27
Lubricants and Fluids for the Food Industry

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27.1 INTRODUCTION

Consider the following facts related to the food industry in the United States:

- About 1.5 million workers are employed by the food industry (nonfarm payrolls). This represents about 14% of the total number of people employed in the U.S. manufacturing sector (Figure 27.1).*
- U.S. households spend 12.6% of their income on food, which comes third after housing and transportation, which represented 33.3% and 17% respectively of the household expenditure in 2014.†
- The agricultural sector contributed about 4.8% of the gross domestic product (GDP) in the United States in 2014.‡
- The food-processing sector in the United States had 21,000 companies that generated revenues of $750 billion in 2015 representing ~37.5% of the global processed food sales of $2 trillion.[1]

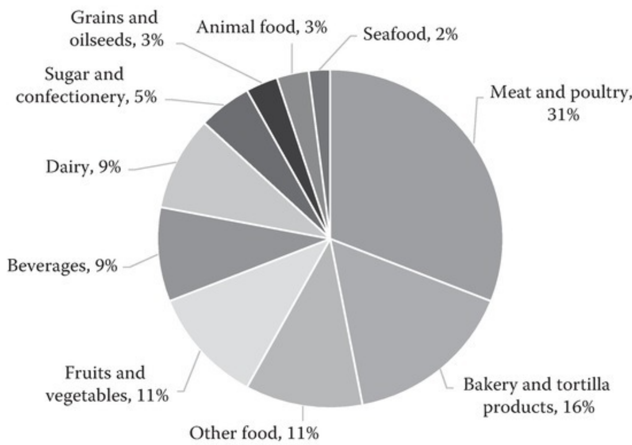

FIGURE 27.1 Employment breakdown in the food industry in the United States (2013). (From An overview of the state of the food processing industry, Pollack papers, http://www.pollock.com/an-overview-of-the-state-of-the-food-processing-industry, 2015.)

The food industry in the United States is thus fairly sizable; it may be extrapolated that the same is applicable to most other countries, albeit with varying numbers.[2] In this chapter, the term "food industry" or "food-processing industry" will be used generically and may encompass any or all of the following stages: manufacturing, processing (including heating and cooling, slicing, dicing, mixing, cooking, bottle filling, carbonation, and blending), and packaging.

Specialized warehousing (refrigerated and atmosphere-controlled[3]) as well as refrigerated mobile transportation constitutes a major component in food manufacturing at all stages: pre-manufacturing (raw materials), during manufacture, and post manufacturing but pre-retail (finished goods). To put this in perspective, there are 4.17 billion cubic feet of refrigerated storage capacity in the United States, with five states contributing to about 37% of the total.[4] Despite its interesting nature, this aspect will not be discussed in this chapter.

The food industry uses raw materials, hard goods used for packaging, as well as utilities and services. Aside from this, a large variety of equipment is used in the food industry and it often relies on a similarly large variety of lubricants and fluids. The focus of this chapter will be on lubricants and fluids preceded by a general overview of the equipment used (Figure 27.2).

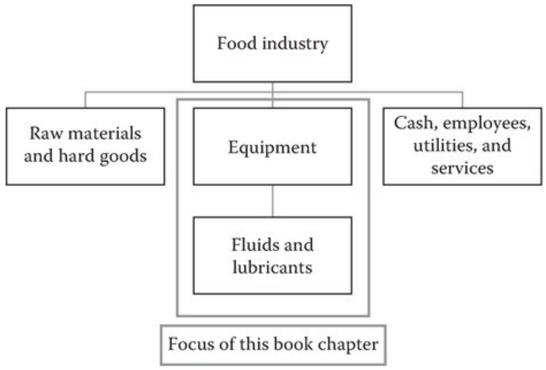

FIGURE 27.2 Food industry—essential components that keep it going.

This chapter will be split into four sections:

1. Equipment used in the food industry
2. Lubricants and fluids used in the food industry[*]
3. Formulation considerations for lubricants and fluids
4. Trends and summary

27.2 EQUIPMENT USED IN THE FOOD INDUSTRY

The equipment used in the food industry ranges from air compressors, hydraulic pumps, hydraulic motor-driven systems, gear drives, and conveyors to cutters and slicers, mixers, homogenizers, filtration systems, and packaging lines. Additionally, heating and cooling systems are extensively used during the manufacture and processing of food (Table 27.1). Depending on the operation, a food-manufacturing plant may have all or some of the equipment mentioned earlier. A lot of the equipment is supplied by "original equipment makers" (OEMs). Like other industries, there are OEMs whose equipment is either directly used by the industry, for example, compressors, or the equipment is integrated into larger systems that are customized for the operation, for example, packaging lines which may involve hydraulic pumps and gear boxes. Some OEMs are exclusively dedicated to the food industry, for example, meat cutting and slicing equipment, while others service a variety of industries. (The reader may refer to Section 27.3.1 for details on OEM approvals, etc.)

