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COMPATIBILITY OF LUBRICANT ADDITIVES WITH HFC REFRIGERANTS AND SYNTHETIC LUBRICANTS

FINAL REPORT
PART 1

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ABSTRACT

Part one of this research provides manufacturers of components of air-conditioning and refrigeration equipment with a useful list of lubricant additives, sources, functional properties, and chemical species. The list in part one is comprised of domestic lubricant additive suppliers and the results of a literature search that was specifically targeted for additives reported to be useful in polyolester chemistry.

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SCOPE

This report presents information gathered from an extensive literature survey of published information and contacting lubricant additive manufacturers to identify existing published data on the analytical chemistry, degradation, and/or interaction of additives with polyolester [POE] lubricants. Included is information on the mode of action of additives on metals in the presence of POEs.

INTRODUCTION

Reliable service lubrication of compressors with POEs that do not contain additives is the optimal goal for hermetic compressor use. Chlorine derived from CFC and HCFC refrigerants is reported to have effective antiwear properties and negates the widespread use of additives in mineral oil lubricated systems. The use of antioxidants for mineral oil and POEs has been reported and seems essential. High silicon aluminum to steel wear seems to be a primary target for additive use while antiwear and antiseize additives seem to be a short term goal for use with HFC/POE mixtures. The interaction of specific heteroatom (non-carbon, non-hydrogen) organic compounds with highly polar surface active synthetic POEs is complex. Information from an extensive literature search describes results from a service base, determined at ambient conditions. Known lubricant additives used in the hermetic compressor industry, the mode of action of several types of additives and some lubricant additive chemistry that demonstrates selective thermal stability in conjunction with the chemical structure were examined.

An objective of the literature search was to investigate commercially available additives and review published information on the class of chemical compounds used as additives with POEs. The search identified chemical compounds that could be added to a pentaerythritol [PE] and trimethyolpropane [TMP] POE base stock lubricant in order to alter and improve its antioxidant [AO], antiwear [AW], antiseize [AS], antifriction [AF], corrosion inhibitor [CI], multifunctional additive [MFA], stability additive [SA] and lubricant composition properties. Although every effort has been made to find chemical compounds that are reported as useful additives, there are undoubtedly some unintentional oversights.

Many reviews discuss the need for POEs (1, 2, 3), their benefits (4) and how carboxylic acid and alcohol selection affects thermal stability and viscosity (2, 5). Early work focused on development of ester lubricants (1) that would outperform mineral oils. The HVAC industry has settled on the PE and TMP base stocks; however, the chemistry and types of POEs in refrigeration compressors is relatively new and nearly all chemical and additive formulations of current refrigeration grade POE lubricants are proprietary. The paucity of this information made performance correlations of currently used refrigeration grade POEs with that of new and old published information nearly impossible. However, the ASHRAE and the MCLR research programs have provided funding to develop fluid property data on most of the currently used POEs (6, 7).

The choice of POEs selected by HVAC engineers was first based on historical CFC and HCFC mineral oil miscibility characteristics. Perhaps assumptions were made on the lubricity of the esters in the hermetic system based on viscosity and how well esters lubricated gears and rolling element bearings in jet aircraft (1). Within the last three years, proactive lubricant suppliers developed POEs suitable for durable compressor service. Currently available POEs differ chemically in one way or another; however, there is still a need to better understand the sensitivity of various compressor designs and engineering characteristics to obtain optimum lubrication.

Alcohols and carboxylic acids are the primary modifiers of HFC miscibility, thermal stability, and fluid properties. Alkyl branching of carboxylic acids promotes HFC miscibility whereas linear acids promote immiscibility. A wide variety of structurally different esters was studied. The results obtained from a stick-slip machine clearly identified esters made of linear acids. These linear acids are better than mixed and branched esters for lubricity. Lubricity also varies with the structure of the alcohol (8). Hermetic compressor engineers require miscibility for good lubricant return properties. These requirements of a POE have dictated reduced lubricity due to branched acid requirements. By properly tailoring the carboxylic acid composition of POEs, an effective balance of liquid/liquid miscibility and lubricity can be obtained.

Sufficient evidence exists that suggests less or partially miscible POEs can return to the compressor. Refrigerant gas equilibrium solubility studies, with single and blended refrigerants, almost equally reduce the viscosity of fully and partially miscible POEs at identical conditions (6). This information should help in selecting POEs that would have better lubricity at the start, namely a more linear product. We cannot expect esters and mineral oils to behave identically. They are two different classes of chemicals with different physical and chemical properties. Many studies and reviews show mineral oil with low viscosity indices to have superior shear viscosities, EHD, and density qualities (9, 10, 11).

The characteristics of a good compressor lubricant are to seal gas spaces, provide a tough hydrodynamic film, provide a dense lubricant sealing wedge on the leading edges of piston rings, and provide good impact films. Chlorine bearing refrigerants promote a mono layer of ferric chloride on metal surfaces. Ferric chloride on metal surfaces is known to provide a lubricious layer resulting in the lubrication performance of mineral oils with CFC and HCFC refrigerants (12).

Unlike naturally occurring hydrocarbon fluids, POEs are synthetic materials that can be widely varied by altering the ratio of linear and branched carboxylic acids. Synthetic POEs can have totally different performance properties amongst suppliers of identical viscosity grades [VG], whereas supplies of refrigeration grade hydrocarbons have a narrower variance.

The most common 32 ISO VG mineral oil used in the refrigeration industry for the last 35 years is a blend of two straight distillation cuts of hydrocarbons. When early lubricants were combined with CFC refrigerants, severe copper plating and thermal instability of hermetic system lubrication were the predominate failure modes. Eventually, a very light acid treatment followed by clay filtration of the same lubricants improved thermal stability of the chlorinated refrigerant lubricant mixture and compressor performance. Pure POEs are normally formed by a single reaction of a pentaerythritol and a combination of mixed acids to achieve a specific lubrication property. POEs may gain improved lubricity by blending base stocks as well as blend stocks of POEs formed from differing stocks of alcohols such as TMPs.

ADDITIVE SELECTION

The use of synthetic POEs in compressors must at least parallel the performance hydrocarbons have with CFC and HCFC refrigerants. If we want additive-free POEs, we need to synthesize into the ester lubricious properties for an additive free system: viscosity, low temperature miscibility and lubricity. These properties need to be built into the structure of the POE by the selection of appropriate acids and alcohols.

Perhaps the overall lubricity of an additized lubricant is a surface energy phenomenon. Metals have high surface energies and POE lubricants are easily adsorbed onto them (8, 13, 14). Compared to mineral oil, esters are polar and are easily attracted to the surface of metals. This fact makes the selection of lubricant additives for PE and TMP POEs suitable for refrigeration service very complex. Increased molecular weight improves the lubricity of an ester due to decreased refrigerant solubility (1). Esters of high molecular weight and carbon content approach the non-polar index properties of mineral oils (14). Non-polar mineral oil or ester fluids have a lower attraction to the metal surfaces allowing polar additives to be adsorbed. However, these same non-polar esters may not be suitable for refrigeration service due to immiscibility and low temperature viscosity.

When the polarity index of esters increase, so does refrigerant miscibility and metal surface competition for potentially useful polar additives (5, 10). The additive that must be selected to either deactivate the surface or provide a polymeric lubricating surface may already be too active to be thermally and chemically stable for long term compressor service (1, 16, 17). Depending on the compressor design, bearing stresses and many other variables such as alignment and surface finish dictate the degree of metal-to-metal contact. Therefore, the ester base fluid selected for compressor service will cover the metal surfaces preferentially, as opposed to the additive, possibly resulting in higher wear characteristics (5).

Mineral oils respond to additive treatment. When mineral oil is exposed to an acid clay clean-up process, heterocyclic materials that contain nitrogen, sulfur and phosphorus are removed. Some of the natural lubricity of naphthenic lubricants and antioxidant qualities of the lubricant are subsequently lost. Fully refined United States Pharmacopoeia [USP] grade white mineral oils are an example that require the antioxidant α-tocopherol [Vitamin E] for storage purposes.

Millions of HVAC system compressors, with an excellent service history, have been produced that use a fully refined white oil with HCFC-22. To compensate for the poor lubricity of a white oil, either tricresyl phosphate [TCP] or butylated triphenyl phosphate [BTPP] are used as lubricant additives. These same lubricant additives have been used with pale yellow oils as well.

Although the structure of esters does affect lubricity, it may also play a role in additive selection as it does with mineral oils (1, 3). At Falex pin-vee block boundary conditions, the additive BTPP is more efficacious than TCP with white oil and R-22. However, the same additives are only half as efficient with pale yellow oils and R-22 under the same test conditions. Some applications for 32 ISO VG pale yellow mineral oils demanded improved thermal stability properties and better sealed tube responses. The antioxidant and metal surface deactivating properties of a metallo dithiodiphosphate were used to promote this effect (17).

The controlled use of specifically designed additives is usually the optimal way to proceed. The use of additives in mineral oil systems is a good example of their longevity. If an additive is required to make POEs survive the expected lifetime of a compressor, and then that additive has a definite lifetime. When an additive provides a good lubrication layer, the presence of that film must not be removed from that surface by the lubricant. In cases when additives are removed by the POEs, wear debris can form and become a circulating contaminant in compressor systems (8). The comparison is made with the ferric chloride layer formed in mineral oil CFC systems. When the hermetic system is dry and free of circulating HCl, the ferric chloride layer is stable to a degree and is not removed by esters or non-polar mineral oils.

LUBRICANT ADDITIVE MANUFACTURERS

The list of lubricant additive manufacturers in Appendix A is comprised of companies that agreed to be included in this literature search. One of the main problems in obtaining information was lack of commercial understanding on the manufacturers' part of the importance of this type of study with regard to ester compounds.

Most of the lubricant additives reported are produced for the automotive arena for use with mineral oil. These materials are generally contaminated with other materials that make concerted studies of additive efficiency in POEs very difficult. Manufacturers are very reluctant to chemically identify trade names of their products for proprietary reasons, which is a major problem for a research study of this type. To fully understand how and why lubricant additives function in various POEs, it is necessary to know the purity and chemistry of the additive.

ANTIOXIDANT ADDITIVES

If not protected in storage, POEs can adsorb water and oxygen to form hydroperoxy oxidation products. Several high performance additives such as phenyl α naphthylamine (PANA) Uniroyal, Octyl α naphthylamine, (Irganox LO-6) Ciba-Geigy, p,p' dioctyldiphenylamine (Vanlube 81) Vanderbilt, or thiodiethylene bis-(3,5,-di-tert-butyl-4-hydroxy) hydrocinnamate (Irganox1035) and 2,6-Di-tert-butyl-dimethylamino-p-cresol are all effective AOs at elevated temperatures in the absence of any iron catalyst (see Appendix A for additional listings). The effectiveness of AOs is dependent on the structure of the POE, including the type of branching, alkyl side chain length, structure of the AO and the temperature range in which it is used.

The list of AOs reported in Appendix B is comprised of references that were cited from chemical literature. The publications were mainly centered on the POE turbine lubricant industry. Ester lubricants used in turbine applications are constructed for thermal stability and high film strength at high use temperatures. Turbine lubricants are probably not suitable for hermetic use due to immiscible properties with HFCs; however, most of the additives used for high temperature work and may still be suitable for hermetic compressor needs.

