4. PRODUCTION, IMPORT/EXPORT, USE, AND DISPOSAL

4.1 PRODUCTION

Background information on production for the three major categories of hydraulic fluids that are the subject of this profile is summarized below. Most hydraulic fluid products involve special formulations or mixtures marketed under specific trade names. Public agencies will seldom attempt to track production figures for such highly specialized product lines. In addition, many of the constituent chemicals used in hydraulic fluids appear in a variety of other products or applications ranging from lubricants to plasticizers. Since hydraulic fluids have not been viewed as the most serious forms of toxicants or site contaminants, there are as yet no reporting requirements for the Toxics Release Inventory (EPA 1995) for hydraulic fluids or any of the major chemical constituents in the three categories of hydraulic fluids discussed below or listed in Tables 3-l through 3-3.

Mineral Oil Hydraulic Fluids. Most mineral oil hydraulic fluids are made from dewaxed paraffin-based crude oils that are blended with additives to impart appropriate properties for the specific use (Newton 1989; Papay 1989, 1991; Wills 1980). The types of additives, which are summarized below, are quite numerous and in some cases (Mattie et al. 1993) may contain organophosphate esters. These additives include extreme pressure additives, which help prevent surface damage under severe loading (organic sulfur-, phosphorus-, and chlorine-containing compounds); anti-wear additives, which prevent wearing under light loads (fatty acids and derivatives, organophosphate esters); corrosion inhibitors, which prevent corrosion by oxygen and water (fatty acids, sulfonates, and salts of fatty acids); oxidation inhibitors, which inhibit oxidation of the hydraulic fluid (phenols, amines, and sulfides); defoamers, which prevent foam formation (silicone oils); viscosity index improvers, which reduce the dependence of viscosity on temperature (polyalphaolefins, polymethacrylates, and polyalkylstyrenes); pour point depressants, which lower the pour point temperature (polymethacrylates and condensation products); demulsifiers, which allow separation of oil and water (ionogenic and non-ionogenic polar compounds); and dispersants, which prevent unwanted deposits (sulfonates and amides) (Moller 1989). The exact nature of each of these additives appears to be trade secret information since none of the Material Safety Data Sheets describing the hydraulic fluids presented in this profile identify these materials. In addition, no information concerning the exact production methods used in manufacturing these hydraulic fluids was located in the available literature. Nonetheless, they are probably manufactured in batch processes and then tested to insure that they conform to the specifications for which they are sold. The number, nature, and amount of each additive used in a batch may depend on availability, cost, or performance.

The carbon number range (hence, viscosity) in mineral oil hydraulic fluids will vary depending on the application of the fluid (IARC 1984; Papay 1989, 1991, 1993; Wills 1980), but probably is in the range of C_{15} to C_{50}. The higher the carbon number, the higher the viscosity; viscosity is a major factor in determining the base stock of a hydraulic fluid (Moller 1989; Papay 1989, 1991, 1993; Shubkin 1993; Wills 1980). A more highly refined mineral oil will have better viscosity properties (i.e., high viscosity index or low dependence of viscosity on temperature) (Moller 1989; Shubkin 1993).

Mineral oil hydraulic fluids are not listed on the Toxics Release Inventory (TRI), so a listing of manufacturing sites cannot be generated from this inventory. U.S. suppliers of mineral oil hydraulic fluids include Amoco, Arco, Chevron, Citgo, Exxon, Mobil, Shell, Texaco, and Union (Wills 1980). Producers include American Lubricants Co., Amoco Oil Co., Anderson Oil & Chemical Co., Inc., Ashland Oil Co., Benz Oil Co., Cepsa Chempet Corp., Chevron U.S.A. Inc., Cities Service Oil Co., Continental Oil Co., Cooks Industrial Lubricants Inc., Drydene Co., Engineered Lubricants Co., Exxon Chemical Co., U.S.A., Exxon Co. U.S.A. (Esso Affiliated Co.), Exxon Research & Engineers Co., Gulf Oil Corp. & Subsidiaries, Interlube Corp., International Refining and Mfg. Co., Luscon Industries Corp., A. Margolis & Son Corp., Metal Lubricant Co., Mobil Oil Corp., Motor Oils Refining Co., Penzoil Co., Shell Co., Shultz Lubricants Inc., Sun Petroleum Products Co., Texaco Inc., Texaco Canada Inc., Total Compagnie Fran&se de Raffinage, Total Compagnie Francaise des Petroles & its Affiliates, Tower Oil & Technology Co., Valvoline Oil Co. (International Division), Vulcan Oil Co., and Arthur C. Withrow Co. (Wills 1980). Much of the publicly available information on mineral oil-based hydraulic fluid production derives from surveys conducted in the late 1970s so it is often difficult to determine which facilities or companies presently carry out significant production activities.

