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REDUCED FRICTION LUBRICATING OILS
CONTAINING FUNCTIONALIZED CARBON NANOMATERIALS

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0001] The present invention relates to lubricating oils of reduced friction.

DESCRIPTION OF THE RELATED ART

[0002] Carbon nanotubes and fullerene materials are the subject of much current interest. Such materials are not soluble in aqueous, organic or hydrocarbon solvents so efforts have been made to functionalize them to render them soluble in one or more solvent categories.

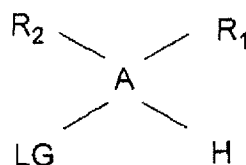
[0003] U.S. Patent 6,187,823 is directed to solubilizing single-walled carbon nanotubes by direct reaction with amines and alkylaryl amines having an uninterrupted carbon chain of at least 5 and preferably 9 carbon atoms in length. The single-walled carbon nanotubes are terminated with carboxylic acid groups, then the carboxylic acid groups are reacted with an amine such as nonylamine or octadecylamine or an alkylaryl amine such as 4-pentylaniline or 4-tetracontylaniline, in an appropriate solvent such as toluene, chlorobenzene, dichlorobenzene, dimethylformamide (DMF) heramethylphosphoramide, dimethylsulfoxide (DMSO) with heating at between 50 to 200°C.

[0004] U.S. Published Application U.S. 2003/0065206 is directed to derivatization and solubilization of insoluble classes of carbon nanomaterials which include fullerenes, including very high molecular weight fullerenic materials generated in fullerenic soot, giant fullerenes, fullerenic polymers, carbon nanotubes and metal-carbon nanoencapsulates. The method involves

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cyclopropanation of the exterior surface of the fullerene or carbon nanotubes. The derivatives formed are described as exhibiting increased solubility in solvents commonly employed, e.g., non-polar hydrocarbons and arene solvents. The cyclopropanation reaction can be performed on fullerenes or carbon nanotubes, the surfaces of which are devoid of any prior functionalization or on fullerenes or carbon nanotubes which have been previously functionalized yet remain insoluble in solvents. The process involves the cyclopropanation reaction as previously applied to soluble fullerenes by Bingel et al. which involves base-induced deprotonation of alpha halo substituted bis-malonates, see e.g. U.S. Patent 5,739,376. The nucleophilic carbanion adds to the fullerene or carbon nanotubes surface, making a new carbon-carbon bond, followed by elimination of the halide ion, completing the cyclopropanation and leaving a derivative group positioned 1, 2 across a carbon-carbon double bond of the fullerene or carbon nanotubes. The reaction is carried out in a heterogeneous mixture in a polar aprotic solvent, e.g. ether, tetrahydrofuran, 1,4-dioxane, dimethoxy-ethane or miscible mixtures thereof. The method is reported as being rapid, does not require heating and does not require the use of strongly coordinating and reactive bases such as amine DBU, but the use of sub-stoichiometric levels of soluble bases such as nitrogen bases and DBU in the presence of an excess quantity of a proton scavenger is also disclosed.

[0005] Various cyclopropanation reagents are described, including:



wherein A is a carbon or silicon atom;

LG is the leaving group which includes —Cl, —Br, —I, —OSO₂R

where R is an optionally substituted alkyl or aryl group;

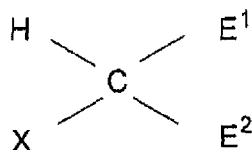
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R_1 and R_2 are independently selected from the group consisting of optionally-substituted alkyl, alkenyl, alkynyl or aryl groups, $-\text{COOR}_3$ groups, $-\text{O}-\text{CO}-\text{R}_3$ groups, $-\text{COR}_3$ groups, $-\text{CO}-\text{N R}_3\text{R}_4$ groups, $-\text{O}-\text{CO}-\text{N R}_3\text{R}_4$ groups, $-\text{CN}$, $-\text{PO}(\text{OR}_3)(\text{OR}_4)$ groups, and $-\text{SO}_2\text{R}_3$ groups wherein R_3 and R_4 are independently selected from hydrogen, an alkyl group, alkenyl group, alkynyl group or aryl group, any one of which may be optionally further substituted. Preferably R_1 and R_2 are both $-\text{COOR}_3$ groups.

[0006] At paragraph [0134] a sample of single-walled nanotubes was reacted under modified Bingel-type conditions with diethylbromomalonate. It is stated that the derivatization protocol works on single-walled nanotubes, multi-walled nanotubes, nanotubes of varied diameter and both natural length and chemically-shortened nanotubes.

[0007] Derivatization renders the derivatized species soluble in common non-polar solvents. Solubility is defined as the dissolution of free molecules (or salts) in the solvent with reversibility to remove the solvent to recover the dissolved molecules or salts. Non-polar solvents are identified as including non-polar organic solvents such as hydrocarbons, and arenes and halogenated arenes, including toluene and benzene.

[0008] U.S. Patent 5,739,376 is directed to fullerene derivatives, methods of preparing derivatized fullerenes and methods of using derivatized fullerenes. The fullerene is derivatized using materials of the formula:

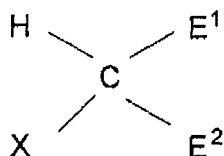


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wherein E^1 and E^2 are identical or different and are each COOH , COOR , CONRR' , CHO , COR , CN , $\text{P(O)(OR}_2\text{)}$ and SO_2R where R and R' are each a straight-chain or branched aliphatic radical (C_1 to C_{20}) which may be unsubstituted, monosubstituted or polysubstituted, and X is $-\text{Cl}$, $-\text{Br}$, $-\text{I}$, $-\text{OSR}_2\text{Ar}$, $-\text{OSO}_2\text{CF}_3$, $-\text{OSO}_2\text{C}_4\text{F}_9$.

[0009] The cyclopropanation reaction is carried out in a base such as alkali metal hydride, alkali metal hydroxide, alkoxide, amide, amine, guanidine at from -78 to 180°C .

[0010] The final product can be made directly by using a material:



wherein E^1 and E^2 are already in their final desired form or intermediate cyclopropanated fullerenes wherein E^1 and E^2 are esters can be saponified to give E^1 to E^2 as corresponding acids, or wherein E^1 and E^2 are alcohols which are reacted with an acid to give esters of the desired carbon number.

[0011] U.S. Published Application U.S. 2006/0210466 is directed to the production of functionalized nanotubes using microwave radiation. The nanotubes material is combined with the functionalizing reactant such as an acid, base, urea, alcohol, organic solvent, benzene, acetone or any other reactant that achieves the desired functionalization reaction, then the mixture is subjected to appropriate microwave conditions to affect the desired functionalization.

[0012] "Retention of Intrinsic Electronic Properties of Soluble Single-Walled Carbon Nanotubes after a Significant Degree of Sidewall Functionalization by the

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Bingel Reaction”, Tomohazu Umegama, et al., *J. Phys. Chem. C* 2007, 111, 9734-9741 reports single-walled carbon nanotubes functionalized at tips and defect sites with multiple alkyl-substituents and on sidewalls with phenyl-substituents to give sufficient solubility to the nanotube derivatives in organic solvents. Sidewall functionalization utilized the Bingel reaction. This article also reports the shortening of single-walled nanotubes using treatment with HCl and HNO₃ aqueous solutions, leaving shortened single-walled carbon nanotubes with carboxylic groups at the upper ends (or tips) and at surface defect sites. These can be reacted with amine materials to yield amide functionalized single-walled carbon nanotubes exhibiting improved dispersibility in common organic solvents such as chloroform, orthodichlorobenzene, tetrahydrofuran.

[0013] “Functionalization of Individual Ultra-Short Single-Walled Carbon Nanotubes”, Jared M. Ashcroft, et al., *Nanotechnology* 17 (2006), 5033-5037 reports the functionalization of 20-80 nm length single-walled carbon nanotubes via in-situ Bingel cyclopropanation. The single-walled carbon nanotubes are shortened via fluorination followed by pyrolysis which both shortens the nanotubes and creates sidewall defects through which various agents can be internally loaded. The shortened single-walled carbon nanotubes are functionalized via the Bingel reaction using a bromomalonate and sodium hydride (NaH) or the Bingel-Hersch reaction using CBr₄ and DBU.

[0014] “Modification of Multi-Walled Carbon Nanotubes with Fatty Acids and Their Tribological Properties as Lubricant Additives”, C. S. Chen, et al., *Carbon* 43 (2005), 1660-1666 teaches the treatment of multi-walled carbon nanotubes with a mixture of sulfuric acid and nitric acid to produce an oxidized material which was then boiled in HCl for two hours. The oxidized material was mechanically milled, then sonically mixed with stearic acid in deionized water to which was added sulfuric acid with additionally refluxing at 100°C for two hours. The reaction mixture was cooled, then extracted with chloroform. Ball milled

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oxidized multi-walled carbon nanotubes and ball-milled stearic acid modified oxidized multi-walled carbon nanotubes were dispersed in pure liquid paraffin through sonication and stirring. Friction and wear tests were performed. The liquid paraffin containing the stearic acid modified multi-walled nanotubes presented lower friction coefficient and wear loss than did the pure liquid paraffin or the liquid paraffin-containing just the ball milled oxidized multi-walled nanotubes. Wear loss and friction coefficient decreased with increasing mass rates of stearic acid to oxidized multi-walled nanotubes up to a mass ratio of 2. Beyond 2, the friction coefficient and wear loss increased.