TABLE 27.1
Types of Equipment and Its Application in the Food Industry[a]

Equipment Type	Application	Extent of Usage in Plants
Compressors	Used to compress air, CO_2, nitrogen, refrigeration gases (ammonia, HFC, etc.), and other specialized gases	100% of plants have air compressors; few exceptions exist
	Air compressors can be used for blow tanks, or moving solid renderings to various locations of the plant including dumpsters	A typical plant may have 3–15 rotary screw air compressors and anywhere from 5 to 40 rotary screw ammonia compressors
Hydraulic systems	Used for various types of work such as lifting or in equipment used for hide pulling	A typical plant has numerous hydraulic systems; some are small integrated into the machinery while some are large centralized systems which send oil out to multiple locations and it is

		returned to a centralized pump
Gear boxes	Used in conveyer systems and chain systems in slaughter houses. Other equipment is blood dryers	Wide usage especially where the product has to be continuously transported from one location to another (which is most plants)
Heat exchangers	Used in heating or cooling processes in plants; usually the fluid flowing through this is coming in hot and is cooled to the temperature needed or vice versa, for example, frozen food manufacturing	Most plants have one or multiple systems with heat exchangers

[a] Part of this information is based on private communication from Mr. Ben Duval, US Petrolon Industrial, Lincoln, NE, 2016.

It is beyond the scope of this book to go into further details of the equipment. For example, it is beyond the scope to describe that type of hydraulic systems (vane or piston), or what type of gears (worm, planetary), or what type of air compressors (screw or reciprocating). Discussion of specific OEMs is also excluded since the "Food Industry Master" serves as an excellent source of this information.[5]

Most of the gear and hydraulic equipment used in the food industry is often lighter duty than what is found in heavy industries such as steel, mining, and so on. However, equipment reliability constitutes a major consideration in the food industry as downtime can be very costly. In many food-processing applications, "just in time" processing of food occurs. For example, chicken operations literally have trucks lined up and deliveries are timed. Any breakdown in operation creates major financial losses. Coupled to this, the food industry continues to focus on higher throughput, which means that machinery is moving at higher speeds and higher temperatures. This means that every effort needs to be made to service and maintain equipment; ideally, longer service intervals automatically reduce the need for backup equipment or additional downtime. As a corollary, the lubricants and fluids used to maintain the equipment need to be of high quality and reliability as well.

27.2.1 Rotating Machinery Used in the Food Industry

Rotating machinery includes pneumatic equipment such as air compressors or hydraulic systems and gear boxes. The rotating equipment generally converts electrical power to mechanical work and is almost ubiquitously used in the food industry. As a consequence, the food industry spends a sizable amount on power transmission equipment purchases (Figure 27.3).

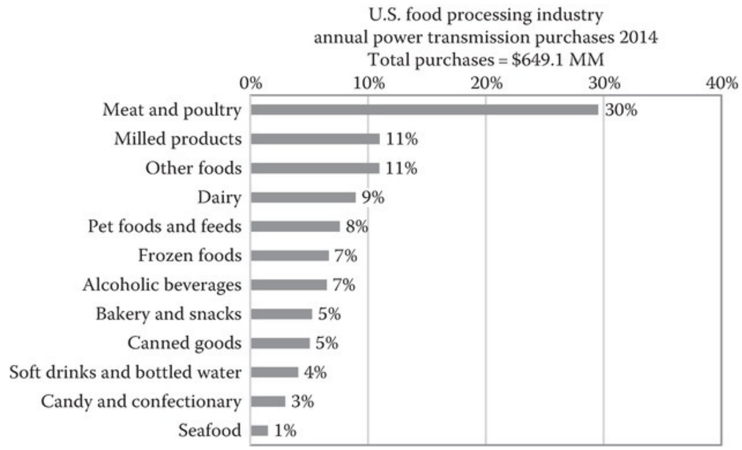

FIGURE 27.3 Annual power transmission purchases by the food-manufacturing industry in the United States. (From An overview of the state of the food processing industry, Pollack papers, http://www.pollock.com/an-overview-of-the-state-of-the-food-processing-industry, 2015.)

