

INHIBITION OF POLYMERIZATION OF UNSATURATED MONOMERS

BACKGROUND OF THE INVENTION

5

1. Field of the Invention

The present invention is directed to the use of a combination of at least one stable nitroxide free radical compound, at least one phenylenediamine, and, optionally, at least one nitroaromatic compound to inhibit the polymerization of ethylenically unsaturated monomers.

2. Description of Related Art

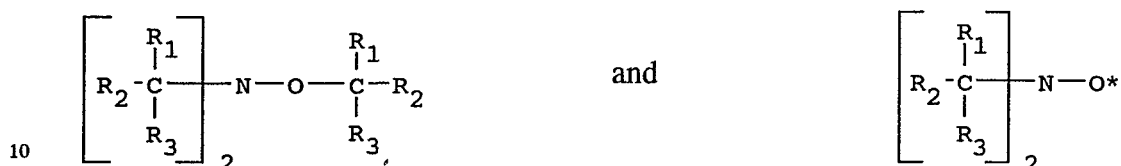
Many ethylenically unsaturated monomers undesirably polymerize at various stages of their manufacture, processing, handling, storage, and use. A particularly troublesome problem is equipment fouling caused by polymerization in the purification stages of the production processes of such monomers. Polymerization, such as thermal polymerization, during their purification results in the loss of the monomer and a loss in production efficiency owing to the deposition of polymer in or on the equipment being used in the purification, the deposits of which must be removed from time to time. Additionally, the formation of soluble polymer leads to loss of monomer, i.e., a lower yield, and an increase in the viscosity of any tars that may be produced. The processing of the tars then requires higher temperature and work (energy cost) to remove residual monomer.

A wide variety of compounds has been proposed and used for inhibiting uncontrolled and undesired polymerization of ethylenically unsaturated monomers. However, these compounds have not been fully satisfactory. Accordingly, there has been a substantial need in the art for improved compositions for inhibiting the polymerization of such monomers during their production and the distillation process

for purifying or separating them from impurities, as well as during transport and storage.

Hindered nitroxyl compounds are known to be very active inhibitors of free radical polymerizations of unsaturated monomers such as styrene, acrylic acid,
 5 methacrylic acid, and the like.

U.S. Patent Number 3,163,677 discloses N,N,O-trisubstituted hydroxylamines and N,N-disubstituted nitroxides of the formulae:



wherein R_1 , R_2 , and R_3 are each an alkyl radical having 1 to 15 carbon atoms. (As used herein, the designation N-O* denotes a stable free radical wherein the asterisk is an unpaired electron.) The N,N,O-trisubstituted hydroxylamines can be used to
 15 make the N,N-disubstituted nitroxides, which are stable free radicals and are said to be useful as polymerization inhibitors.

U.S. Patent Number 3,334,103 discloses that nitroxides can be prepared from the corresponding heterocyclic amine wherein the nitrogen atom of the nitroxide group is attached to other than a tertiary carbon of an aliphatic group (i.e., the
 20 nitrogen atom forms a part of a heterocyclic nucleus). These nitroxides are said to have useful properties similar to those described for the N,N-disubstituted nitroxides of U.S. Patent Number 3,163,677.

U.S. Patent Number 3,372,182 discloses that a great variety of N,N-disubstituted, stable, free radical nitroxides not otherwise readily available can be prepared by a simple and convenient process that comprises pyrolyzing in an inert reaction medium virtually any hydroxylamine that is susceptible to cleavage of the O-C bond, e.g., tri-t-butylhydroxylamine.

U.K. Patent Number 1,127,127 discloses that acrylic acid can be stabilized against polymerization by the addition thereto of a nitroxide having the essential skeletal structure:



wherein R₁, R₂, R₃, and R₄ are alkyl groups and no hydrogen is bound to the remaining valencies on the carbon atoms bound to the nitrogen. The two remaining valencies that are not satisfied by R₁ to R₄ or nitrogen can also form part of a ring (e.g., 2,2,6,6 tetramethyl-4-hydroxy-piperidine-1-oxyl).

U.S. Patent Number 3,422,144 discloses stable, free radical nitroxides of the formula:



wherein R is selected from the group consisting of tertiary alkyl, aryl, alkaryl, haloaryl, carboxyaryl, alkoxyaryl, alkylthioaryl, pyridyl, and dialkylaminoaryl, and R' is tertiary alkyl. These nitroxides are said to be useful as traps for reactive free

radicals both in the counting of free radicals and for inhibiting oxidation and free radical polymerization.

U.S. Patent Number 3,494,930 discloses free radicals of the nitroxide type for use as initiators of free radical reactions, collectors of free radicals, polymerization
5 inhibitors or antioxidants. They are constituted by nitrogenous bicyclic compounds in which one of the bridges comprises solely the nitroxide radical group and, in particular, by aza-9-bicyclo (3,3,1) nonanone-3-oxyl-9, and by aza-9-bicyclo (3,3,1) nonane oxyl-9.

U.S. Patent Number 3,873,564 discloses compounds and a method for
10 assaying enzymes by adding to a medium containing an enzyme a stable free radical compound having a stable free radical functionality which, when subjected to an enzyme-catalyzed reaction, changes the environment of the free radical functionality. By following the change in the electron spin resonance spectrum as affected by the change in environment, the type of enzyme and the activity of the enzyme can be
15 determined.

The compounds found useful are normally stable nitroxide radicals with an enzyme labile functionality. Other compounds include two cyclic nitroxide containing rings joined by a chain having an enzyme labile functionality.

U.S. Patent Number 3,966,711 teaches that 2,2,7,7-tetraalkyl- and 2,7-
20 dispiroalkylene-5-oxo-1,4-diazacycloheptanes substituted in the 4-position by mono- or tetravalent radicals are powerful light-stabilizers for organic polymers. They are said to possess higher compatibility than their 4-unsubstituted homologues, from which they can be synthesized by reactions known for N-alkylation. Preferred substituents in the 4-position are alkyl, alkylene, alkenyl, aralkyl, and esteralkyl

groups. The 1-nitroxyls derived from the imidazolidines by oxidation with hydrogen peroxide or percarboxylic acids are also said to be good light stabilizers.

U.S. Patent Number 4,182,658 discloses a method for preventing the polymerization of a readily polymerizable vinyl aromatic compound during
5 distillation at elevated temperatures within a distillation apparatus that is subject to an emergency condition, such as a power outage. This method comprises force-feeding a supplemental polymerization inhibitor having a high solubility in the vinyl aromatic compound and a long duration of efficiency into each of the distillation vessels of a conventional distillation apparatus in an amount sufficient to prevent polymerization
10 therein.

European Patent Application 0 178 168 A2 discloses a method for inhibiting the polymerization of an α,β -ethylenically unsaturated monocarboxylic acid during its recovery by distillation by using a nitroxide free radical.