[0015] “Functionalization of Single-Walled Carbon Nanotubes via the Bingel Reaction”, Karl S. Coleman, et al., J. Am. Chem. Soc. 2003, 125, 8722-8723 teaches the cyclopropanation of single-walled carbon nanotubes. Single-walled carbon nanotubes were annealed under vacuum at 1000°C for three hours to remove any carboxylic acid groups present on the surface. The decarboxylated single-walled carbon nanotubes were suspended in dry orthodichlorobenzene (ODCB) to which was added diethyl bromomalonate and 1,8-diazabicyclo[5.4.0]undecene (DBU). The mixture was reacted with stirring for two hours and a modified single-wall nanotubes material bearing $>C(COOEt)_2$ groups on the sidewall was isolated. This material was then either trans-esterified with 2-(methylthio) ethanol in diethyl ether and further contacted with a gold colloid to produce functionalized single-walled carbon nanotubes with gold attached to the functional group, or the material was trans-esterified with the sodium or lithium salt of 1H,1H,2H,2H-perfluoro decan-1-ol. These reactions resulted in the introduction of chemical markers into the single-walled carbon nanotubes to facilitate atomic force microscopy visualization and ^{19}F NMR and XPS spectroscopy for surface characterization.

DESCRIPTION OF THE INVENTION

[0016] The present invention is directed to a method for reducing the friction of lubricating oils by the addition to the lubricating oil of containing functionalized carbon nanomaterials in an amount wherein the functionalized carbon nanomaterials are just soluble in the lubricating oil and not dispersed solids.

[0017] Carbon nanostructure materials which are functionalized include, by way of example and not limitation, nanohorns, fullerenes, nanoanions, single-wall carbon nanotubes, multi-walled carbon nanotubes and nonocomposites which may or may not have had their surfaces decarboxylated. More particularly the functionalized carbon nanostructure materials are functionalized carbon nanotubes, preferably single-wall carbon nanotubes, more preferably short single-wall carbon nanotubes, and which have had their surfaces decarboxylated.

[0018] Fullerenes are cage-like carbon allotropes of the formula (C_{20+2m}) (where m is an integer). They contain twelve five-membered rings and also any number, but at least, two six-membered rings of carbon atoms. The most well known fullerene is the C60 fullerene, also commonly identified as "buckyball".

[0019] Of the numerous carbon nanostructure materials, carbon nanotubes have become the most interesting.

[0020] Carbon nanotubes can be single-walled or multi-walled materials.

[0021] Multi-walled carbon nanotubes consist of concentrically nested tube-like graphene structures with each successive concentric shell having a larger diameter than the next inner shell which it surrounds. Multi-walled carbon nanotubes can contain from two to multiple dozens of concentric tubes.

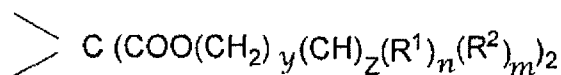
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[0022] Single-walled carbon nanotubes, as the name implies, consist of a single tubular carbon graphene structure, i.e. a single layer of carbon atoms. Single-walled carbon nanotubes, therefore, ideally comprise a single layer of hexagonal carbon rings (a graphene sheet) that has rolled up to form a seamless cylinder. Incomplete rollup nanotubes may also results in holes (defects) in the nanotubes.

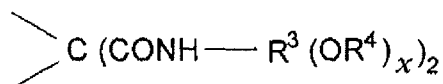
[0023] Such cylinders have diameters of anywhere from 0.05 to 2 micron, preferably 0.1 to 1 micron and lengths of many nanometers, even many centimeters, for an extremely high length to diameter ratio.

[0024] Preferably the carbon nanostructure material which is functionalized in the process of the present invention is a short single-walled carbon nanotube and which preferably has had its surface decarboxylated. The invention will be described hereinafter with reference to the non-limiting example of short single-walled carbon nanotubes.

[0025] The functionalized short single-walled carbon nanotubes are single-walled carbon nanotubes between 1 to 10, preferably 1 to 0.5, microns in length and 0.01 to 50 nanometers in diameter and bear at their edges and along the sidewall functional groups of the structure:



or



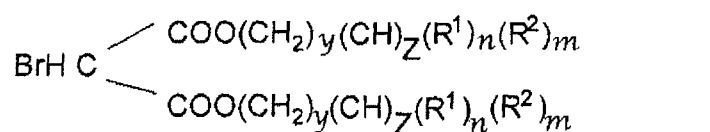
wherein R^1 and R^2 are the same or different and are selected from hydrogen or C_1 to C_{18} alkyl groups provided at least one of R^1 and R^2 is not hydrogen, preferably

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R^1 and R^2 in total amount to at least 14 carbons, y is 0 to 10, preferably 0 to 5, more preferably 1, Z is 0 or 1, preferably 1, n and m are integers ranging from 0 to 2 provided $n+m$ is at least 1, R^3 is a C_1 to C_{15} alkyl or C_6 to C_{10} aryl group, R^4 is a C_2 to C_{14} alkyl group, C_6 to C_{10} aryl, C_1 to C_{10} alkylaryl or C_1 to C_{10} arylalkyl group, and x is an integer ranging from 0 to up to the replaceable valance of the R^3 group, preferably 1 to 3.

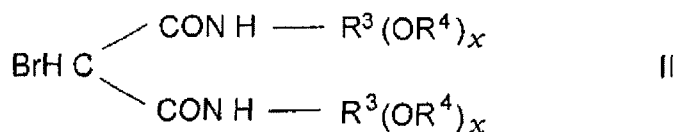
[0026] Short single-walled carbon nanotubes are secured either by starting with single-walled carbon nanotubes of the aforesaid length or, alternatively, long single-walled carbon nanotubes are shortened by oxidation using an aqueous solution of HNO_3 of 1 to 7 molar strength or a mixture of HCl and HNO_3 at a 3 to 1 volume ratio of concentrated HCl to concentrated HNO_3 or 3 to 1 volume ratio of concentrated H_2SO_4 and HNO_3 producing single-walled carbon nanotubes of reduced length but containing carboxylic groups along the edges and at surface sidewall defect sites. The short single-walled carbon nanotubes are subjected to annealing at high temperatures, to decarboxylate the short single-walled carbon nanotubes. Procedures to shorten long single-walled carbon nanotubes are known in the art; see for example Bull. Korean Chem. Society 2004, Vol. 25, No. 9, 1301-1302 and for decarboxylating carbon nanotubes; see for example JACS 2003, 125, 8722-8723.

[0027] The carbon nanostructure material, preferably decarboxylated short single-walled carbon nanotubes, are 100% carbon surface materials subjected to [2+1] cyclopropanation using:



or

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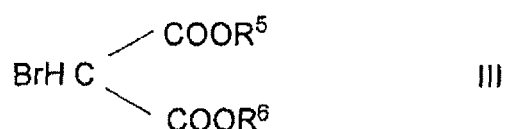


wherein R^1 , R^2 , R^3 , R^4 , y , Z , m , n and x are as previously defined wherein the carbon nanostructure material, preferably decarboxylated short-walled carbon nanotubes, is suspended in chlorinated benzene, preferably dry orthodichlorobenzene, and the materials of formula I or II and 1,8-diazabicyclo[5.4.0] undecene (DBU) are added to the suspended carbon nanostructure material in chlorinated benzene in multiple additions over time or dropwise over time to yield the desired functionalized carbon nanostructure material which is distinguished by having at least twice the level of substitution as compared to functionalized carbon nanostructure material made using the same materials of formula I or II and the DBU as are added in the multiple additions or dropwise but which are added all at once in a single addition, and even if the same total amount of such materials are added all at once in a single addition as is added in total in the multiple additions or dropwise. By multiple additions as used herein and in the appended claims is meant that the suspended carbon nanostructure material is mixed with quantities of materials of formula I or II and DBU at least twice, preferably at least three times, or more, over time with intervals between each addition sufficient for reaction to occur between the suspended carbon nanostructure material and the material of formula I or II in the presence of the DBU, such interval being at least six hours, preferably six hours to four days, more preferably twelve hours to four days. Alternatively, materials of formula I or II and the DBU can be added to the carbon nanostructure material dropwise over time, preferably over a period of at least two days, more preferably over a period of at least four days, with stirring at a drop rate of one drop every thirty seconds to thirty minutes, preferably one to ten minutes. The temperature is held at from 40 to 70°C, preferably 50 to 60°C, during each addition of the multiple addition or during the dropwise addition and for one to four days, preferably three days, following the final addition step practiced by the

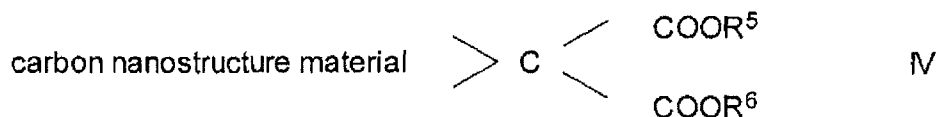
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practitioner, the choice between dropwise addition and multiple additions and of the number of additions or the duration of the dropwise additions being left to the discretion of the practitioner provided that if the multiple addition procedure is adopted, there are at least two additions of the materials of formula I or II in DBU to the carbon nanomaterial suspended in the chlorinated benzene.

