a weight-average molecular weight M_w of 200,000 g/mol to 800,000 g/mol.

A further object is directed to the viscosity index improver as mentioned further above, wherein the polyalkyl(meth)acrylate copolymer is selected from the group consisting of:

Polymer 1, consisting of 11.0 wt% of polybutadiene-based macromonomer (MM), 79.93 wt% of nBMA, 13.35 wt% of LMA, 0.25 wt% of MMA and 1.47 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 540,000 g/mol ± 20%, i.e. in the range of 432,000 g/mol to 648,000 g/mol;

Polymer 2, consisting of 11.0 wt% of polybutadiene-based macromonomer (MM), 79.93 wt% of nBMA, 13.35 wt% of LMA, 0.25 wt% of MMA and 1.47 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 499,000 g/mol ± 20%, i.e. in the range of 399,200 g/mol to 598,800 g/mol;

Polymer 3, consisting of 11.5 wt% of polybutadiene-based macromonomer (MM), 70.0 wt% of nBMA, 16.0 wt% of LMA, 2.0 wt% of SMA, 0.25 wt% of MMA and 0.255 wt% of styrene, having an average carbon number of 5.05 and a weight-average molecular weight Mw in the range of 579,000 g/mol ± 20%, i.e. in the range of 463,200 g/mol to 694,800 g/mol.

Polymer 4, consisting of 11.5 wt% of polybutadiene-based macromonomer (MM), 68.0 wt% of nBMA, 18.0 wt% of LMA, 2.0 wt% of SMA, 0.25 wt% of MMA and 0.25 wt% of styrene, having an average carbon number of 5.19 and a weight-average molecular weight Mw in the range of 655,000 g/mol ± 20%, i.e. in the range of 524,000 g/mol to 786,000 g/mol;

Polymer 5, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 74.6 wt% of nBMA, 11.7 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.64 and a weight-average molecular weight Mw in the range of 363,000 g/mol ± 20%, i.e. in the range of 290,400 g/mol to 435,600 g/mol;

Polymer 6, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.1 wt% of nBMA, 13.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 586,000 g/mol ± 20%, i.e. in the range of 468,800 g/mol to 681,600 g/mol;

Polymer 7, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.1 wt% of nBMA, 13.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 603,000 g/mol ± 20%, i.e. in the range of 482,400 g/mol to 723,600 g/mol;

Polymer 8, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.1 wt% of nBMA, 13.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 506,000 g/mol ± 20%, i.e. in the range of 404,800 g/mol to 607,200 g/mol;

Polymer 9, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.84 and a weight-average molecular weight Mw in the range of 644,000 g/mol ± 20%, i.e. in the range of 515,200 g/mol to 772,800 g/mol;

Polymer 10, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.84 and a weight-average molecular weight Mw in the range of 626,000 g/mol ± 20%, i.e. in the range of 500,800 g/mol to 751,200 g/mol;

Polymer 11, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.84 and a weight-average molecular weight Mw in the range of 510,000 g/mol ± 20%, i.e. in the range of 408,000 g/mol to 612,000 g/mol;

Polymer 12, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 69.1 wt% of nBMA, 17.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene, having an average carbon number of 4.98 and a weight-average molecular weight Mw in the range of 619,000 g/mol ± 20%, i.e. in the range of 495,200 g/mol to 742,800 g/mol;

Polymer 13, consisting of 15.0 wt% of polybutadiene-based macromonomer (MM), 65.6 wt% of nBMA, 19.0 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene, having an average carbon number of 5.13 and a weight-average molecular weight Mw in the range of 569,000 g/mol ± 20%, i.e. in the range of 455,200 g/mol to 682,800 g/mol;

Polymer 14, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 74.8 wt% of nBMA, 12.8 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene, having an average carbon number of

4.70 and a weight-average molecular weight Mw in the range of 528,000 g/mol ± 20%, i.e. in the range of 422,400 g/mol to 633,600 g/mol;

Polymer 15, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.9 wt% of nBMA, 13.7 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene, having an average carbon number of 4.76 and a weight-average molecular weight Mw in the range of 528,000 g/mol ± 20%, i.e. in the range of 422,400 g/mol to 633,600 g/mol; and

Polymer 16, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.86 and a weight-average molecular weight Mw in the range of 526,000 g/mol ± 20%, i.e. in the range of 420,800 g/mol to 631,200 g/mol.

A further object is directed to the viscosity index improver as mentioned further above, wherein the polyalkyl(meth)acrylate copolymer is selected from the group consisting of:

Polymer 1, consisting of 11.0 wt% of polybutadiene-based macromonomer (MM), 79.93 wt% of nBMA, 13.35 wt% of LMA, 0.25 wt% of MMA and 1.47 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 540,000 g/mol ± 20%, i.e. in the range of 432,000 g/mol to 648,000 g/mol;

Polymer 2, consisting of 11.0 wt% of polybutadiene-based macromonomer (MM), 79.93 wt% of nBMA, 13.35 wt% of LMA, 0.25 wt% of MMA and 1.47 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 499,000 g/mol ± 20%, i.e. in the range of 399,200 g/mol to 598,800 g/mol;

Polymer 3, consisting of 11.5 wt% of polybutadiene-based macromonomer (MM), 70.0 wt% of nBMA, 16.0 wt% of LMA, 2.0 wt% of SMA, 0.25 wt% of MMA and 0.255 wt% of styrene, having an average carbon number of 5.05 and a weight-average molecular weight Mw in the range of 579,000 g/mol ± 20%, i.e. in the range of 463,200 g/mol to 694,800 g/mol.

Polymer 4, consisting of 11.5 wt% of polybutadiene-based macromonomer (MM), 68.0 wt% of nBMA, 18.0 wt% of LMA, 2.0 wt% of SMA, 0.25 wt% of MMA and 0.25 wt% of styrene, having an average carbon number of 5.19 and a weight-average molecular weight Mw in the range of 655,000 g/mol ± 20%, i.e. in the range of 524,000 g/mol to 786,000 g/mol;

Polymer 5, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 74.6 wt% of nBMA, 11.7 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number

of 4.64 and a weight-average molecular weight Mw in the range of 363,000 g/mol ± 20%, i.e. in the range of 290,400 g/mol to 435,600 g/mol;

Polymer 6, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.1 wt% of nBMA, 13.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 586,000 g/mol ± 20%, i.e. in the range of 468,800 g/mol to 681,600 g/mol;

Polymer 7, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.1 wt% of nBMA, 13.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 603,000 g/mol ± 20%, i.e. in the range of 482,400 g/mol to 723,600 g/mol;

Polymer 8, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.1 wt% of nBMA, 13.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 506,000 g/mol ± 20%, i.e. in the range of 404,800 g/mol to 607,200 g/mol;

Polymer 9, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.84 and a weight-average molecular weight Mw in the range of 644,000 g/mol ± 20%, i.e. in the range of 515,200 g/mol to 772,800 g/mol;

Polymer 10, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.84 and a weight-average molecular weight Mw in the range of 626,000 g/mol ± 20%, i.e. in the range of 500,800 g/mol to 751,200 g/mol;

Polymer 11, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.84 and a weight-average molecular weight Mw in the range of 510,000 g/mol ± 20%, i.e. in the range of 408,000 g/mol to 612,000 g/mol;

Polymer 12, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 69.1 wt% of nBMA, 17.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene, having an average carbon number of 4.98 and a weight-average molecular weight Mw in the range of 619,000 g/mol ± 20%, i.e. in the range of 495,200 g/mol to 742,800 g/mol; and

Polymer 13, consisting of 15.0 wt% of polybutadiene-based macromonomer (MM), 65.6 wt% of nBMA, 19.0 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene, having an average carbon number of 5.13 and a weight-average molecular weight Mw in the range of 569,000 g/mol ± 20%, i.e. in the range of 455,200 g/mol to 682,800 g/mol.

The carrier oils to be used in the compositions according to the present invention comprise oils of lubricating viscosity. Such oils include natural and synthetic oils, oils derived from hydrocracking, hydrogenation, and hydro-finishing, unrefined, refined, re-refined oils or mixtures thereof.

The carrier oils may also be defined as specified by the American Petroleum Institute (API) (see April 2008 version of "Appendix E-API Base Oil Interchangeability Guidelines for Passenger Car Motor Oils and Diesel Engine Oils", section 1.3 Subheading 1.3. "Base Stock Categories").

The API currently defines five groups of lubricant base stocks (API 1509, Annex E - API Base Oil Interchangeability Guidelines for Passenger Car Motor Oils and Diesel Engine Oils, September 2011). 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; Group IV are polyalphaolefins; and Group V are all others, including e.g. ester oils. Ester oils which can be used in accordance with the present invention are preferably selected from the group consisting of diisononyl adipate and bis(2-ethylhexyl)sebacate.
The table below illustrates these API classifications.

Group	Saturates	Sulphur content	Viscosity Index (VI)
I	< 90%	> 0.03%	80-120
II	at least 90%	not more than 0.03%	80-120
III	at least 90%	not more than 0.03%	at least 120
IV	All polyalphaolefins (PAOs)		
V	All others not included in Groups I, II, III or IV (e.g. ester oils)		

The kinematic viscosity at 100°C (KV100) of appropriate apolar base oils and base oil mixtures used to prepare the compositions in accordance with the present invention is preferably in the range of 3.6 mm^2/s to 5.6 mm^2/s according to ASTM D445.

In accordance with the present invention, the base oil (B) is preferably selected from the group consisting of API Group II oils, API Group III oils and mixtures thereof.

In accordance with the present invention, the base oil (B) has preferably an aniline point of 105°C or higher.

In accordance with the present invention, the base oil (B) has preferably a Noack evaporation loss at 150°C for 12 hours of 0% to 10%.

The viscosity index improvers according to the present invention are characterized by their contribution to a low product viscosity (bulk viscosity) at 40°C (BV40). Good VI improver additive handling is given if the respective additive has a BV40 of equal to or less than 3000 mm^2/s, preferably of equal to or less than 2000 mm^2/s, preferably of equal to or less than 1000 mm^2/s.