ANTIWEAR ADDITIVES

The main type of compounds used for AW activity are various linear, branched or substituted aryl and alkyl chain forms of phosphorous that may contain sulfur or halogen heteroatoms. Generally, the compounds listed in Appendix C are phosphate esters, phosphonates, and the more reactive phosphites. Many of these compounds are also reported as AS and anitscuffing agents as well.

Phosphites are very reactive towards metals but can be modified by aryl or alkyl structural variations. They are also very good AOs in trace amounts. Aryl and alkyl phosphonates are compounds that exhibit good bench test performance but are frequently found to be reactive and form loose product substrate bonds. Diarylether phosphate diester diphosphate congeners are reported as being effective in refrigerator POEs (see Appendix C; Ref. 16).

Many of the additive compounds found effective in POEs in this and other categories are not commercially available. Therefore, many of the effective additive compounds are being missed only because most of the lubricant and compressor companies are not in the mindset of organic synthesis. Companies that are in the business of producing lubricant additives and selling refrigeration grade POEs are not inclined to divulge the information on the structural significance of additive performance.

ANTIFRICTION ADDITIVES

Although similar in performance to AW additives, the list of AF additives reported in Appendix D shows that AF compounds can be comprised of the same heteroatoms as AW compounds. This list is small and does not represent many compounds commercially available except possibly for dibenzyl disulfide. The activity of sulfides is known to replace the oxide layers on wearing iron parts forming ferric sulfide (see Appendix D; Ref. 7, 8). Sulfide reaction products are dense and easily sloughed off in low viscosity thin film friction conditions. Hence, additives that use sulfur as one of the heteroatoms need to be very carefully selected for hermetic compressor use. Sulfur containing impurities may be found in commercial sulfur bearing products. These impurities may be the primary cause of unwanted ferric sulfide contaminants whereas the pure intended sulfur compound may not cause unwanted ferric sulfide contaminants and would provide the expected response.

ANTISEIZE ADDITIVES

Zinc dithiodiphosphates (ZDTPs) are well known materials useful in hermetic compressor systems with CFC and HCFC refrigerants as AS, AW and surface deactivating agents. The negative features of these materials are their purity and ash content of the additive upon ignition. Therefore, additives found useful as AS agents are individually comprised of sulfur, phosphates, and phosphites as listed in Appendix E. Generally, ZDTPs performance is related to adsorption properties on the rubbing surface and thermal decomposition whereas the sulfur additives are affected mainly by the thermal decomposition properties on the iron surfaces in POE systems.

CORROSION INHIBITORS

The CIs comprised of benzotriazole [BZT] and its aryl derivatives are the most widely used copper [yellow] metal deactivators and are detailed in Appendix F. Lubricant compositions using BZT, TCP and quinizarin and/or amine AOs are reported to be effective CI mixtures (see Appendix F; Ref. 4). Phenylthiadiazole propionates are synergistic with BZT and zinc dibutyl dithiophosphates in PE esters.

MULTIFUNCTIONAL ADDITIVES

A study of lubricant additives would be incomplete if no mention was made of MFAs. The literature is replete with patents for these additive types but most are focused for mineral oil use. Most of the published MFA compounds are complex mixtures and may be suitable for the less polar and more immisible refrigerant POEs. These compounds are reported as suitable for mineral oils. A MFA comprised of BZT and a 2-ethylhexyl amine base structure along with small amounts of TCP is found in Mobil EAL-22A. The list seen in Appendix G is comprised of publications that have used a variety of phosphorus and sulfur compounds as MFAs. There seems to be no one specific type of compound that predominates this class of materials.

LUBRICANT STABILIZERS

The one class of compounds that seems to predominate stability agents is epoxides of naturally occurring and synthetic materials. Epoxides seem like useful compounds for many applications but their chemistry dictates a very good route to potential varnishes. Also known as acid catchers, acyclic and aliphatic epoxides, can also react with AW and CI agents and may also be potential skin sensitizers. However, compositions excluding epoxides are reported that are synergistic with phosphates and phosphites along with epoxides and ZDTPs. However, Appendix H also lists dialkyldisulfides with phenylphosphite derivatives as stability agents.

LUBRICANT COMPOSITIONS

Compressor engineers of the CFC era are very much accustomed to having additive-free mineral oils. In today's market of POE lubricant supplies, most POEs are sold as compositions containing some kind of additive, albeit, at very low levels. Therefore, several literature references were obtained as lubricant additive compositions and are reported in Appendix I. The compositions are similar to CI and are in concert with Appendix G.

DISCUSSION

If you are fortunate enough to start out with a clean, debris free system, hermetic compressor applications are expected to endure long life by hydrodynamic lubrication. We are assuming that reduced wear observed with CFC and HCFC mineral oil applications is partially due to friction reduction by the formation of ferric chloride on running surfaces. This may not have been the case when compressors were first designed some 20 or 30 years ago and modifications were necessary for optimization over the years. Since POEs are reported to have lower viscosity pressure characteristics than mineral oils, there appears to be a need for compressor design changes (11).

Today, the HVAC industry wants machines that were designed for mineral oil lubrication to operate equally well with POEs. Mineral oils and POEs are completely different chemical compounds with different physical properties. Results of solution viscosity data at specified pressure and temperature conditions show refrigerant viscosity reduction to be nearly the same as with HCFC-22 and mineral oil. Perhaps the HFC reduction pressure viscosity characteristics of POE solutions do not produce the same dense fluid films formed by mineral oil refrigerant solutions under identical mechanical conditions. Minimal machine changes may include pinned piston pins, larger bearing surfaces and larger rolling elements.

It would be naive to assume there is no reaction of POEs in HFC atmospheres with metals when lubricant films fail. Compared to hydrocarbons, the polar POEs can instill a reaction surface between active metals such as aluminum and steel in the presence of a fluorinated substance. The chemistry of mineral oils with HCFCs may be preventing the redox reaction. Alternately, POEs may enhance the redox reaction with HFCs and metals when lubricant films fail. Mineral oils have mechanical limitation with R-22 and some machine designs. Over many years, engineers and chemists learned how to compensate for these problems and have developed very reliable products. Similarly, this same effort may be necessary for POE products. Durability of compressors is dependent on a hydrodynamic film for long life. The quest for a synthetic lubricant may not be fulfilled with the simple use of additized POEs.

Most of the reported additives have been active in high temperature ambient systems and only a few are reported as useful in oxygen free hermetic systems. The use of additives is widespread in hermetic systems using mineral oils and triaryl phosphate esters. These products can be obtained in pure form without other chemicals present. Commercially available additives useful in ambient applications are generally very impure and contain mineral oil carriers. However, many of the additives reported are not commercially available, even in experimental quantities, and limit further study.

Consequently, we are missing many opportunities if we do not investigate the structural aspects of additives for use in hermetic systems with POEs and other lubrication systems. An effort should be made to research chemical structural types, commercial or developmental, that are known pure products and to evaluate the tribochemical reactivity of these compounds in test conditions known not to cause wear in test machines at mixed boundary regimes.

COMPLIANCE WITH AGREEMENT

Imagination Resources, Inc. is in compliance with the agreement.

PRINCIPAL INVESTIGATOR EFFORT

The principal Investigator, Mr. Richard C. Cavestri, Ph.D., has directed and performed the necessary activities for the completion of this contract.

APPENDICES FORMAT

The structure of the appendices is short summary passages of either a full paper or an abstract. Structures of the chemical compounds have been omitted to minimize confusion. In each appendix there are CAS Index numbers of many of the compounds so that the reader, if interested, can search that specific compound and learn all its sources and uses.

Each Appendix (B through I) has its own reference section. These sections are comprised of the CAS index citation, patent numbers, the original developer, and the main reference paper. This is done to ease further literature searches, if needed, by the reader.

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APPENDIX A
Lubricant Additive Manufacturers

APPENDIX A
Lubricant Additives Manufacturers

NAME	FUNCTION	FLUID TYPE	CHEMISTRY	COMPANY
Irganox L 06	Antioxidant	Compressor Oils	High purity alkylated phenyl alpha naphthylamine	Ciba-Geigy Corporation
Irganox L 57	Antioxidant	Turbine Oils Compressor Oils	Liquid alkylated diphenylamine	Ciba-Geigy Corporation
Irganox L 64	Antioxidant	Turbine Oils Compressor Oils	Liquid blend of phenolic/ aminic antioxidants	Ciba-Geigy Corporation
Irganox L 109	Antioxidant	Turbine Oils Compressor Oils	Bis-2,6-di-tert-butylphenol derivative	Ciba-Geigy Corporation
Irganox L 118	Antioxidant	Turbine Oils Compressor Oils	Liquid sulfur containing hindered phenol	Ciba-Geigy Corporation
Irganox L 134	Antioxidant	Turbine Oils Compressor Oils	Liquid blend of phenolic antioxidants	Ciba-Geigy Corporation
Irganox L 135	Antioxidant	Turbine Oils Compressor Oils	Liquid hindered phenol	Ciba-Geigy Corporation
Irganox 1010	Antioxidant	Turbine Oils Compressor Oils	Hindered phenol	Ciba-Geigy Corporation
Irganox 1035	Antioxidant	Turbine Oils Compressor Oils	Sulfur containing hindered bis-phenol	Ciba-Geigy Corporation
Irgalube TPPT	EP/Antiwear Agents	Compressor Oils	Triphenyl phosphorothionate	Ciba-Geigy Corporation
Irgalube 63	EP/Antiwear Agents	Hydraulic Oils	Liquid dithiophosphate	Ciba-Geigy Corporation
Irgalube 349	EP/Antiwear Agents	Engine Oils	Liquid amine phosphate	Ciba-Geigy Corporation
Irgamet 39	Corrosion Inhibitors/ Metal Passivators	Turbine Oils Compressor Oils	Oil soluble triazole derivative	Ciba-Geigy Corporation
Irgamet 42	Corrosion Inhibitors/ Metal Passivators	Hydraulic Oils Compressor Oils	Water soluble triazole derivative	Ciba-Geigy Corporation
Irgacor L 12	Corrosion Inhibitors/ Metal Passivators	Turbine Oils Compressor Oils	Alkenyl succinc acid half ester	Ciba-Geigy Corporation
Irgacor L 190	Corrosion Inhibitors/ Metal Passivators	Hydraulic Oils	Water soluble polycarboxylic acid	Ciba-Geigy Corporation