[0028] In another embodiment, the carbon nanostructure material, preferably short single-wall carbon nanotube material, more preferably decarboxylated short single-wall carbon nanotube material, is suspended in chlorinated benzene and materials of formula III:

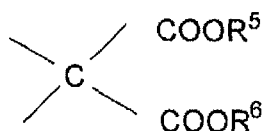


wherein R^5 and R^6 are the same or different, preferably the same, and are selected from methyl, ethyl or propyl groups, preferably methyl groups, and DBU are added to the suspended carbon nanostructure material in multiple additions over time or dropwise over time to yield an intermediate product of the formula:



The terms “multiple additions” and “dropwise” in this embodiment have the same meaning as previously recited except in this instance it is material III which is being added in the described manner. By so doing, the surface of the carbon nanostructure material, and in the case of the shortened single-walled carbon nanotubes, both the surface of the walls and the tips at the end of the tubes, are substituted with the

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in an amount at least twice the level of substitution obtained when the carbon nanostructure material is reacted with material of formula III and the DBU in a single addition.

[0029] The material of formula IV is then subjected to trans-esterification or trans-amidation using esterification or amidation agents of the type and formula which when reacted with the material of formula IV results in the production of a functionalized carbon nanostructure material being functional groups corresponding to the functional groups previously identified as (a) or (b), the transesterification or amidation reaction being conducted at a temperature in the range of from 0 to 65°C in an appropriate catalyst such as Group I alkali metal hydroxide in a chlorobenzene solvent such as ODCB.

[0030] The amount of esterification or amidation agent used is an amount sufficient to fully esterify or amide the material of formula IV. By fully esterify or amide is meant adding quantities of esterification or amidation reactants sufficient so that upon spectroscopic analysis of the product the addition of more of such reactant does not result in any change in the spectrum.

[0031] A wide range of lubricating base oils is known in the art. Lubricating base oils are both natural oils and synthetic oils. Natural and synthetic oils (or mixtures thereof) can be used unrefined, refined, or rerefined (the latter is also known as reclaimed or reprocessed oil). Unrefined oils are those obtained directly from a natural or synthetic source and used without added purification. These include shale oil obtained directly from retorting operations, petroleum oil obtained directly from primary distillation, and ester oil obtained directly from an esterification process. Refined oils are similar to the oils discussed for unrefined oils except refined oils are subjected to one or more purification steps to improve

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at least one lubricating property. One skilled in the art is familiar with many purification processes. These processes include solvent extraction, secondary distillation, acid extraction, base extraction, filtration and percolation. Rerefined oils are obtained by processes analogous to refined oils but using an oil that has been previously used.

[0032] Groups I, II, III, IV and V are broad categories of base oil stocks developed and defined by the American Petroleum Institute (API Publication 1509, www.API.org) to create guidelines for lubricant base oils. Group I base stocks generally have a viscosity index of between about 80 to 120 and contain greater than about 0.03% sulfur and/or less than about 90% saturates. Group II base stocks generally have a viscosity index of between about 80 to 120, and contain less than or equal to about 0.03% sulfur and greater than or equal to about 90% saturates. Group III stocks generally have a viscosity index greater than about 120 and contain less than or equal to about 0.03% sulfur and greater than about 90% saturates. Group IV includes polyalphaolefins (PAO). Group V base stock includes base stocks not included in Groups I-IV. The table below summarizes properties of each of these five groups.

	Base Oil Properties		
	Saturates	Sulfur	Viscosity Index
Group I	<90 and/or	>0.03% and	≥80 and <120
Group II	≥90 and	≤0.03% and	≥80 and <120
Group III	≥90 and	≤0.03% and	≥120
Group IV	Includes polyalphaolefins (PAO) and GTL products		
Group V	All other base oil stocks not included in Groups I, II, III or IV		

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[0033] Natural oils include animal oils, vegetable oils (castor oil and lard oil, for example), and mineral oils. Animal and vegetable oils possessing favorable thermal oxidative stability can be used. Of the natural oils, mineral oils are preferred. Mineral oils vary widely as to their crude source; for example, as to whether they are paraffinic, naphthenic or mixed paraffinic-naphthenic. Oils derived from coal or shale are also useful. Natural oils vary also as to the method used for their production and purification; for example, their distillation range and whether they are straight run or cracked, hydrotreated, or solvent extracted.

[0034] Group II and/or Group III hydroprocessed or hydrocracked base stocks, and synthetic oils such as polyalphaolefins, alkyl aromatics and synthetic esters are well known base stock oils.

[0035] Synthetic oils include hydrocarbon oil. Hydrocarbon oils include oils such as polymerized and interpolymers of olefins (polybutenes, polypropylenes, propylene isobutylene copolymers, ethylene-olefin copolymers, and ethylene-alphaolefin copolymers, for example). Polyalphaolefin (PAO) oil base stocks are a commonly used synthetic hydrocarbon oil. By way of example, PAOs derived from C₈, C₁₀, C₁₂, C₁₄ olefins or mixtures thereof may be utilized. See U.S. Patents 4,956,122; 4,827,064; and 4,827,073, which are incorporated herein by reference in their entirety.

[0036] The hydrocarbyl aromatics can be used as base oil or base oil component and can be any hydrocarbyl molecule that contains at least about 5% of its weight derived from an aromatic moiety such as a benzenoid moiety or naphthenoid moiety, or their derivatives. These hydrocarbyl aromatics include alkyl benzenes, alkyl naphthenes, alkyl diphenyl oxides, alkyl naphthols, alkyl diphenyl sulfides, alkylated bis-phenol A, alkylated thiodiphenol, and the like. The aromatics can be mono-alkylated, dialkylated, polyalkylated, and the like. The aromatics can be mono- or poly-functionalized. The hydrocarbyl groups can also be comprised of mixtures of alkyl groups, alkenyl groups, alkynyl, cycloalkyl

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groups, cycloalkenyl groups and other related hydrocarbyl groups. The hydrocarbyl groups can range from about C₆ up to about C₆₀ with a range of about C₈ to about C₄₀ often being preferred. A mixture of hydrocarbyl groups is often preferred. The hydrocarbyl group can optionally contain sulfur, oxygen, and/or nitrogen containing substituents. The aromatic group can also be derived from natural (petroleum) sources, provided at least about 5% of the molecule is comprised of an above-type aromatic moiety. Viscosities at 100°C of approximately 3 cSt to about 50 cSt are preferred, with viscosities of approximately 3.4 cSt to about 20 cSt often being more preferred for the hydrocarbyl aromatic component. In one embodiment, an alkyl naphthalene where the alkyl group is primarily comprised of 1-hexadecene is used. Other alkylates of aromatics can be advantageously used. Naphthalene or methyl naphthalene, for example, can be alkylated with olefins such as octene, decene, dodecene, tetradecene or higher, mixtures of similar olefins, and the like. Useful concentrations of hydrocarbyl aromatic in a lubricant oil composition can be about 2% to about 25%, preferably about 4% to about 20%, and more preferably about 4% to about 15%, depending on the application.

[0037] Esters comprise a useful base stock. Additive solvency and seal compatibility characteristics may be secured by the use of esters such as the esters of dibasic acids with monoalkanols and the polyol esters of monocarboxylic acids. Esters of the former type include, for example, the esters of dicarboxylic acids such as phthalic acid, succinic acid, sebacic acid, fumaric acid, adipic acid, linoleic acid dimer, malonic acid, alkyl malonic acid, alkenyl malonic acid, etc., with a variety of alcohols such as butyl alcohol, hexyl alcohol, dodecyl alcohol, 2-ethylene alcohol, etc. Specific examples of these types of esters include dibutyl adipate, di(2-ethylhexyl) sebacate, di-n-hexyl furmarate, dioctyl sebacate, diisooctyl azelate, diisodecyl azelate, dioctyl phthalate, didecyl phthalate, dieicosyl sebacate, etc.