U.S. Patent Number 4,665,185 discloses a process for the efficient
15 preparation of nitroxyls of sterically hindered amines by the oxidation of the amine using a hydroperoxide in the presence of a small amount of a metal ion catalyst, at moderate temperature for a short period of time, to give the nitroxyl in high yield and purity.

U.S. Patent Number 4,774,374 discloses a vinyl aromatic composition
20 stabilized against polymerization comprising (a) a vinyl aromatic compound and (b) an effective amount of a stabilizer system in which the active ingredient consists essentially of an oxygenated species formed by the reaction of oxygen and an N-aryl-N'-alkyl-p-phenylenediamine. Also disclosed is a process for inhibiting the polymerization of vinyl aromatic compounds employing such an oxygenated species.

U.S. Patent Number 5,254,760 teaches that the polymerization of a vinyl aromatic compound, such as styrene, is very effectively inhibited during distillation or purification by the presence of at least one stable nitroxyl compound together with at least one aromatic nitro compound.

5 U.S. Patent Numbers 5,545,782 and 5,545,786 disclose that nitroxyl inhibitors in combination with some oxygen reduce the premature polymerization of vinyl aromatic monomers during the manufacturing processes for such monomers. Even small quantities of air used in combination with the nitroxyl inhibitors are said to result in vastly prolonged inhibition times for the monomers.

10 U.S. Patent Number 5,711,767 discloses that the use of nitroxide compounds alone or in combination with aromatic amines, such as substituted phenylenediamines, or phenolic antioxidants provides an effective way to prevent oxidative degradation and gum formation in gasolines.

U.S. Patent Number 5,907,071 discloses that the polymerization of vinyl
15 aromatic monomers such as styrene is inhibited by the addition of a composition of a stable hindered nitroxyl radical and an oxime compound.

U.S. Patent Number 5,910,232 teaches that inhibition performance in styrene processing is improved through the addition of a stable nitroxide free radical compound to the styrene feed and to the reflux of at least one column. A non-toxic
20 retarder, such as phenylenediamine, may also optionally be added to the styrene feed and to the reflux.

European Patent Application 0 765 856 A1 discloses a stabilized acrylic acid composition in which the polymerization of the acrylic acid is inhibited during the distillation process for purifying or separating the acrylic acid as well as during

transport and storage. The compositions comprise three components: (a) acrylic acid, (b) a stable nitroxyl radical, and (c) a dihetero-substituted benzene compound having at least one transferable hydrogen (e.g., a quinone derivative such as the monomethyl ether of hydroquinone (MEHQ)). During the distillation process,

5 transport, and storage, components (b) and (c) are present in a polymerization-inhibiting amount. During the distillation process, oxygen (d) is preferably added with components (b) and (c). According to the specification, examples of suitable nitroxide free radical compounds include di-t-butyl nitroxide; di-t-amyl nitroxide; 2,2,6,6-tetramethyl-piperidinyloxy; 4-hydroxy-2,2,6,6-tetramethyl-piperidinyloxy;

10 4-oxo-2,2,6,6-tetramethyl-piperidinyloxy; 4-dimethylamino-2,2,6,6-tetramethyl-piperidinyloxy; 4-amino-2,2,6,6-tetramethyl-piperidinyloxy; 4-ethanoyloxy-2,2,6,6-tetramethyl-piperidinyloxy; 2,2,5,5-tetramethylpyrrolidinyloxy; 3-amino-2,2,5,5-tetramethylpyrrolidinyloxy; 2,2,5,5-tetramethyl-1-oxa-3-azacyclopentyl-3-oxy;

2,2,5,5-tetramethyl-1-oxa-3-pyrrolinyl-1-oxy-3-carboxylic acid; and 2,2,3,3,5,5,6,6-

15 octamethyl-1,4-diazacyclohexyl-1,4-dioxy.

WO 97/46504 concerns substance mixtures containing: (A) monomers containing vinyl groups; and (B) an active amount of a mixture which inhibits premature polymerization of the monomers containing vinyl groups during their purification or distillation and contains: (i) between 0.05 and 4.5 wt %, relative to

20 the total mixture (B), of at least one N-oxyl compound of a secondary amine which has no hydrogen atom at the α -C atoms; and (ii) between 99.95 and 95.5 wt % relative to the total mixture (B), of at least one nitro compound. The publication also discloses a process for inhibiting the premature polymerization of monomers, and the use of mixture (B) for inhibiting the premature polymerization of monomers.

WO 98/02403 relates to inhibiting the polymerization of vinyl aromatic compounds by using a mixture of a phenol and a hydroxylamine. It is said that the process is useful in ethylbenzene dehydrogenation effluent condenser systems and styrene-water separator vent gas compressor systems and that it effectively inhibits
5 polymerization of monomers, preventing the formation of a polymer coating on condenser and compressor equipment, thus reducing the necessity for cleaning of equipment surfaces.

WO 98/14416 discloses that the polymerization of vinyl aromatic monomers such as styrene is inhibited by the addition of a composition of a stable hindered
10 nitroxyl radical and an oxime compound.

WO 98/25872 concerns substance mixtures containing: (A) compounds containing vinyl groups; (B) an active amount of a mixture which inhibits premature polymerization of the compounds containing vinyl groups and contains: (i) at least one N-oxyl compound of a secondary amine which does not carry any hydrogen
15 atoms on the α -carbon atoms; and (ii) at least one iron compound; (C) optionally nitro compounds; and (D) optionally co-stabilizers. The publication also discloses a process for inhibiting the premature polymerization of compounds (A) containing vinyl groups, and the use of (B) optionally mixed with nitro compounds (C) and/or co-stabilizers (D) for inhibiting the premature polymerization of radically
20 polymerizable compounds and stabilizing organic materials against the harmful effect of radicals.

WO 99/20584 (U.S. Patent No. 5,955,643) discloses that polymerization can be inhibited during the anaerobic production of styrene through the addition of a combination of a stable nitroxide free radical compound and a non-toxic phenylenediamine compound.

5 CS-260755 B1 is directed to the preparation of 4-substituted-2,2,6,6-tetramethylpiperidine nitroxyls as olefin stabilizers.

SU-334845 A1 is directed to the inhibition of the radical polymerization of oligoester acrylates using iminoxyl radical inhibitors of a given formula.

SU-478838 is directed to the inhibition of the radical polymerization of
10 oligoester acrylates and the prevention of oligomeric peroxides using a binary polymerization inhibitor comprising quinone.

FR 2,761,060 relates to the prevention of premature polymerization of styrene during its production by dehydrogenation of ethylbenzene by injecting into the process effluent a radical inhibitor based on an oxyl-tetramethylpiperidine derivative.