27.2.2 Other Equipment Used in the Food Industry

Numerous other pieces of equipment are used in the food industry such as cutters, slicers, mixers, sifters, homogenizers, can seamers, ovens, and associated systems, which include heating and cooling systems. Direct fired or natural gas–powered heaters and boilers are also common. Aside from this, there are several ancillary pieces of equipment such as filtration devices, waste handlers, and other specialized equipment. Last but not least, food-packaging lines constitute a big portion of equipment, which is often located at the point of exit in a plant. Food-packaging equipment can get extremely sophisticated with multiple filling lines often requiring the use of inter gas or carbonation for sodas and beverages, and sometimes for handling perishable items.

27.3 LUBRICANTS AND FLUIDS USED IN THE FOOD INDUSTRY

With the wide usage of equipment, it is not surprising that food plants use a fair amount of lubricants and fluids (Figure 27.4).

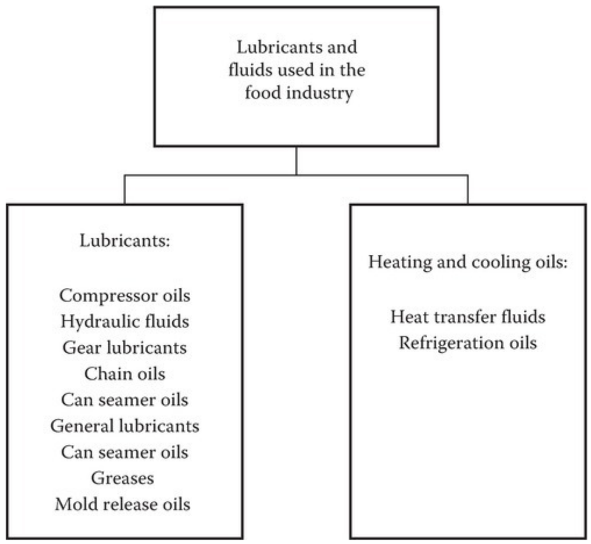

FIGURE 27.4 Types of lubricants and fluids used in the food industry.

The total volume of fluids used in a plant is dependent on many factors starting with the size of the plant and the nature of the operation.

There are generally numerous lubricant fluids used. Typically hydraulic fluids, gear oils, and compressor oils constitute the bulk of the annual lubricating fluid volume. This is followed by specialized fluids such as (but not limited to) chain oils and can-seaming oils. Fill volumes and change intervals vary for fluids. Greases, pastes, and aerosols are also used but are excluded from the discussion.

Heating and cooling constitutes a key function in the industry. The process is facilitated by the use of heat transfer systems (utilizing heat transfer fluids) and refrigeration systems (utilizing refrigeration compressor oils). These constitute a fairly significant category of non-lubricant fluids used in a plant. The highest volume of heat transfer fluids and refrigeration oil generally occurs at start-up while subsequent fills occur due to servicing or operational losses and/or upgrades. A list of types of fluids used in a food plant and typical change intervals is given in Table 27.2.

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TABLE 27.2
Type of Fluid and Typical Change Interval in a Food Plant

Type of Fluid	Typical Change Interval	Typical Volume in a Large Beef Processing Plant[a]
Air compressor oil	Depends on name plate oil life; typically 2,000, 4,000, 6,000, 8,000, 12,000 h	220–440 gal
Hydraulic fluid	At least annual or more frequent	10,000–15,000 gal
Industrial gear oil	Long-lasting	500–1,000 gal
Chain oil	Consumable	Varies
Vacuum pump oils	Depends on application	220–330 gal
Grease and miscellaneous lubricants, e.g., aerosols	Grease—often filled for life bearings	Varies
Heat transfer fluid	Long-lasting except for leaks; more frequent with commonly sold paraffinic oils	5000–30,000 gal
Ammonia (R-717) refrigeration oil	Unlikely to require change	440–660 gal

[a] Private communication from Mr. Ben Duval, President, US Petrolon Industrial, Lincoln, NE, April 2016.