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[0038] Particularly useful synthetic esters are those which are obtained by reacting one or more polyhydric alcohols, preferably the hindered polyols (such as the neopentyl polyols; e.g., neopentyl glycol, trimethylol ethane, 2-methyl-2-propyl-1,3-propanediol, trimethylol propane, pentaerythritol and dipentaerythritol) with alkanoic acids containing at least about four carbon atoms, preferably C₅ to C₃₀ acids such as saturated straight chain fatty acids including caprylic acid, capric acids, lauric acid, myristic acid, palmitic acid, stearic acid, arachic acid, and behenic acid, or the corresponding branched chain fatty acids or unsaturated fatty acids such as oleic acid, or mixtures of any of these materials.

[0039] Suitable synthetic ester components include the esters of trimethylol propane, trimethylol butane, trimethylol ethane, pentaerythritol and/or dipentaerythritol with one or more monocarboxylic acids containing from about 5 to about 10 carbon atoms. These esters are widely available commercially; for example, the Mobil P-41 and P-51 esters of ExxonMobil Chemical Company.

[0040] Non-conventional or unconventional base stocks and/or base oils include one or a mixture of base stock(s) and/or base oil(s) derived from: (1) one or more Gas-to-Liquids (GTL) materials, as well as; (2) hydrodewaxed, or hydroisomerized/cat (and/or solvent) dewaxed base stock(s) and/or base oil(s) derived from synthetic wax, natural wax or waxy feeds, mineral and/or non-mineral oil waxy feed stocks such as gas oils, slack waxes (derived from the solvent dewaxing of natural oils, mineral oils or synthetic; e.g., Fischer-Tropsch feed stocks), natural waxes, and waxy stocks such as gas oils, waxy fuels hydrocracker bottoms, waxy raffinate, hydrocrackate, thermal crackates, foots oil or other mineral, mineral oil, or even non-petroleum oil derived waxy materials such as waxy materials received from coal liquefaction or shale oil, linear or branched hydrocarbyl compounds with carbon number of about 20 or greater, preferably about 30 or greater and mixtures of such base stocks and/or base oils.

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[0041] GTL materials are materials that are derived via one or more synthesis, combination, transformation, rearrangement, and/or degradation/deconstructive processes from gaseous carbon-containing compounds, hydrogen-containing compounds and/or elements as feed stocks such as hydrogen, carbon dioxide, carbon monoxide, water, methane, ethane, ethylene, acetylene, propane, propylene, propyne, butane, butylenes, and butynes. GTL base stocks and/or base oils are GTL materials of lubricating viscosity that are generally derived from hydrocarbons; for example, waxy synthesized hydrocarbons, that are themselves derived from simpler gaseous carbon-containing compounds, hydrogen-containing compounds and/or elements as feed stocks. GTL base stock(s) and/or base oils include oils boiling in the lube oil boiling range (1) separated/fractionated from synthesized GTL materials such as, for example, by distillation and subsequently subjected to a final wax processing step which involves either or both of a catalytic dewaxing process, or a solvent dewaxing process, to produce lube oils of reduced/low pour point; (2) synthesized wax isomerates, comprising, for example, hydrodewaxed or hydroisomerized cat and/or solvent dewaxed synthesized wax or waxy hydrocarbons; (3) hydrodewaxed or hydroisomerized cat and/or solvent dewaxed Fischer-Tropsch (F-T) material (i.e., hydrocarbons, waxy hydrocarbons, waxes and possible analogous oxygenates); preferably hydrodewaxed or hydroisomerized/followed by cat and/or solvent dewaxing dewaxed F-T waxy hydrocarbons, or hydrodewaxed or hydroisomerized/followed by cat (or solvent) dewaxing dewaxed, F-T waxes, or mixtures thereof.

[0042] GTL base stock(s) and/or base oil(s) derived from GTL materials, especially hydrodewaxed or hydroisomerized/followed by cat and/or solvent dewaxed wax or waxy feed, preferably F-T material derived base stock(s) and/or base oil(s), are characterized typically as having kinematic viscosities at 100°C of from about 2 mm²/s to about 50 mm²/s (ASTM D445). They are further characterized typically as having pour points of -5°C to about -40°C or lower

(ASTM D97). They are also characterized typically as having viscosity indices of about 80 to about 140 or greater (ASTM D2270).

[0043] In addition, the GTL base stock(s) and/or base oil(s) are typically highly paraffinic (>90% saturates), and may contain mixtures of monocycloparaffins and multicycloparaffins in combination with non-cyclic isoparaffins. The ratio of the naphthenic (i.e., cycloparaffin) content in such combinations varies with the catalyst and temperature used. Further, GTL base stock(s) and/or base oil(s) typically have very low sulfur and nitrogen content, generally containing less than about 10 ppm, and more typically less than about 5 ppm of each of these elements. The sulfur and nitrogen content of GTL base stock(s) and/or base oil(s) obtained from F-T material, especially F-T wax, is essentially nil. In addition, the absence of phosphorus and aromatics make this material especially suitable for the formulation of low SAP products.

[0044] The term GTL base stock and/or base oil and/or wax isomerase base stock and/or base oil is to be understood as embracing individual fractions of such materials of wide viscosity range as recovered in the production process, mixtures of two or more of such fractions, as well as mixtures of one or two or more low viscosity fractions with one, two or more higher viscosity fractions to produce a blend wherein the blend exhibits a target kinematic viscosity.

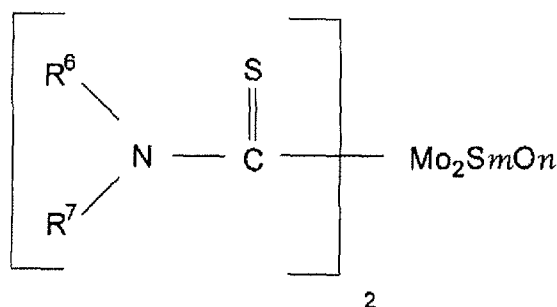
[0045] The functionalized carbon nanomaterials made according to the recited process are dissolved in the lubricating oil base stock and/or base oil, the functionalized carbon nanomaterials being added to the lubricating oil base stock or base oil, and the resulting mixture then being subjected to liquid/solid separation means such as filtration or centrifugation to remove any suspended functionalized carbon nanomaterial from the oil leaving only a lubricating oil containing functionalized carbon nanomaterial dissolved therein in an amount in the range 10 ppm to 10 wt%, preferably about 10 to 1000 ppm, more preferably about 50 to 250 ppm.

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[0046] The difference between solubility/dissolution and dispersion is a well known concept in chemistry and physics. Dispersion is the diffusion (suspension) of solid material in solvents without any chemical or physical interaction with the solvent and the solid material may remain suspended or become deposited or settle out over time. Solubility/dissolution of a material in a solvent occurs when that material's molecules and the solvent molecules exhibit intermolecular forces of attraction that holds these molecules together.

[0047] The lubricating oil of reduced friction comprising the lubricating oil base stock/base oil and functionalized carbon nanomaterials dissolved therein made using the multiaddition or dropwise addition technique which exhibits a higher degree of substitution than comparable materials made via the single addition technique recited in the prior art, may further contain an additive amount of an organomolybdenum component, e.g. molybdenum dithiocarbamate (Moly DTC) or molybdenum dithiophosphate (Moly DTP) or other organic molybdenum compounds, including trinuclear molybdenum DTC or DTP or an organomolybdenum-nitrogen complex component. Such organomolybdenum component or organomolybdenum-nitrogen complex component can be present in the lubricating oil in an amount sufficient to contribute from about 10 to 600 ppm, preferably about 50 to 400 ppm molybdenum to the lubricating oil.

[0048] Molybdenum dithiocarbamates (Moly DTC) are materials generally of the formula:



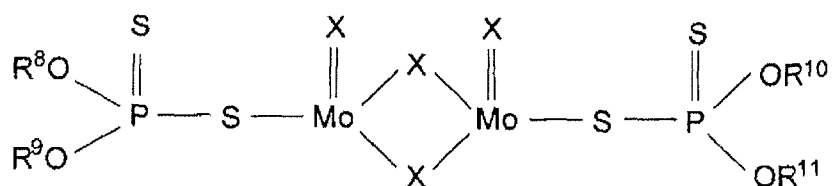
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wherein R^6 and R^7 are independently a hydrocarbon group with 8 to 18 carbon atoms and may or may not be the same, m and n are a positive integer provided that $m+n=4$.

[0049] Examples of the hydrocarbon group having 8 to 18 carbon atoms, represented by R^6 and R^7 in the general formula include hydrocarbon groups such as an alkyl group having 8 to 18 carbon atoms, an alkenyl group having 8 to 18 carbon atoms, a cycloalkyl group having 8 to 18 carbon atoms, an aryl group having 8 to 18 carbon atoms, an alkylaryl group and an arylalkyl group. The above alkyl and alkenyl groups may be linear or branched. In the lubricating oil composition of the present invention, it is particularly preferable that the hydrocarbon group represented by R^6 and R^7 have 8 carbon atoms.