15 The foregoing are incorporated herein by reference in their entirety.

SUMMARY OF THE INVENTION

As used herein, the abbreviation TEMPO stands for 2,2,6,6-tetramethyl-1-piperidinyloxy. Thus, 4-amino-TEMPO is 4-amino-2,2,6,6-tetramethyl-1-piperidinyloxy; 4-hydroxy-TEMPO is 4-hydroxy-2,2,6,6-tetramethyl-1-
20 piperidinyloxy (also known in the art as HTEMPO); 4-oxo-TEMPO is 4-oxo-2,2,6,6-tetramethyl-1-piperidinyloxy; and so on.

Phenylenediamines (PDA's), nitroaromatics, and nitroxyls are known polymerization inhibitors. PDA's often require air injection to be effective as inhibitors. Since PDA's and nitroxyls are considered true inhibitors, they are often used with nitrophenol compounds (retarders) to provide protection in the case of

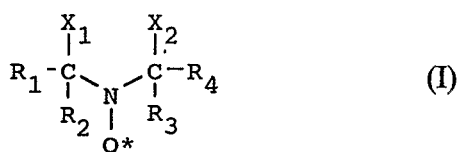
5 failure in the inhibitor feed system of a monomer manufacturing plant.

It has now been found that the combination of a nitroxyl and a PDA, or the combination of a nitroxyl, a PDA, and a nitroaromatic compound, has a positive synergistic effect on the total inhibiting ability of the system. In particular, it has been found that combining a small amount of a nitroxyl with a typical PDA or a

10 typical PDA/nitroaromatic compound inhibiting system significantly increases the efficiency of the inhibiting system under anaerobic and aerobic conditions.

More particularly, the present invention is directed to a method for inhibiting the premature polymerization of ethylenically unsaturated monomers comprising adding to said monomers an effective amount of:

- 15 A) at least one inhibitor having the following structural formula:



- 20 B) at least one phenylenediamine, and, optionally,

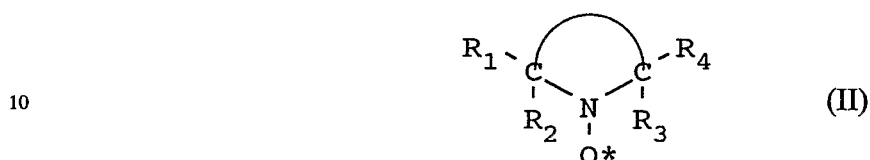
- C) at least one nitroaromatic compound.

In formula (I), R_1 and R_4 are independently selected from the group consisting of hydrogen, alkyl, and heteroatom-substituted alkyl and R_2 and R_3 are independently selected from the group consisting of alkyl and heteroatom-substituted alkyl; and X_1

and X_2 (1) are independently selected from the group consisting of halogen, cyano, $COOR_7$, $-S-COR_7$, $-OCOR_7$, (wherein R_7 is alkyl or aryl), amido, $-S-C_6H_5$, carbonyl, alkenyl, or alkyl of 1 to 15 carbon atoms, or (2) taken together, form a ring structure with the nitrogen, preferably of five, six, or seven members.

5 The present invention is directed preferably to a method for inhibiting the premature polymerization of ethylenically unsaturated monomers comprising adding to said monomers an effective amount of

A) at least one inhibitor having the structural formula:



wherein R_1 and R_4 are independently selected from the group consisting of hydrogen, alkyl, and heteroatom-substituted alkyl and R_2 and R_3 are independently selected from the group consisting of alkyl and heteroatom-substituted alkyl, and the

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portion represents the atoms necessary to form a five-, six-, or seven-membered heterocyclic ring,

20 B) at least one phenylenediamine, and

C) at least one nitroaromatic compound.

The atoms necessary to complete the ring referred to above are preferably carbon atoms, but heteroatoms, such as O, N, P, or S, may also be present.

In formula (II), R_1 and R_4 are independently selected from the group consisting of hydrogen, alkyl, and heteroatom-substituted alkyl and R_2 and R_3 are independently selected from the group consisting of alkyl and heteroatom-substituted alkyl; and X_1 and X_2 (1) are independently selected from the group consisting of
 5 halogen, cyano, COOR_7 , $-\text{S}-\text{COR}_7$, $-\text{OCOR}_7$, (wherein R_7 is alkyl or aryl), amido, $-\text{S}-\text{C}_6\text{H}_5$, carbonyl, alkenyl, or alkyl of 1 to 15 carbon atoms, or (2) taken together, form a ring structure with the nitrogen, preferably of five, six, or seven members.

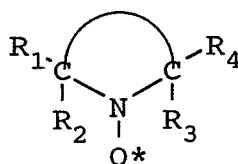
The effective amount of the combination of nitroxyl, phenylenediamine, and nitroaromatic compounds is typically about 1 to 5,000 ppm, based on the weight of
 10 the ethylenically unsaturated monomer, although amounts outside this range may be appropriate depending upon the conditions of use. The amount of the combination of nitroxyl, phenylenediamine, and nitroaromatics compound is preferably about 5 to about 1,000 ppm, based on the weight of the ethylenically unsaturated monomer.

15 DESCRIPTION OF THE PREFERRED EMBODIMENTS

As stated above, in one preferred aspect, the present invention is directed to a method for inhibiting the premature polymerization of ethylenically unsaturated monomers comprising adding to said monomers an effective amount of

A) at least one inhibitor having the structural formula:

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wherein R_1 and R_4 are independently selected from the group consisting of hydrogen, alkyl, and heteroatom-substituted alkyl and R_2 and R_3 are independently selected from the group consisting of alkyl and heteroatom-substituted alkyl, and the

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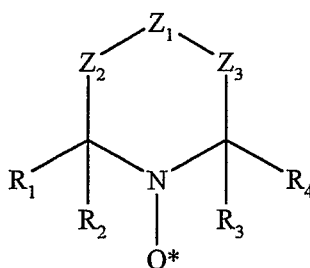
portion represents the atoms necessary to form a five-, six-, or seven-membered heterocyclic ring; and

B) at least one phenylenediamine, and, optionally,

10 C) at least one nitroaromatic compound.

Accordingly, one of the several classes of cyclic nitroxides that can be employed in the practice of the present invention can be represented by the following structural formula:

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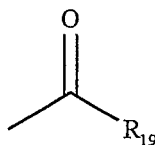


wherein Z_1 , Z_2 , and Z_3 are independently selected from the group consisting of oxygen, sulfur, secondary amines, tertiary amines, phosphorus of various oxidation
 20 states, and substituted or unsubstituted carbon atoms, such as $>CH_2$, $>CHCH_3$,
 $>C=O$, $>C(CH_3)_2$, $>CHBr$, $>CHCl$, $>CHI$, $>CHF$, $>CHOH$, $>CHCN$,
 $>C(OH)CN$, $>CHCOOH$, $>CHCOOCH_3$, $>CHCOOC_2H_5$, $>C(OH)COOC_2H_5$,
 $>C(OH)COOCH_3$, $>C(OH)CHOHC_2H_5$, $>CNR_5R_6$, $>CCONR_5R_6$, $>C=NOH$,
 $>C=CH-C_6H_5$, $>CF_2$, $>CCl_2$, $>CBr_2$, $>Cl_2$, $>CPR_{13}R_{14}R_{15}$, and the like, where

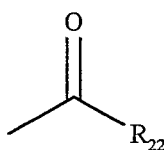
R_5 and R_6 are independently selected from the group consisting of hydrogen, alkyl, aryl, and acyl and R_{13} , R_{14} , and R_{15} are independently selected from the group consisting of unshared electrons, alkyl, aryl, $=O$, OR_{16} , and $NR_{17}R_{18}$, where R_{16} , R_{17} , and R_{18} are independently selected from the group consisting of hydrogen, alkyl, and aryl. Where R_5 and/or R_6 are alkyl, it is preferred that they be a lower alkyl (i.e., one having one to four carbon atoms, e.g., methyl, ethyl, propyl, butyl, and isomers thereof).