No information concerning the specific production volumes of mineral oil hydraulic fluids was found in the available literature. The National Petroleum Refiners Association (NPRA 1992) reported that- 192 million gallons of automatic transmission fluids, universal tractor hydraulic/transmission fluids, energy/shock absorber and power steering fluids, and other automotive hydraulic fluids were sold in 1991. Virtually all of these fluids are mineral oil hydraulic fluids (Chrisope and Landry 1993; Papay 1989, 1991; Wills 1980). This volume is lower than sales volumes for 1990 (216 million gallons), 1989 (221 million gallons), 1988 (223 million gallons), 1987 (220 million gallons), and 1986 (210 million gallons) (NPRA 1992).

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Water-in-oil emulsion hydraulic fluids are made from paraffin- or naphthenic-based crudes (i.e., mineral oil) and combined with water, bridging solvents (e.g., ethylene glycol [bridging solvents, in this case, increase the solubility of mineral oil in water and probably help stabilize the emulsion]), and emulsifiers (Houghton 1992; Quaker 1993; Wills 1980). Production methods are probably similar to those for the mineral oil hydraulic fluids. Suppliers include Mobil, Conoco, Shell, Sun, Houghton, Hurlburt, and Quaker (Quaker 1993; Wills 1980). Some water-in-oil emulsion hydraulic fluids contain ethylene glycol (Houghton 1992; Quaker 1993), which is subject to reporting under TRI. Nonetheless, since ethylene glycol is used in numerous other applications and represents 110% of the total volume of water-in-oil emulsion hydraulic fluids, it is not anticipated that information concerning releases on the TRI will be indicative of water-in-oil emulsion hydraulic fluid use.

In 1991, ≈12.5 million gallons of fire resistant fluids (probably including water-in-oil emulsions) were sold; this is the lowest sales volume since 1985 (NPRA 1992). No detailed breakdown of water-in-oil emulsion hydraulic fluids was provided in NPRA (1992).

Organophosphate Ester Hydraulic Fluids. Organophosphate esters are made by condensing an alcohol (aryl or alkyl) with phosphorus oxychloride in the presence of a metal catalyst (Muir 1984) to produce trialkyl, tri(alkyl/aryl), or triaryl phosphates. For the aryl phosphates, phenol or mixtures of alkylated phenols (e.g., isobutylated phenol, a mixture of several *t*-butylphenols) are used as the starting alcohols to produce potentially very complex mixtures of organophosphate esters. Some phosphate esters (e.g., tricresyl and trixylyl phosphates) are made from phenolic mixtures such as cresylic acid, which is a complex mixture of many phenolic compounds. The composition of these phenols varies with the source of the cresylic acid, as does the resultant phosphate ester. The phosphate esters manufactured from alkylated phenylated phenols are expected to have less batch-to-batch variations than the cresylic acid derived phosphate esters. The differences in physical properties between different manufacturers of the same phosphate ester are expected to be larger than batch-to-batch variations within one manufacturer.

The synthesis of organophosphate ester compounds dates to the mid-1800s. From an early date, the most commercially useful compounds for lubricants, plasticizers, and hydraulic fluids were in the chemical family of the tertiary esters. Before 1970, products were introduced based on alkyl aryl phosphates that could contain chlorinated aromatic hydrocarbons. One of the main human health concerns about organophosphate esters is the potential for neurotoxicity reactions, in particular a condition known as organophosphate-induced delayed neurotoxicity (OPIDN). Tri-*ortho*-cresyl phosphate (TOCP) has been identified as one of the more potent OPIDN neurotoxins in humans, and was formerly a constituent in some organophosphate ester hydraulic fluid products (Marino 1992; Marino and Placek 1994). Production processes now routinely remove virtually all the TOCP. For instance, tricresyl phosphate (TCP) products now typically are manufactured to contain over 98% meta and para isomers and virtually no TOCP (Marino and Placek 1994). Products containing these compounds associated with OPIDN have now entirely disappeared from commercial use, and the vast majority of the industrial organophosphate esters are based on triaryl phosphates with no halogenated components (Marino 1992). At waste disposal sites, however, site contaminants from older product formulations containing the *ortho* form may be encountered.