[0050] Specific examples of the hydrocarbon group represented by R^6 and R^7 include octyl, nonyl, decyl, undecyl, dodecyl, tridecyl, octenyl, noneyl, decenyl, undecenyl, dodecenyl, tridecenyl, tetradecenyl, hexadecenyl, octadecenyl, dimethylcyclohexyl, ethylcyclohexyl, methylcyclohexylmethyl, cyclohexylethyl, propylcyclohexyl, butylcyclohexyl, heptylcyclohexyl, dimethylphenyl, methylbenzyl, phenethyl, naphthyl and dimethylnaphthyl groups.

[0051] Molybdenum dithiophosphates (Moly DTP) are materials generally of the formula:



wherein R^8 , R^9 , R^{10} and R^{11} are the same or different hydrocarbyl groups containing 8 to 18 carbon atoms, X is oxygen or sulfur, preferably R^8 to R^{11} are C_8 to C_{18} alkyl, alkenyl, cycloalkyl, aryl, alkylaryl, aralkyl, more preferably alkyl, most preferably C_8 to C_{10} alkyl.

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[0052] The term “organo molybdenum-nitrogen complexes” as used in the text and appended claims to define certain molybdenum complexes useful in the present invention embrace the organo molybdenum-nitrogen complexes described in U.S. Patent 4,889,647. The complexes are reaction products of a fatty oil, diethanolamine and a molybdenum source. Specific chemical structures have not been assigned to the complexes. U.S. Patent 4,889,647 reports an infrared spectrum for a typical reaction product of that invention; the spectrum identifies an ester carbonyl band at 1740 cm^{-1} and an amide carbonyl band at 1620 cm^{-1} . The fatty oils are glyceryl esters of higher fatty acids containing at least 12 carbon atoms up to 22 carbon atoms or more. The molybdenum source is an oxygen-containing compound such as ammonium molybdates, molybdenum oxides and mixtures.

[0053] Other organo molybdenum complexes which can be used in the present invention are tri-nuclear and molybdenum-sulfur compounds described in EP 1 040 115 and WO 99/31113 and the molybdenum complexes described in U.S. Patent 4,978,464.

[0054] The reduced friction lubricating oils containing the functionalized carbon nanomaterials may also contain additive amounts of other lubricating oil performance enhancing additives such as detergents, dispersants, metal deactivators, pour point depressants, anti-oxidants, corrosion inhibitors, viscosity index improvers, viscosity modifiers, anti-wear/extreme pressure additives, soot compatibility agents, anti-foam agents, inhibitors, anti-rust additives, etc., all materials already well known in the art to the practitioner and documented in “Lubricants and Related Products” by Klamann, Verlag Chemie, Deerfield Beach, FL ISBN 0-89573-177-0, “Lubricant Additives” by M. W. Ranney, Nokes Data Corporation, Parkridge, NJ (1978) and “Lubricant Additives”, C. V. Smallheer and R. K. Smith, Legiers Helen Company, Cleveland, OH (1967).

Example

[0055] In the following example, the reactants were either acquired from a commercial source or prepared as follows:

[0056] A) Carbon nanotubes (CNTs) were obtained from Shenzhen Nanotech Port Co., Ltd. (L-SWNT, diameter < 2 nm, length 5-15 μm , 50% SWCNT, 40% MWCNT, <5% amorphous carbon). The CNTs were oxidatively shortened and purified as well as thermally decarboxylated prior to being functionalized. (a) Shortening of CNT: Shortening of CNTs increase the solubility of such material. CNTs (1 g) were suspended in three M $\text{HNO}_{3,\text{aq}}$ (50 mL), sonicated for 5 minutes at room temperature, and then refluxed for 60 hours. The CNTs were filtered off (PTFE membrane filter, 0.45 μm) and washed with deionized water to give shortened CNTs substituted at the tip and surface of this sidewall with carboxylic acid groups. Heating of the oxidized CNTs at 450°C in a flow of dry N_2 for 3-4 hours quantitatively removes all carboxylic acid groups. This procedure shortened/cut the carbon nanotube from 5-15 microns to 300-500 nanometer. These shortened carbon nanotubes were characterized as follows:

[0057] B) High Resolution Transmission Electron Microscopy (HR-TEM) was performed on a JEOL 2010F FEG TEM/STEM at 200 kV. Dilute solutions of CNTs in THF were dropped onto a carbon-coated copper grid and the solvent was allowed to evaporate. Thermal gravimetric analysis with mass spectrometric detection of evolved gases was conducted on a Mettler Toledo TGA SDTA 851e that was attached to a Pfeiffer Vacuum ThermoStar™ mass spectrometer (1-300 amu) via a thin glass capillary. Helium (99.99%) was used to purge the system with a flow rate of 60 mL/min. Samples were held at 25°C for 30 minutes before being heated to 1000°C or 550°C at rates of 2°C/min or 5°C/min. A mass range between 14 m/z and 300 m/z was constantly scanned. UV-VIS spectra of solutions in different solvents were recorded on a Varian Cary 50. FT-IR measurements were performed on a Bruker Vector 22. Powder X-Ray Diffraction

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(XRD) measurements were run on a Bruker D8 Discover diffractometer equipped with a GADDS 2D-detector and operated at 40 kV and 40 mA. CuK α 1 radiation ($\lambda = 1.54187 \text{ \AA}$) was used and the initial beam diameter was 0.5 mm. Spectra were evaluated in EVA and plotted with Origin. Raman spectras were recorded on a Renshaw inVia Raman Spectroscopy instrument at an excitation wavelength of 633 nm and 50% power.

[0058] C) Malonate esters used to functionalize the short single-walled carbon nanotubes were either acquired from a commercial source and used without purification or were synthesized as follows:

[0059] C-1 – Synthesis of dihexadecyl malonate: H₂SO₄ (conc) (0.1 mL, 0.0036 mol%) was slowly added to a mixture of dimethyl malonate (2 g, 0.015 mol) and hexadecanol (15 mL, 0.061 mol) and the mixture was heated at reflux until all dimethyl malonate was converted according to TLC (approximately 4 days). The product mixture was dissolved in dichloromethane (DCM), extracted with water (3 times) and dried over MgSO₄. An analytically pure sample was obtained by column chromatography on silica gel using a 1:9 mixture of ethylacetate/hexane. Yield: 5.5 g (65.7%), see JP 57067510.

[0060] C-2 – Synthesis of 2-bromo dihexadecyl malonate: *p*-Toluene sulfonic acid monohydrate (1.03 g, 0.0054 mol) and N-bromosuccinimide (0.64 g, 0.0035 mol) were slowly added to a stirred solution of dihexadecyl malonate (2 g, 0.0036 mol) in CH₃CN (20 mL). The resulting mixture was heated at reflux for 2 hours, evaporated and dissolved in dichloromethane. The organic layer was washed with H₂O, dried over MgSO₄, and concentrated. An analytically pure sample was obtained by column chromatography on silica gel using a 1:4 mixture of ethylacetate/hexane. Yield: 1.8 g, 78.9%.

[0061] See: Menger, F. M.; Johnston, D. E., Jr., Specific enzyme-induced decapsulation. *Journal of the American Chemical Society* (1991), 113(14), 5467-8.

[0062] C-3 – Synthesis of bis(2-hexyldecyl malonate): H_2SO_4 (conc) (0.1 mL, 0.0036 mol) was slowly added to a mixture of dimethyl malonate (3 g, 0.022 mol) and 2-hexyl-1-decanol (19.7 mL, 0.068 mol) and the mixture was heated at reflux until all dimethyl malonate was converted according to TLC (approximately 6 days). The product mixture was dissolved in dichloromethane (DCM), extracted with water (3 times) and dried over MgSO_4 . An analytically pure sample was obtained by column chromatography on silica gel using a 1.5:8.5 mixture of ethylacetate/hexane. Yield: 8.1 g (64.5%).

[0063] C-4 – Synthesis of bis(2-hexyldecyl)-2-bromomalonate: *p*-Toluene sulfonic acid monohydrate (2.80 g, 0.014 mol) and *N*-bromosuccinimide (1.74 g, 0.009 mol) were slowly added to a stirred solution of bis(2-hexadecyl malonate) (5.4 g, 0.009 mol) in CH_3CH (30 mL). The resulting mixture was heated at reflux for 2 hours, evaporated and dissolved in dichloromethane. The organic layer was washed with H_2O , dried over MgSO_4 and concentrated. An analytically pure sample was obtained by column chromatography on silica gel using a 1:4 mixture of ethylacetate/hexane. Yield: 4.3 g (70.5%).