Where R_5 and/or R_6 are aryl, it is preferred that they be aryl of from 6 to 10 carbon atoms, e.g., phenyl or naphthyl, which, in addition, may be substituted with non-interfering substituents, e.g., lower alkyl groups, halogens, and the like.

Where R_5 and/or R_6 are acyl, it is preferred that they be acyl of the structure



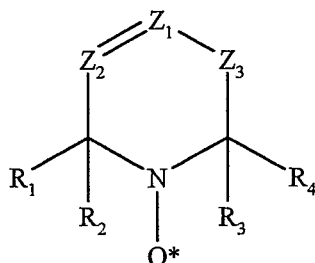
where R_{19} is alkyl, aryl, OR_{20} , or $NR_{20}R_{21}$ and where R_{20} and R_{21} are alkyl, aryl, or



where R_{22} is alkyl or aryl. Where R_{19} , R_{20} , R_{21} , or R_{22} are alkyl, they are preferably alkyl of from 1 to 15 carbon atoms, more preferably lower alkyl of from 1 to 4 carbon atoms, as described above. Where R_{19} , R_{20} , R_{21} , or R_{22} are aryl, they are preferably aryl of from 6 to 10 carbon atoms, as described above.

Another of the several classes of cyclic nitroxides that can be employed in the practice of the present invention can be represented by the following structural formula:

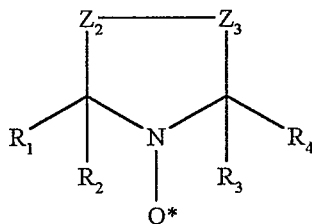
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wherein Z_1 and Z_2 , which may be the same or different, are nitrogen or substituted or
 10 unsubstituted carbon atoms, such as $=C(H)-$, $=C(CH_3)-$, $=C(COOH)-$,
 $=C(COOCH_3)-$, $=C(COOC_2H_5)-$, $=C(OH)-$, $=C(CN)-$, $=C(NR_5R_6)-$,
 $=C(CONR_5R_6)-$, and the like, and where Z_3 , R_5 , and R_6 are as described above.

The cyclic nitroxides employed in the practice of the present invention can also be derived from five-membered rings. These compounds are of the structure:

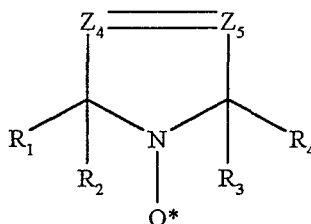
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20 wherein Z_2 and Z_3 , which may be the same or different, are sulfur, oxygen, primary amines, secondary amines, phosphorus of various oxidation states, or substituted or unsubstituted carbon atoms, such as, $>CH_2$, $>CHCH_3$, $>C=O$, $>C(CH_3)_2$,
 $>CHBr$, $>CHCl$, $>CHI$, $>CHF$, $>CHOH$, $>CHCN$, $>C(OH)CN$,
 $>CHCOOH$, $>CHCOOCH_3$, $>CHCOOC_2H_5$, $>C(OH)COOC_2H_5$,

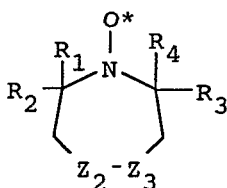
$>C(OH)COOCH_3$, $>C(OH)CHOHC_2H_5$, $>CNR_5R_6$, $>CCONR_5R_6$, $>C=NOH$,
 $>C=CH-C_6H_5$, CF_2 , CCl_2 , CBr_2 , Cl_2 , $>CPR_{13}R_{14}R_{15}$, and the like, wherein the
several R groups are as described above.

The cyclic nitroxides employed in the practice of the present invention can
5 also have the structure:



10 wherein Z_4 and Z_5 , which can be the same or different, can be nitrogen or a
substituted or unsubstituted carbon atom, such as $=C(H)-$, $=C(CH_3)-$, $=C(COOH)-$,
 $=C(COOCH_3)-$, $=C(COOC_2H_5)-$, $=C(OH)-$, $=C(CN)-$, $=C(NR_5R_6)-$,
 $=C(CONR_5R_6)-$, and the like, where R_5 and R_6 are as described above.

Another class of cyclic nitroxides that can be employed in the practice of the
15 present invention is of the structure:



20 wherein Z_2 and Z_3 , which may be the same or different, are sulfur, oxygen, primary
amines, secondary amines, or substituted or unsubstituted carbon atoms, such as,
 $>CH_2$, $>CHCH_3$, $>C=O$, $>C(CH_3)_2$, $>CHBr$, $>CHCl$, $>CHI$, $>CHF$,
 $>CHOH$, $>CHCN$, $>C(OH)CN$, $>CHCOOH$, $>CHCOOCH_3$, $>CHCOOC_2H_5$,
 $>C(OH)COOC_2H_5$, $>C(OH)COOCH_3$, $>C(OH)CHOHC_2H_5$, $>CNR_5R_6$,

$> \text{CCONR}_5\text{R}_6$, $> \text{C}=\text{NOH}$, $> \text{C}=\text{CH}-\text{C}_6\text{H}_5$, CF_2 , CCl_2 , CBr_2 , Cl_2 , and the like, where R_5 and R_6 are as described above.

Further, two or more nitroxyl groups can be present in the same molecule, for example, by being linked through one or more of the Z-type moieties by a linking group E, as disclosed in U.S. Patent Number 5,254,760, which is incorporated
5 herein by reference.