A further object of the present invention is directed to a lubricating oil composition, comprising:

(A) 1 wt% to 4 wt% of a polyalkyl(meth)acrylate copolymer, comprising:
  (a) 10 wt% to 15 wt%, preferably 11 wt% to 13 wt%, of one or more polybutadiene-based macromonomer having a number-average molecular weight of 2,000 g/mol to 10,000 g/mol;
  (b) 85 wt% to 90 wt%, preferably 87 wt% to 89 wt%, of linear or branched C4-20 alkyl(meth)acrylates;
  (c) 0 wt% to 1 wt% of methyl (meth)acrylate; and
  (d) 0 wt% to 5 wt% of styrene,
  wherein the polyalkyl(meth)acrylate copolymer is characterized by an average carbon number of 4.5 to 5.5 and the average carbon number corresponds to the molar average of all carbon atoms present in the alkyl residues of the alkyl (meth)acrylates forming the polyalkyl (meth)acrylate copolymer;
(B) 81 wt% to 99 wt% of a base oil; and
(C) 0 to 15% wt% of one or more further additives.

The content of each component (A), (B) and (C) is based on the total composition of the lubricating oil composition.
In a particular embodiment, the proportions of components (A), (B) and (C) add up to 100% by weight.

The content of each component (a), (b), (c) and (d) is based on the total composition of the polyalkyl(meth)acrylate copolymer.
In a particular embodiment, the proportions of components (a), (b), (c) and (d) add up to 100% by weight.

A further object of the present invention is directed to the lubricating oil composition as mentioned further above, wherein the polyalkyl(meth)acrylate copolymer (A) comprises the following monomers:

  (a) 10 wt% to 15 wt%, preferably 11 wt% to 13 wt%, of one or more polybutadiene-based macromonomer having a number-average molecular weight of 2,000 g/mol to 10,000 g/mol;
  (b1) 65 wt% to 75 wt% of butyl (meth)acrylate; and
  (b2) 10 wt% to 20 wt% of C10-20 alkyl (meth)acrylates;

(c) 0 wt% to 1 wt% of methyl (meth)acrylate; and

(d) 0 wt% to 5 wt% of styrene.

The content of each component (a), (b1), (b2), (c) and (d) is based on the total composition of the polyalkyl(meth)acrylate copolymer.
In a particular embodiment, the proportions of components (a), (b1), (b2), (c) and (d) add up to 100% by weight.

Preferably, the total concentration of the one or more additives (C) is 0.05 wt% to 15 wt%, more preferably 3 wt% to 10 wt%, based on the total weight of the lubricating oil composition.

The lubricating oil composition according to the invention may also contain, as component (C), further additives selected from the group consisting of conventional VI improvers, dispersants, defoamers, detergents, antioxidants, pour point depressants, antiwear additives, extreme pressure additives, friction modifiers, anticorrosion additives, dyes and mixtures thereof.

Conventional VI improvers include hydrogenated styrene-diene copolymers (HSDs, US4116 917, US3772196 and US4788316), especially based on butadiene and isoprene, and also olefin copolymers (OCPs, K. Marsden: "Literature Review of OCP Viscosity Modifiers", Lubrication Science 1 (1988), 265), especially of the poly(ethylene-co-propylene) type, which may often also be present in N/O-functional form with dispersing action, or PAMAs, which are usually present in N-functional form with advantageous additive properties (*boosters*) as dispersants, wear protection additives and/or friction modifiers (DE 1 520 696 to Röhm and Haas, WO 2006/007934 to RohMax Additives).

Compilations of VI improvers and pour point improvers for lubricant oils, especially motor oils, are detailed, for example, in T. Mang, W. Dresel (eds.): "Lubricants and Lubrication", Wiley-VCH, Weinheim 2001: R. M. Mortier, S. T. Orszulik (eds.): "Chemistry and Technology of Lubricants", Blackie Academic & Professional, London 1992; or J. Bartz: "Additive für Schmierstoffe", Expert-Verlag, Renningen-Malmsheim 1994.

Appropriate dispersants include poly-(isobutylene) derivatives, for example poly(isobutylene)succinimides (PIBSIs), including borated PIBSIs; and ethylene-propylene oligomers having N/O functionalities.
Dispersants (including borated dispersants) are preferably used in an amount of 0 to 5 wt%, based on the total amount of the lubricating oil composition.

Suitable defoamers are silicone oils, fluorosilicone oils, fluoroalkyl ethers, etc..
The defoaming agent is preferably used in an amount of 0.005 wt% to 0.1 wt%, based on the total amount of the lubricating oil composition.

The preferred detergents include metal-containing compounds, for example phenoxides; salicylates; thiophosphonates, especially thiopyrophosphonates, thiophosphonates and phosphonates; sulfonates and carbonates. As metal, these compounds may contain especially calcium, magnesium and barium. These compounds may preferably be used in neutral or overbased form.
Detergents are preferably used in an amount of 0.2 wt% to 1 wt%, based on the total amount of the lubricating oil composition.

The suitable antioxidants include, for example, phenol-based antioxidants and amine-based antioxidants. Phenol-based antioxidants include, for example, octadecyl-3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate; 4,4' -methylenebis(2,6-di-tert-butylphenol); 4,4' -bis(2,6-di-t-butylphenol); 4,4' -b is(2-methyl-6-t-butylphenol); 2,2' -methylenebis(4-ethyl-6-t-butylphenol); 2,2' -methylenebis(4-methyl-6-t-butyl phenol); 4,4' -butyl idenebis(3-methyl-6-t-butylphenol); 4,4'-isopropylidenebis(2,6-di-t-butylphenol); 2,2'-methylenebis(4-methyl-6-nonylphenol); 2,2'-isobutylidenebis(4,6-dimethylphenol); 2,2'-methylenebis(4-methyl-6-cyclohexylphenol); 2,6-di-t-butyl-4-methylphenol; 2,6-di-t-butyl-4-ethyl-phenol; 2,4-dimethyl-6-t-butylphenol; 2,6-di-t-amyl-p-cresol; 2,6-di-t-butyi-4-(N,N'-dimethylaminomethylphenol); 4,4'thiobis(2-methyl-6-t-butylphenol); 4,4'-thiobis(3-methyl-6-t-butylphenol); 2,2'-thiobis(4-methyl-6-t-butylphenol); bis(3-methyl-4-hydroxy-5-t-butylbenzyl) sulfide; bis(3,5-di-t-butyl-4-hydroxybenzyl) sulfide; n-octyl-3-(4-hydroxy-3,5-di-t-butylphenyl)propionate; n-octadecyl-3-(4-hydroxy-3,5-di-t-butylphenyl)propionate; 2,2'-thio[diethyl-bis-3-(3,5-di-t-butyl-4-hydroxyphenyl)propionate], etc. Of those, especially preferred are bis-phenol-based antioxidants and ester group containing phenol-based antioxidants.
The amine-based antioxidants include, for example, monoalkyldiphenylamines such as monooctyldiphenylamine, monononyldiphenylamine, etc.; dialkyldiphenylamines such as 4,4' -dibutyldiphenylamine, 4,4'-dipentyldiphe nylamine, 4,4'- dihexyldiphenylamine, 4,4'-diheptyldiphenylamine, 4,4'-dioctyldiphenylamine, 4,4'-dinonyldiphenylamine, etc.; polyalkyldiphenylamines such as tetrabutyldiphenylamine, tetrahexyldiphenylamine, tetraoctyldiphenylamine, tetranonyldiphenylamine, etc.; naphthylamines, concretely alpha-naphthylamine, phenyl-alpha-naphthylamine and further alkyl-substituted phenyl-alpha-naphthylamines such as butylphenyl-alpha-naphthylamine, pentylphenyl-alpha-naphthylamine, hexylphenyl-alpha-naphthylamine, heptylphenyl-alpha-naphthylamine, octylphenyl-alpha-naphthylamine, nonylphenyl-alpha-naphthylamine, etc. Of those, diphenylamines are preferred to naphthylamines, from the viewpoint of the antioxidation effect thereof.
Suitable antioxidants may further be selected from the group consisting of compounds containing sulfur and phosphorus, for example metal dithiophosphates, for example zinc dithiophosphates (ZnDTPs), "OOS triesters" = reaction products of dithiophosphoric acid with activated double bonds from olefins, cyclopentadiene, norbornadiene, alpha-pinene, polybutene, acrylic esters, maleic esters (ashless on combustion); organosulfur compounds, for example dialkyl sulfides, diaryl sulfides, polysulfides, modified thiols, thiophene derivatives, xanthates, thioglycols, thioaldehydes, sulfur-containing carboxylic acids; heterocyclic sulfur/nitrogen compounds, especially dialkyldimercaptothiadiazoles, 2-

mercaptobenzimidazoles; zinc bis(dialkyldithiocarbamate) and methylene bis(dialkyldithiocarbamate); organophosphorus compounds, for example triaryl and trialkyl phosphites; organocopper compounds and overbased calcium- and magnesium-based phenoxides and salicylates.
Antioxidants are used in an amount of 0 to 15 wt%, preferably 0.1 to 10 wt%, more preferably 0.5 to 5 wt%, based on the total amount of the lubricating oil composition.

The pour-point depressants include ethylene-vinyl acetate copolymers, chlorinated paraffin-naphthalene condensates, chlorinated paraffin-phenol condensates, polyalkylstyrenes, etc.
The amount of the pour point depressant is preferably from 0.1 to 5 wt%, based on the total amount of the lubricating oil composition.

The preferred antiwear and extreme pressure additives include sulfur-containing compounds such as zinc dithiophosphate, zinc di-C3-12-alkyldithiophosphates (ZnDTPs), zinc phosphate, zinc dithiocarbamate, molybdenum dithiocarbamate, molybdenum dithiophosphate, disulfides, sulfurized olefins, sulfurized oils and fats, sulfurized esters, thiocarbonates, thiocarbamates, polysulfides, etc.; phosphorus-containing compounds such as phosphites, phosphates, for example trialkyl phosphates, triaryl phosphates, e.g. tricresyl phosphate, amine-neutralized mono- and dialkyl phosphates, ethoxylated mono- and dialkyl phosphates,phosphonates, phosphines, amine salts or metal salts of those compounds, etc.; sulfur and phosphorus-containing anti-wear agents such as thiophosphites, thiophosphates, thiophosphonates, amine salts or metal salts of those compounds, etc.
The antiwear agent may be present in an amount of 0 to 3 wt%, preferably 0.1 wt% to 1.5 wt%, more preferably 0.5 wt% to 0.9 wt%, based on the total amount of the lubricating oil composition.