NAME	FUNCTION	FLUID TYPE	CHEMISTRY	COMPANY
Amine O	Corrosion Inhibitors/ Metal Passivators	Turbine Oils	Oleyl imidazoline	Ciba-Geigy Corporation
Irganox ML 729	Additive Blends Antioxidant	Hydraulic Oils	Metal passivator blend	Ciba-Geigy Corporation
Irganox ML 810	Additive Blends Antioxidant	Hydraulic Oils	Corrosion inhibitor/ antiwear agent blend	Ciba-Geigy Corporation
Irganox ML 820	Additive Blends Antioxidant	Hydraulic Oils	Corrosion inhibitor blend	Ciba-Geigy Corporation
Irganox ML 840	Additive Blends Antioxidant	Hydraulic Oils	Corrosion inhibitor/ antiwear agent blend	Ciba-Geigy Corporation
Antara LL-550	EP Agent Corrosion inhibitor	Semi-synthetic	Anionics	Rhone-Poulenc
Alkamuls PSMS-20	Lubricity	Semi-synthetic	Nonionics	Rhone-Poulenc
Cyclomide DC-212/5E	Corrosion inhibitor Lubricity High foam	Semi-synthetic	Nonionics	Rhone-Poulenc
Cyclomide DC-212M	Corrosion inhibitor High foam	Semi-synthetic	Nonionics	Rhone-Poulenc
Cyclomide DL 203/S	Lubricity High foam	Semi-synthetic	Nonionics	Rhone-Poulenc
Cyclomide DS 28D	Lubricity Corrosion inhibitor High foam	Semi-synthetic	Nonionics	Rhone-Poulenc
Cyclomide LIPA	Lubricity High foam	Semi-synthetic	Nonionics	Rhone-Poulenc
Cuvan 484 (Proprietary)	Corrosion inhibitor Metal deactivator Ashless	Industrial Oils Automobile Oils	2,5 dimercapto-1,3,4-thiadiazole derivative	Vanderbilt
Molyvan L	Antioxidant EP/Antiwear Agent	Hydraulic Fluids Compressor Oils	Sulfurized oxymolybdenum organophosphoro-dithioate	Vanderbilt
Molyvan 807 (Proprietary)	Antioxidant Non-phosphorous Friction Reducer	Industrial Oils	Molybdenum-sulfur compound	Vanderbilt
Molyvan 822 (Proprietary)	Antioxidant Non-phosphorous Friction Reducer	Turbine Oils	Organo molybdenum dithiocarbamate	Vanderbilt
Molyvan 855 (Proprietary)	Friction reducer	Engine Oils	Organo molybdenum complex	Vanderbilt

NAME	FUNCTION	FLUID TYPE	CHEMISTRY	COMPANY
Molyvan 856B (Proprietary)	Friction reducer	Engine Oils	Organo molybdenum complex	Vanderbilt
Rokon	Corrosion inhibitor Metal deactivator Mild EP agent	Industrial Oils Hydraulic Oils	2-mercaptobenzo-thiazole	Vanderbilt
Vanchem DMTD	Chemical Intermediate	Chemical Intermediate	2,5-dimercapto-1,3,4-thiadiazole	Vanderbilt
Vanlube AZ	Antioxidant Metal deactivator Antiwear Agent Corrosion Inhibitor		Zinc diamyldithio-carbamate	Vanderbilt
Vanlube DND	Antioxidant Ashless	Industrial Oil Greases	Dinonyldiphenyl amine	Vanderbilt
Vanlube NA	Antioxidant Ashless	Turbine Oils Compressor Oils	Alkylated diphenylamines	Vanderbilt
Vanlube PCX	Antioxidant Ashless Synergist	Turbine Oils Hydraulic Oils	2,6-di-butyl-p-cresol	Vanderbilt
Vanlube PNA (Proprietary)	Antioxidant	Turbine Oils Hydraulic Oils	Alkylated phenylalphanaph-thylamine	Vanderbilt
Vanlube RD	Antioxidant Ashless	"UCON" Fluids *	Polymerized 1,2-dihydro-2,2,4-trimethylquinoline	Vanderbilt
Vanlube SB (Proprietary)	EP/Antiwear Agent	Industrial Oils	Sulfurized hydrocarbons	Vanderbilt
Vanlube SL	Antioxidant Ashless	Compressor Oils Hydraulic Oils Turbine Oils	Substituted diphenylamines	Vanderbilt
Vanlube SS	Antioxidant Ashless	Hydraulid Fluids Industrial Oils	Octylated diphenylamines	Vanderbilt
Vanlube 73	Antioxidant EP/Antiscuff Agent Corrosion inhibitor	Industrial Oils	Antimony dialkyldi-thiocarbamate	Vanderbilt
Vanlube 81	Antioxidant Ashless Corrosion inhibitor	Industrial Oils	p,p'-dioctyldi-phenylamine	Vanderbilt
Vanlube 601 (Proprietary)	EP Agent Metal Deactivator Ashless	Compressor Oils	Heterocyclic sulfur-nitrogen compound	Vanderbilt
Vanlube 622	Antioxidant EP Agent Antiwear/Antiscuff Agent	Industrial Oils	Antimony dialkyl-phosphorodithioate	Vanderbilt

NAME	FUNCTION	FLUID TYPE	CHEMISTRY	COMPANY
Vanlube 648	Antioxidant EP Agent Antiwear/Antiscuff Agent Corrosion inhibitor		Antimony dialkyl- phosphorodithioate	Vanderbilt
Vanlube 664 (Proprietary)	Antioxidant Metal Deactivator Rust inhibitor	Hydraulic Oils		Vanderbilt
Vanlube 672 (Proprietary)	EP/Antiwear Agent Ashless	Lubricating Oils	Amine Phosphate	Vanderbilt
Vanlube 691-C (Proprietary)	Metal deactivator Chelating agent Ashless Corrosion inhibitor	Turbine Oils Hydraulic Fluids	Synergistic blend	Vanderbilt
Vanlube 692 (Proprietary)	EP/Antiwear Agent Mild Antioxidant Ashless	Compressor Oils	Aromatic amine-phosphate	Vanderbilt
Vanlube 704 (Proprietary)	Metal Deactivator Corrosion Inhibitor Rust inhibitor	Compressor Oils	Synergistic blend	Vanderbilt
Vanlube 719 (Proprietary)	Antioxidant EP/Antiwear Agent Corrosion inhibitor	Industrial Oils	Organic chemical blend	Vanderbilt
Vanlube 727 (Proprietary)	Antioxidant Antiwear Agent Ashless	Compressor Oils Turbine Oils	Organic chemical blend	Vanderbilt
Vanlube 732 (Proprietary)	Antioxidant Antiwear Agent Ashless	Industrial Oils	Dithiocarbamate derivative	Vanderbilt
Vanlube 7611M (Proprietary)	Ashless Antiwear Agent	Compressor Oils	Organic chemical additive	Vanderbilt
Vanlube 7723	EP/Antiwear Agent Ashless	Hydraulic Oils Turbine Oils	Methylene bis(dibutyldthio- carbamate)	Vanderbilt
Vanlube 804S (Proprietary)	EP/Antiwear Agent Rust inhibitor Corrosion inhibitor		Synergistic blend of additives	Vanderbilt
Vanlube 829	Antioxidant EP/Antiwear Agent		Substituted 1,3,4-thiadiazole	Vanderbilt
Vanlube 848 (Proprietary)	Antioxidant	Compressor Oils Turbine Oils	Octylated diphenylamine	Vanderbilt
Vanlube 849 (Proprietary)	Antioxidant	Industrial Oils	Alpha Methyl styrenated diphenyhlamine	Vanderbilt
Vanlube 869 (Proprietary)	Antioxidant EP Agent	Industrial Oils	Blend	Vanderbilt

NAME	FUNCTION	FLUID TYPE	CHEMISTRY	COMPANY
Vanlube 8610 (Proprietary)	Antioxidant EP Agent	Industrial Oils	Blend	Vanderbilt
Vanlube 871 (Proprietary)	Antioxidant Antiwear Agent Ashless	Industrial Oils	2,5-dimercapto-1,3,4-thiadiazole derivative	Vanderbilt
Vanlube 881-P (Proprietary)	Antioxidant Antiwear Agent Ashless	Industrial Oils	2,5-dimercapto-1,3,4-thiadiazole derivative	Vanderbilt
Vanlube 887E (Proprietary)	Ashless Antioxidant	Synergist	Tolutriazole compound in ester	Vanderbilt
Durasyn 162	Antioxidant	Industrial Oils Hydraulic Fluids	Polyalphaolefin 287 = MW 5.54/40ºC = cSt	Albemarle
Durasyn 164	Antioxidant	Industrial Oils Hydraulic Fluids	Polyalphaolefin 437 = MW 16.8/40ºC = cSt	Albemarle
Durasyn 166	Antioxidant	Industrial Oils Hydraulic Fluids	Polyalphaolefin 529 = MW 31.0/40ºC = cSt	Albemarle
Durasyn 168	Antioxidant	Industrial Oils Hydraulic Fluids	Polyalphaolefin 596 = MW 45.8/40ºC = cSt	Albemarle
Durasyn 170	Antioxidant	Industrial Oils Hydraulic Fluids	Polyalphaolefin 632 = MW 62.9/40ºC = cSt	Albemarle
Naugalube AMS	Antioxidant Thermal stability	Compressor Oils Hydraulic Oils		Uniroyal Chemical
Naugalube 500	Antioxidant	Industrial Oils	alkylated phenyl-α-naphthylamine	Uniroyal Chemical
Naugard Pana	Antioxidant	Industrial Oils	alkylated phenyl-α-naphthylamine	Uniroyal Chemical
Naugalube 680	Antioxidant	Industrial Oils	alkylated diphenyl-amine	Uniroyal Chemical
Naugalube 438L	Antioxidant	Industrial Oils	nonylated diphenylamine	Uniroyal Chemical
Naugalube 438	Antioxidant	Industrial Oils	Octylated diphenylamine	Uniroyal Chemical
Naugalube 640	Antioxidant	Industrial Oils	Octylated, butylated diphenylamine	Uniroyal Chemical
Cobratec 911S	Antioxidant Corrosion inhibitor			PMC Specialties Group

NAME	FUNCTION	FLUID TYPE	CHEMISTRY	COMPANY
Cobratec TT – 100	Antioxidant Corrosion inhibitor	Hydraulic Fluids	Tolyltriazole 133.16 = MW	PMC Specialties Group
Cobratec – 99	Antioxidant Corrosion inhibitor	Hydraulic Fluids	Benzotriazole 119.12 = MW	PMC Specialties Group
NaMBT – 50	Corrosion inhibitor	Chemical Intermediate	Sodium 2-Mercapto-benzothiazole (can be neutralized)	PMC Specialties Group
Anthranillic Acid	Antioxidant Corrosion inhibitor	Industrial Oils	o-Aminobenzoic Acid	PMC Specialties Group
Anthranilamide	Corrosion Inhibitor	Jet Engines	o-Aminobenzamide	PMC Specialties Group
Cobratec PT	Blended treatment additives Corrosion inhibitor		Blend of corrosion inhibitors 20%	PMC Specialties Group
Cobratec TT50-A	Blended Corrosion inhibitor		50% CO-TT-100 in triethanolamine	PMC Specialties Group
NA-Lube AO-130	Antioxidant Ashless	Hydraulic Fluids Compressor Fluids	Nonylated diphenylamine 17/100ºC = cSt	King Industries
NA-Lube AO-140	Antioxidant Ashless	Hydraulic Fluids Compressor Fluids	Octylated butylated diphenylamine 300/40ºC = cSt	King Industries
NA-Lube AO-150	Antioxidant Ashless	Hydraulic Fluids Compressor Fluids	Octylated styrenated diphenylamine 14/100ºC = cSt	King Industries
NA-Lube AO-120	Antioxidant Ashless	Hydraulic Fluids Compressor Fluids	Refined p,p'-Dioctyldiphenylamine	King Industries
NA-Lube AO-110	Antioxidant Ashless	Hydraulic Fluids Compressor Fluids	p,p'- Dioctyldiphenylamine	King Industries
NA-SUL CA/DITA	Rust/Corrosion Inhibitor	Compressor Oils Hydraulic Fluids Synthetic Lubricants	45% Calcium Dinonylnaphthalene Sulfonate in Diisotridecyl Adipate	King Industries
Rhodafac MD-12-116	Thermal/Oxidative stability	Surfactant	Anionic	Rhone-Poulenc
Rhodafac PE-510	Corrosion inhibitor	Surfactant	Anionic	Rhone-Poulenc
Rhodaquat CPB-85	Corrosion inhibitor	Surfactant	Cationic	Rhone-Poulenc