As stated above, for all structures above, R_1 and R_4 are independently selected from the group consisting of hydrogen, alkyl, and heteroatom-substituted alkyl and R_2 and R_3 are independently selected from the group consisting of alkyl and
10 heteroatom-substituted alkyl. The alkyl (or heteroatom-substituted alkyl) groups R_1 through R_4 can be the same or different and preferably contain 1 to 15 carbon atoms, e.g., methyl, ethyl, propyl, butyl, pentyl, hexyl, heptyl, octyl, nonyl, decyl, undecyl, dodecyl, tridecyl, tetradecyl, pentadecyl, and the like, and isomers thereof, e.g., t-butyl, 2-ethylhexyl, and the like. It is more preferred that R_1 through R_4 be
15 independently selected lower alkyl (or heteroatom-substituted lower alkyl) of one to four carbon atoms (e.g., methyl, ethyl, propyl, butyl, and isomers thereof). Where heteroatom substituents are present, they can, for example, include halogen, oxygen, sulfur, nitrogen, and the like. It is most preferred that all of R_1 through R_4 be methyl.

20 Examples of suitable nitroxide free radical compounds that can be used in combination with the phenylenediamine and nitroaromatic compounds in the practice of the present invention, include, but are not limited to:

N,N-di-*tert*-butylnitroxide;

N,N-di-*tert*-amylnitroxide;

- N-tert*-butyl-2-methyl-1-phenyl-propylnitroxide;
N-tert-butyl-1-diethylphosphono-2,2-dimethylpropylnitroxide;
2,2,6,6-tetramethyl-piperidinyloxy;
4-amino-2,2,6,6-tetramethyl-piperidinyloxy;
5 4-hydroxy-2,2,6,6-tetramethyl-piperidinyloxy;
4-oxo-2,2,6,6-tetramethyl-piperidinyloxy;
4-dimethylamino-2,2,6,6-tetramethyl-piperidinyloxy;
4-ethanoyloxy-2,2,6,6-tetramethyl-piperidinyloxy;
2,2,5,5-tetramethylpyrrolidinyloxy;
10 3-amino-2,2,5,5-tetramethylpyrrolidinyloxy;
2,2,4,4-tetramethyl-1-oxa-3-azacyclopentyl-3-oxy;
2,2,4,4-tetramethyl-1-oxa-3-pyrrolinyl-1-oxy-3-carboxylic acid;
2,2,3,3,5,5,6,6-octamethyl-1,4-diazacyclohexyl-1,4-dioxy;
4-bromo-2,2,6,6-tetramethyl-piperidinyloxy;
15 4-chloro-2,2,6,6-tetramethyl-piperidinyloxy;
4-iodo-2,2,6,6-tetramethyl-piperidinyloxy;
4-fluoro-2,2,6,6-tetramethyl-piperidinyloxy;
4-cyano-2,2,6,6-tetramethyl-piperidinyloxy;
4-carboxy-2,2,6,6-tetramethyl-piperidinyloxy;
20 4-carbomethoxy-2,2,6,6-tetramethyl-piperidinyloxy;
4-carbethoxy-2,2,6,6-tetramethyl-piperidinyloxy;
4-cyano-4-hydroxy-2,2,6,6-tetramethyl-piperidinyloxy;
4-methyl-2,2,6,6-tetramethyl-piperidinyloxy;
4-carbethoxy-4-hydroxy-2,2,6,6-tetramethyl-piperidinyloxy;

- 4-hydroxy-4-(1-hydroxypropyl)-2,2,6,6-tetramethyl-piperidinyloxy;
4-methyl-2,2,6,6-tetramethyl-1,2,5,6-tetrahydropyridine -1-oxyl;
4-carboxy-2,2,6,6-tetramethyl-1,2,5,6-tetrahydropyridine -1-oxyl;
4-carbomethoxy-2,2,6,6-tetramethyl-1,2,5,6-tetrahydropyridine -1-oxyl;
5 4-carbethoxy-2,2,6,6-tetramethyl-1,2,5,6-tetrahydropyridine -1-oxyl;
4-amino-2,2,6,6-tetramethyl-1,2,5,6-tetrahydropyridine -1-oxyl;
4-amido-2,2,6,6-tetramethyl-1,2,5,6-tetrahydropyridine -1-oxyl;
3,4-diketo-2,2,5,5-tetramethylpyrrolidinyloxy;
3-keto-4-oximino-2,2,5,5-tetramethylpyrrolidinyloxy;
10 3-keto-4-benzylidene-2,2,5,5-tetramethylpyrrolidinyloxy;
3-keto-4,4-dibromo-2,2,5,5-tetramethylpyrrolidinyloxy;
2,2,3,3,5,5-hexamethylpyrrolidinyloxy;
3-carboximido-2,2,5,5-tetramethylpyrrolidinyloxy;
3-oximino-2,2,5,5-tetramethylpyrrolidinyloxy;
15 3-hydroxy-2,2,5,5-tetramethylpyrrolidinyloxy;
3-cyano-3-hydroxy-2,2,5,5-tetramethylpyrrolidinyloxy;
3-carbomethoxy-3-hydroxy-2,2,5,5-tetramethylpyrrolidinyloxy;
3-carbethoxy-3-hydroxy-2,2,5,5-tetramethylpyrrolidinyloxy;
2,2,5,5-tetramethyl-3-carboxamido-2,5-dihydropyrrole-1-oxyl;
20 2,2,5,5-tetramethyl-3-amino-2,5-dihydropyrrole-1-oxyl;
2,2,5,5-tetramethyl-3-carbethoxy-2,5-dihydropyrrole-1-oxyl;
2,2,5,5-tetramethyl-3-cyano-2,5-dihydropyrrole-1-oxyl;
bis(1-oxyl-2,2,6,6-tetramethylpiperidin-4-yl)succinate;
bis(1-oxyl-2,2,6,6-tetramethylpiperidin-4-yl)adipate;

- bis(1-oxyl-2,2,6,6-tetramethylpiperidin-4-yl)sebacate;
bis(1-oxyl-2,2,6,6-tetramethylpiperidin-4-yl)n-butylmalonate;
bis(1-oxyl-2,2,6,6-tetramethylpiperidin-4-yl)phthalate;
bis(1-oxyl-2,2,6,6-tetramethylpiperidin-4-yl)isophthalate;
5 bis(1-oxyl-2,2,6,6-tetramethylpiperidin-4-yl)terephthalate;
bis(1-oxyl-2,2,6,6-tetramethylpiperidin-4-yl)hexahydroterephthalate;
N,N'-bis(1-oxyl-2,2,6,6-tetramethylpiperidin-4-yl)adipamide;
N-(1-oxyl-2,2,6,6-tetramethylpiperidin-4-yl)-caprolactam;
N-(1-oxyl-2,2,6,6-tetramethylpiperidin-4-yl)-dodecylsuccinimide;
10 2,4,6-tris-[N-butyl-N-(1-oxyl-2,2,6,6-tetramethylpiperidin-4-yl)]-s-triazine;
4,4'-ethylenebis(1-oxyl-2,2,6,6-tetramethylpiperazin-3-one);
and the like.