Organophosphate ester hydraulic fluids are not listed on the TRI, so a listing of manufacturing sites cannot be generated from this inventory. U.S. suppliers of organophosphate ester hydraulic fluids include Akzo, Chevron, FMC, Houghton, Mobil, and Monsanto (Akzo 1989, 1991, 1992; FMC 1991c, 1992a, 1992b, 1992c, 1992d; Wills 1980).

No information on recent production volumes of organophosphate esters used in hydraulic fluids was found in the available literature.

Polyalphaolefin Hydraulic Fluids. Polyalphaolefins are made by oligomerizing alphaolefins such as 1-decene in the presence of a catalyst (Newton 1989; Shubkin 1993; Wills 1980). The crude reaction mixture is quenched with water, hydrogenated, and distilled. The number of monomer units present in the product polyalphaolefin oil depends on a number of reaction parameters including the type of catalyst, reaction temperature, reaction time, and pressure (Shubkin 1993). The exact combination of reaction parameters used by a manufacturer is tailored to fit the end-use of the resulting polyalphaolefin oil. A typical polyalphaolefin oil prepared from 1 -decene and $BF_3 \bullet n\text{-}C_4,H_9,OH$ catalyst at 30 °C contains predominantly trimer (C_{30} hydrocarbons) with much smaller amounts of dimer, tetramer, pentamer, and hexamer. While 1 -decene is the most common starting material, other alphaolefins can be used, depending on the needs of the product oil.

The final oil contains a large number of isomers (e.g., the trimer of I-decene contains many C_{30} isomers, the tetramer contains many C_{30} isomers) which result from skeletal branching during the oligomerization (Shubkin 1993). Polyalphaolefin oils are many times classified by their kinematic viscosity at 100 °C; the higher the viscosity, the longer the average chain length of the polyalphaolefin. The isomer distribution of a polyalphaolefin oil used in a particular hydraulic fluid will depend on the application. A polyalphaolefin oil contains a narrower range of molecular weights than a comparable mineral oil (Chrisope and Landry 1993; Shubkin 1993).

Polyalphaolefin hydraulic fluids have many advantages over the mineral oil counterparts including low temperature flow characteristics, lower volatility, and oxidative stability (Chrisope and Landry 1993; Shubkin 1993). Certain polyalphaolefins maintain good operational characteristics and have been proposed for use in hydraulic systems in U.S. military aircraft (Kinkead et al. 1992b).

U.S. manufacturers of alphaolefins include Ethyl Corp., Shell Chemical Co., Shell Oil Co., and Texaco Chemical Co. (USITC 1993). More than 1 billion pounds of alphaolefins were produced in 1991 (USITC 1993), but no information concerning the volume of alphaolefins used in the production of polyalphaolefin hydraulic fluids was found in the available literature.

4.2 IMPORT/EXPORT

No information on the import/export of mineral oil hydraulic fluids, organophosphate ester hydraulic fluids, or polyalphaolefin hydraulic fluids was found in the available literature.

4.3 USE

Hydraulic fluids are a very diverse class of mixtures that are used in mechanical systems for transmitting pressure (Wills 1980). The choice of which hydraulic fluid class and which specific hydraulic fluid to use in a particular application is based on a number of factors including the type of application, environment, and equipment using the fluid.

Mineral Oil Hydraulic Fluids. Mineral oil hydraulic fluids are used in numerous applications such as automobile automatic transmissions (hydrokinetic transmission) and power steering units, elevators, farm equipment (including lifting and tilting mechanisms), mining, energy, chemical manufacturing,primary metals, machining, and manufacturing (such as forklift trucks, loading systems, metal working machines and systems, hydrostatic transmissions, and work-holding systems) (Papay 1993; Wills 1980). Mineral oil-based hydraulic fluids constitute the largest class of hydraulic fluids and are used in a large number of industrial, commercial, and consumer applications.

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Water-in-oil emulsion hydraulic fluids are used not only in applications such as those described above, but also where leaking hydraulic fluid could contact an ignition source such as in mines, general industry, and rolling mills (Wills 1980). They are temperature sensitive and do not withstand freezing temperatures; their applications, therefore, are limited to environments where freezing temperatures do not exist.