NAME	FUNCTION	FLUID TYPE	CHEMISTRY	COMPANY
Miramine TO	Corrosion inhibitor	Surfactant	Cationic	Rhone-Poulenc
Alkamuls600-DO	Metal Working Fluids Lubricants	Surfactant	Nonionic	Rhone-Poulenc
Alkamuls CO-15	Metal Working Fluids	Surfactant Hydraulic Fluids	Nonionic	Rhone-Poulenc
Alkamuls SML	Lubricants	Surfactant	Nonionic	Rhone-Poulenc
Igepal CO-430	Corrosion inhibitor Ashless	Surfactant	Nonionic	Rhone-Poulenc
Igepal CO-850		Surfactant	Nonionic	Rhone-Poulenc
Cetyl Alcohol NF	Lubricant additive	Intermediate	Cetyl Alcohol Flaked	Rhone-Poulenc
Cetyl Stearyl Alcohol	Lubricant additive	Intermediate	Cetyl Stearyl Alcohol Flaked	Rhone-Poulenc
Uvi-Nox 1494	Antioxidant	Intermediate		Rhone-Poulenc
Lyndcoat 10,15,20 RTU	Lubricant	Intermediate		Rhone-Poulenc
Lubrhophos LB-400	EP additive Rust inhibitor	Hydraulic Fluids	Linear Alkyl Ethoxy	Rhone-Poulenc
Lubrhophos LL-550	EP additive Corrosion inhibitor	Lubricant	Linear Alkyl Ethoxy	Rhone-Poulenc
Lubrhophos LP-700	EP additive	Lubricant	Aryl Ethoxy	Rhone-Poulenc
Alkamuls SMO	Oil Soluble ester	Lubricant		Rhone-Poulenc
Antarox	Oil Soluble	Lubricant		Rhone-Poulenc
Additin RC 3038	Antiwear Corrosion inhibitor	Metal Working Fluids	Zinc dialkyldithio-phosphate (can be neutralized)	RheinChemie

NAME	FUNCTION	FLUID TYPE	CHEMISTRY	COMPANY
Additin RC 3180	Antiwear Corrosion inhibitor	Metal Working Fluids	2-ethylhexyl zinc dithiophosphate (can be neutralized)	RheinChemie
Additin RC 3580	Antiwear Friction modifier		2-ethylhexyl molybdenum dithiophosphate	RheinChemie
Additin RC 3740	Antiwear Ashless		Amine neutralized phosphoric acid partial ester of aliphatic alcohols	RheinChemie
Additin RC 3760	EP/Antiwear Agent Ashless	Hydraulic Oils Compressor Oils Turbine Oils	Amine neutralized phosphoric acid partial ester of aliphatic alcohols	RheinChemie
Additin RC 3770	Antiwear Ashless	Hydraulic Oils	Phosphorus-sulfur compound	RheinChemie
Additin RC 6301-A	Antiwear Corrosion inhibitor	Hydraulic Fluids	Zinc diamyldithio-carbamate	RheinChemie
Additin RC 6320-A	Antiwear Ashless		Antimony diamyldithiocarbamate	RheinChemie
Additin RC 6340-A	EP/Antiwear Agent Ashless	Heavy Metal-Free Greases Industrial Oils Hydraulic Fluids	Methylene-bis-dialkyl-dithiocarbamate	RheinChemie
Additin M 10242-A	Antiwear Corrosion inhibitor	Hydraulic Fluids	Zinc dialkyldithio-phosphate	RheinChemie
Additin M 10279	Antiwear	Lubricants	2-ethylhexyl antimony dithiophosphate	RheinChemie
Additin M 10306	Antiwear Ashless		Amine dialkydithio-phosphate	RheinChemie
Additin RC 7001-A	Antioxidant	Synthetic Lubricants Hydraulic Fluids	Mixture of alkylated diphenylamines	RheinChemie
Additin RC 7005-A	Antioxidant	Compressor Oils Turbine Oils	Alkylated diphenylamine	RheinChemie
Additin RC 7010	Antioxidant		Polymeric trimethyldihydroquin-oline	RheinChemie
Additin RC 7110	Antioxidant	Hydraulic Fluids Turbine Oils Compressor Oils	2,6-di-tert. butyl-4-methylphenol	RheinChemie
Additin RC 7130	Antioxidant	Hydraulic Fluids Turbine Oils Compressor Oils	Phenyl-α-naphthylamine	RheinChemie

NAME	FUNCTION	FLUID TYPE	CHEMISTRY	COMPANY
Additin M 10264-A	Antioxidant	Hydraulic Fluids Turbine Oils Compressor Oils	2,6-di-tert. butylphenol	RheinChemie
Additin M 10277	Antioxidant	Hydraulic Fluids Turbine Oils Compressor Oils	Aminic antioxidant	RheinChemie
Additin M 10314-A	Antioxidant	Synthetic Lubricants Mineral Oils Hydraulic Fluids	Alkylated diphenylamines	RheinChemie
Additin M 10323	Antioxidant	Turbine Oils Compressor Oils Natural/Synthetic Esters	Dimeric, steric hindered phenol	RheinChemie
Additin RC 8210	Antioxidant Ashless Non-ferrous metal Deactivator	Turbine Oils Compressor Oils	Dimercaptothia-diazole derivative	RheinChemie
Additin RC 9202	Additive package	Hydraulic Fluids	Blend of thermal and hydrolytically stable zinc dialkyldithio- phosphate and barium sulfonate	RheinChemie
Additin RC 9204	Additive package	Hydraulic Fluids	Blend of thermal and hydrolytically stable zinc dialkyldithio- phosphate and calcium sulfonate	RheinChemie
Additin RC 9301	Additive package	Compressor Oils	Blend of phosphorus - sulfur compounds with oxidation and corrosion inhibitors	RheinChemie
Additin RC 9303	Additive package	Ashless High Performance Compressor Oils with Antiwear Properties	Blend of phosphorus - sulfur compounds with oxidation and corrosion inhibitors	RheinChemie
Additin 9308	Additive package	Turbine Oils Compressor Oils Hydraulic Oils	Blend of antioxidants, corrosion inhibitors and non-ferrous metal deactivators	RheinChemie
Additin RC 9451	Additive package	Hydraulic Oils	Blend of phosphorus - sulfur compounds with anticorrosion additives	RheinChemie
Additin M 10143-A	Additive package	Hydraulic Oils	Blend of antioxidants and corrosion inhibitors	RheinChemie
Additin M 10295	Additive package	Hydraulic Oils	Blend of S-carrier with antiwear, corrosion inhibitors and non-ferrous metal deactivators	RheinChemie

NAME	FUNCTION	FLUID TYPE	CHEMISTRY	COMPANY
Syn-O-Ad P-310	EP/Antiwear Agent	Pure Component	Dioctylhydrogen phosphonate	Akzo Chemicals, Inc.
Syn-O-Ad P-312	EP/Antiwear Agent	Pure Component	Tributyl phosphite	Akzo Chemcials, Inc.
Syn-O-Ad P-316	EP/Antiwear Agent	Pure Component	Dibutylhydrogen phosphonate	Akzo Chemcials, Inc.
Syn-O-Ad P-374	EP/Antiwear Agent	Pure Component	Trioctyl (2-ethylhexyl) phosphite	Akzo Chemcials, Inc.
Syn-O-Ad P-399	EP/Antiwear Agent	Pure Component	Triphenyl phosphite	Akzo Chemicals, Inc.
Syn-O-Ad P-408	EP/Antiwear Agent	Pure Component	Tridecyl acid phosphate	Akzo Chemcials, Inc.
Syn-O-Ad P-412	EP/Antiwear Agent	Pure Component	Octyl acid phosphate	Akzo Chemcials, Inc.
Syn-O-Ad P-415	EP/Antiwear Agent	Pure Component	Amyl (iso) acid phosphate	Akzo Chemcials, Inc.
Syn-O-Ad P-417	EP/Antiwear Agent	Pure Component	Butyl acid phosphate	Akzo Chemicals, Inc.
Syn-O-Ad 8412	EP/Antiwear Agent	Pure Component	Tributyl phosphate	Akzo Chemcials, Inc.
Syn-O-Ad 8475M	EP/Antiwear Agent	Pure Component	Trixylenyl (mixed) phosphate	Akzo Chemcials, Inc.
Syn-O-Ad 8478	EP/Antiwear Agent	Pure Component	Butylated triphenyl phosphate	Akzo Chemcials, Inc.
Syn-O-Ad 8478LW	EP/Antiwear Agent	Pure Component	Butylated triphenyl phosphate	Akzo Chemicals, Inc.
Syn-O-Ad 8479	EP/Antiwear Agent	Pure Component	Isodecyldiphenyl phosphate	Akzo Chemcials, Inc.
Syn-O-Ad 8480	EP/Antiwear Agent	Pure Component	Propylated triphenyl phosphate	Akzo Chemcials, Inc.
Syn-O-Ad 8484	EP/Antiwear Agent	Pure Component	? - Butylated triphenyl phosphate	Akzo Chemcials, Inc.
Syn-O-Ad 8485	EP/Antiwear Agent	Pure Component	Butylated triphenyl phosphate	Akzo Chemicals, Inc.