[0064] C-5 – Synthesis of dimethyl-2-bromomalonate: *p*-Toluene sulfonic acid monohydrate (11.0 g, 0.057 mol) and *N*-bromosuccinimide (1.74 g, 0.009 mol) were slowly added to a stirred solution of dimethyl malonate (5.0 g, 0.037 mol) in CH_3CH (30 mL). The resulting mixture was heated at reflux for 2 hours, evaporated and dissolved in dichloromethane. The organic layer was washed with H_2O , dried over MgSO_4 and concentrated. An analytically pure sample was obtained by column chromatography on silica gel using a 1:4 mixture of ethylacetate/hexane. Yield: 6.0 g (76.0%).

[0065] See: (1) Wolfe, Saul; Ro, Stephen; Kim, Chan-Kyung; Shi, Zheng, Canadian Journal of Chemistry (2001), 79(8), 1238-1258; (2) Matsumoto, Kiyoshi; Uchida, Takane; Yagi, Yoshiko; Tahara, Hiroshi; Acheson, R. Morrin, Heterocycles (1985), 23(8), 2041-3.

Examples

[0066] I. Preparation of $\text{CNT}>\text{C}(\text{COOC}_{16}\text{H}_{33})_2$ (CNT-16): Shortened and decarboxylated CNT compound (150 mg) was suspended in 50 mL of dry ortho-dichlorobenzene (*o*-DCB) by sonication (5 minutes). 2-Bromo dihexadecyl malonate (0.95 g, 1.5 mmol) and 1,8-diazabicyclo[5.4.0]undecene (DBU) (0.45 g, 3.0 mmol) were added and the mixture was allowed to react in a sonicator at 60°C. Three days after the initial batch of reactants was combined, additional amounts of 2-bromo dihexadecyl malonate (0.95 g, 1.5 mmol) and 1,8-diazabicyclo[5.4.0]undecene (DBU) (0.45 g, 3.0 mmol) were added with the reaction being run for a total of 9 days. The reaction mixture was cooled to about 25°C and filtered through a 0.45 μm PTFE filter. A small amount of CNT compound passed through this membrane filter and was collected by twice filtering the filtrate through a 0.1 μm VCTP membrane filter. The filter residue was washed with ethanol until the filtrate became clear to give 29 mg of CNT compound after drying in vacuum ($<10^{-2}$ mbar) for 6 hours. The first filter residue (0.45 μm PTFE filter) was suspended in ethanol and collected by centrifugation. This process was repeated 5 times to remove all organic contaminants. Finally, the obtained CNT compound was suspended in dichloromethane, sonication and heating was avoided, filtered off by passing the mixture through a 0.45 μm filter and dried in vacuum ($<10^{-2}$ mbar) for 6 hours. Yield 95 mg. IR (KBr, cm^{-1}): 1740 (C=O), 2923 2959 (CH₂). Raman (LL=633, P = 50%, cm^{-1}): 1334, 1587, 2625. Estimated number of ligands based on TGA is 1 per 22 carbon atoms of CNT.

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[0067] II. Preparation of CNT>C[(COOCH₂CH(C₆H₁₃)(C₈H₁₇))₂ (CNT-6,10):
Shortened and decarboxylated CNT compound (50 mg) was suspended in 20 mL of dry ortho-dichlorobenzene (*o*-DCB) by sonication (5 minutes). Bis(2-hexyldecyl) 2-bromomalonate (0.64 g, 1.0 mmol) and 1,8-diazabicyclo[5.4.0]undecene (DBU) (0.31 g, 2.0 mmol) were added and the mixture was allowed to react in a sonicator at 60°C. Additional amounts of di(2-hexyldecyl) 2-bromomalonate (0.64 g, 1.0 mmol) and 1,8-diazabicyclo[5.4.0]undecene (DBU) (0.31 g, 2.0 mmol) were added after 3 and 6 days of reaction with the reaction being run for a total of 9 days. The reaction mixture was cooled to about 25°C and filtered through a 0.45 µm PTFE filter. A small amount of CNT compound passed through this membrane filter. The filter residue was washed with ethanol until the filtrate became clear to give 7 mg of CNT compound after drying in vacuum (<10⁻² mbar) for 6 hours.

[0068] The first filter residue (0.45 µm PTFE filter) was suspended in ethanol and collected by centrifugation. This process was repeated 5 times to remove all organic contaminants. Finally, the obtained CNT compound was suspended in DCM, sonication and heating was avoided, filtered off by passing the mixture through a 0.45 µm filter and dried in vacuum (<10⁻² mbar) for 6 hours. Yield: 63 mg. IR (KBr, cm⁻¹): 1744 (C=O), 2920, 2850 (CH₂). Raman (LL=633, P=50%, cm⁻¹): 1330, 1591, 2617. Estimated number of ligands based on TGA is 1 per 480 C-atoms of CNT.

[0069] III. Synthesis of CNT>C[CONH-Ph(OC₁₂)₃]₂ (CNT-NPhC₁₂):
Shortened and decarboxylated CNT compound (80 mg) was suspended in 20 mL of dry ortho-dichlorobenzene (*o*-DCB) by sonication (5 minutes). Dimethyl-2-bromomalonate (0.32 g, 1.5 mmol) and 1,8-diazabicyclo[5.4.0] undecene (DBU) (0.46 g, 3.0 mmole) were added and the mixture was allowed to react in a sonicator at 60°C. Additional amounts of dimethyl-2-bromomalonate (0.32 g, 1.5 mmol) and 1,8-diazabicyclo[5.4.0] undecene (DBU) (0.46 g, 3.0 mmol) were

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added after 3 days of the 5 day reaction period. At the end of this period, 3,4,5-tris(dodecyloxy)aniline (2.6 g, 4 mmol) was gradually added to the reaction mixture over 5 days and the mixture was sonicated at 60°C for another 5 days. The reaction mixture was cooled to 25°C and filtered through a 0.46 µm PTFE filter. No CNT compound passed through this membrane filter because larger aggregates than for the previous CNT compounds were formed. The filter residue was suspended in ethanol and collected by centrifugation. This process was repeated 5 times to remove all organic contaminants. Finally, the obtained CNT compound was suspended in DCM, sonication and heating was avoided, filtered off by passing the mixture through a 0.45 µm filter and dried in a vacuum ($<10^{-2}$ mbar) for 6 hours. Yield: 131 mg. IR (KBr, cm^{-1}): 1745 (CONH, 2921, 2851 (CH_2), 3441 (NH). Raman (LL=633, P=50%, cm^{-1}): 1334, 1590, 2631. Estimated number of ligands based on TGA is 1 per 900 C-atoms of CNT.

[0070] The solubilities of the CNT-16 and CNT-6,10 materials in different solvents was investigated. Solubility is difficult to define for CNT materials because of their large size and strong van-de-Waals interactions (aggregation). All solubility measurements reported here are based on UV/VIS adsorption measurements of saturated solutions based on a calibration curve obtained in toluene solution.

[0071] For comparison purposes two additional batches of CNT-6,10 materials were made but not employing the multiple addition technique outlined in Example II.

[0072] In Comparison I the shortened and decarboxylated CNT compound (50 mg) was suspended in 200 ml of dry orthodichlorobenzene (*o*-DCB) by sonication (5 minutes). Bis-(2 hexyldecyl) 2-bromomalonate (0.64 g, 1.0 mmol) and 1,8-diazabicyclo[5.4.0] undecene (DBU) (0.31 g, 2.0 mmol) were added once and the mixture was allowed to react in a sonicator at 60°C for 4 days.

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[0073] In Comparison II the shortened and decarboxylated CNT compound (50 mg) was suspended in 20 ml of dry ortho-dichlorobenzene (*o*-DCB) by sonication (5 minutes). Bis-(2 hexyldecyl) 2-bromomalonate (1.28 g, 2 mmol) and 1,8-diazabicyclo [5.4.0] undecene (DBU) (0.62 g, 4.0 mmol) were added once and the mixture was allowed to react in a sonicator 60°C for 4 days.

[0074] In both Comparison I and Comparison II, the product purification technique recited in Example II was employed.

[0075] Adsorbance values (at a recited wavelength) of CNTs in different solvents at room temperature after centrifugation to remove suspended solids is reported in Table 1. The values in parentheses are the calculated concentration of the solutions in mg of CNT/dm³ of solvent.

[0076] In regard to CNT-NPhC₁₂, excess CNT-NPhC₁₂ was suspended and dissolved in DCM by sonication at 45°C for 30 minutes. The absorption of this solution/suspension was monitored for 4 days and a constant value was obtained after 1 day (55% of the original absorption obtained 5 minutes after sonication). Centrifugation (1200 g) of a freshly sonicated solution for 20 minutes resulted in the same absorption as a solution that settled for 1 day while filtration of a freshly sonicated solution through a 0.45 micron filter gave a 10% larger absorbance value. Identical results were obtained in toluene solution. In Table 1 below the absorbance reported is for the freshly sonicated/centrifuged material.