27.3.1 Special Considerations for Lubricants and Fluids Used in the Food Industry

27.3.1.1 OEM Approvals

One must be very mindful of OEM guidelines for the recommended fluids and lubricants used. Often, an OEM may offer its own branded fluid which is developed to best work in their equipment. Furthermore, the equipment warranty may be tied to the usage of the OEM-branded fluid. The choice of lubricants and fluids should be made according to the following order: OEM-branded fluids, OEM-approved or OEM-recommended fluids, a fluid known to be an equivalent.

27.3.1.2 Regulatory Compliance

While there is no mandated law that requires the use of specific fluids, there are several regulations and specific industry-accepted practices that apply to the food industry requiring the use of specific lubricants and fluids. There is also a growing trend overseas regarding applying these as well as local regulations.[6]

- Good manufacturing practices (GMP)
- Hazard analysis critical control point (HAACP)
- National Sanitation Foundation (NSF) registration for lubricants and fluids
- Compliance with other certifications/approvals (Kosher, Halal, others)
- ISO certifications (ISO 9001, ISO 21469)
- Responsible care certifications (RC140001)

If one decides to purchase fluids that meet all of these requirements, then the list of available suppliers and fluids becomes narrower. Due to this, the fluids and lubricants market for the food industry is often considered a niche market.

27.3.1.3 NSF Registration

Lubricants are one of the most widely used and serviced fluids in food manufacturing. While the term “food-grade lubricants” is widely used in the industry (for H1 lubricants), it is the author’s opinion that this term should be avoided; it is misleading in that the end user may be led to believe that the lubricants meet the same safety standards as edible food and/or food ingredients, which is not the case. The term “incidental food contact lubricants” should be used instead and only for H1 lubricants. Furthermore, the United States Department of Agriculture (USDA) has strict guidelines on how much contamination of food by the lubricant or fluid is tolerated and the percentage of contamination is rather low.

From a historical perspective, the USDA first initiated guidelines for incidental food contact lubricants (this was mainly driven by meat- and poultry-processing plants) but abruptly discontinued the program in 1998, and it was then taken over by the National Sanitation Foundation (NSF), Ann Arbor, MI. An alternate attempt by the Underwriters Laboratory (UL), Chicago, IL, was initiated but for various reasons the NSF program is now the program of choice. While lubricants can be self-certified, most food manufactures now expect NSF registration from their suppliers. This stems from increased awareness of the program, mainly due to the diligent efforts of the NSF, which have been coupled with a highly efficient and reliable system of scrutiny and approvals. The online availability of the information at the NSF website (www.nsf.org) plus well-organized annual steering committee meetings has lent further value to the program.[7]

The industry is increasingly using lubricants and fluids registered with the NSF in Ann Arbor, MI, under the following categories:

NSF H1: Lubricants where indirect contact with food is possible
NSF H2: Lubricants where no contact with food is possible
NSF H3: Trolley and miscellaneous oils
NSF 3H: Release agents for direct food contact
NSF HT1: Heat transfer fluids where indirect contact with food is possible
NSF HX1: Category for components—base oils and additives

The distinction between the categories is shown in Table 27.3.

TABLE 27.3
Classification of Lubricants Used in the Food Industry

Lubricant/Fluid Classification	Application	Compliance
H1	Application where there is possibility of food contact	21 CFR Section 178.3570 or NSF review[a]
H2	Application where there is no possibility of food contact	Not defined but generally the lubricants must be free of any toxic heavy metals or ingredients; also subject to NSF review
H3	Trolley oils	None defined
HT1	Heat transfer fluids	21 CFR Section 178.3570 or NSF review
3H[a]	Release agents	21 CFR 172.878, GRAS substances and defoamers 21 CFR 173.340 (a)(1) and (a)(2)

[a] Greases are excluded but are classified as H1 or H2.

The NSF program for lubricants (H1–H3 categories) falls under its "Nonfood Compounds" program, which also includes "Water Treatment Compounds" (G1–G7), "Cleaners" (A1–A8), "Non-processing Area Products" (C1–C3), and some other registrations. Lubricants constituted 9889 registrations in 2015, which represented 54% of all the nonfood registrations. Since 2009, the lubricant category (H1 and HX-1) has seen a steady increase in registrations with approximately 6250 registrations in 2009 and 9889 registrations in 2015.[2]

27.3.1.3.1 NSF Registration Process

The NSF registration is initiated via a formal application process that requires full disclosure of components, the trade name of the product, and a representative label. The application is then reviewed at the NSF against a list of registered components and the limits of use set for these components. Should all criteria be met, an NSF registration number in the appropriate category (H1, H2, H3, HT1, HX-1) is granted. Should any component not be on the registered list, additional information is often required by the NSF and approval is not guaranteed. Rebrand registrations are also permitted.