Friction modifiers used may include mechanically active compounds, for example molybdenum disulfide, graphite (including fluorinated graphite), poly(trifluoroethylene), polyamide, polyimide; compounds that form adsorption layers, for example long-chain carboxylic acids, fatty acid esters, ethers, alcohols, amines, amides, imides; compounds which form layers through tribochemical reactions, for example saturated fatty acids, phosphoric acid and thiophosphoric esters, xanthogenates, sulfurized fatty acids; compounds that form polymer-like layers, for example ethoxylated dicarboxylic partial esters, dialkyl phthalates, methacrylates, unsaturated fatty acids, sulfurized olefins or organometallic compounds, for example molybdenum compounds (molybdenum dithiophosphates and molybdenum dithiocarbamates MoDTCs) and combinations thereof with ZnDTPs, copper-containing organic compounds.
Friction modifiers may be used in an amount of 0 to 6 wt%, preferably 0.05 wt% to 4 wt%, more preferably 0.1 wt% to 2 wt%, based on the total amount of the lubricating oil composition.

Some of the compounds listed above may fulfil multiple functions. ZnDTP, for example, is primarily an antiwear additive and extreme pressure additive, but also has the character of an antioxidant and corrosion inhibitor (here: metal passivator/deactivator).

The above-detailed additives are described in detail, inter alia, in T. Mang, W. Dresel (eds.): "Lubricants and Lubrication", Wiley-VCH, Weinheim 2001; R. M. Mortier, S. T. Orszulik (eds.): "Chemistry and Technology of Lubricants".

The polyalkyl(meth)acrylate based polymers in accordance with the invention can be prepared by free-radical polymerization and by related methods of controlled free-radical polymerization, for example ATRP (= atom transfer radical polymerization) or RAFT (= reversible addition fragmentation chain transfer).

Standard free-radical polymerization is detailed, inter alia, in Ullmann's Encyclopedia of Industrial Chemistry, Sixth Edition. In general, a polymerization initiator and optionally a chain transfer agent are used for this purpose.

The usable initiators include azo initiators widely known in the technical field, such as AIBN and 1,1-azobiscyclohexanecarbonitrile, and also peroxy compounds such as methyl ethyl ketone peroxide, acetylacetone peroxide, dilauryl peroxide, tert-butyl per-2-ethylhexanoate, ketone peroxide, tert-butyl peroctoate, methyl isobutyl ketone peroxide, cyclohexanone peroxide, dibenzoyl peroxide, tert-butyl peroxybenzoate, tert-butyl peroxyisopropylcarbonate, 2,5-bis(2-ethylhexanoylperoxy)-2,5-dimethylhexane, tert-butyl peroxy-2-ethylhexanoate, tert-butyl peroxy-3,5,5-trimethylhexanoate, dicumyl peroxide, 1,1-bis(tert-butylperoxy)cyclohexane, 1,1-bis(tert-butylperoxy)-3,3,5-trimethylcyclohexane, cumyl hydroperoxide, tert-butyl hydroperoxide, bis(4-tert-butylcyclohexyl) peroxydicarbonate, mixtures of two or more of the aforementioned compounds with one another, and mixtures of the aforementioned compounds with unspecified compounds which can likewise form free radicals. Suitable chain transfer agents are especially oil-soluble mercaptans, for example n-dodecyl mercaptan or 2-mercaptoethanol, or else chain transfer agents from the class of the terpenes, for example terpinolene.

The ATRP method is known in the art. It is assumed that this is a "living" free-radical polymerization, but no restriction is intended by the description of the mechanism. In these processes, a transition metal compound is reacted with a compound having a transferable atom group. This involves transfer of the transferable atom group to the transition metal compound, as a result of which the metal is oxidized. This reaction forms a free radical which adds onto ethylenic groups. However, the transfer of the atom group to the transition metal compound is reversible, and so the atom group is transferred back to the growing polymer chain, which results in formation of a controlled polymerization system. It is accordingly possible to control the formation of the polymer, the molecular weight and the molecular weight distribution.

This reaction regime is described, for example, by J.-S. Wang, et al., J. Am. Chem. Soc, vol. 117, p. 5614-5615 (1995), by Matyjaszewski, Macromolecules, vol. 28, p. 7901-7910 (1995). In addition, patent applications WO 96/30421, WO 97/47661, WO 97/18247, WO 98/40415 and WO 99/10387 disclose variants of the above-elucidated ATRP. In addition, the polymers of the invention can also be obtained via

RAFT methods, for example. This method is described in detail, for example, in WO 98/01478 and WO 2004/083169.

The polymerization can be conducted under standard pressure, reduced pressure or elevated pressure. The polymerization temperature is also uncritical. In general, however, it is in the range from -20 to 200°C, preferably 50 to 150°C and more preferably 80 to 130°C.

The polymerization can be conducted with or without solvent. The term "solvent" should be understood here in a broad sense. The solvent is selected according to the polarity of the monomers used, it being possible with preference to use 100N oil, comparatively light gas oil and/or aromatic hydrocarbons, for example toluene or xylene.

The invention has been further illustrated by the following non-limiting examples.

Experimental part

Abbreviations

Aramco	Aramco PRIMA® 100, Group II base oil commercially available from Motiva with a KV100 of 4.26 mm^2/s and a KV40 of of 20.98 mm^2/s
Berylane	Berylane 230SPP base oil commercially available from Total with a KV100 of 1.01 mm^2/s and a KV40 of 2.39 mm^2/s
BMA	butyl methacrylate
BV40	bulk viscosity @40°C
CE	comparative example
DDM	n-dodecyl mercaptan
DINA	diisononyl adipate, Plastomoll® DNA commercially available from BASF with a KV100 of 3.2 mm^2/s and a KV40 of 12.0 mm^2/s
DUB GREEN DOS	bis(2-ethylhexyl)sebacate commercially available from Stearinerie Dubois with a KV100 of 3.21 mm^2/s and a KV40 of 11.5 mm^2/s
GTL3	Fischer-Tropsch derived base oil, Risella X415 commercially available from Shell with a KV100 of 2.7 mm^2/s and a KV40 of 9.8 mm^2/s
GTL4	Fischer-Tropsch derived base oil, Risella X420 commercially available from Shell with KV100 of 4.12 mm^2/s, a KV40 of 18.5 mm^2/s and an aniline point of 122.2°C
KV40	kinematic viscosity @40°C, measured according to ASTM D7042
KV100	kinematic viscosity @100°C, measured according to ASTM D7042
LMA	lauryl methacrylate, 73% C12, 27% C14, all linear
MM	macromonomer
MMA	methyl methacrylate
M_n	number-average molecular weight

M_w	weight-average molecular weight
NB 3020	Nexbase® 3020, Group III base oil from Neste with a KV100 of 2.2 mm^2/s and a KV40 of 7.73 mm^2/s
NB 3043	Nexbase® 3043, Group III base oil from Neste with a KV100 of 4.3 mm^2/s and a KV40 of 20.1 mm^2/s
nBMA	n-butyl methacrylate
OLOA® 55501	DI Package for PCMO (passenger car motor oil) commercially available from Oronite
PDI	Polydispersity index
SMA	stearyl methacrylate, 33% C16, 67% C18, all linear
Sty	styrene
tBPO	tert-butyl-2-ethylperoxyhexanoate
VI	viscosity index, measured according to ASTM D 2270
Yubase 6	Group III base oil from SK Lubricants with a KV100 of 6.52 mm^2/s, a KV40 of 36.82 mm^2/s and an aniline point of 125.4°C

Test methods

The polyalkyl(meth)acrylate copolymer according to the present invention and the comparative examples were characterized with respect to their molecular weight and PDI.

Molecular weights were determined by size exclusion chromatography (SEC) using commercially available polymethylmethacrylate (PMMA) standards. The determination is effected by gel permeation chromatography with THF as eluent (flow rate: 1 mL/min; injected volume: 100 µl).

Columns: 5 SDV Columns 8 x 300 mm resp. 8 x 50 mm (company PSS at Mainz)
1 Solvent-Peak Separation Column 8 x100 mm (company Shodex)

No.	Type		Dimension	Serial no.
Precolumn	SDV	10 µ	8 X 50 mm	91121224
1	SDV LXL	10 µ	8 X 300 mm	6013101
2	SDV LinL	10 µ	8 X 300 mm	6082302
3	SDV 100Å	10 µ	8 X 300 mm	0071401
4	SDV 100Å	10 µ	8 X 300 mm	0070508
5	KF-800D		8 X 100 mm	2007012

Instruments:	Agilent 1100 Series	Pump G1310A
	PSS SECcurity	Inline-Degaser 409-0024
	Agilent 1260 Series	Autosampler G1329B

Agilent 1260 Series	UV-Detector G1314B
Agilent 1100 Series	RI-Detector G1362A
Agilent 1100 Series	Control-Module G1323B
Techlab	Column oven K-5

Oven:	Temperature 35°C
Eluent:	Tetrahydrofuran
	Eluent is continuously distilled and circulated by pump
Flow rate:	1 mL / min
Injected volume:	100 µL
Detection:	RI: Temperature 35°C
	UV: Wavelength 239 nm
Delay volume:	0.175 mL (between UV- and RI-signal)
Software:	PSS WinGPC-Software
Concentration sample solution:	2 g/L (Mw > 106: 1 g/L ... 0.5 g/L)
Standards:	PMMA (for example PSS (Mainz) or Polymer Laboratories)
Concentration standard solution: (narrow distribution)	1 g/L (for Mw > 106: 0.5 g/L, Mw > 2*106: 0.25 g/L)
Internal standard:	1,2-Dichlorobenzene →0.2 µL to 99.8 µL Sample

The additive compositions including the polyalkyl(meth)acrylate copolymer according to the present invention and comparative examples were characterized with respect to their bulk viscosity at 40°C (BV40) to ASTM D7042 (Stabinger viscometer). For BV40 measurement, as a pretreatment, the sample was heated to 120°C and slowly cooled to room temperature over 24 hours, provided that the upper limit for Stabinger viscometer is 30,000 mm^2/s.

The base oil (carrier oil as well) and base oil mixtures were characterized with respect to their viscosity index (VI) to ASTM D 2270, kinematic viscosity at 40°C (KV40) and 100°C (KV100) to ASTM D7042.

The Noack evaporation loss of the base oils and base oil mixtures was determined at 150°C for 12 hours to CEC L-40B, provided that the test was conducted three times of 4 hours, for a total of 12 hours.

The aniline point of the base oils and base oil mixtures was determined to ASTM D611.

The lubricating oil compositions including the polyalkyl(meth)acrylate copolymer according to the present invention and comparative examples were characterized with respect to kinematic viscosity at 40°C (KV40) and 100°C (KV100) to ASTM D7042, the viscosity index (VI) to ASTM D 2270, high-temperature high-shear viscosity at 80°C, 100°C and 150°C to CEC L-036, and Noack evaporation loss at 150°C for

12 hours to CEC L-40B, provided that the test was conducted three times of 4 hours, for a total of 12 hours.