[0077] These molecules have different extinct coefficients, and therefore absorb and emit light with different energies depending on their structures. Calculated concentration in this case was arrived at by measuring the absorption at the appropriate wave length, determining the extinction coefficient from the spectra, and then plot it against the reference graph. It is a standard procedure known as the Beer-Lambert law which relates the absorbance of UV/Vis light, the

concentration of the sample, the length of the light path, and the molar absorptivity.

Table 1

Solvent	CNT-16 (Example I)	CNT-6,10 (Example II)	CNT-6,10 Comparison I	CNT-6,10 Comparison II	CNT-NPhC ₁₂ (Example III)
THF (350 nm)	0.787 (40.36)	0.381 (19.54)			
CHCl ₃ (350 nm)	1.585 (81.28)	1.212 (62.15)	0.634 (29.72)	0.630 (29.58)	1.7363 (89.03)
DCM (350 nm)	n.a.	n.a.			
Toluene (350 nm)	0.346 (17.74)	0.516 (26.46)			
Hexane (350 nm)	0.043 (2.21)	0.110 (5.64)			0.2553 (15.68)
Special Oil (400 nm)	0.098 (5.76)	0.158 (9.29)			0.8725 (8.80)
5W-30 (400 nm)	0.866 (50.94)	0.349 (20.53)			0.9300 (7.88)

[0078] Solubility of the CNT precursor, the decarboxylate short single-walled carbon nanotube before the functionalization reaction, in chloroform is 1.07 mg/dm³. Consequently, the functionalization reaction increased their solubility by a factor of up to 89 as read directly from the calibration curve or by a factor of 76 based on direct calibration from peak intensity.

[0079] As can be seen by considering CNT-6,10 product of Example II versus the CNT-6,10 product of Comparison I and Comparison II, functionalization employing a single addition step (Comparison I) and regardless of whether it employs in that single addition step a double amount of reactant (Comparison II), the products exhibit an adsorption of 0.634 and 0.630, respectively, while CNT-6,10 made using multiple additions of the malonate/DBU reactants exhibits an adsorption of 1.212, double the value, indicative of an at least doubling of the level of substitution achieved by the multiple addition process versus the single addition process exemplary of the techniques used in the prior art.

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High Frequency Rig Studies

[0080] Functionalized CNT showed reduced friction in GTL and formulated oil relative to Moly trimer, especially at high temperature of the test procedure.

[0081] The HFRR is a standard high frequency friction rig test ASTM (D6079). HFRR conditions used: 2°C/minute for 75 minutes, temperature range 30 to 180°C.

Nanotube Friction Modifiers

Time, min	GTL	GTL+0.2 wt% Moly	GTL + 100 ppm CNT-NPhC ₁₂	0W40 Max Visom with Moly	0W40 Max. Visom w/o Moly	0W40 Max. Visom ¹ w/o Moly+100 ppm CNT-NPhC ₁₂
Friction						
0	0.081	0.074	0.064	0.072	0.082	0.074
20	0.090	0.085	0.082	0.083	0.086	0.082*
40	0.079	0.051	0.085	0.079	0.085	0.081*
60	0.114	0.042	0.050	0.069	0.115	0.050
80	0.120	0.044	0.050	0.044	0.124	0.050
100	0.120	0.057	0.050	0.050	0.123	0.046
120	0.120	0.068	0.038	0.061	0.127	0.038
135	0.120	0.072	0.034	0.069	0.129	0.031
* The value reported is likely a tribological effect. It is also so small that it is within the experimental error of this instrument.						
¹ A lubricating oil base stock made by hydroisomerizing a slack wax secured from a petroleum source.						

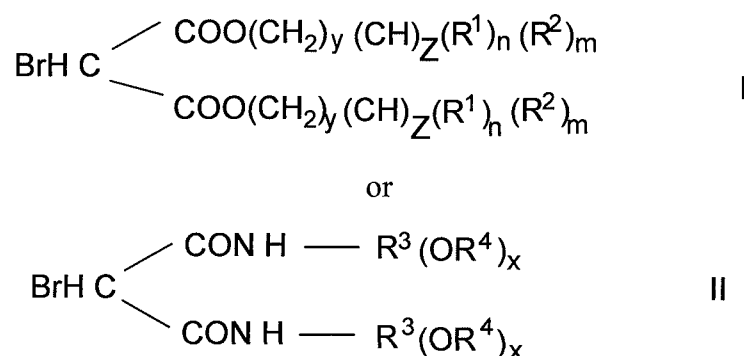
[0082] As can be seen, the presence of a solution amount of as little as 100 ppm CNT-NPhC₁₂ in the lubricating oil (GTL or a Visom-based 0W40 oil (absent moly) resulted in the long term reduction of friction as compared to GTL per se or GTL containing as much as 0.2 wt% molydendum, as well as compared to a Visom-based 0W40 oil with or without moly. The data beginning at 100 minutes

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is the most significant showing that at high temperature (180°C) and for the long term for lubricating oils containing very low levels of the functionalized carbon nanostructure materials, low concentrations of such materials dissolved in the lubricating oil as compared to being suspended or dispersed in the lubricating oil, the friction is reduced to a level about four times lower than for the oil alone and at least about two times lower than for the oil containing a conventional friction modifier. This friction reduction at higher temperatures and for an extended period of time is essential for fuel economy retention.

CLAIMS:

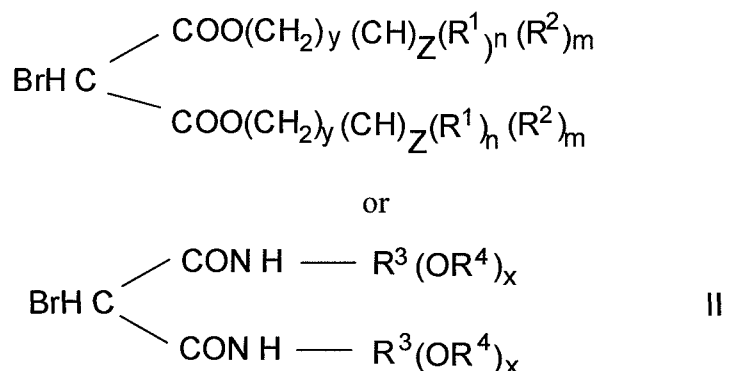
1. A method for reducing the friction of a lubricating oil comprising a base stock or base oil by dissolving in the base stock or base oil from 10 ppm to 10 wt% of a functionalized carbon nanostructure material which functionalized carbon nanostructure material is made by a process comprising: (1) suspending a carbon nanostructure material in a chlorinated benzene solvent; and (2) adding to the suspension of (1), in at least 2 additions over a reaction time ranging from 2 days to 4 days between each addition, materials of the formula:



wherein R^1 and R^2 are the same or different hydrogen or C_1 to C_{18} alkyl groups provided at least one of R^1 and R^2 is not hydrogen, y is 0 to 10, Z is 0 or 1, n and m are integers ranging from 0 to 2 provided $n+m$ is at least 1, R^3 is a C_1 to C_{15} alkyl or C_6 to C_{10} aryl group, R^4 is a C_2 to C_{14} alkyl group, C_6 to C_{10} aryl, C_1 to C_{10} alkylaryl or C_1 to C_{10} arylalkyl group, and x is an integer ranging from 0 up to the replaceable valence of the R^3 group, and 1,8-diazabicyclo[5.4.0] undecene (DBU), wherein the resulting functionalized carbon nanostructure material has at least twice the level of functionalization as compared to functionalized carbon nanostructure material made using the same carbon nanostructure material and material of formula I or II and DBU when the materials of formula I or II and DBU are added to the carbon nanostructure material all at once in a single addition.