NAME	FUNCTION	FLUID TYPE	CHEMISTRY	COMPANY
L-42659				The Elco Corporation
L-44667				The Elco Corporation
L-44668				The Elco Corporation
L-44669				The Elco Corporation
L44670				The Elco Corporation
Durad 125	EP/Antiwear Agent	Pure Component	Tricresyl phosphate	FMC/Durad
Durad 220X	EP/Antiwear Agent	Pure Component	Trixylenyl phosphate	FMC/Durad
Durad 110	EP/Antiwear Agent	Pure Component 25cSt/38°C	Isopropyl pheny phosphate	FMC/Durad
Durad 150	EP/Antiwear Agent	Pure Component 30cSt/38°C	Isopropyl pheny phosphate	FMC/Durad
Durad 220	EP/Antiwear Agent	Pure Component 45cSt/38°C	Isopropyl pheny phosphate	FMC/Durad
Durad 300	EP/Antiwear Agent	Pure Component 68cSt/38°C	Isopropyl pheny phosphate	FMC/Durad
TBP	EP/Antiwear Agent	Pure Component 2.7cSt	Tributyl phosphate	FMC/Durad
TBEP	EP/Antiwear Agent	Pure Component 6.8cSt	Tributoxy phosphate	FMC/Durad
TOP	EP/Antiwear Agent	Pure Component 8.0cSt	Trioctly phosphate	FMC/Durad

Lubricant Additives Manufacturers

Akzo Chemicals Inc.
300 South Riverside Plaza
Chicago, IL 60606
312-906-7011

PMC Specialties Group, Inc.
501 Murray Road
Cincinnati, OH 45217
513-242-3300

Uniroyal Chemical Co., Inc.
World Headquarters Benson Road
Middlebury, CT 06749-0001
203-573-3399

Albemarle Corporation
451 Florida Street
Baton Rouge, LA 70801
800-535-3030

King Industries Specialty Chemicals
Science Road
Norwalk, CT 06852
800-431-7900

FMC Corporation
P.O. Box 8
Princeton, NJ 08543
609-951-3380

Ciba-Geigy
7 Skyline Drive
Hawthorne, NY 10532-2188
800-431-1900

Rhone-Poulenc Ag Company
P.O. Box 425
Cranbury, NJ 08512
800-922-2189

R. T. Vanderbilt Co., Inc.
30 Winfield Street
Norwalk, CT 06856-5150
203-853-1400

The Elco Corporation
1000 Belt Line Street
Cleveland, OH 44109-2800
216-749-2605

RheinChemie
1008 Whitehead Road Ext.
Trenton, NJ 08638
609-771-9100

APPENDIX B
Antioxidant Additives

APPENDIX B
Main - Antioxidant (AO)
Side - Antiseize, Antiwear and Anticorrosive (AS) (AW) (AC)

Cpd. #	CASI Index #	Summary of abstract, Chemical name, reported test lubricant and reported test.	Ref. #
1		Alkylated 1,3,4-thiadiazoles, derived from 2,5-dimercapto-1,3,4 thiadiazole, and in particular the 5 position is substituted by any alkylthio, 2-hydroxy alkylthio, alkylhydroxy, aminos or hydroxy group are effective **AO/AW** agents.	1
2 3	65127-79-9 65127-80-21	The thermal stability and wear performance of PE monocarboxylic acids are dramatically improved with "P", "S" and "N" containing compounds. Specifically bis[p-(β-naphthylamino)phenyl] thiophosphono diethylamide (65127-79-9) or [p-(β-naphthylamino)phenyl]thiophosphono bis(diethylamide) (65127-80-21).	2
4 5	149-30-4 123-30-8	Evidence of improved PE ester (mono and dicarboxylic acid) performance is strictly due to reduced radical formation (EPR) with 2 mercapto benzothiazole (149-30-4) and p-hydroxyphenylamine (123-30-8) at elevated temperature 300°C.	3
6		Significant **AO** activity of a refrigerator PE (simple) ester in presence of Fe, Al and Cu compounds with N-(phenylcarboxyl) succinamic.	4
7		Synergistic **AO** activity with 1-[di(4-octylphenyl)amino methyl] tolutriazole with either methylene bis(di-n-butyldithiocarbamate), 2,6-di-t-butyl-4-sec-butylphenol, 2,6-di-t-butyl-4-sec-butylphenol, 2,6-di-t-butyl-4-methylphenol and butylated phenol. Best ratio is 1-4:1-4 but not to exceed 5%.	5
8		For MO and PE lubricants, a derivative of BHT gave superior performance in the sealed tube tests with R-12.	6
9	126-73-8	PE's synthesized in the presence of tributyl phosphate had superior **AO** and **AW** activity over those formed with no catalyst over ZnO.	7
10		The **AO** activity of Cu complexes in PE esters with Cu monohydroperoxide decreased as their stability and degree of molecular planarity decreased as in 2-dimethyl amino phenol; and 2, butylaminophenol over a 2 pipendlphenol analog. Was better than Cu acetylacetonate.	8
11 12 13	135-88-6 40079-51-4 25811-35-2	Phenyl-2-naphthylamine (135-88-6) and p-octylphenyl-2-naphthylamine (40079-51-4) Amine **AO**'s decompose at 200°C in the presence of air and PE's. Quinone imines, are formed. Nitroxyl radicals contributes to the degradation by occurrence of cyclic quinone iminoxide. There is no evidence the PE was involved. "VIPA"	9
14		The synergistic **AO** effect of phenols and thioethers is due to the formation of phenoxy radicals and thioethers. Therefore organic thioethers and disulfides decompose peroxides and peroxy radicals.	10
15		Better **AO** activity than a simple phenolic additive. The mixture of 2,6-di-t-butyl 4-methylphenol, diphenylamine nonyl and ditridecyl 3,3' thiodipropionate for synthetic lubricants and are commercial products.	11
16		Especially suitable as **AO**'s for PE's, are benzothiazolines. Derivative contain –NH_2, -OH, -CH_2Cl, alkoxy, aryloxy, and many others. Ring substitutions are widely used.	12
16	28452-78-01	Better **AO** effect than open chain amines with PE's is 3,7-di-isooctyl phenothiazine (28452-78-01) is formed by alkylation of phenazine with BuBr in MeOH with Zn and H_2SO_4 Catalyst.	13
17	73947-36-1	PE esters decompose faster at 250-300°C in inert gases with **AO**'s than without them. Thermal decomposition catalyst by **AO**'s.	14
18	118-82-1	With HCFC's and other heat pump working fluids, MO and synthetic, 0.5% of 4,4'-methylene bis(2,6-bis-t-butyl phenol) (118-82-1) proved to be effective at 200°C with Fe, Al and Cu coupons.	15
19 20	90-30-2 945-51-7	Maximal **AO** effect when used in combination was phenyl-α-naphthylamine, and 0.5% diphenyl sulfoxide (945-51-7) 0.25 and Cu metal. Used singularly system fails with sludge.	16

Cpd. #	CASI Index #	Summary of abstract, Chemical name, reported test lubricant and reported test.	Ref. #
21 19	14516-71-3 90-30-2	An organic "S" and nickel complex, 2% [2,2'-thiobis(4-t-octyl phenolato butyl aminenickel)] (14516-71-3) and arylamine (90-30-2), of a PE at 450°F.	17
22 23 24 25 26	14118-06-0 123-31-9 88-58-4 87-87-6 51209-23-5	The redox of 1,2,4-trichlorophenothiazin-3-ol (51209-23-5) to 1,2,4-trichloro-3H-phenthiazin-3-one (14118-06-0) in the presence of hydroquinone (123-71-9) 2,5 di-t-butylhydroquinone (88-58-4) and tetrachlorohydroquinone (87-87-6) resulted in significant **AO** activity at 170°C in synthetic lubricants.	18
19	90-30-2	The effects of structure activity relationships (SAR) are given for several arylamine compounds.	19
27	56866-31-0	In PE C_{5-9} esters, bis(4-phenylaminophenyl) N,N-diethylamidophosphate had a remarkable **AO** effect at 240°C in air. Compared to Neozone.	20
28		Metal 2,2'-dithiobis(4-octylphenolates) have a remarkable **AO** effect due to their participation in peroxy radicals chain termination and the decomposition of peroxides.	21
19 29 30 31	90-30-2 101-67-7 1845-40-0 87442-01-1	PE, neopentyl and TMP esters are synergestically protected by (90-30-2) and p,p'-dioctyldiphenylamine (101-67-5) when alkali metal carboxylate are present, i.e. NaEOTA (1845-40-0) and LI pentafluorobenzoic acid (87442-01-1), thioureas and heterocyclic amines.	22
32	77-58-7	With PAG's - (90-30-2) 1% with dibutyl tin dilaurate (77-58-7) gave very stable high temperature and **AO** activity in refrigerators.	23
33		For ester oils TCP, arylamine and benzothiazole was an effective combination at high temperatures.	24
34 35	70591-67-2 122-37-2	Methyl 4-(p-anilinophenoxy) butyrate (70591-67-2) formed by condensation with methyl 4-chlorobutyrate (3153-37-5) and p-anilinophenol (122-37-2) had significant **AO** activity with PE; TMP's and diesters at 450°C.	25
36	68792-46-1	Suitable for PE's and TMP's, o,o-bis(2-t-butyl-4,6-dimethylphenyl)5-3,5 di-t-butyl-r-hydroxy benzyl dithiophosphate (68792-46-1) in the presence of Cu, Fe and Pb was superior to phenolic **AO**.	26
37 38	1709-70-2 15834-04-5	**AO** (1709-70-2) 1,3,5-trimethyl-2,4,6-tris(3,5-di-t-butyl-4-hydroxy benzyl) benzene was studied to be effective with PE (15834-04-5)	27
39		The most effective of a series of **AO**'s containing -N, -P and S was naphthylaminophenyl phosphonic acid amides. With PE's of $C_5 – C_9$ carboxylic acids.	28
40		The unreacted zinc dialkyl dithiophosphate are the primary true **AO's** and not their decomposition products that terminate peroxy radicals.	29
41 42 43 44 45 46 47	72241-09-9 72241-10-2 63257-63-6 63409-44-9 72241-11-3 72241-12-4 1520-99-6	The effect of N,N'-bis(m-methoxyphenyl)-p-phenylenediamine (72241-09-9), 2,4-dimethoxybenzylidene bis(allylphenol), p-hydroxybenzylid=enebis(alkylphenol), 2,2-bis(3,5-di-tert-butyl-4-hydroxybenzyloxy)ethane (72241-10-2), and dicyclohexyl N-(p-methoxyphenyl)aminosuccinate (63257-63-6), di-Me N-(p-hydroxyphenyl)aminosuccinate (63409-44-9), N-dioctyl(p-hydroxyphenyl)aminosuccinate (72241-11-3), tetrabenzyl N,N'-peperazinediyldisuccinate (72241-12-4), and 2,5-bis(butylamino)quinone (1520-99-6) **AO's** on oxide. of synthetic ester oil at 230°C in the presence or absence of Cu, Al, and steel as catalysts are studied.	30
48 49	629-78-2 7204-35-5	The influence of a t-butyl group is evident with the superior **AO** activity of 4-t-butyl-2-phenyl amino methylphenol (6296-78-2) over 2-dimethyl aminomethyl-4-methylphenol (7204-35-5) with PE esters at 122°C with air or with peroxy catalysis.	31
50		Possibly suitable with PE's and TMP's, the combination of ZDTP's with chlorinated hydrocarbons ($C_2 – C_6$) and alkyl sulfides or sulfurized carboxylic acids. Effective synergistic **AO** and **AW** properties are reported.	32
51 52 53 54	78-16-0 103-23-1 101-67-7 90-30-2	TMP (78-16-0) and diesters (103-23-1) were effectively inhibited with **AO** P,P'-dioctyldiphenylamine (101-67-7) or (90-30-2), studied as thin films, at 350-550°F. A synergistic concentration is noted. There is an interaction with ester oxidation and wear metal appearance.	33