Synthesis of a hydroxylated hydrogenated polybutadiene

The macroalcohol prepared was a hydroxypropyl-terminated hydrogenated polybutadiene having a mean molar mass M_n = 4750 g/mol.

The macroalcohol was synthesized by an anionic polymerization of 1,3-butadiene with butyllithium at 20-45°C. On attainment of the desired degree of polymerization, the reaction was stopped by adding propylene oxide and lithium was removed by precipitation with methanol. Subsequently, the polymer was hydrogenated under a hydrogen atmosphere in the presence of a noble metal catalyst at up to 140°C and pressure 200 bar. After the hydrogenation had ended, the noble metal catalyst was removed, and organic solvent was drawn off under reduced pressure. Finally, the base oil NB 3020 was used for dilution to a polymer content of 70 wt%.

The vinyl content of the macroalcohol was 61%, the hydrogenation level > 99% and the OH functionality > 98%. These values were determined by H-NMR (nuclear magnetic resonance spectroscopy).

Synthesis of macromonomer (MM)

In a 2 L stirred apparatus equipped with saber stirrer, air inlet tube, thermocouple with controller, heating mantle, column having a random packing of 3 mm wire spirals, vapor divider, top thermometer, reflux condenser and substrate cooler, 1000 g of the above-described macroalcohol are dissolved in 450 g of methyl methacrylate (MMA) by stirring at 60°C. Added to the solution are 20 ppm of 2,2,6,6-tetramethylpiperidin-1-oxyl radical and 200 ppm of hydroquinone monomethyl ether. After heating to MMA reflux (bottom temperature about 110°C) while passing air through for stabilization, about 20 g of MMA are distilled off for azeotropic drying. After cooling to 95°C, 0.30 g of $LiOCH_3$ is added and the mixture is heated back to reflux. After the reaction time of about 1 hour, the top temperature has fallen to ~64°C because of methanol formation. The methanol/MMA azeotrope formed is distilled off constantly until a constant top temperature of about 100°C is established again. At this temperature, the mixture is left to react for a further hour. For further workup, the bulk of MMA is drawn off under reduced pressure. Insoluble catalyst residues are removed by pressure filtration (Seitz T1000 depth filter). The content of NB 3020 "entrained" into the copolymer syntheses described further down was taken into account accordingly.

Synthesis of comb polymers

Examples 1, 3, 4, 6, 7, 9, 10, 12-14 and 17:

In a beaker, the monomer feed mix was made up according to Table 1. A 2 liter 4-neck round-bottom flask with saber stirrer, nitrogen blanketing, thermometer, heater, and reflux condenser was charged with the initial charge mix shown in Table 1 and heated to 100°C while stirring. During the heating phase, nitrogen was passed through the reaction flask for inertization. On attainment of 100°C, initiator for initial charge mix shown in Table 1 was introduced into the reaction flask; at the same time, the monomer feed mix was fed into the reactor. The feed time was 3 hours; the reaction temperature was kept constant at 100°C. After the end of feed, the reaction temperature was increased to 110°C. Then the first initiator feed shown in Table 1 was done over 60 minutes. After that , initiator oil mix shown in Table 1 was fed over 2 hours. Then the batch was kept at 110°C for 30 minutes. The dilution oil shown in Table 1 was charged into the reaction flask and held the batch for 1 hour. The reaction temperature was cooled down to room temperature while stopping stirring to avoid gel generation. 1600 g of a high-viscosity solution was obtained.

Example 5:

In a beaker, the monomer feed mix was made up according to Table 1. A 2 liter 4-neck round-bottom flask with saber stirrer, nitrogen blanketing, thermometer, heater, and reflux condenser was charged with the initial charge mix shown in Table 1 and heated to 95°C while stirring. During the heating phase, nitrogen was passed through the reaction flask for inertization. On attainment of 95°C, initiator for initial charge mix shown in Table 1 was introduced into the reaction flask; at the same time, the monomer feed mix was fed into the reactor. The feed time was 3 hours; the reaction temperature was kept constant at 95°C. After the end of feed, it was held for 15 minutes. Then the oil feed shown in Table 1 was fed over 180 minutes. The initiator for oil feed shown in Table 1 was charged into the oil feed in 75 minutes after start of the dilution feed. In the end of feed, the batch was kept at 95°C for 2 hours. Final step initiator shown in Table 1 was charged into the reaction flask. The batch was kept at 95°C for 2 hours. The dilution oil shown in Table 1 was charged into the reaction flask and held the batch for 1 hour. The reaction temperature was cooled down to room temperature while stopping stirring to avoid gel generation. 1600 g of a high-viscosity solution was obtained.

Examples 2, 11, 15, 16:

In a beaker, the monomer feed mix was made up according to Table 1. A 2 liter 4-neck round-bottom flask with saber stirrer, nitrogen blanketing, thermometer, heater, and reflux condenser was charged with the initial charge mix shown in Table 1 and heated to 100°C while stirring. During the heating phase, nitrogen was passed through the reaction flask for inertization. On attainment of 100°C, initiator for initial charge mix shown in Table 1 was introduced into the reaction flask; at the same time, the monomer feed mix was fed into the reactor. The feed time was 3 hours; the reaction temperature was kept constant at 100°C. After the end of feed, the reaction temperature was kept at 100°C for 30 minutes. Then the initiator oil mix shown in Table 1 was fed over 2 hours. Then the batch was kept at 100°C for 30 minutes. The dilution oil shown in Table 1 was charged into the reaction flask and held the batch for 1 hour. The

reaction temperature was cooled down to room temperature while stopping stirring to avoid gel generation. 1600 g of a high-viscosity solution was obtained.

Example 8:

In a beaker, the monomer feed mix was made up according to Table 1. A 2 liter 4-neck round-bottom flask with saber stirrer, nitrogen blanketing, thermometer, heater, and reflux condenser was charged with the initial charge mix shown in Table 1 and heated to 100°C while stirring. During the heating phase, nitrogen was passed through the reaction flask for inertization. On attainment of 100°C, initiator for initial charge mix shown in Table 1 was introduced into the reaction flask; at the same time, the monomer feed mix was fed into the reactor. The feed time was 3 hours; the reaction temperature was kept constant at 100°C. After the end of feed, the reaction temperature was increased to 110°C. Then the initiator oil mix shown in Table 1 was fed over 2 hours. Then the batch was kept at 110°C for 30 minutes. The dilution oil shown in Table 1 was charged into the reaction flask and held the batch for 1 hour. The reaction temperature was cooled down to room temperature while stopping stirring to avoid gel generation. 1600 g of a high-viscosity solution was obtained.

Example CE-1:

In a beaker, the monomer feed mix was made up according to Table 1. A 2 liter 4-neck round-bottom flask with saber stirrer, nitrogen blanketing, thermometer, heater, and reflux condenser was charged with the initial charge mix shown in Table 1 and heated to 91°C while stirring. During the heating phase, nitrogen was passed through the reaction flask for inertization. On attainment of 91°C, initiator for initial charge mix shown in Table 1 was introduced into the reaction flask; at the same time, the monomer feed mix was fed into the reactor. The feed time was 3 hours; the reaction temperature was kept constant at 91°C. After the end of feed, it was held for 45 minutes. Then the oil feed shown in Table 1 was fed over 180 minutes. The initiator for oil feed shown in Table 1 was charged into the oil feed in 75 minutes after start of the dilution feed. In the end of feed, the batch was kept at 91°C for 15 hours. The dilution oil shown in Table 1 was charged into the reaction flask and held the batch for 1 hour. The reaction temperature was cooled down to room temperature while stopping stirring to avoid gel generation. 1600 g of a high-viscosity solution was obtained.

Example CE-2:

In a beaker, the monomer feed mix was made up according to Table 1. A 2 liter 4-neck round-bottom flask with saber stirrer, nitrogen blanketing, thermometer, heater, and reflux condenser was charged with the initial charge mix shown in Table 1 and heated to 95°C while stirring. During the heating phase, nitrogen was passed through the reaction flask for inertization. On attainment of 95°C, initiator for initial charge mix shown in Table 1 was introduced into the reaction flask; at the same time, the monomer feed mix was fed into the reactor. The feed time was 3 hours; the reaction temperature was kept constant at 95°C. After the end of feed, it was held for 45 minutes. Then the oil feed shown in Table 1 was fed over 180 minutes. The initiator for oil feed shown in Table 1 was charged into the oil feed in 75 minutes after

start of the dilution feed. In the end of feed, the batch was kept at 95°C for 15 hours. The dilution oil shown in Table 1 was charged into the reaction flask and held the batch for 1 hour. The reaction temperature was cooled down to room temperature while stopping stirring to avoid gel generation. 1600 g of a high-viscosity solution was obtained.

Examples CE-3 to CE-8

Example CE-3 corresponds to Example 1 disclosed in WO 2024/033156, Example CE-4 corresponds to Example 2 disclosed in WO 2024/033156, Example CE-5 corresponds to Example 6 disclosed in WO 2024/033156, Example CE-6 corresponds to Example 7 disclosed in WO 2024/033156, Example CE-7 corresponds to Example 8 disclosed in WO 2024/033156 and Example CE-8 corresponds to Example 9 disclosed in WO 2024/033156. All examples CE-3 to CE-8 were prepared following the protocols as disclosed in WO 2024/033156.

Table 1: Monomer mixtures used to prepare polymers according to the present invention.