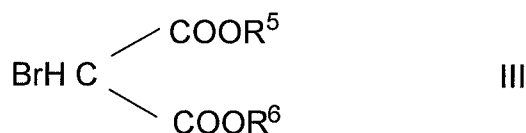
2. A method for reducing the friction of a lubricating oil comprising a base stock or base oil by dissolving in the base stock or base oil from 10 ppm to 10 wt% of a functionalized carbon nanostructure material which functionalized carbon nanostructure material is made by a process comprising: (1) suspending a carbon

nanostructure material in a chlorinated benzene solvent; and (2) adding to the suspension of (1), dropwise over a reaction time ranging from 2 days to 4 days at a rate of one drop every thirty seconds to thirty minutes, material of the formula:

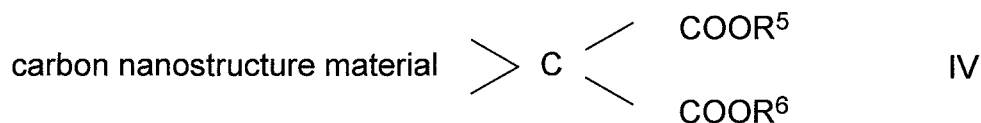


wherein R^1 and R^2 are the same or different hydrogen or C_1 to C_{18} alkyl groups provided at least one of R^1 and R^2 is not hydrogen, y is 0 to 10, Z is 0 or 1, n and m are integers ranging from 0 to 2 provided $n+m$ is at least 1, R^3 is a C_1 to C_{15} alkyl or C_6 to C_{10} aryl group, R^4 is a C_2 to C_{14} alkyl group, C_6 to C_{10} aryl, C_1 to C_{10} alkylaryl or C_1 to C_{10} arylalkyl group, and x is an integer ranging from 0 to up to the replaceable valence of the R^3 group, and 1,8-diazabicyclo[5.4.0] undecene (DBU), wherein the resulting functionalized carbon nanostructure material has at least twice the level of functionalization as compared to functionalized carbon nanostructure material made using the same carbon nanostructure material and material of formula I or II and DBU when the materials of formula I or II and DBU are added to the carbon nanostructure material all at once in a single addition.

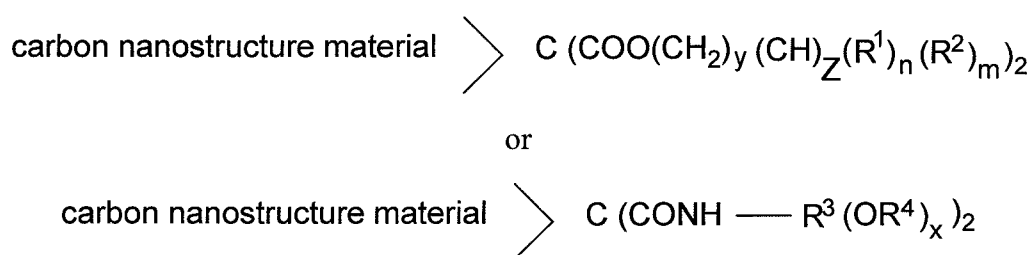
3. A method of reducing the friction of a lubricating oil comprising a base stock or base oil by dissolving in the base stock or base oil from 10 ppm to 10 wt% of a functionalized carbon nanostructure material which functionalized carbon nanostructure material is made by a process comprising: (1) suspending a carbon nanostructure material in a chlorinated benzene solvent; (2) adding of the suspension of (1), in at least 2 additions over a reaction time ranging from 2 days to 4 days between each addition, material of the formula:



wherein R⁵ and R⁶ are the same or different and are selected from methyl, ethyl or propyl groups and DBU to yield a product of the formula:



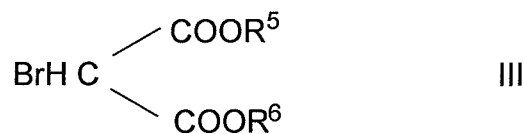
and (3) trans-esterifying or trans-amidating material of formula IV with an esterification or amidation agent of the type which when reacted with the material of formula IV results in the production of a functionalized carbon nanostructure material of the formula:



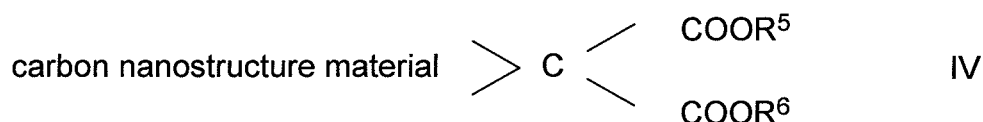
wherein R¹ and R² are the same or different hydrogen or C₁ to C₁₈ alkyl groups provided at least one of R¹ and R² is not hydrogen, y is 0 to 10, preferably 0 to 5 and Z is 0 or 1, n and m are integers ranging from 0 to 2 provided n+m is at least 1, R³ is a C₁ to C₁₅ alkyl or C₆ to C₁₀ aryl group, R⁴ is a C₂ to C₁₄ alkyl group, C₆ to C₁₀ aryl, C₁ to C₁₀ alkylaryl or C₁ to C₁₀ arylalkyl group, and x is an integer ranging from 0 to up to the replaceable valence of the R³ group, wherein the resulting functionalized carbon nanostructure material has at least twice the level of functionalization as compared to functionalized carbon nanostructure material made using the same carbon nanostructure material and material of formula III and DBU when the materials of formula III and DBU are added to the carbon nanostructure material all at once in a single addition.

4. A method for reducing the friction of a lubricating oil comprising a base stock or base oil by dissolving in the base stock or base oil from 10 ppm to 10 wt% of a functionalized carbon nanostructure material which functionalized carbon nanostructure material is made by a process comprising: (1) suspending a carbon nanostructure material in a chlorinated benzene solvent; (2) adding to the suspension

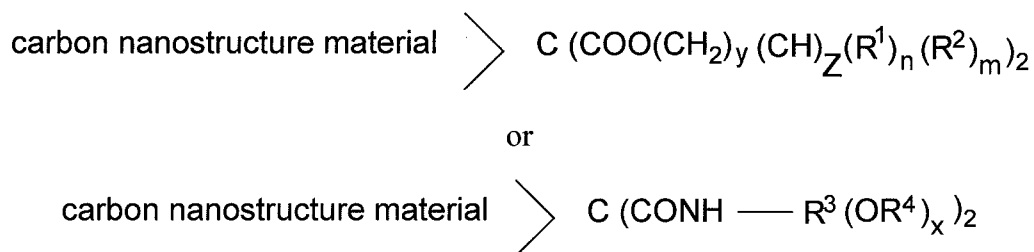
of (1), dropwise over a reaction time ranging from 2 days to 4 days at a rate of one drop every thirty seconds to thirty minutes, material of the formula:



wherein R^5 and R^6 are the same or different and are selected from methyl, ethyl or propyl groups, and 1,8-diazabicyclo[5.4.0]undecene (DBU) to yield a product of the formula:



and (3) trans-esterifying or trans-amidating the material of formula IV with an esterification or amidation agent of the type which when reacted with the material of formula IV results in the production of a functionalized carbon nanostructure material of the formula:



wherein R^1 and R^2 are the same or different hydrogen or C_1 to C_{18} alkyl groups provided at least one of R^1 and R^2 is not hydrogen, y is 0 to 10, preferably 0 to 5 and Z is 0 or 1, n and m are integers ranging from 0 to 2 provided $n+m$ is at least 1, R^3 is a C_1 to C_{15} alkyl or C_6 to C_{10} aryl group, R^4 is a C_2 to C_{14} alkyl group, C_6 to C_{10} aryl, C_1 to C_{10} alkylaryl or C_1 to C_{10} arylalkyl group, and x is an integer ranging from 0 to up to the replaceable valence of the R^3 group, wherein the resulting functionalized carbon nanostructure material has at least twice the level of functionalization as compared to functionalized carbon nanostructure material made using the same carbon nanostructure material and material of formula III and DBU when the materials of formula III and DBU are added to the carbon nanostructure material all at once in a single addition.

5. The method of claim 1 wherein the carbon nanostructure material is single-walled carbon nanotubes.

6. The method of claim 5 wherein the single-walled carbon nanotubes are short single-walled nanotubes having a length between 1 to 10 microns and a diameter between 0.01 to 50 nanometers.

7. The method of claim 2 wherein the carbon nanostructure material is single-walled carbon nanotubes.

8. The method of claim 7 wherein the single-walled carbon nanotubes are short single-walled carbon nanotubes having a length between 1 to 10 microns and a diameter between 0.01 to 50 nanometers.

9. The method of claim 3 wherein the carbon nanostructure material is single-walled carbon nanotubes.

10. The method of claim 9 wherein the single-walled carbon nanotubes are short single-walled carbon nanotubes having a length between 1 to 10 microns and a diameter between 0.01 to 50 nanometers.

11. The method of claim 4 wherein the carbon nanostructure material is single-walled carbon nanotubes.

12. The method of claim 11 wherein the single-walled carbon nanotubes are short single-walled carbon nanotubes having a length between 1 to 10 microns and a diameter between 0.01 to 50 nanometers.

13. The method of claim 1, 5 or 6 wherein the carbon nanostructure material has had its surface decarboxylated.

14. The method of claim 2, 7 or 8 wherein the carbon nanostructure material has had its surface decarboxylated.

15. The method of claim 3, 9 or 10 wherein the carbon nanostructure material has had its surface decarboxylated.

16. The method of claim 4, 11 or 12 wherein the carbon nanostructure material has had its surface decarboxylated.

17. The method of claim 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12 wherein the temperature is held at from 40 to 70°C during the addition step and for one to four days following the final addition of the material to the suspended carbon nanostructure materials.

18. The method of claim 1, 2, 3 or 4 wherein the lubricating oil further contains an additive amount of an organomolybdenum compound.