Cpd. #	CASI Index #	Summary of abstract, Chemical name, reported test lubricant and reported test.	Ref. #
55 56 57 19	76586-14-6 25265-63-8 101-77-9 90-30-2	Principally for PE's, N-(2,5-di-t-heptyl-4-hydroxylphenyl) naphthylamine (76586-14-6), N,N'-dinaphthyl-p-phenylene diamine (25265-63-8) and bi(p-anilinophenyl)methane (101-77-9) were better **AO**'s than (90-30-2) at low and high temperature with Fe, Al and Cu compounds at 225°C for 20 hours.	34
58		A novel HPLC method was developed using UV detection to monitor the depletion of 2-di(alkylphonyl)amine with time. (90-30-2) had an experimental decay whereas the formed was linear in PE's.	35
59	128-37-0	BTH was monitored with FTR as a QC method for PE's.	36
60 61 62		Testing methods for used turbine oils are discussed, and the testing methods used in the lab of the Refinery Rijeka are described. The concentration of the oxidation inhibitor di-t-Bu-p-cresol (128-37-0) is detected by IR spectophotometry, mechanical impurities are detected by filtration (DIN 51592), an foaming characteristics of oils are detected according to ASTM D 892 at 24°C. The H_2O and air separation abilities of the oils are detected according to IP 19 and DIN 51381, respectively.	37
19	90-30-2	PE's are not affected until all of (90-30-2) is consumed in the Penn State Micro Oxidation text. (90-30-2) form polymers and are monitored by GPC with UV detection.	38
63	92507-98-7	With synthetic lubricants and PE's N-ethyl-N-phenyl-p-chloro thiobenzamide (92507-98-7) easily formed by reaction with p-chlorobenzaldohyde (104-88-1) with sulfur and the secondary amine was formed and is significantly better than N-propylthiobenzamide.	39
64 65 66	119-99-7 13020-57-0 1137-42-4	A test method is described that evaluates the synergistic effect of S-, and P- containing compounds, heterocyclic amine, diamines and 2-hydroxbenzophenanes - (117-98-7), 3-OH (13020-57-0) and 4-OH (1137-42-4) at various temperatures.	40
67 68	8068-26-6 51005-08-4	Adequate **AO** and **AW** protection with dialkyldithiophosphate (ZDTP) (51005-08-4), but is inadequate as an **AO** without the presence of the **AO** (80068-26-6). The ZDTP alone promotes oxidation even in the presence of BHT (128-37-0) commonly used in PE's.	41
69	41484-35-9	The **AO** bisdithio phenylalkylester (41484-35-9) greatly reduced the decomposition of PE's in the presence of air and metals and improved wear performance as well.	42
70		Greatly improved **AO** performance was formed with PE's, 90, containing tris(nonylphenyl)phosphite, 1, and dinonyldiphenylamine, 10, in a static test.	43
71 59	 128-37-0	The presence of the S-atom in 2-alkylthio derivatives of BHT (128-37-0) greatly improves **AO** and metal deactivator performance in PE's.	44
72		For refrigerators, a neopentyl glycol ester was blended with 2-ethylhexanoic acid glycidyl ester (0.7%) to be an **AO** and **AC** for Cu with refrigerants at 200°C and HCFC-22.	45
73		A structural arrangement that promotes electron donation promotes **AO** activity, whereas strong H bonding detracts. Therefore 4,4' dihydroxy diphenyl sulfide or ether is better than the bisphenols moiety, alone with mixed PE esters.	46
74		An **AO** compound useful in organic materials susceptible to oxidative deterioration, present at 0.01 - 10 wt % concentration is a mixture I of p-butylated and octylated, o-ethylated diphenylamines containing 2,2'-diethyldiphenylamine, 4,4'-di-t-octyl-2,2'-diethyldiphenylamine, 4,4'-di-t-butyl-2,2'-diethyldiphenylamine, 4-t-butyl-4'-t-octyl-2,2'-diethyldiphenylamine, 4-t-butyl-2,2'-diethyldiphenylamine, and 4-t-octyl-2,2'diethyldiphenylamine. The compound is liquid at ambient temperatures.	47
75		Lubrizol 1097, a zinc dithiophosphate or mixtures of alkyl, aryl, alkylaryl or arylalkyl having at least 3 C atoms for use in mono hydroxyl PAG and HFC-134a.	48
76		Reduction product of Me-3-(3,5-di-t-butyl-4-hydroxyphenyl)propinonate (Metilox) with Dobanol and $LiNH_2$ gave protection to air at 135°C for 82 days from unprotected material.	49
77		**AO** properties of 0.3-0.5 wt % and 0.2-0.9 wt % of 2,6-di-t-butylphenol and t-p-amylphenol phosphites.	50
78	130-78-5	A mixed acid PE ester, and some di-PE ester with **AO**'s of 1,1,3-tris(2-methyl-4-hydroxy-5-t-butylphenyl)-butane or 2,6-di-t-Bu-4-methylphenol, acid scavengers polypropylene glycol diglycidyl ester, or 3,4-epoxycyclohexylmethyl-3,4-epoxy-cyclohexane carboxylate, EP trilauryl phosphate ( ) or TCP (130-78-5).	51
79		Diphenylamine, p-OH-diphenylamine or di-iso-octyldiphenylamine. Excellent thermal stability with PE and copper powder at 150°C in air.	52

Cpd. #	CASI Index #	Summary of abstract, Chemical name, reported test lubricant and reported test.	Ref. #
80		Based on metal and steric effect, Co appear to have the best **AO** activity. The steric effect shows iso-propyl > cyclohexyl > t-butyl group in the performance of metalo dialkyl dithiophosphates.	53
81		Hydroperoxides and not peroxides in oil can greatly increase wear of steel parts. The mechanism is hydroperoxides reduced the surface coating formed by **AW** additives.	54
82 83 84 85 86	51772-35-1 26603-23-6 130-7-85 81-64-1 97-74-5	The **AO** mixture m-t-(octylphenyl)-α-naphthylamine (51772-35-1), octylphenylamine (26603-23-6) TCP (130-78-5) and quinazanin (81-64-1) thermal stability improved and reduced TAN formation when 0.05 wt % bis(dimethylthiocarbomoyl) sulfide (97-74-5) was added to the ???	55
87 88 89 90 91	51772-35-1 26603-23-6 1330-78-5 81-64-1 2254-94-6	Branched PE ester when mixed with n(t-octylphenyl)-α-naphthylamine (51772-35-1) bis(octylphenyl)amine (26603-23-6), TCP (1330-78-5), quinizarin (81-64-1) and N-methylbenzothiazole-2-thione (2254-94-6), promoted minimal viscosity and hydrolysis changes.	56
92 93 94 95	77-99-6 59113-36-9 491-19-0 4627-22-9	Polyhydric alcohols enhance the oxidative stability of PE and TMP esters. Hence, 1,1,1 trimethylolpropanol (77-99-6) diglycerol (59113-36-9) or xylitan (491-19-0) with bis (4-t-Bu-phenyl)amine (4627-22-9) participate in the chain termination reaction with peroxides breaking the amine-peroxide complex.	57
96	19047-85-9	Dilauryl phosphonate (19047-85-9) prevented sludge formation with lubricants and refrigerants - attn 40 days at 175°C.	58

Note: **MO = Mineral Oil**
EP = Extreme Pressure
PE = Pentaerythritol Ester
QC = Quality Control
TMP = Trimethyl Propane
TCP = Tricresyl Phosphate

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APPENDIX C
Antiwear Additives

APPENDIX C
Main - Antiwear Additive (AW)
Side - Antiseize, Antioxidant and Antiscuffing (AS) (AO) (ASC)

Cpd. #	CASI Index #	Summary of abstract, Chemical name, reported test lubricant and reported test.	Ref. #
1		The thermal and hydrolytic stability of dithiophosphoric acids are mostly affected by copper, lead and not by stainless steel decrease the activation energy of these title compounds. Neutralization needs to be carried out below 70°C in a stainless steel reaction. Unknown polyols.	1
2		To esters with triglycerides for 134a congeners - 40% - 95% of a PAO with AB. and 5 to 60% PE or TMP esters. Good hydrolytic stability and non-hydroscopicity	2
3		Tris (fluoroalkyl) phosphates for use with C_5 to C_9 PE esters $POCl_3$ with $H(CF_2CF_2)_nCH_2OH$ (n = 1-3) give this fluoroalkyl) phosphates best at ≤200°C and at >100°C better than TCP. Best with decreased fluoroalkyl group length.	3
4		Fatty amine salts with polyfluoro carboxylic acids. Perfluoroalkyliodide carboxylic acids and N,N-bis(2-ethyl hexyl) amines with other amines. PE POE's.	4
5		Base is TMP or PE caprate, dilarylhydrogen phosphate, tripolyoxyethylene decylether phosphate or triphenyl dipropylene glycol diphosphate And the amine is tri(2-ethylhexyl)amine with di(2-ethylhexyl)amine.	5
6	88439-25-2	Chlorinated hexachlorobicyclo [2.2.1]hept-2-en an effective **AS/AW** agent.	6
7	120-78-5	2,2'-dithiobis(benzothiazole) and/or di(4-hydroxy-3,5-dialkyl benzyl)sulfide, 0.07% showed a better wear scar in the four ball tester than without. Test fluid is a MO and an ester not named.	7
8	82144-66-9	Ash free dithio phosphates. Especially effective is O,O-didodecyl N-[2-(2-aminoethyl)aminoethyl]thiophosphroamidate.	8
9 10 11	84376-13-6 84376-14-7 84376-12-5	Thermally stable alkyl polyhalophenyl ethers were found extremely effective in refrigerants and lubricants. Most effective are octadecyl 2,4,6-trichlorophenyl ether, 2-ethylhexyl 2,4-dichlorophenyl ether and 2-octyl 2,4-dichlorophenyl ether.	9
12		Thermally and hydrolytically stable chlorine containing **AW** and **ASC** additives for lubricating oils. A review with 34 references.	10
13		The **AS** properties of $[(RO_2)_2PS_2]_2Zn$ and other derivatives and ("R"=Alky) is temperature dependent and the recomposition into the title compounds. The mode of action is that a coating is formed on the metal surface. The temperature is about 150-200°C; mineral and synthetic.	11
14 15	25088-57-7 10332-32-8	Reaction of Dialkyl H phosphate (25088-57-7) and PE mono oleate [10332-32-8] or PE mixed esters with oleic acid forms an **AW** product.	12
16		Normal alkyl phosphates and phosphites smaller wear scars than with the corresponding branched alkyl and aryl esters. The reactivity of the additives did not correlate with **AW** properties. This is due to the adsorption of the additives or formation of a friction polymer.	13
17		Significantly important in wear properties of a pure PE-C_5-C_9 fatty acid ester is with 0.05 to 0.2 wt % of 2-0-hydroxy phenyl benzoxazole.	14
18		Review article for EP/**AW** additives for PE's - GER. (Ciba-Geigy).	15
19		Diarylether phosphate esters, $(PhO)_2(PO)O(CH_2CHCH_3O)_2{=}(PO)(OPh)_2$ (0.1%), significantly improves the wear of refrigerator oils over the singular use of tricresyl phosphate. 1.0% tested using Falex and compressors.	16
20		Diarylether phosphate diester diphosphate, $(PhO)_2P{=}O[CH_2CH(CH_3)O]_2P(OPh)_2$ as a significant improvement over TCP.	17
21		A 2-imino-1-propyl-3-(3 phenoxy-2-hydroxy propyl) benzimidazoline with bis(2-methoxymethyl or bis(2-ethoxyethyl) adipate, with synthetic PE's.	18