Example # new		**1**	**2**	**3**	**4**	**5**	**6**
Initial charge mixture	Aramco [g]	0	193.1	0	0	0	0
	Berylane [g]	0	0	0	0	0	0
	NB3043 [g]	133.1	0	189.9	175.0	149.5	104.6
	NB3020 [g]	0	0	12.11	11.15	0	95.1
	DINA [g]	59.98	0	0	0	0	0
	DUB GREEN DOS [g]	0	0	0	0	39.9	0
	Yubase 6 [g]	0	0	0	0	0	0
	MM [g]	47.07	47.07	65.61	60.46	34.2	68.5
	LMA [g]	26.66	26.66	31.95	33.12	23.4	26.34
	MMA [g]	0	0	0	0	0.499	0
	BMA [g]	147.6	147.6	139.8	125.1	149.0	146.0
	Sty [g]	0	0	0	0	2.90	0
	SMA [g]	0	0	3.99	3.68	0	0
Initiator for initial charge mixture	tBPO [g]	0.207	0.187	0.222	0.204	0.599	0.198
Monomer feed mixture	Aramco [g]	0	187.4	0	0	0	0
	Berylane [g]	0	0	0	0	0	0
	NB3043	187.4	0	177.7	163.8	149.5	101.8

Example # new		1	2	3	4	5	6
	[g]						
	NB3020 [g]	0	0	0	0	0	77.3
	DINA [g]	0	0	0	0	0	0
	DUB GREEN DOS [g]	0	0	0	0	39.9	0
	Yubase 6 [g]	0	0	0	0	0	0
	MM [g]	15.69	15.69	0	0	34.2	0
	LMA [g]	26.66	26.66	31.95	33.12	23.4	26.4
	MMA [g]	1	1	1	0.92	0.499	0.998
	BMA [g]	147.6	147.6	139.8	125.1	149.0	146.0
	Sty [g]	5.87	5.87	1	0.92	2.90	5.79
	SMA [g]	0	0	0	3.68	0	0
	tBPO [g]	0.32	0.519	0.296	0.273	0.599	0.269
Oil feed	NB3043 [g]	0	0	0	0	199.7	0
Initiator for oil feed	tBPO [g]	0	0	0	0	0.799	0
1st initiator feed	10% tBPO in NB3043 [g]	1.066	0	0.986	0.909	0	0.896
Final step initiator	tBPO [g]	0	0	0	0	0.799	0
Initiator oil mix feed	NB3043 [g]	447.8	0	447.8	412.6	0	447.9
	Aramco [g]		448.6				
	Yubase 6 [g]	0	0	0	0	0	0
	tBPO [g]	0.479	0.479	0.479	0.442	0	0.479
Dilution oil	NB3043 [g]	351.5	0	351.5	449.6	598.8	351.5
	Aramco [g]		351.6				
	Yubase 6 [g]	0	0	0	0	0	0
Total	[g]	1600	1600	1600	1600	1600	1600

Table 1 continued: Monomer mixtures used to prepare polymers according to the present invention.

Example # new		7	8	CE-1	9	10	11
Initial charge mixture	Aramco [g]	0	192.9	0	0	0	199.7

Example # new		7	8	CE-1	9	10	11
	Berylane [g]	0	0	95.4	0	0	0
	NB3043 [g]	139.7	0	105.0	104.6	173.7	0
	NB3020 [g]	0	0	0	95.1	10.3	0
	DINA [g]	60	0	0	0	0	0
	DUB GREEN DOS [g]	0	0	0	0	0	0
	Yubase 6 [g]	0	0	0	0	0	0
	MM [g]	68.5	51.35	68.1	68.5	63.1	68.46
	LMA [g]	26.4	26.36	26.4	30.4	28.0	30.35
	MMA [g]	0	0	0.433	0	0	0
	BMA [g]	146.0	146	146.0	142.0	130.8	142
	Sty [g]	0	0	0.398	0	0	0
	SMA [g]	0	0	0	0	0	0
Initiator for initial charge mixture	tBPO [g]	0.220	0.187	0.331	0.110	0.203	0.198
Monomer feed mixture	Aramco [g]	0	185.9	0	0	0	179.1
	Berylane [g]	0	0	77.1	0	0	0
	NB3043 [g]	179.1	0	101.3	101.8	165.0	0
	NB3020 [g]	0	0	0	77.3	0	0
	DINA [g]	0	0	0	0	0	0
	DUB GREEN DOS [g]	0	0	0	0	0	0
	Yubase 6 [g]	0	0	0	0	0	0
	MM [g]	0	17.12	0.314	0	0	0
	LMA [g]	26.4	26.36	26.4	30.4	28.0	30.35
	MMA [g]	0.998	1	0.566	0.998	0.919	1
	BMA [g]	146.0	146	146.0	142.0	130.8	142
	Sty [g]	5.79	5.79	5.39	5.79	5.34	5.79
	SMA [g]	0	0	0	0	0	0
	tBPO [g]	0.298	0.516	0.268	0.269	0.275	0.484

Example # new		7	8	CE-1	9	10	11
Oil feed	NB3043 [g]	0	0	201.6	0	0	0
Initiator for oil feed	tBPO [g]	0	0	0.798	0	0	0
1st initiator feed	10% tBPO in NB3043 [g]	0.994	0	0	0.896	0.916	0
Final step initiator	tBPO [g]	0	0	0	0	0	0
Initiator oil mix feed	NB3043 [g]	447.8	0	0	448.0	412.6	0
	Aramco [g]	0	448.6	0	0	0	448.6
	Yubase 6 [g]	0	0	0	0	0	0
	tBPO [g]	0.479	0.479	0	0.479	0.442	0.479
Dilution oil	NB3043 [g]	351.5	0	598.3	351.5	449.6	351.5
	Aramco [g]		351.5				
	Yubase 6 [g]	0	0	0	0	0	0
Total	[g]	1600	1600	1600	1600	1600	1600

Table 1 continued: Monomer mixtures used to prepare polymers according to the present invention.

Example # new		12	13	14	CE-2
Initial charge mixture	Aramco [g]	0	0	0	0
	Berylane [g]	0	0	0	99.1
	NB3043 [g]	188.5	188.5	197.0	107.9
	NB3020 [g]	11.2	11.2	6.1	0
	DINA [g]	0	0	0	0
	DUB GREEN DOS [g]	0	0	0	0
	Yubase 6 [g]	0	0	0	0
	MM [g]	68.46	68.5	85.6	85.4
	LMA [g]	30.35	34.3	37.9	37.9
	MMA [g]	0	0	0	0.344
	BMA [g]	142	138.0	131.0	131.1
	Sty [g]	0	0	0	0.227
	SMA	0	0	0	0

Example # new		12	13	14	CE-2
	[g]				
Initiator for initial charge mixture	tBPO [g]	0.22	0.220	0.320	0.344
Monomer feed mixture	Aramco [g]	0	0	0	0
	Berylane [g]	0	0	0	73.5
	NB3043 [g]	179.1	179.1	170.5	96.7
	NB3020 [g]	0	0	0	0
	DINA [g]	0	0	0	0
	DUB GREEN DOS [g]	0	0	0	0
	Yubase 6 [g]	0	0	0	0
	MM [g]	0	0	0	0.243
	LMA [g]	30.35	34.3	37.9	38.0
	MMA [g]	1	0.998	0.798	0.455
	BMA [g]	142	138.0	131.0	131.1
	Sty [g]	5.79	5.79	0.798	0.572
	SMA [g]	0	0	0	0
	tBPO [g]	0.298	0.298	0.396	0.255
Oil feed	NB3043 [g]	0	0	0	198.7
Initiator for oil feed	tBPO [g]	0	0	0	0.800
1st initiator feed	10% tBPO in NB3043 [g]	0.994	0.994	1.32	0
Final step initiator	tBPO [g]	0	0	0	0
Initiator oil mix feed	NB3043 [g]	0	447.8	447.2	0
	Yubase 6 [g]	447.8	0	0	0
	tBPO [g]	0.479	0.479	0.479	0
Dilution oil	NB3043 [g]	0	351.5	351.5	597.0
	Yubase 6 [g]	351.5	0	0	0
Total	[g]	1600	1600	1600	1600

Table 1 continued: Monomer mixtures used to prepare polymers according to the present invention.

Example # new		15	16	17
Initial charge mixture	Aramco [g]	0	0	0
	Berylane [g]	0	0	0
	NB3043 [g]	135.5	135.5	132.9
	NB3020 [g]	0	0	0
	DINA [g]	59.97	59.97	59.98
	DUB GREEN DOS [g]	0	0	0
	Yubase 6 [g]	0	0	0
	MM [g]	51.35	51.35	51.35
	LMA [g]	25.56	27.36	30.34
	MMA [g]	0	0	0
	BMA [g]	149.4	147.6	142.0
	Sty [g]	0	0	0
	SMA [g]	0	0	0
Initiator for initial charge mixture	tBPO [g]	0.211	0.211	0.208
Monomer feed mixture	Aramco [g]	0	0	0
	Berylane [g]	0	0	0
	NB3043 [g]	183.4	183.4	186.0
	NB3020 [g]	0	0	0
	DINA [g]	0	0	0
	DUB GREEN DOS [g]	0	0	0
	Yubase 6 [g]	0	0	0
	MM [g]	17.12	17.12	17.12
	LMA [g]	25.56	27.36	30.35
	MMA [g]	0.8	0.8	0.99
	BMA [g]	149.4	147.6	142
	Sty [g]	0.8	0.8	5.79
	SMA [g]	0	0	0

Example # new		15	16	17
	tBPO [g]	0.418	0.418	0.318
Oil feed	NB3043 [g]	0	0	0
Initiator for oil feed	tBPO [g]	0	0	0
1st initiator feed	10% tBPO in NB3043 [g]	0	0	1.061
Final step initiator	tBPO [g]	0	0	0
Initiator oil mix feed	NB3043 [g]	448.7	448.7	447.7
	Yubase 6 [g]	0	0	0
	tBPO [g]	0.479	0.479	0.479
Dilution oil	NB3043 [g]	351.5	351.5	351.5
	Yubase 6 [g]	0	0	0
Total	[g]	1600	1600	1600

The net compositions of the polymers prepared according to the present invention and of the comparative examples are shown in the following Table 2.

Table 2: Net compositions of the polymers prepared according to the present invention and comparative examples.

Polymer Example #	MM [wt%]	nBMA [wt%]	LMA [wt%]	SMA [wt%]	MMA [wt%]	Sty [wt%]
1	11.0	73.93	13.35	--	0.25	1.47
2	11.0	73.93	13.35	--	0.25	1.47
3	11.5	70.0	16.0	2.0	0.25	0.25
4	11.5	68.0	18.0	2.0	0.25	0.25
5	12.0	74.6	11.7	--	0.25	1.45
6	12.0	73.1	13.2	--	0.2	1.50
7	12.0	73.1	13.2	--	0.2	1.50
8	12.0	73.1	13.2	--	0.2	1.5
CE-1	12.0	73.1	13.2	--	0.2	1.50
9	12.0	71.1	15.2	--	0.25	1.45
10	12.0	71.1	15.2	--	0.25	1.45
11	12.0	71.1	15.2	--	0.25	1.45
12	12.0	71.1	15.2	--	0.25	1.45
13	12.0	69.1	17.2	--	0.2	1.50
14	15.0	65.6	19.0	--	0.2	0.20
15	12.0	74.8	12.8	--	0.2	0.2
16	12.0	73.9	13.7	--	0.2	0.2
17	12.0	71.1	15.2	--	0.25	1.45

Polymer Example #	MM [wt%]	nBMA [wt%]	LMA [wt%]	SMA [wt%]	MMA [wt%]	Sty [wt%]
CE-2	15.0	65.6	19.0	--	0.2	0.20
CE-3 (Ex 1 of WO 2024/033156)	11.2	68.5	8.4	11.2	0.5	0.2
CE-4 (Ex 2 of WO 2024/033156)	11.2	68.5	0.6	19.0	0.5	0.2
CE-5 (Ex 6 of WO 2024/033156)	11.2	61.6	1.4	25.1	0.5	0.2
CE-6 (Ex 7 of WO 2024/033156)	11.2	51.8	1.4	25.1	0.5	0.2
CE-7 (Ex 8 of WO 2024/033156)	11.2	46.9	1.4	25.1	0.5	0.2
CE-8 (Ex 9 of WO 2024/033156)	11.2	68.5	15.6	--	0.5	0.2

CE = comparative example

Certain properties (average C-number, Mw, Mn, PDI) of the polymers prepared according to the present invention and of the comparative examples are disclosed in the following Table 3.