27.3.1.3.1.1 Approval of Components and Base Oils

Additive components and base oils used in the formulation of H1 lubricants must belong to a specific section in the Code of Federal Regulations, Book 21. These sections include the following[8]:

- Incidental food contact lubricants (21 CFR Section 178.3570)
- Prior sanctions list (21 CFR Section 181)
- "Generally Recognized as Safe" (GRAS) (21 CFR Section 182)

As noted earlier, the NSF is the primary entity that registers H1 lubricants.[9] All ingredients and base oils that belong to the 21 CFR lists have now been classified as HX-1 or H1 respectively by the NSF.

Section 178.3570 specifically contains ingredients that can be used as lubricating additives or base oils for incidental food contact applications. To be listed in this section, the supplier has to petition the Food and Drug Administration (FDA). This review could result in an opinion letter from the FDA (which generally applies to chemical equivalents such as in cases where the sodium salt is listed but the potassium salt is not) or a full review for new ingredients. A full review can be very expensive and time-consuming. Over the years, a key global supplier headquartered in Germany has effectively developed, petitioned, and won approval for a large number of its additives. These are listed in Section 178.3570. On the base oil side, there are many suppliers who have successfully passed FDA scrutiny.

The prior sanctions list does not specifically include ingredients for use in incidental food contact lubricants. However, if ingredients on these lists will function as additives or base oils, they may be used in incidental food contact lubricants. The prior sanctions list does not change as its components have been grandfathered due to history of safe use.

GRAS is a well-established list that contains numerous ingredients which are mostly of value for food use but there are some ingredients on the GRAS list that have lubricating properties. For example, vegetable oils would fit into this category as they are listed on the GRAS list and can be used as lubricant base oils. Likewise, lecithin and certain fatty acids are GRAS-listed and may also be used in lubricants. In order to include ingredients on the GRAS list, the supplier can either self-affirm its GRAS status or petition the FDA.

27.3.1.3.1.2 Registration of the Fully Formulated Lubricants and Fluids

Generally, lubricant suppliers to the food industry undertake the exercise of registering their products as H1 or H2 lubricants with the NSF. It must be noted that NSF registration is not mandatory and suppliers may self-certify their products.

27.3.1.4 Other Certifications/Approvals

The two key approvals are Kosher and Halal. Food-manufacturing facilities that make Kosher and Halal food usually expect that the ingredients as well as the fluids and lubricants they use would also have Kosher and Halal approvals.

For Kosher and Halal manufacturers of additives, base oils or finished lubes must generally meet two distinct levels of compliance:

- The plant and process where the product is made must generally be Kosher- or Halal-compliant.
- All the components used in the finished lubricant or fluids must themselves be Kosher- or Halal-certified.

Due to this, it is typical to seek out two letters from the Kosher- and Halal-certifying authorities: one for the facility and one for the products. Jewish dietary laws are termed "kosher."[10] Although there may be slight differences in interpretation by various kosher-certifying agencies, the ingredients and/or facility must meet the following criteria:

> The products cannot mix meat and milk products or contain pork and related products. Moreover, if there is an animal-derived product then the animal must be slaughtered according to kosher guidelines. From a procedural standpoint no product should be processed on equipment that is processing non-Kosher material. In such cases, special cleaning and 24-hour wait periods apply.

In the United States, there are about 300 agencies that offer kosher certification. The Orthodox Union in Manhattan, New York, is the largest and certifies about 4500 facilities in 68 countries. The process involves a fee and a mandatory visit to the facilities by a rabbi. In order to maintain certification, a company must be willing to pay the requisite fee and be amenable to unannounced inspections.

Muslim dietary laws require the imposition of "halal" (meaning lawful vs. "haram," which means unlawful), which means that the facility and/or ingredients must meet the following criteria[11]:

> Kosher approvals described earlier and additionally animal products must be made using Halal laws. Alcohol must be excluded from a product and so should pork-derived products. The Islamic Food and Nutrition Council of America (IFANCA), Chicago, Illinois issues Halal certificates, and the process involves a fee as well as annual inspections.