Cpd. #	CASI Index #	Summary of abstract, Chemical name, reported test lubricant and reported test.	Ref. #
22 23 24	128-37-0 122-39-4 90-30-2	Ionol or BHT derivative, diphenyl amine or diphenyl amino-phenyl or naphthylamine dramatically improves the tribochemical stability of PE based esters.	19
25		The transition from low to high wear coincided with the breakdown and disappearance of a tough thin reactive lubricant layer, which consisted mainly of phosphates and replacement by oxides. The molecular structure and thermal stability of the additives are discussed. Therefore, phosphates and antioxidants provide a considerable synergistic effect.	20
26		2,5-bis(O-hydroxyphenyl)-4-oxo-1,3-diazol. Significant **AW** and **ASC** agent in synthetic lubricants.	21
27		An adduct of an oxazoline with oleic and isostaric acids and trishydroxy methyl aminomethane and P_2O_5 reduced the sliding friction of syntheic PE and natural lubricants.	22
28 29 30 31	72264-17-6 30863-12-8 72264-18-7 72264-19-8	Easily formed derivatives of 1,3,5 Triazine, 2,4,6 Triol form ashless phosphates and thio amine esters. The effect of 1-5 wt % ashless I [X,Y = OP(CH_2CHMe_2)$_2$] [72264-17-6], and I (X,Y = $SCSNEt_2$) [30863-12-8], I [X,Y = SP(S)(OCH_2 = $CHMe_2$)$_2$] (II) [72264-18-7], I (X,Y = SCH_2Ph) (III) [72264-19-8], and I (X = $SCSNEt_2$, Y = alkylphenoxy) **AW** additives on the properties of lubricating oil M 11 was studied with a 4-ball friction machine. The II and III gave the best improvement of the **AW** properties of the oil.	23
32		At 1%, the partial PE ester with heptanoic acid and with $POCl_3$ or $(EtO)_3PO$ proved to be effective **AW** agents in PE's and mineral oil.	24
33		A critical concentration exists for the competitive adsorption of amine, (1°>2°>3°) for the metal surface with phosphorus containing **AW** additives causing a reduction of **AW** properties.	25
34		A new undisclosed triaryl phosphate ester with superior thermal and hydrolytic stability was reported (Durad) and is an effective **AW** agent.	26
35		Perfluorinated amino alcohols and esters found to be effective **AW** agents - for synthetic fluids and hydraulic oils.	27
36		A simple "P" free synthesis of a fatty acid thio ester. Oleic acid is reacted with a methyl-thio glycolate, or with n,n-dimethyl amino ethanethiol to form the addition for synthetic fluids.	28
37		A 5% concentration of TCP is necessary to adequately cover all of the reactive metal surfaces - otherwise the metal was coated with oxidative product of TCP and the synthetic lubricant. By FTIR and DSC.	29
38		A cinnamic acid derivative, S-cinnamyl-O,O-diisopropyl dithiophosphate is an effective **ASC** agent in synthetic lubricants.	30
39		(Benzothiazolylthio) Triazines have good **AW** and **AO** performance. Thus cyannric chloride was aminated by HN($CH_2CHEtBu$)$_2$ and then thioetherified by 2-mercapto benzothiazole.	31
40		An **AW** and **AO** is a phosphorous containing diacylamine. Thus dibutyl phosphite or bis(nonylphenyl) phosphite is alkylated with a diarylamine like n-octylphenyl-1-naphthylamine and useful in synthetic esters.	32
41		The wear results of ZDTP in esters suggest that an electron transfer process plays a very important role in the formation of corrosive species from esters. "VIPA" by 4-ball.	33
42		Dibutyl-3,5-di-t-Butyl-4-hydroxy benzyl phosphonates (DBP) was far superior to ZDDP's the mix of DBP and ZDDP was better than ZDDP alone in esters - by 4-ball test.	34
43		Review detailing the structural significance and effectiveness of halogen containing compounds.	35
44		2-hydroxy-5-alkylthio 1,3,4 thiadiazoles wherein the alkyl group may be hydroxy or phenoxy group are effective **AW** and **AO** in lubricants.	36
45		Aminomethyl dithiophosphates, condensation products of di(alkylaryl) dithiophosphonic acid with HCHO and ethanol amine were superior **AW** and oxidants **AO** in synthetic lubricants.	37
46		Polyolesters containing carboxylic acids have improved wear property and is due to their adsorption properties onto metal surfaces.	38
47		A tripentaerythritol neoheptanoil and neopentainoil and succinic acid ester with di-Bu phosphite 0.625 part benzotriazole 0.02 part, R-134a 90 parts.	39
48		A phosphoralated benzotriazole derivative are activated by load bearing conditions in PE esters.	40

49		A refrigeration compressor ester fluid with diphenyloctyl phosphite and TCP ( ) had excellent **AW** properties.	41
50		1,1,1-Trichlorononane; excellent EP and **AW** properties with synthetic esters and hydrocarbons at 0.05 to 10 wt % by 4-ball test	42
51		PE ester with a secondary phosphite ester, secondary groups may be C_{1-20} with or without O-content. Thus di-2-ethylhexyl hydrogen phosphite, dilauryl hydrogen phosphite and dioleyl hydrogen phosphite are very effective as **AW** and EP agents.	43
52		A mixture of thio containing compounds (S-containing) additive and 0.1-10 wt % of epoxide compounds dramatically improve aluminum to steel wear in PE esters and synthetic lubricants.	44
53		A PE ester containing a molybedunum oxysulfide diorgano phosphono dithionate i.e. $[(RO)_2PS_2]_2MO_2S_xO_y$ and the MO_2 diorgano dithiocarbamate $[R'_2NCS_2]_2MO_2S_xO_y$ are effective with R-134a systems.	45
54		Phosphonic, thiophosphonic and phosphorus acid neutral ester-type additives in the lubricating capacity of C_6-C_9 PE esters.	46
55 56	71-36-3 104-76-7	High temperature stability (210°C) additive, comprised of a mix of P_2S_5, BuOH (71-36-3) and 2-ethylhexanol (104-76-7) and saponificatio with ZnO with PE esters.	47
57		Benzotriazole derivatives (0.005-10 wt %) greatly improve the **AW** properties of refrigerator lubricants, i.e. PE esters, and PAG's with R-134a, 32, 125, 152 and 143a. Where $R_1 + R_2$ are independently alkyl of C_4 to C_{18}.	48
58		The di isoctylester of 2,2'-[1,3,4-thiadiazole-2,5-diylbis(thio)]bis[acetic acid] is readily formed and dramatically improves the lubricating properties of an oil by 100%.	49
59	85705-05-1	Chlorobenzylchlorotoluene (85705-05-1) are additives to many lubricants and promotes excellent **AW** properties.	50
60		Tris(alkylphenyl) phosphite, 2-(3,5-dialkyl-2-hydroxyphenyl) benzotriazole had good high temperature stability with refrigerator lubricants and HCFC and HFC's.	51
61		Varied O_2 concentration dramatically affect the sulfide to sulfate ratios in wear scars with test machines at boundry conditions. Varied O_2 concentrations produced varies results.	52
62	90357-65-6	Under boundary conditions, a glycolate dithiophosphonic acid salt, [dithiophosphoric acid, O,O'-(propylglycolate)Zn salt (90357-65-6)] gave superior **AW** and **AS** properties.	53
63	132-65-0	Dibenzothiophene (132-65-0) give good lubricity to PE and TMP esters in refrigerators.	54

Note: **MO = Mineral Oil**
EP = Extreme Pressure
PE = Pentaerythritol Ester
TCP = Tricresyl Phosphate
TMP = Trimethyl Propane
PAG = Polyalkylene Glycol

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APPENDIX D
Antifriction Additives

APPENDIX D
Main - Antifriction (AF)
Side - Antiwear and Antiscuffing (AW) (ASC)

Cpd. #	CASI Index #	Summary of abstract, Chemical name, reported test lubricant and reported test.	Ref. #
1		**ASC** and **AF** properties are attributed to the chlorine in 1-(6-chloro-2-benzothiazolyl)thiocarbamides and appear to be better than dialkyldithiophosphates.	1
2		Easily formed chlorinated ester of tri and tetrachlorobutanol are excellent **AF**/**AW** additives. The functional ester may also contain S-, P- and N- atoms.	2
3		Ashless **AF** additives, containing S-, P- and N-, preferred is di(octylphenyl) diethylenetriamine dithiophosphates and an amino boron complex. The temperature kinetic method is suitable to differentiate with regard to **AF** properties.	3
4		Perfluoropolyethers are reported effective **AF**/**AW** additives for use in compressor and lubricating oil at 0.2 wt %.	4
5		Malonate esters gave **AF** and **AW** agents in MO and synthetic esters. A di-ethyl succinate ester was very efficient, suggesting pentagmal or hexagonal aluminum surfaces structure are not necessary for wear reduction.	5
6	5503-22-0	**AF** properties are obtained from PE containing P-, then pentaerythritol bis(decylphosphite) (5503-22-0) 2%, greatly reduces friction and wear and is useful with PE's.	6
7 8	150-60-7 4563-57-4	Dibenzyl disulfide (150-60-7) enhances the **AF** and **AW** properties of decyclohexyl zinc dithiophosphate (4563-57-9) by replacing FeOx layer under high loads and other regimes.	7
9		Metalodithiophosphate form both reversible and irreversible reaction layers. Thereby bis(dialkyl phosphorothioyl) disulfides are formed from DTP's with oxide layer on steel followed by cation expulsion.	8

Note: **MO = Mineral Oil**
EP = Extreme Pressure
PE = Pentaerythritol Ester

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APPENDIX E
Antiseize Additives

APPENDIX E
Main - Antiseize (AS)

Cpd. #	CASI Index #	Summary of abstract, Chemical name, reported test lubricant and reported test.	Ref. #
1		**AS** effects of S-compounds, with TMP esters, polyaphaolefin (PAO) and dialkyl adipate (DAA) with a 4-ball. Adsorption and thermal decay on Fe powder. With sulfur additives, the **AS** actions in the synthetic oils were affected mainly by the thermal decomposition characteristics on the Fe surfaces in the synthetic oils. With phosphates, however, the **AS** actions in the synthetic oils were affected by the adsorption activity on the rubbing surfaces in the synthetic oils. With ZDP, **AS** action in the synthetic oils were affected by both the adsorption activity on the rubbing surfaces and the thermal decomposition characteristics in the synthetic oils.	1
2		**AS** and thermal properties are improved of synthetic lubricants with mixtures of phosphates and phosphites in refrigerator compressors.	2
3	115-77-5 107-21-1	PE esters show good lubricity and **AS** behavior when a strong thin oxide film is formed in air and N_2/O_2 with PE (115-77-5) and ethylene glycol (EG) esters (C_5-C_9). Stronger films are formed with EG esters. Therefore the lubricant properties depend in the electron acceptor/donor properties of the esters.	3

Note: **MO = Mineral Oil**
EP = Extreme Pressure
PE = Pentaerythritol Ester
TMP = Trimethyl Propane