Table 3: Properties of the polymers prepared according to the present invention and comparative examples (average C-number, Mw, Mn, PDI).

Polymer Example #	Average C-No.	M_w [g/mol]	M_n [g/mol]	PDI
1	4.73	540,000	126,000	4.29
2	4.73	499,000	127,000	3.93
3	5.05	579,000	144,000	4.02
4	5.19	655,000	146,000	4.5
5	4.64	363,000	104,000	3.5
6	4.73	586,000	133,000	4.4
7	4.73	603,000	142,000	4.2
8	4.73	506,000	114,000	4.43
CE-1	4.73	534,000	121,000	4.4
9	4.84	644,000	124,000	5.2
10	4.84	626,000	139,000	4.5
11	4.84	510,000	125,000	4.07
12	4.84	626,000	139,000	4.5
13	4.98	619,000	139,000	4.4
14	5.13	569,000	125,000	4.6
15	4.70	528,000	133,000	4.0
16	4.76	528,000	132,000	4.0
17	4.86	526,000	134,000	4.0
CE-2	5.13	567,000	124,000	4.6

Polymer Example #	Average C-No.	M_w [g/mol]	M_n [g/mol]	PDI
CE-3 (Ex 1 of WO 2024/033156)	5.3	740,000	150,000	5.0
CE-4 (Ex 2 of WO 2024/033156)	5.4	772,000	144,000	5.4
CE-5 (Ex 6 of WO 2024/033156)	6.0	738,000	119,000	6.2
CE-6 (Ex 7 of WO 2024/033156)	6.6	744,000	127,000	5.9
CE-7 (Ex 8 of WO 2024/033156)	7.0	735,000	126,000	5.8
CE-8 (Ex 9 of WO 2024/033156)	5.2	620,000	125,000	5.0

CE = comparative example

The weight-average molecular weights of the polyalkyl(meth)acrylate copolymers are in the range of 363,000 g/mol (Example 5) to 655,000 g/mol (Example 4). The polydispersity indices are in the range of 3.5 (Example 5) to 5.2 (Example 9). The average carbon numbers, corresponding to the molar average of all carbon atoms present in the alkyl residues of the alkyl (meth)acrylates forming the polyalkyl (meth)acrylate copolymers, are in the range of 4.64 (Example 5) to 5.19 (Example 4).

The additive compositions comprising a polymer and a carrier oil composition as well as their viscometric properties are disclosed in the following Table 4.

Table 4: Additive compositions and their viscometric properties.

Additive Composition #	Polymer Example #	Carrier oil composition (COC)	Ratio wt% polymer:wt%COC	KV100 (carrier oil) [mm^2/s]	KV40 (carrier oil) [mm^2/s]	Aniline Point (carrier oil) [°C]	Noack (carrier oil) [%]	BV40 (composition) [mm^2/s]	Ratio c averag C / KV1
A1	**1**	1.57 wt% Nexbase 3020 93.43 wt% Nexbase 3043 5.00 wt% DINA	25:75	4.20	19.26	108.9	2.1	1206	1.13
A2	**2**	1.57 wt% Nexbase 3020 98.43 wt% Aramco	25:75	4.21	20.65	109.5	3.9	1261	1.12
A3	**3**	2.65 wt% Nexbase 3020 97.35 wt% Nexbase 3043	25:75	4.23	19.60	115.5	2.3	1452	1.19
A4	**4**	2.38 wt% Nexbase 3020 97.62 wt% Nexbase 3043	23:77	4.24	19.65	115.5	2.3	681	1.23
A5	**5**	1.71 wt% Nexbase 3020 91.62 wt% Nexbase 3043 6.67 wt% DUB GREEN DOS	25:75	4.18	19.06	107.3	2.1	600	1.11
A6	**6**	16.09 wt% Nexbase 3020 83.91 wt% Nexbase 3043	25:75	3.87	17.24	113.1	5.9	642	1.22
A7	**7**	1.71 wt% Nexbase 3020 93.29 wt% Nexbase 3043 5.00 wt% DINA	25:75	4.19	19.27	108.9	2.1	968	1.13
A8	**8**	1.71 wt% Nexbase 3020 98.29 wt% Aramco	25:75	4.21	20.62	109.5	3.9	1122	1.12
A9 (CE)	**CE-1**	1.71 wt% Nexbase 3020 83.91 wt% Nexbase 3043 14.38 wt% Berylane 230SPP	25:75	3.45	14.56	111.6	16.2	2135	1.37
A10	**9**	16.09 wt% Nexbase 3020 83.91 wt% Nexbase 3043	25:75	3.86	17.24	113.1	5.9	1496	1.25
A11	**10**	2.38 wt% Nexbase 3020 97.62 wt% Nexbase 3043	23:77	4.24	19.65	115.6	2.2	308	1.14
A12	**11**	1.71 wt% Nexbase 3020 98.29 wt% Aramco	25:75	4.21	20.62	109.5	3.9	1985	1.15

Additive Composition #	Polymer Example #	Carrier oil composition (COC)	Ratio wt% polymer:wt%COC	KV100 (carrier oil) [mm^2/s]	KV40 (carrier oil) [mm^2/s]	Aniline Point (carrier oil) [°C]	Noack (carrier oil) [%]	BV40 (composition) [mm^2/s]	Ratio c averag C / KV1
A13	**12**	2.65 wt% Nexbase 3020 30.72 wt% Nexbase 3043 66.63 wt% Yubase 6	25:75	5.58	29.33	121.8	2.0	345	0.867
A14	**13**	2.65 wt% Nexbase 3020 97.35 wt% Nexbase 3043	25:75	4.23	19.6	115.5	2.3	972	1.18
A15	**14**	2.65 wt% Nexbase 3020 97.35 wt% Nexbase 3043	25:75	4.23	19.00	115.5	2.3	1783	1.21
A16 (CE)	**CE-2**	2.14 wt% Nexbase 3020 83.45 wt% Nexbase 3043 14.40 wt% Berylane 230SPP	25:75	3.44	14.49	110.6	16.3	70513	1.49
A17	**15**	1.71 wt% Nexbase 3020 93.29 wt% Nexbase 3043 5.00 wt% DINA	25:75	4.19	19.27	108.9	2.1	1332	1.12
A18	**16**	1.71 wt% Nexbase 3020 93.29 wt% Nexbase 3043 5.00 wt% DINA	25:75	4.19	19.27	108.9	2.1	1382	1.14
A19	**17**	1.71 wt% Nexbase 3020 93.29 wt% Nexbase 3043 5.00 wt% DINA	25:75	4.19	19.27	108.9	2.1	2888	1.16
A20	**CE-3**	1.6 wt% Nexbase 3020 89.5 wt% Nexbase 3043 8.9 wt% Group II/III oil	25:75	4.35	20.58	112.6	10.8	5717	1.22
A21	**CE-4**	1.6 wt% Nexbase 3020 89.5 wt% Nexbase 3043 8.9 wt% Group II/III oil	25:75	4.35	20.58	112.6	10.8	72271	1.24
A22	**CE-5**	1.6 wt% Nexbase 3020 89.5 wt% Nexbase 3043 8.9 wt% Group II/III oil	25:75	4.35	20.58	112.6	10.8	438260	1.38
A23	**CE-6**	1.6 wt% Nexbase 3020 89.5 wt% Nexbase 3043 8.9 wt% Group II/III oil	25:75	4.35	20.58	112.6	10.8	37294	1.52

Additive Composition #	Polymer Example #	Carrier oil composition (COC)	Ratio wt% polymer:wt%COC	KV100 (carrier oil) [mm^2/s]	KV40 (carrier oil) [mm^2/s]	Aniline Point (carrier oil) [°C]	Noack (carrier oil) [%]	BV40 (composition) [mm^2/s]	Ratio c averag C / KV1
A24	**CE-7**	1.6 wt% Nexbase 3020 89.5 wt% Nexbase 3043 8.9 wt% Group II/III oil	25:75	4.35	20.58	112.6	10.8	17219	1.61
A25	**CE-8**	1.6 wt% Nexbase 3020 89.5 wt% Nexbase 3043 8.9 wt% Group II/III oil	25:75	4.35	20.58	112.6	10.8	4605	1.20

CE = comparative example

Group II/III oil = light process oil with a KV100 of 1 cSt

The results presented in Table 4 show that additive compositions comprising 20 wt% to 30 wt% of a polyalkyl(meth)acrylate copolymer defined in accordance to the present invention and 70 wt% to 80 wt% of a base oil or base oil mixture having KV100 of 3.6 mm^2/s to 5.6 mm^2/s show good handling properties, i.e. low bulk viscosity of the VI improver additive product at 40°C (BV40) of lower than 3000 mm^2/s and preferably lower than 2000 mm^2/s.

For example, Additive Compositions A6-A9 were prepared with polymers having the same composition but carrier oils having different KV100. The KV100 of the carrier oil composition of Additive Compositions A6-A8 are higher than 3.6 mm^2/s, whereas the KV100 of the carrier oil composition of Comparative Example A9 is lower than 3.6 mm^2/s. This leads to a much higher bulk viscosity (BV40).

Similar results are retrieved for Additive Compositions A15 versus A16.

Furthermore, the values presented in the last column of Table 4 show that the higher the ratio of average C-number / KV100, the higher is the bulk viscosity BV40 of the additive composition.