While neither of these is mandatory, the potential customer base that expects adherence to these certifications is significant. In 2010, there were about 13 million Jews and almost 1.6 billion Muslims worldwide, which translates to a sizable customer base.

27.3.1.5 Other Factors to Consider for Incidental Food Contact Lubricants

In addition to the considerations indicated earlier, the manufacturer may consider using "good manufacturing practices" (GMPs) or registration against specific "International Standards Organization" (ISO) standards such as 9001, 21469 or against the American Chemistry Council's Responsible Care RC14001 initiative.

GMP involves self-established protocols during manufacture that can ran range from cleaning protocols to analysis for heavy metals and can be self-managed. The ISO standards, which are now common, involve annual audits and fees.

All the registrations involved add cost to the entire process. This is generally reflected in the price of these lubricants when compared to conventional lubricants. An excellent overview of challenges encountered in the development and manufacture of incidental food contact lubricants has been recently published.[12]

Figure 27.5 provides a summary of various criteria that must be met at the ingredient level, the finished fluid or grease level, or the plant level.

Ingredients Additives Other components Base oils	Finished lubricants and fluids[a] Lubricating oils Heat transfer fluids	Facility Manufacturing and packaging sites
21 CFR sections Incidental food contact Lubricants 178.3570 GRAS 182 Prior sanctions 181 Other NSF HX-1 Kosher Halal	21 CFR Sections Incidental food contact Lubricants 178.3570 GRAS 182 Prior sanctions 181 Other NSF H-1 Kosher Halal ISO 21469 OEM approvals	Facility[a] GMP Kosher Halal ISO 21469 ISO 9001

FIGURE 27.5 Summary of criteria for incidental food contact lubricants. [a]*Note:* Greases, pastes, and aerosols are excluded from the discussion; as are H2 lubricants and 3H category fluids (release oils).

27.4 FORMULATION AND APPLICATION CONSIDERATIONS FOR LUBRICANTS AND FLUIDS

27.4.1 Formulation Considerations for Lubricants

Lubricants are generally comprised of additives and base oils that are formulated together to meet specific performance requirements. These requirements may be dictated by the OEM (OEM-specific) or by industry standards (DIN, AGMA, NLGI). When such requirements do not exist, qualified lubricant or fluid suppliers, based on their knowledge, may offer products fit for the purpose.

27.4.1.1 Components Used in Incidental Food Contact Lubricants

Under the USDA program, the components that could be used in incidental food contact lubricants belonged either to the 21 CFR Section 178.3570, the GRAS list, or the prior sanctions list. Therefore, there was no specific category for lubricant components. The finished lubricants were then registered by the USDA under the NSF H1 category. Since the NSF took over the program, a new category termed NSF HX-1 has been created for components, which include additives, thickeners, and base oils. Finished lubricants are still classified under the NSF H1 category.

27.4.1.1.1 Base Oils for Incidental Food Contact Lubricants

Whether the lubricant is an oil or grease, the base oil is often the majority ingredient in a formulation. Reference was made to the FDA review of components and in a review of mineral oils, the presence of aromatics in mineral base oils is not tolerated. This led to the approval and use of technical white mineral oil as a base oil. While there may be some speculation, it could be argued that the fact that poly-α-olefins (PAOs) and polybutenes/polyisobutylenes (PIBs) are free of aromatics may have formed one of the bases on which approval was granted. In addition to hydrocarbon base oils, polyalkylene glycols (PAGs) are also NSF-registered. More recently, the variety of esters and oil-soluble polyalkylene glycols (OSPs)[13] have been NSF-registered as NSF HX-1. The benefit of esters is the ability to solubilize additives and varnish while OSPs are not only compatible with both PAGs and hydrocarbon base oils but also result in cleaner lubricants.[14] Additionally, technology is available for vegetable oil–based incidental food contact lubricants and is covered in a U.S. patent.[15] Vegetable oils can be used by virtue of their GRAS status. This means that a wider range of base oils is now available to a formulator (Table 27.4) than it was at the time of writing of the first edition of this book.