In the past, hydraulic fluids using mineral oils sometimes included such additives as PCBs to improve the thermal resistance or other properties of the resulting fluids. While such uses of PCBs have been discontinued, PCBs at NPL sites may be encountered as a component where hydraulic fluids are a site contaminant (ATSDR 1993b).

Organophosphate Ester Hydraulic Fluids. Military and commercial performance needs for fire resistance, a wide range of operating temperatures, and improved safety in handling and storage provided the impetus for the development of many types of organophosphate esters as synthetic lubricant products and feedstocks during the 1940s and 1950s (Marino and Placek 1994). Organophosphate ester hydraulic fluids are used where fire retardancy is needed, such as on aircraft, in marine applications, in electrohydraulic control systems of steam turbines, and in industrial systems where leaking fluid might contact an ignition source (Papay 1993; Wills 1980). In addition, organophosphate esters also are used as antiwear additives in hydraulic fluids and other lubricants; of the organophosphate esters discussed in this profile, Durad 110, 125, 220B, and 300 are categorized by their manufacturers as antiwear additives and not as hydraulic fluids (FMC 1991 c, 1991 d, 1992a, 1992b; Marino and Placek 1994). When used as hydraulic fluids or lubricants, organophosphate esters act as solvents on a variety of hydrocarbon-based seals, hoses, paints, coatings, and elastomers used with machinery or other equipment. Without proper maintenance, leaks from seal and hose failures can lead to spills and releases to the environment (Marion and Placek 1994).

Polyalphaolefin Hydraulic Fluids. Polyalphaolefin hydraulic fluids have properties comparable to the most effective components in mineral oil and are used in applications identical to mineral oil hydraulic fluids (Chrisope and Landry 1993; Papay 1993; Shubkin 1993; Wills 1980). Polyalphaolefins are more expensive than mineral oil, and this may limit their use in industry. In addition, polyalphaolefin hydraulic fluids are used in military applications such as aircraft and missile hydraulic systems, tank recoil and hydraulic systems, and aerospace test stands (Shubkin 1993).

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4.4 DISPOSAL

Mineral Oil Hydraulic Fluids. Disposal of used mineral oil hydraulic fluids is regulated as used oil under the Solid Waste Disposal Act as amended by the Resource Conservation and Recovery Act (RCRA) and as amended by the Used Oil Recycling Act (42 U.S.C. 6901,6905,6935,6937-6939, and 6074, see 40 CFR parts 260,261,266,271, and 279). Used mineral oil hydraulic fluids to be recycled are not listed as hazardous wastes and can be burned for energy recovery or recycled. In general, the newer mineral oil hydraulic fluids (including water-in-oil emulsion fluids) do not contain known chemicals or other materials that are listed in 40 CFR 261 (RCRA) and can be burned for energy recovery or recycled. However, this may not apply to some of the older hydraulic fluids, particularly those containing PCBs.

Organophosphate Ester Hydraulic Fluids. Disposal of used organophosphate ester hydraulic fluids is regulated as used oil under the Solid Waste Disposal Act as amended by the RCRA and as amended by the Used Oil Recycling Act (42 U.S.C. 6901,6905,6935,6937-6939, and 6074, see 40 CFR parts 260,261, 266,271, and 279). Used organophosphate ester hydraulic fluids to be recycled are not listed as hazardous wastes and can be burned for energy recovery or recycled. In general, the newer organophosphate ester hydraulic fluids do not contain known chemicals or other materials that are listed in 40 CFR 261 (RCRA) and can be burned for energy recovery or recycled.

Polyalphaolefin Hydraulic Fluids. Disposal of used polyalphaolefin hydraulic fluids is regulated as used oil under the Solid Waste Disposal Act as amended by the RCRA and as amended by the Used Oil Recycling Act (42 U.S.C. 6901, 6905, 6935, 6937-6939, and 6074, see 40 CFR parts 260, 261, 266, 271, and 279). Used polyalphaolefin hydraulic fluids to be recycled are not listed as hazardous wastes and can be burned for energy recovery or recycled. In general, the new polyalphaolefin hydraulic fluids covered in this profile do not contain known chemicals or other materials that are listed in 40 CFR 261 (RCRA) and can be burned for energy recovery or recycled.