Evaluation of VI improvers in formulations

To demonstrate the effect of the polymers prepared in accordance with the present invention as well as of the comparative examples on the KV40 performance of lubricating oil compositions different formulation examples were prepared and the corresponding values are measured. Formulations with GTL4 and GTL3 as base oil were prepared by using formulation targets of 0W16 according to SAE J300; i.e. it was formulated to an HTHS150 target of 2.3 mPas and Noack target of 4% by adjusting amount of GTL3, GTL4 and the polymers as described in Table 2 above. The resulting treat rate was typically between 10 wt% and 13 wt% for the polymers which are in accordance with the present invention. As DI package was used the commercially available OLOA 55501. It was added for all examples in the usual amount of 8.9 wt%.

Characteristic EO formulation properties (KV100, KV40, VI, HTHS100, HTHS80) were measured and are summarized in the following Table 5.

Table 5: Formulation examples

Formulation #	**B1**	**B2**	**B3**	**B4**	**B5**	**B6 (CE)**
Polymer Example used	**1**	**2**	**6**	**7**	**8**	**CE-1**
Additive Composition	**A1**	**A2**	**A6**	**A7**	**A8**	**A9 (CE)**
treat rate [wt%]	11.1	10.7	11.2	11.4	11	10.1
solid polymer content [wt%]	2.775	2.675	2.80	2.85	2.75	2.525

Formulation #	**B1**	**B2**	**B3**	**B4**	**B5**	**B6 (CE)**
Polymer Example used	**1**	**2**	**6**	**7**	**8**	**CE-1**
Additive Composition	**A1**	**A2**	**A6**	**A7**	**A8**	**A9 (CE)**
GTL4 [wt%]	29	32	34.8	28.7	31.8	50.2
GTL3 [wt%]	51	48.4	45.1	51	48.3	30.8
DI package [wt%]	8.9	8.9	8.9	8.9	8.9	8.9
Total	100.0	100.0	100.0	100.0	100.0	100.0
Noack as VII [%]	1.6	2.9	4.4	1.6	2.9	12.2
	Analytical Data					
HTHS150 [mPa·s]	2.29	2.29	2.33	2.32	2.29	2.32
HTHS100 [mPa·s]	3.74	3.72	3.76	3.63	3.86	3.84
HTHS80 [mPa·s]	5.26	5.35	5.37	5.27	5.34	5.64
KV100 [mm^2/s]	6.12	6.08	6.26	6.43	6.18	6.12
KV40 [mm^2/s]	19.71	20.51	20.31	19.91	20.19	21.82
VI	297	278	296	318	292	256
Noack150*12hr (calculation) [%]	4.0	4.0	4.0	4.0	4.0	4.0

CE = comparative example

Table 5 continued: Formulation examples

Formulation #	**B7**	**B8**	**B9**	**B10**	**B11**	**B12 (CE)**
Polymer Example used	**9**	**10**	**11**	**13**	**14**	**CE-2**
Additive Composition used	**A10**	**A11**	**A12**	**A14**	**A15**	**A16 (CE)**
treat rate [wt%]	10.3	11.8	10.5	11	10.5	9.3
solid polymer content [wt%]	2.575	2.714	2.625	2.75	2.625	2.325
GTL4 [wt%]	35.2	28.6	32.2	29.32	29.8	50.6
GTL3 [wt%]	45.6	50.7	48.4	50.78	50.8	31.2

Formulation #	**B7**	**B8**	**B9**	**B10**	**B11**	**B12 (CE)**
Polymer Example used	**9**	**10**	**11**	**13**	**14**	**CE-2**
Additive Composition used	**A10**	**A11**	**A12**	**A14**	**A15**	**A16 (CE)**
DI package [wt%]	8.9	8.9	8.9	8.9	8.9	8.9
Total	100.0	100.0	100.0	100.0	100.0	100.0
Noack as VII [%]	4.4	1.7	2.9	1.7	1.7	12.3
	Analytical Data					
HTHS150 [mPa·s]	2.3	2.29	2.29	2.29	2.3	2.3
HTHS100 [mPa·s]	3.77	3.77		3.87	4.08	4.06
HTHS80 [mPa·s]	5.36	5.18		5.27	5.48	5.82
KV100 [mm^2/s]	6.33	6.47	6.28	6.71	6.84	6.41
KV40 [mm^2/s]	20.29	19.88	20.3	20.3	21.14	22.47
VI	302	322	298	331	323	267
Noack150*12hr (calculation) [%]	4.0	4.0	4.0	4.0	4.0	3.9

CE = comparative example

Table 5 continued: Formulation examples

Formulation #	**B13**	**B14**	**B15**
Polymer Example used	**15**	**16**	**17**
Additive Composition used	**A17**	**A18**	**A19**
treat rate [wt%]	10.8	10.6	10.9
solid polymer content [wt%]	2.7	2.26	2.73
GTL4 [wt%]	29.3	29.5	29.2
GTL3 [wt%]	51	51	51
DI package [wt%]	8.9	8.9	8.9
Total	100.0	100.0	100.0

Formulation #	**B13**	**B14**	**B15**
Polymer Example used	**15**	**16**	**17**
Additive Composition used	**A17**	**A18**	**A19**
Noack as VII [%]	1.6	1.6	1.6
	Analytical Data		
HTHS150 [mPa·s]	2.3	2.29	2.33
HTHS100 [mPa·s]	3.67	3.73	3.76
HTHS80 [mPa·s]	5.22	5.2	5.2
KV100 [mm^2/s]	6.13	6.18	6.31
KV40 [mm^2/s]	19.6	19.61	19.79
VI	300	304	311
Noack150*12hr (calculation) [%]	4.0	4.0	4.0

CE = comparative example

Formulations B1 to B5 and B7 to B11 contain the Additive Compositions which are in accordance with the present invention. They are all soluble in the 0W16 formulation and all show relatively low HTHS80 values between 5.27 mPa*s (Formulation B4) and 5.48 mPa*s (Formulation B11). To the contrary, Formulations B6 and B12 (Comparative Examples) show significantly higher HTHS80 values of 5.64 mPa*s and 5.82 mPa*s, respectively.

In addition, the Additive Compositions which are in accordance with the present invention all show relatively low KV40 values between 19.71 mm^2/s (Formulation B1) and 21.14 mm^2/s (Formulation B11). To the contrary, Formulations B6 and B12 (Comparative Examples) show significantly higher KV40 values of 21.82 mm^2/s and 22.47 mm^2/s, respectively.

Furthermore, the inventive formulations have higher VIs.

Claims

1. A viscosity index improver, comprising:

(A) 20 wt% to 30 wt% of a polyalkyl(meth)acrylate copolymer being selected from the group consisting of:

Polymer A, consisting of 11.0 wt% of polybutadiene-based macromonomer (MM), 73.93 wt% of nBMA, 13.35 wt% of LMA, 0.25 wt% of MMA and 1.47 wt% of styrene and having an average carbon number of 4.73;

Polymer B, consisting of 11.5 wt% of polybutadiene-based macromonomer (MM), 70.0 wt% of nBMA, 16.0 wt% of LMA, 2.0 wt% of SMA, 0.25 wt% of MMA and 0.25 wt% of styrene and having an average carbon number of 5.05,

Polymer C, consisting of 11.5 wt% of polybutadiene-based macromonomer (MM), 68.0 wt% of nBMA, 18.0 wt% of LMA, 2.0 wt% of SMA, 0.25 wt% of MMA and 0.25 wt% of styrene and having an average carbon number of 5.19;

Polymer D, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 74.6 wt% of nBMA, 11.7 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene and having an average carbon number of 4.64;

Polymer E, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.1 wt% of nBMA, 13.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene and having an average carbon number of 4.73;

Polymer F, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene and having an average carbon number of 4.84;

Polymer G, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 69.1 wt% of nBMA, 17.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene and having an average carbon number of 4.98;

Polymer H, consisting of 15.0 wt% of polybutadiene-based macromonomer (MM), 65.6 wt% of nBMA, 19.0 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene and having an average carbon number of 5.13;

Polymer I, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 74.8 wt% of nBMA, 12.8 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene and having an average carbon number of 4.70;

Polymer J, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.9 wt% of nBMA, 13.7 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene and having an average carbon number of 4.76; and

Polymer K, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene and having an average carbon number of 4.86;

wherein the alkyl (meth)acrylate copolymers have a weight-average molecular weight M_w of 200,000 g/mol to 800,000 g/mol; and

(B) 70 wt% to 80 wt% of a base oil having a KV100 of 3.6 mm^2/s to 5.6 mm^2/s, determined to ASTM D445,

wherein the viscosity index improver has a bulk viscosity at 40°C (BV40) of equal to or less than 3000 mm^2/s.

2. The viscosity index improver according to claim 1, wherein the polybutadiene-based macromonomer has a number-average molecular weight of 4,000 g/mol to 6,000 g/mol, preferably 4,500 g/mol to 5,000 g/mol.

3. The viscosity index improver according to claim 1 or 2, wherein the viscosity index improver has a bulk viscosity at 40°C (BV40) of equal to or less than 2000 mm^2/s.

4. The viscosity index improver according to claim 1, 2 or 3, wherein the base oil (B) is selected from the group consisting of API Group II oils, API Group III oils and mixtures thereof.

5. The viscosity index improver according to claim 1, 2, 3 or 4, wherein the base oil (B) has an aniline point of 105°C or higher, determined to ASTM D611.

6. The viscosity index improver according to claim 1, 2, 3, 4 or 5, wherein the base oil (B) has a Noack evaporation loss at 150°C for 12 hours of 0% to 10%, determined to CEC L-40B.

7. The viscosity index improver according to claim 1, 2, 3, 4, 5 or 6, wherein the polyalkyl(meth)acrylate copolymer (A) is selected from the group consisting of:

Polymer 1, consisting of 11.0 wt% of polybutadiene-based macromonomer (MM), 79.93 wt% of nBMA, 13.35 wt% of LMA, 0.25 wt% of MMA and 1.47 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 540,000 g/mol ± 20%, i.e. in the range of 432,000 g/mol to 648,000 g/mol;

Polymer 2, consisting of 11.0 wt% of polybutadiene-based macromonomer (MM), 79.93 wt% of nBMA, 13.35 wt% of LMA, 0.25 wt% of MMA and 1.47 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 499,000 g/mol ± 20%, i.e. in the range of 399,200 g/mol to 598,800 g/mol;

Polymer 3, consisting of 11.5 wt% of polybutadiene-based macromonomer (MM), 70.0 wt% of nBMA, 16.0 wt% of LMA, 2.0 wt% of SMA, 0.25 wt% of MMA and 0.255 wt% of styrene, having an average carbon number of 5.05 and a weight-average molecular weight Mw in the range of 579,000 g/mol ± 20%, i.e. in the range of 463,200 g/mol to 694,800 g/mol.