TABLE 27.4
Typical Properties of Base Oils

Base Oil	ISO Viscosity Range	Pour Point (°C)	Antioxidant Response[a]
Technical white mineral oil	32/46	−9	Excellent
Group II oils	32/46	−9	Excellent
PAO	32/46	<−30	Excellent
PIB	220 to >1000		Good
PAG	32/46	−12	Good
Vegetable oils	32 and 220	−15	Moderate to poor
Esters	46–1000	−45	Good
Silicones	46	−50	[b]
Perfluoro oils	32	~−12	[b]

[a] Subjective comparison.
[b] Most additives are not soluble in these base oils.

The approval of new base oils such has esters has helped the development of improved lubricants. For example, a key supplier of synthetic air compressor oils has recently developed a 12,000 h air compressor oil that is NSF H1-registered. The data on this product are shown in Table 27.5.[16]

TABLE 27.5
Air Compressor Oil with >8000 h Life That Uses PAO and an NSF HX-1 Registered Ester

CPI®-4265-68-F
EXP-5158
S010-3864-12-736
OS343168A

Physical and Analytical Test Results

Properties	Test Method	LZ Test Code	ISO VG 46	ISO VG 68
Viscosity	ASTM D445			
40°C		D445_40	46.88	68.18
100°C		D445_100	7.71	10.56
Viscosity index	ASTM D2270	D2270	132	143
Density (g/mL)	ASTM D4052			
15.6°C		D4052_15.6	0.8551	0.8579
20.0°C		D4052_XX	0.9517	0.8552
Total acid number (mgKOH/g)	ASTM D974	D974	0.77	0.18
Neutralization number (mgKOH/g)	ASTM D664	D664		
TAN—inflection			0.7	0.1
TAN—buffer point (aqueous)			0.7	0.1
Flash point (°C)	ASTM D92	D92	262	288
Fire point (°C)	ASTM D92	D92	298	302
Pour point (°C)	ASTM D5950	D5950	−51	−42
ICP trace levels	ICP 7	1272		
Sulfur				
Color	ASTM D1500	D1500	L0.5	L0.5
Foaming tendency (mL)	ASTM D892	D892		
Sequence I				340/0
Sequence II				20/0
Sequence III				360/0
Demulsibility	ASTM D1401	D1402_54	42-38-0 (15)	40-38-2 (15)
Copper strip corrosion	ASTM D130	D130	1B	1B
Rust test	ASTM D665 A and B			
Part A		D665_A	Pass	Pass
Part B		D665_B	Pass	Pass
Air separation (min)	ASTM D3427			6.6
RPVOT (min)	ASTM D2272	D2272	—	2668
PDSC (min)	PDSC_FINOIL	PDSC_FINOIL	—	151.6

Properties	Test Method	LZ Test Code	Results
Foaming tendency (mL)	ASTM D892	D892	
Sequence I			340/0
Sequence II			20/0
Sequence III			360/0
Demulsibility	ASTM D1401	D1402_54	40-38-2 (15)
Copper strip corrosion	ASTM D130	D130	1B
Rust test	ASTM D665 A & B		
Part A		D665_A	Pass
Part B		D665_B	Pass
Air separation (min)	ASTM D3427		6.6
RPVOT (min)	ASTM D2272	D2272	2668
PDSC (min)	PDSC_FINOIL	PDSC_FINOIL	151.6
NOACK volatility	ASTM D5800	D5800_200	
Carbon residue	ASTM D189	D189	
Seal compatibility	ASTM D5662		
Fluoroelastomer			
Volume change (%)			1.00%
Durometer change (points)			−2
Tensile change (%)			3%
Elongation change (%)			−3%
Polyacrylate			
Volume change (%)			0.00%
Durometer change (points)			5
Tensile change (%)			25.60%
Elongation change (%)			−34.90%
Nitrile			
Volume change (%)			1.00%
Durometer change (points)			−1
Tensile change (%)			−7.00%
Elongation change (%)			−25.70%

Properties	Test Method	LZ Test Code	Results
Dielectric constant	ISO 17025	DIELEC_CONST	
20.3°C			2.48
96°C			2.33
149.3°C			2.24
Electrical conductivity (ps/cm)	ASTM D2624	COND-1	
21°C			0.08
Thermal conductivity (W/mK)	ASTM E1530	TC-OIL	
44.64°C			0.198
74.27°C			0.183
104.05°C			0.178
123.81°C			0.173
Heat capacity	ASTM E1269	CP-DSC	
40°C			2.220
50°C			2.259
60°C			2.297
70°C			2.336
80°C			2.375
90°C			2.412
100°C			2.450
110°C			2.490
120°C			2.532
130°C			2.568
140°C			2.607
Latent heat (kcal/mol)		LATENT_HEAT	10.6
Vapor pressure(torr)	ASTM D2897		
100°F			0.010
150°F			0.043
200°F			0.140
250°F			0.40
300°F			1.00
350°F			2.3