It is preferred that one member of the combination employed in the practice of the present invention be 4-amino-2,2,6,6-tetramethyl-piperidinyloxy (4-amino-
15 TEMPO), 4-oxo-2,2,6,6-tetramethylpiperidinyloxy (4-oxo-TEMPO), 4-hydroxy-2,2,6,6-tetramethylpiperidinyloxy (4-hydroxy-TEMPO), or 2,2,6,6-tetramethylpiperidinyloxy (TEMPO).

Such stable nitroxide free radical compounds can be prepared by known methods. (See, for example, U.S. Patent Numbers 3,163,677; 3,334,103;
20 3,372,182; 3,422,144; 3,494,930; 3,502,692; 3,873,564; 3,966,711; and 4,665,185; which are incorporated herein by reference.) They are suitable for use over a wide range of temperatures, but distillation temperatures employed with the ethylenically unsaturated monomers that are stabilized by the process of the present invention typically range from about 60°C to about 180°C, preferably from about 70°C to

about 165°C, and, more preferably, from about 80°C to about 150°C. Such distillations are generally performed at an absolute pressure in the range of about 10 to about 1,200 mm of Hg.

Preferred embodiments of the instant invention comprise a process wherein

5 the synergistic mixture is from 1 to 95% by weight of the nitroxyl compound and 99 to 5% by weight of the phenylenediamine or the combination of the phenylenediamine and the aromatic nitro compound where the ratio of phenylenediamine to aromatic nitro compound is 5:1 to 1:5. A more preferred embodiment comprises the mixture which is from 5 to 75% by weight of nitroxyl

10 compound and 95 to 25% by weight of the phenylenediamine or the combination of the phenylenediamine and the aromatic nitro compound where the ratio of phenylenediamine to aromatic nitro compound is 2:1 to 1:2. A still more preferred embodiment comprises the mixture which is from 10 to 50% by weight of nitroxyl compound and 90 to 50% by weight of the phenylenediamine or the combination of

15 the phenylenediamine and the aromatic nitro compound where the ratio of phenylenediamine to aromatic nitro compound is 1:1.

Some examples of substituted phenylenediamines which are useful in this invention are listed below:

- N,N'-di-isopropyl-p-phenylenediamine,
- 20 N,N'-di-*sec*-butyl-p-phenylenediamine,
- N,N'-di-*sec*-butyl-o-phenylenediamine,
- N,N'-bis(1,4-dimethylpentyl)-p-phenylenediamine,
- N,N'-bis(1-ethyl-3-methyl-pentyl)-p-phenylenediamine,
- N,N'-bis(1-methylheptyl)-p-phenylenediamine,

- N,N'-dicyclohexyl-p-phenylenediamine,
N,N'-diphenyl-p-phenylenediamine,
N,N'-di-(2-naphthyl)-p-phenylenediamine,
N-isopropyl-N'-phenyl-p-phenylenediamine,
5 N-sec-butyl-N'-phenyl-o-phenylenediamine,
N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine,
N-(1-methylheptyl)-N'-phenyl-p-phenylenediamine,
N-cyclohexyl-N'-phenyl-p-phenylenediamine,
N,N'-dimethyl-N,N'-di-sec-butyl-p-phenylenediamine;
10 most especially N,N'-di(1,4-dimethylpentyl)-p-phenylenediamine.

Preferably, the nitroaromatic compound is selected from the group consisting of:

- 1,3-dinitrobenzene,
1,4-dinitrobenzene,
2,6-dinitro-4-methylphenol,
15 2-nitro-4-methylphenol,
2,4-dinitro-1-naphthol,
2,4,6-trinitrophenol,
2,4-dinitro-6-methylphenol,
2,4-dinitrochlorobenzene,
20 2,4-dinitrophenol,
2,4-dinitro-6-sec-butylphenol,
4-cyano-2-nitrophenol,
3-iodo-4-cyano-5-nitrophenol, and the like.

Preferably, the nitroaromatic compound contains a phenolic group as well as the nitro group. More preferably, the nitroaromatic compound contains a phenolic group, at least two nitro groups, and at least one alkyl group. Such alkyl groups preferably contain from 1 to 8 carbon atoms, such as methyl, ethyl, propyl, butyl, 5 pentyl, hexyl, heptyl, octyl, and isomers thereof, e.g., sec-butyl, t-butyl, 2-ethylhexyl, and the like. More preferably, the alkyl group is a lower alkyl of from 1 to 4 carbon atoms. Most preferably, the nitroaromatic compound is 2,6-dinitro-4-sec-butylphenol or 2,4-dinitro-6-sec-butylphenol.

The ethylenically unsaturated monomer, the inhibition of the premature 10 polymerization of which is an object of the present invention, can be any such monomer for which unintended polymerization during its manufacture, purification, storage, and/or distribution is a problem. Among those monomers that will benefit from the practice of the present invention are: styrene, α -methylstyrene, styrene sulfonic acid, vinyltoluene, divinylbenzenes, polyvinylbenzenes, alkylated styrene, 15 2-vinylpyridine, acrylonitrile, methacrylonitrile, methyl acrylate, ethyl acrylate, methyl methacrylate, ethyl methacrylate, acrylic acid, methacrylic acid, butadiene, chloroprene, isoprene, and the like.

The ethylenically unsaturated monomers will not necessarily be stabilized indefinitely by the presence of the inhibitor blend, especially when the monomers are 20 heated as in distillation, but they can be considered to be stabilized as long as A) there is a measurable increase in the time for which they can be heated before the onset of polymerization in a static system, or B) the amount of polymer made at a constant temperature remains constant over time in a dynamic system.

Those skilled in the art will understand that, if desired, additional free radical scavengers can be included in the stabilized compositions. For example, air or O₂, as disclosed in U.S. Patent Numbers 5,545,782 and 5,545,786, can be added, as can the dihetero-substituted benzene compounds having at least one transferable hydrogen,
5 e.g., a quinone derivative such as the mono-methyl-ether of hydroquinone disclosed in European Patent Application 0 765 856 A1, and other inhibitors well-known to those skilled in the art. The disclosures of the foregoing are incorporated herein by reference in their entirety.

The polymerization inhibitor composition can be introduced into the monomer
10 to be protected by any conventional method. It can be added as a concentrated solution in suitable solvents to the feed or just upstream from the point of desired application by any suitable means. In addition, the individual inhibiting components can be injected separately into the distillation train along with the incoming feed or through separate entry points, provided there is an efficient distribution of the
15 inhibitors. Since the inhibitors are gradually depleted during the distillation operation, it is generally advantageous to maintain the appropriate amount of the inhibitor mixture in the distillation apparatus by adding inhibitors during the course of the distillation process. Adding inhibitors can be done either on a generally continuous basis or intermittently, in order to maintain the concentration of inhibitor
20 mixture above the minimum required level.

The advantages and the important features of the present invention will be more apparent from the following examples.

EXAMPLES

Procedure for Dynamic Reboiler Test with Feed Shut-Off

Preparation of Feed Solution.