Polymer 4, consisting of 11.5 wt% of polybutadiene-based macromonomer (MM), 68.0 wt% of nBMA, 18.0 wt% of LMA, 2.0 wt% of SMA, 0.25 wt% of MMA and 0.25 wt% of styrene, having an average carbon number of 5.19 and a weight-average molecular weight Mw in the range of 655,000 g/mol ± 20%, i.e. in the range of 524,000 g/mol to 786,000 g/mol;

Polymer 5, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 74.6 wt% of nBMA, 11.7 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.64 and a weight-average molecular weight Mw in the range of 363,000 g/mol ± 20%, i.e. in the range of 290,400 g/mol to 435,600 g/mol;

Polymer 6, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.1 wt% of nBMA, 13.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 586,000 g/mol ± 20%, i.e. in the range of 468,800 g/mol to 681,600 g/mol;

Polymer 7, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.1 wt% of nBMA, 13.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 603,000 g/mol ± 20%, i.e. in the range of 482,400 g/mol to 723,600 g/mol;

Polymer 8, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.1 wt% of nBMA, 13.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 506,000 g/mol ± 20%, i.e. in the range of 404,800 g/mol to 607,200 g/mol;

Polymer 9, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.84 and a weight-average molecular weight Mw in the range of 644,000 g/mol ± 20%, i.e. in the range of 515,200 g/mol to 772,800 g/mol;

Polymer 10, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.84 and a weight-average molecular weight Mw in the range of 626,000 g/mol ± 20%, i.e. in the range of 500,800 g/mol to 751,200 g/mol;

Polymer 11, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.84 and a weight-average molecular weight Mw in the range of 510,000 g/mol ± 20%, i.e. in the range of 408,000 g/mol to 612,000 g/mol;

Polymer 12, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 69.1 wt% of nBMA, 17.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene, having an average carbon number of 4.98 and a weight-average molecular weight Mw in the range of 619,000 g/mol ± 20%, i.e. in the range of 495,200 g/mol to 742,800 g/mol;

Polymer 13, consisting of 15.0 wt% of polybutadiene-based macromonomer (MM), 65.6 wt% of nBMA, 19.0 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene, having an average carbon number of 5.13 and a weight-average molecular weight Mw in the range of 569,000 g/mol ± 20%, i.e. in the range of 455,200 g/mol to 682,800 g/mol;

Polymer 14, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 74.8 wt% of nBMA, 12.8 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene, having an average carbon number of 4.70 and a weight-average molecular weight Mw in the range of 528,000 g/mol ± 20%, i.e. in the range of 422,400 g/mol to 633,600 g/mol;

Polymer 15, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.9 wt% of nBMA, 13.7 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene, having an average carbon number of 4.76 and a weight-average molecular weight Mw in the range of 528,000 g/mol ± 20%, i.e. in the range of 422,400 g/mol to 633,600 g/mol; and

Polymer 16, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.86

and a weight-average molecular weight Mw in the range of 526,000 g/mol ± 20%, i.e. in the range of 420,800 g/mol to 631,200 g/mol.

8. Lubricating oil composition, comprising:

(A) 1 wt% to 4 wt% of a polyalkyl(meth)acrylate copolymer selected from the group consisting of:

Polymer A, consisting of 11.0 wt% of polybutadiene-based macromonomer (MM), 73.93 wt% of nBMA, 13.35 wt% of LMA, 0.25 wt% of MMA and 1.47 wt% of styrene and having an average carbon number of 4.73;

Polymer B, consisting of 11.5 wt% of polybutadiene-based macromonomer (MM), 70.0 wt% of nBMA, 16.0 wt% of LMA, 2.0 wt% of SMA, 0.25 wt% of MMA and 0.25 wt% of styrene and having an average carbon number of 5.05,

Polymer C, consisting of 11.5 wt% of polybutadiene-based macromonomer (MM), 68.0 wt% of nBMA, 18.0 wt% of LMA, 2.0 wt% of SMA, 0.25 wt% of MMA and 0.25 wt% of styrene and having an average carbon number of 5.19;

Polymer D, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 74.6 wt% of nBMA, 11.7 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene and having an average carbon number of 4.64;

Polymer E, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.1 wt% of nBMA, 13.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene and having an average carbon number of 4.73;

Polymer F, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene and having an average carbon number of 4.84;

Polymer G, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 69.1 wt% of nBMA, 17.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene and having an average carbon number of 4.98;

Polymer H, consisting of 15.0 wt% of polybutadiene-based macromonomer (MM), 65.6 wt% of nBMA, 19.0 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene and having an average carbon number of 5.13;

Polymer I, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 74.8 wt% of nBMA, 12.8 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene and having an average carbon number of 4.70;

Polymer J, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.9 wt% of nBMA, 13.7 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene and having an average carbon number of 4.76; and

Polymer K, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene and having an average carbon number of 4.86;

wherein the alkyl (meth)acrylate copolymers have a weight-average molecular weight M_w of 200,000 g/mol to 800,000 g/mol;

(B) 81 wt% to 99 wt% of a base oil; and

(C) 0 to 15 wt% of one or more further additives.

9. The lubricating oil composition according to claim 8, wherein the polyalkyl(meth)acrylate copolymer (A) is selected from the group consisting of:

Polymer 1, consisting of 11.0 wt% of polybutadiene-based macromonomer (MM), 79.93 wt% of nBMA, 13.35 wt% of LMA, 0.25 wt% of MMA and 1.47 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 540,000 g/mol ± 20%, i.e. in the range of 432,000 g/mol to 648,000 g/mol;

Polymer 2, consisting of 11.0 wt% of polybutadiene-based macromonomer (MM), 79.93 wt% of nBMA, 13.35 wt% of LMA, 0.25 wt% of MMA and 1.47 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 499,000 g/mol ± 20%, i.e. in the range of 399,200 g/mol to 598,800 g/mol;

Polymer 3, consisting of 11.5 wt% of polybutadiene-based macromonomer (MM), 70.0 wt% of nBMA, 16.0 wt% of LMA, 2.0 wt% of SMA, 0.25 wt% of MMA and 0.255 wt% of styrene, having an average carbon number of 5.05 and a weight-average molecular weight Mw in the range of 579,000 g/mol ± 20%, i.e. in the range of 463,200 g/mol to 694,800 g/mol.

Polymer 4, consisting of 11.5 wt% of polybutadiene-based macromonomer (MM), 68.0 wt% of nBMA, 18.0 wt% of LMA, 2.0 wt% of SMA, 0.25 wt% of MMA and 0.25 wt% of styrene, having an average carbon number of 5.19 and a weight-average molecular weight Mw in the range of 655,000 g/mol ± 20%, i.e. in the range of 524,000 g/mol to 786,000 g/mol;

Polymer 5, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 74.6 wt% of nBMA, 11.7 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.64 and a weight-average molecular weight Mw in the range of 363,000 g/mol ± 20%, i.e. in the range of 290,400 g/mol to 435,600 g/mol;

Polymer 6, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.1 wt% of nBMA, 13.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 586,000 g/mol ± 20%, i.e. in the range of 468,800 g/mol to 681,600 g/mol;

Polymer 7, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.1 wt% of nBMA, 13.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 603,000 g/mol ± 20%, i.e. in the range of 482,400 g/mol to 723,600 g/mol;

Polymer 8, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.1 wt% of nBMA, 13.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene, having an average carbon number of 4.73 and a weight-average molecular weight Mw in the range of 506,000 g/mol ± 20%, i.e. in the range of 404,800 g/mol to 607,200 g/mol;

Polymer 9, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.84 and a weight-average molecular weight Mw in the range of 644,000 g/mol ± 20%, i.e. in the range of 515,200 g/mol to 772,800 g/mol;

Polymer 10, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.84 and a weight-average molecular weight Mw in the range of 626,000 g/mol ± 20%, i.e. in the range of 500,800 g/mol to 751,200 g/mol;

Polymer 11, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.84 and a weight-average molecular weight Mw in the range of 510,000 g/mol ± 20%, i.e. in the range of 408,000 g/mol to 612,000 g/mol;

Polymer 12, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 69.1 wt% of nBMA, 17.2 wt% of LMA, 0.2 wt% of MMA and 1.5 wt% of styrene, having an average carbon number of 4.98 and a weight-average molecular weight Mw in the range of 619,000 g/mol ± 20%, i.e. in the range of 495,200 g/mol to 742,800 g/mol;

Polymer 13, consisting of 15.0 wt% of polybutadiene-based macromonomer (MM), 65.6 wt% of nBMA, 19.0 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene, having an average carbon number of 5.13 and a weight-average molecular weight Mw in the range of 569,000 g/mol ± 20%, i.e. in the range of 455,200 g/mol to 682,800 g/mol;

Polymer 14, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 74.8 wt% of nBMA, 12.8 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene, having an average carbon number of 4.70 and a weight-average molecular weight Mw in the range of 528,000 g/mol ± 20%, i.e. in the range of 422,400 g/mol to 633,600 g/mol;

Polymer 15, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 73.9 wt% of nBMA, 13.7 wt% of LMA, 0.2 wt% of MMA and 0.2 wt% of styrene, having an average carbon number of 4.76 and a weight-average molecular weight Mw in the range of 528,000 g/mol ± 20%, i.e. in the range of 422,400 g/mol to 633,600 g/mol; and

Polymer 16, consisting of 12.0 wt% of polybutadiene-based macromonomer (MM), 71.1 wt% of nBMA, 15.2 wt% of LMA, 0.25 wt% of MMA and 1.45 wt% of styrene, having an average carbon number of 4.86 and a weight-average molecular weight Mw in the range of 526,000 g/mol ± 20%, i.e. in the range of 420,800 g/mol to 631,200 g/mol.

10. The lubricating oil composition according to claim 8 or 9, wherein the base oil (B) is selected from the group consisting of API Group II oils, API Group III oils and mixtures thereof.

11. The lubricating oil composition according to claim 8, 9, 10 or 11, characterized in that component (C) is selected from the group consisting of conventional VI improvers, dispersants, defoamers, detergents, antioxidants, pour point depressants, antiwear additives, extreme pressure additives, friction modifiers, anticorrosion additives, dyes and mixtures thereof.