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APPENDIX F
Corrosion Inhibitors

APPENDIX F
Main - Corrosion Inhibitors (CI)
Side - Antioxidants and Antiwear (AO) (AW)

Cpd. #	CASI Index #	Summary of abstract, Chemical name, reported test lubricant and reported test.	Ref. #
1 2	95-14-7 106-20-7	Derivatives of Benzotriazole optimized for metal protection and solubles in MO and synthetics. Optimally in a 1:1:1 ratio, benzotriazole (95-14-7), formaldehyde and Bis(2-ethylhexyl) amine (106-20-7) protects Cu, and can be optimally formulated for esters.	1
3 1	95-14-7	Synergistic activity is reported for derivatives of phenylbenzotriazole, neutral and halogenated as well. Zn di-Bu dithiophosphates and 2-(2-hydroxy-3,5-di-t-butylphenyl) benzotriazole. Protection of Cu, Sn, bearing metals and **AW** performance is reported.	2
4 5	122-60-1 1330-78-5	For rotary compressors, **CI** are reported for phenylglycidyl ether (122-60-1) and TCP (1330-78-5) in MO and synthetics.	3
5 6 7 8 9	1330-78-5 82056-09-5 26603-23-6 81-64-1 29956-99-8	Good high temperature **CI** and **AO** performance is reported for PE's when t-octylphenyl naphthylamine (82056-09-5) 1.5%, dioctyldiphenylamine (26603-23-6) 1%, TCP (1330-78-5) 2%, quinizarin (81-64-1) 0.1%, and di-t-octyldisulfide (29956-99-8) are used.	4
10 11	128-39-2 7059-16-7	MO and PE derived fluids have superior corrosion performance when zinc dioctyl dithiophosphate (7059-16-7) 0.45% and 2,6-di-t-butylphenol (128-39-2) 0.2%.	5
12 13 1	115-77-5 26603-23-6 95-14-7	Epoxides and diepoxides are decomposed by amine **AO** in PE's. Therefore 1,-naphthylamine (115-77-5), dioctyl diphenylamine (26603-23-6) or benzotriazole (95-14-7). Glycidol (556-52-5) and diepoxides are effective **CI**'s.	6
14		PE's show negligible corrosion of metals with the absence of air. In the presence of air, the oxide tarnishes of Cu and Fe is composed of the carboxylic acid components of the PE.	7
15 1	95-14-7	A unique ashless benzotriazole derivative incorporating S-, and P-, had superior **CI**, **AO**, and **AW** activity. May be considered a multifunctional compound. Hence five S-(1H-benzotriazole-l-yl) methyl, O.O'-dialkyl dithiophosphate derivatives were studied in MO and PE's.	8
16 5 1 17 18	1330-78-5 95-14-7 101-67-7 90-30-2	A complex PE ester had remarkable **CI** and **AO** activity when containing. TCP (1330-78-5) 2%, BZT (95-14-7) 4-octyl-N-(4-octylphenyl) benzenamine (101-67-7) 1%, and phenyl-α-naphthylamine (90-30-2) 1%.	9
19		A - TMP adipate caprylate shows only traces of corrosion on Cu, Fe, and Al strips in HCFC-22 when hydroxy phenyl steric acids are used.	10
20 21 1	52449-44-2 25377-81-5 90-30-2	A useful composition for PE' ester is Zn di-Bu dithiophosphate; (25377-81-5) 1%, BZT (90-30-2) 0.05%, and Bu 3,5-di-t-Bu-4-hydroxy phenyl thiadiazole propionate (52449-44-2) 0.05%.	11
22	64598-06-7	Maleic anhydride ester of BZT (95-14-7) product esters (64598-06-7) with remarkable **CI** activity - in esters.	12

Note: **MO = Mineral Oil**
EP = Extreme Pressure
PE = Pentaerythritol Ester

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APPENDIX G
Multifunctional Additives

APPENDIX G
Main - Multifunctional Additives (MFA)
Side - Antioxidants, Antiwear, Corrosion Inhibitor and Anticorrosive (AO) (AW) (CI) (AC)

Cpd. #	CASI Index #	Summary of abstract, Chemical name, reported test lubricant and reported test.	Ref. #
1	64086-04-0	Effective as **AO**, **AW**, EP and dispersent in MO and synthetic lubricants are S- triazine derivatives and superior EP agents are the hindered thio, thioamides and thiophosphorus compound. Simply formed, triethylphosphite is reacted with cyanunic chlorine in acetone to form the title series.	1
2		Thiadiazol derivative found to be efficient **AW**, **AO**, **AC**, **MFA**'s in ester hydraulic fluids. The preferred most easily formed additives are N,S-bis[bis(2-ethylhexyl)aminomethyl]-2,5-demercapto-1,3,4 thiadiazole.	2
3		A direct reaction of a PE ester containing 2-free OH groups. The PE is reacted with oleic acid, treated with P_2S_5 and boric acid. The clear oil was neutralized with ZnO. This decreased friction and improved stability.	3
4		Excellent **MFA** for synthetics and possible PE's. Reacting methylate BZT with Irgalube 349 (Arom.AminePhosphate) was a superior **AO**, **AW** agent.	4
5 6 7 8	122-39-4 111-13-7 7445-47-8 101-67-7	The reaction product of diphenylamine (122-39-4) and 2-octanone (111-13-7) in HCl, in Herco lube (A) (7445-47-8) and p,p'-dioctyldiphenylamine (101-67-7) was a **MFA**, of **AO** and **CI**.	5
9		Treating the intermediate of O,O'-diisopropyldithiophosphonic acid with t-nonyl-(2,3-epoxy propyl) thioether with isododecenyl succinic anhydride yields a **MFA** that has remarkable **AO**, **AW**, and EP properties in synthetic and ester hydraulic fluids.	6
10		A readily available neuroleptic agent potentially suitable for PE esters is comprised of variable benzothiazolyl, benzothiadiazolyl, benzotriazolyl and benzotriazol derivatives - such as - 3-(1-piperazinyl)-1,2-benzisothiazole, and 5-(2 chloroethyl)-6-chlorooxindole form.	7

Note: **MO = Mineral Oil**
EP = Extreme Pressure
PE = Pentaerythritol Ester

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APPENDIX H
Lubricant Stabilizers

APPENDIX H
Main - Stability
Side - Antiwear (AW)

Cpd. #	CASI Index #	**Summary of abstract, Chemical name, reported test lubricant and reported test.**	Ref. #
1		Epoxides of D-limonene, L-Limonene, α-pinene and L-Carvone are excellent toward stability of sludge, stability, copper-plating properties, with PAG's, ethers and esters.	1
2	130-78-5	The oxidation behavior of TCP (130-78-5) was studied by the Wilhemy-Arrhenius kinetic model, and shows it to be 1st order, requires high activation energy and shows a linear dependence on temperature. Model may be useful for other phosphate esters.	2
3		Alicyclic epoxy compound improved stability of TMP and PE esters by reducing formed acids.	3
4		Improved thermal stability toward R-123 and R-123a with dioctadecyl disulfide (Hostanox SE-10), Hostanox 03, and Tris[2t-Bu-4-Thio-(2'-methyl-4'-OH-5'-t-Bu)phenyl-5-methyl]phenyl phosphite (Hostanox O5P1).	4
5		Patented composition of branched and mixed PE esters with 0.1 - 5.0 % triaryl phosphates and/or triaryl phosphites, with benzotriazole derivatives and epoxy compounds and chelating metal passivator.	5
6 7 8	96477-26-8 68855-17-4 96477-25-7	Diesters decyl 2,2,4-trimethyladipate (96477-26-8) and isotridecyl adipate (96477-25-7) and TMP heptanoate (68855-17-4) affect the thermal stability of Zn dialkyl dithiophosphate additive due to competing reactions with the esters. (i.e. alkyl exchange and complex formation)	6
9		Chlorinated fatty acid esters 0.01 to 20 wt % with branched and mixed acid PE and TMP esters. With epoxied stabilizers - show improved performance with R-134a and other HFC's.	7
10		Chloride contamination is controlled in PAG and POE lubricant systems with phenylglycidyl ether, 0.01 -2.0 wt % and tricresyl phosphite ester, and organo tin compounds such as triphenyl-Sn hydroxide.	8
11		PE esters with 50% MO or synthetic hydrocarbon oils and aryl or akrylalkyl glycidyl ethers react with free carboxylic acids generated by hydrolysis, present an increase in TAN.	9
12		Di methyl phosphite in both **AW** and thermal stabilizer for POE's and PAG's but show very good miscibility.	10
13		Lubricants for refrigerators were stabilized (0.05 - 1.0 wt %) with epoxytetradecane, phenyl glycidyl ether, iso-Bu glycidyl ether and epoxidized soybean oil were used.	11
14	25448-25-3	For mineral and synthetic refrigerator oils, triisodecyl phosphite (25448-25-3) ester gave good stability to lubricants.	12

Note: **MO = Mineral Oil**
EP = Extreme Pressure
PE = Pentaerythritol Ester
TMP = Trimethyl Propane
TCP = Tricresyl Phosphate
PAG = Polyalkylene Glycol
POE = Polyolester

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APPENDIX I
Lubricant Compositions

APPENDIX I
Main - Compositions
Side - Corrosion Inhibitor (CI)

Cpd. #	CASI Index #	Summary of abstract, Chemical name, reported test lubricant and reported test.	Ref. #
1		Composition of TMP and PE esters with MO and AB's in the 5 - 90 wt % range with phosphonic and/or phosphorous acid esters and HFC refrigerants.	1
2	130-78-5	Suitable for PE and TMP esters, for HFC use, are TCP (130-78-5), triphenyl phosphate, tris-dichloropropyl phosphate, tris-chloroethyl phosphate, 2-ethylhexyl acid phosphate, tri decyl acid phosphate, oleyl acid phosphate, oleylamine salt of 2-ethylhexyl acid phosphate, octadecyl acid phosphate and laurylamine salt of 2-ethylhexyl acid phosphate, and demonstrates excellent thermal stability.	2
3		Suitable for PE and TMP ester as a complex additive comprised of an epoxy ester phosphate in 0.05 - 5.0 wt % range.	3
4 5 6 7	101-67-7 90-30-2 1330-78-5 95-14-7	Good lubricity was reported for mixed acid PE esters when treated with 1 - 10% of mono substituted neopentyl glycol or TMP with C_5-C_{18} acids and containing p,p'-dioctyldiphonylamine (101-67-7), phenyl-x-naphthylamine (90-30-2), TLP (1330-78-5) and benzotriazole (95-14-7).	4
8 9 10	90-30-2 95-14-7 10025-06-6	A mixed acid PE ester composition containing N-phenyl-α-naphthylamine (90-30-2), benzotriazole (95-14-7) and a **CI** oleylsarcosine (10025-06-6) gave very good high temperature stability and corrosion protection.	5
6		Improved thermal stability is obtained with PE and TMP mixed acid esters with thioodipropionic acid.	6

Note: **MO = Mineral Oil**
EP = Extreme Pressure
PE = Pentaerythritol Ester
TMP = Trimethyl Propane
TCP = Tricresyl Phosphate
TLP = Trilauryl Phosphate

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