T-Butylcatechol (TBC) is removed from commercially available styrene by
5 distillation under vacuum. Removal of TBC is verified by caustic titration. The
desired amount of inhibitor(s) is added to this TBC-free styrene either directly or by
first making a concentrated solution of the inhibitor in TBC-free styrene followed by
further dilution with TBC-free styrene.

10 Procedure for Reboiler Test.

A quantity of the Feed Solution containing inhibitor (blend) at the desired
charge (stated as a wt/wt total inhibitor to styrene) is added to a round-bottom flask
(the "Pot") and heated to the desired temperature (usually 116° C) and brought to
reflux by adjusting the pressure/vacuum. Once the Pot contents are at temperature, a
15 continuous stream of fresh Feed Solution is begun at a rate that will add the volume
of the initial Pot solution to the Pot over a period of time called the residence time
(typically one hour). At the same time that the fresh Feed Solution flow is begun,
the Bottoms Stream flow is also begun. The Bottoms Stream is solution in the Pot
that is removed at the same rate as the fresh Feed Solution is added. The equal flows
20 of Feed and Bottoms streams cause the quantity in the Pot to remain constant over the
time of the experiment while allowing continuous replenishment of inhibitor. This
procedure simulates the way inhibitors are used in a distillation train of a plant
producing vinyl monomers. The experiment continues with flow in and out of the
Pot for a specified period of time, typically seven hours. Samples are collected

hourly from the Bottoms Stream. These samples are analyzed for polymer content via the methanol turbidity method. The amount of polymer in the samples is an indication of effectiveness of the inhibitor being tested. "Average Polymer Make" is the average of the polymer content values for samples taken after four hours running.

5

Procedure for Feed Shut-Off.

At the end of the Reboiler Test Run (typically seven hours), a sample is collected from the Bottoms Stream. This sample corresponds to Feed Shut-Off Time = 0 minutes. The flows of fresh Feed Solution and Bottoms Stream are stopped.

10 The vacuum and temperature are monitored and adjusted to maintain boiling at the desired temperature of the experiment. Samples are periodically removed from the Pot (typically every five minutes). These samples are analyzed for polymer content via the methanol turbidity method. Data during this time is used to generate the "Feed Shut-Off Curve" for the run.

15 A less steep slope in the Feed Shut-Off Curve (slower rate of polymer production over time) indicates a more effective inhibiting system in the event of a loss of feed in the plant. A longer period of time before initiation of significant polymer formation is also an indication of a more effective inhibiting system in the event of a loss of feed in the plant. A preferred system will have a long delay prior
20 to initiation of polymer formation followed by a slow rate of polymer production once initiated.

The above procedure is carried out to provide the following data, which are indicative of the decrease in polymer made (weight percent polymer in reboiler) by addition of 4-oxo-TEMPO (a nitroxyl) to N-phenyl-N'-(1,4-dimethylpentyl)-p-phenylenediamine (PDA)/2,4-dinitro-6-sec-butyl phenol (DNBP) mixtures.

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Table 1	
Inhibiting System	Average Polymer Make (wt %)
300 ppm DNBP/200 ppm PDA	0.091
300 ppm DNBP/140 ppm PDA/15 ppm nitroxyl	0.037
300 ppm DNBP/200 ppm PDA/3cc per min air	0.006
10 270 ppm DNBP/180 ppm PDA/13 ppm nitroxyl/ 3cc per min air	0.002

Table 2 Steady State Reboiler Data (Weight Percent Polymer)	
Inhibiting System	Average Polymer Make (wt %)
500 ppm DNBP/air sparge	0.1275
250 ppm DNBP/250 ppm PDA/air sparge	0.0490
12 ppm Nitroxyl/244 ppm DNBP/244 ppm PDA/air sparge	0.0030
500 ppm DNBP/ambient	0.2143
300 ppm DNBP/200 ppm PDA/ambient	0.0905
15 ppm Nitroxyl/300 ppm DNBP/140 ppm PDA/ambient	0.0371
500 ppm DNBP/Argon degas	0.2060
250 ppm DNBP/250 ppm PDA/Argon degas	0.0835
12 ppm Nitroxyl/244 ppm DNBP/244 ppm PDA/Argon degas	0.0379
500 ppm DNBP/Argon sparge	0.2348
250 ppm DNBP/250 ppm PDA/Argon sparge	0.2300
12 ppm Nitroxyl/244 ppm DNBP/244 ppm PDA/Argon sparge	0.1925
500 ppm PDA/ambient	0.4067
12 ppm nitroxyl/488 ppm PDA/ambient	0.0034
100 ppm nitroxyl/ambient	0.0019

Air sparge = subsurface sparge of air at 3 cc/min throughout the run while

maintaining vacuum required to maintain boiling at designated temperature.

Ambient = no presparge of feed: run made at the vacuum required to maintain

boiling at designated temperature with no gases injected into the system.

Argon degas = Feed pretreated with Argon sparge for 15 minutes prior to run; run

made at the vacuum required to maintain boiling at designated temperature

with no gases injected into the system.

Argon sparge = subsurface sparge of argon at 3 cc/min throughout the run while

maintaining vacuum required to maintain boiling at designated temperature.

The above data show that adding small quantities of nitroxyl under all atmospheric conditions (totally anaerobic to the addition of extra air) provides a synergistic enhancement to the inhibition performance of the system.

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Table 3 Feed Shut-Off Data (Weight Percent Polymer)											
P	0	5	10	15	20	25	30	35	40	45	50
A	0.154	0.158	0.156	0.178	0.15	0.162	0.185	0.18	0.22	0.25	0.26
B	0.017	0.025	0.054	0.079	0.097	0.118	0.154	0.18	0.192	0.212	0.238
C	0.0032	0.0043	0.019	0.033	0.075	0.104	0.126	0.156	0.176	0.194	0.178
D	0.215	0.25	0.25	0.28	0.275	0.285	0.32	0.385	0.395	0.435	0.445
E	0.1	0.098	0.116	0.178	0.18	0.205	0.325	0.31	0.285	0.295	0.34
F	0.049	0.05	0.066	0.084	0.104	0.136	0.168	0.194	0.234	0.23	0.285
G	0.24	0.23	0.22	0.225	0.25	0.255	0.305	0.36	0.39	0.385	0.435
I	0.0235	0.03	0.056	0.081	0.118	0.144	0.195	0.23	0.25	0.295	0.345
J	0.233	0.233	0.226	0.26	0.28	0.293	0.31	0.326	0.333	0.375	0.415
K	0.23	0.23	0.245	0.29	0.34	0.37	0.405	0.425	0.43	0.51	0.52
L	0.2	0.212	0.222	0.265	0.32	0.4	0.43	0.48	0.49	0.52	0.55
M	0.54	1.09	1.44	1.9	2.75	3.65	4.05	4.7	4.8	5.6	5.1
N	0.0036	0.196	0.6	1.11	1.76	2.18	2.4	2.9	3.45	3.4	4.9
O	0.0024	0.0024	0.043	0.65	1.03	1.38	2.12	3.1	3.85	4.25	—

A = 500 ppm DNBP (Dinitrobutylphenol)/air sparge

B = 250 ppm DNBP/250 ppm PDA/air sparge

C = 12 ppm Nitroxyl/244 ppm DNBP/244 ppm PDA/air sparge

D = 500 ppm DNBP/ambient

25 E = 300 ppm DNBP/200 ppm PDA/ambient

F = 15 ppm Nitroxyl/300 ppm DNBP/140 ppm PDA/ambient

G = 500 ppm DNBP/Argon degas

I = 12 ppm Nitroxyl/244 ppm DNBP/244 ppm PDA/Argon degas

J = 500 ppm DNBP/Argon sparge

K = 250 ppm DNBP/250 ppm PDA/Argon sparge

L = 12 ppm Nitroxyl/244 ppm DNBP/244 ppm PDA/Argon sparge

5 M = 500 ppm PDA/ambient

N = 12 ppm nitroxyl/488 ppm PDA/ambient

O = 100 ppm nitroxyl/ambient

P = Minutes after Feed Shut-Off

The data of Table 3 indicate that the addition of a nitro aromatic compound
10 provides additional safety protection in case of a production upset, i.e., an added
enhancement to the nitroxyl/PDA inhibitor system.

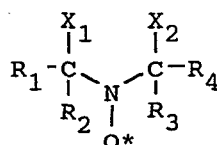
In view of the many changes and modifications that can be made without
departing from principles underlying the invention, reference should be made to the
appended claims for an understanding of the scope of the protection to be afforded
15 the invention.

CLAIMS

What is claimed is:

1. A method for inhibiting the premature polymerization of ethylenically unsaturated monomers comprising adding to said monomers an effective amount of

5 A) at least one stable hindered nitroxyl compound having the structural formula:

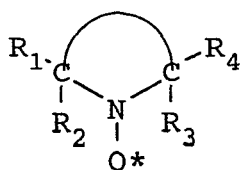


wherein R₁ and R₄ are independently selected from the group consisting of hydrogen,
 10 alkyl, and heteroatom-substituted alkyl and R₂ and R₃ are independently selected from
 the group consisting of alkyl and heteroatom-substituted alkyl; and X₁ and X₂ (1) are
 independently selected from the group consisting of halogen, cyano, COOR₇, -S-
 COR₇, -OCOR₇, wherein R₇ is alkyl or aryl, amido, -S-C₆H₅, carbonyl, alkenyl, or
 alkyl of 1 to 15 carbon atoms, or (2) taken together, form a ring structure with the
 15 nitrogen;

B) at least one phenylenediamine, and, optionally,

C) at least one nitroaromatic compound.

2. The method of claim 1 wherein the stable hindered nitroxyl compound is of
 20 the structural formula:



wherein R_1 and R_4 are independently selected from the group consisting of hydrogen, alkyl, and heteroatom-substituted alkyl and R_2 and R_3 are independently selected from the group consisting of alkyl and heteroatom-substituted alkyl, and the

5



portion represents the atoms necessary to form a five-, six-, or seven-membered heterocyclic ring.

10 3. The method of claim 2 wherein the stable hindered nitroxyl compound is 4-amino-2,2,6,6-tetramethylpiperidinyloxy.

4. The method of claim 2 wherein the stable hindered nitroxyl compound is 4-oxo-2,2,6,6-tetramethylpiperidinyloxy.

15

5. The method of claim 2 wherein the stable hindered nitroxyl compound is 4-hydroxy-2,2,6,6-tetramethylpiperidinyloxy.

6. The method of claim 1 wherein the ethylenically unsaturated monomer is
20 selected from the group consisting of styrene, α -methylstyrene, styrene sulfonic acid, vinyltoluene, divinylbenzenes, polyvinylbenzenes, alkylated styrene, 2-vinylpyridine, acrylonitrile, methacrylonitrile, methyl acrylate, ethyl acrylate, methyl methacrylate, ethyl methacrylate, acrylic acid, methacrylic acid, butadiene, chloroprene, and isoprene.

7. The method of claim 6 wherein the ethylenically unsaturated monomer is styrene.
8. The method of claim 7 wherein the stable hindered nitroxyl compound is 4-
5 amino-2,2,6,6-tetramethylpiperidinyloxy.
9. The method of claim 7 wherein the stable hindered nitroxyl compound is 4-oxo-2,2,6,6-tetramethylpiperidinyloxy.
- 10 10. The method of claim 7 wherein the stable hindered nitroxyl compound is 4-hydroxy-2,2,6,6-tetramethylpiperidinyloxy.
11. The method of claim 2 wherein the the ethylenically unsaturated monomer is selected from the group consisting of styrene, α -methylstyrene, styrene sulfonic acid,
15 vinyltoluene, divinylbenzenes, polyvinylbenzenes, alkylated styrene, 2-vinylpyridine, acrylonitrile, methacrylonitrile, methyl acrylate, ethyl acrylate, methyl methacrylate, ethyl methacrylate, acrylic acid, methacrylic acid, butadiene, chloroprene, and isoprene.
- 20 12. The method of claim 11 wherein the ethylenically unsaturated monomer is styrene.
13. The method of claim 12 wherein the stable hindered nitroxyl compound is 4-amino-2,2,6,6-tetramethylpiperidinyloxy.

14. The method of claim 12 wherein the stable hindered nitroxyl compound is 4-oxo-2,2,6,6-tetramethylpiperidinyloxy.
15. The method of claim 12 wherein the stable hindered nitroxyl compound is 4-
5 hydroxy-2,2,6,6-tetramethylpiperidinyloxy.
16. The method of claim 1 wherein the phenylenediamine is N-phenyl-N'-(1,4-dimethylpentyl)-p-phenylenediamine.
- 10 17. The method of claim 1 wherein the nitro aromatic compound is present and is 2,4-dinitro-6-*sec*-butyl phenol.
18. The method of claim 1 wherein the nitro aromatic compound is present and is 2,4-dinitrophenol.
- 15 19. The method of claim 1 wherein the nitro aromatic compound is present and is 2,4-dinitro-*o*-cresol.
- 20 20. The method of claim 1 wherein the nitro aromatic compound is present and is 2,6-dinitro-*p*-cresol.
21. The method of claim 16 wherein the nitro aromatic compound is present and is 2,4-dinitro-6-*sec*-butyl phenol.

22. The method of claim 16 wherein the nitro aromatic compound is present and is 2,4-dinitrophenol.

23. The method of claim 16 wherein the nitro aromatic compound is present and
5 is 2,4-dinitro-*o*-cresol.

24. The method of claim 16 wherein the nitro aromatic compound is present and is 2,6-dinitro-*p*-cresol.