Week Number	65°C @ Room Temp	Room Temp. @ Room Temp.	0°C @ 0°C	−18°C @ −18°C	0°C @ Room Temp.	−18°C @ Room Temp.
0		C				
1	C	C	C	C	C	C
2	C	C	C	C	C	C
3	C	C	C	C	C	C
4	C	C	C	C	C	C
8	C	C				

27.4.1.1.2 Additives

27.4.1.1.2.1 Thickeners

Typically, varying viscosity grades of lubricants are required. Common viscosity grades for various lubricants are listed in Table 27.6.

TABLE 27.6
Typical Viscosity Ranges for Incidental Food Contact Lubricants

Fluid Type	ISO Viscosity Range (Typical)
Hydraulic fluids	32–68 (46–68)
Gear oils	100–460 (220)
Air compressor oils	32–100 (46)

Polyisobutylenes (PIBs; Figure 27.6) are effective thickeners for mineral oil lubricants.

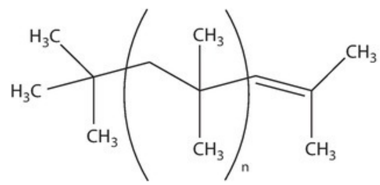


FIGURE 27.6 Chemical structure of PIB. Increasing “n” increases the molecular weight of the PIB and its thickening efficiency.

The thickening efficiency of a commercially available PIB is shown in Figure 27.7.[17] PIBs are available in various viscosity grades. Special handling of PIBs is required as the viscosity of the PIB itself increases. PIBs are soluble in hydrocarbon oils but may be insoluble in water-insoluble PAGs and certain esters. Vegetable oils have a limited viscosity range between ISO 32–46, which limits their usage in higher-viscosity applications, and PIB is generally incompatible.

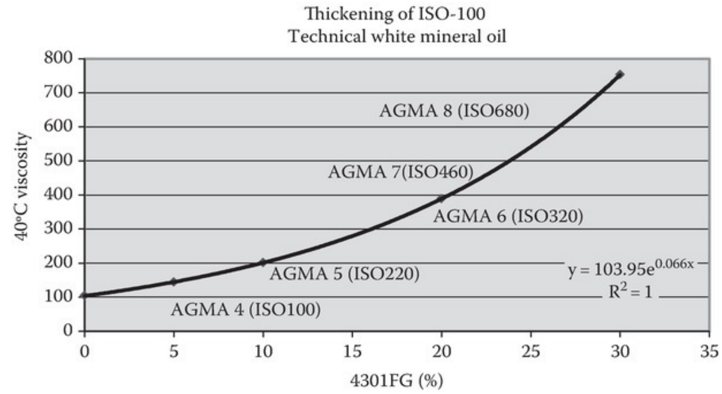


FIGURE 27.7 Increasing the ISO grade of incidental food contact lubricants.

27.4.1.1.2.2 Tackifiers

Tackifiers are used to impart stringiness to a lubricant, which in turn improves its adherence to surfaces. An excellent general review on this topic is available.[18] Tackifiers find use in chain oils used in the food industries. Traditionally, tack has been qualitatively measured and is often tested by the "sticky finger test." Here the number of strings between two fingers is counted and a large number of strings indicates better tack. A recent publication mentions that substantial progress has been made toward quantifying tack using an open-siphon method that ultimately measures "free jet" length (Figure 27.8), which is correlated with the tackiness.[19] Tack was found to be a result of exudation of solvent from a swollen gel in dilute polymer solutions of the tackifier in oil. Tack depends on the MW and concentration of the polymer and its viscoelastic properties. The only NSF HX-1-registered tackifiers are high-molecular-weight polybutene tackifiers. These polymers have the ability to "extend" and are also oxidatively stable due to their low level of unsaturation.

FIGURE 27.8 Free jet length resulting from tack. (From Breitner, A., 2015 nonfood compounds registration & ISO 21469 certification program update, NSF Steering Committee Meeting, 2015.)

27.4.1.1.2.3 Pour Point Depressants

While low-temperature properties are important in industrial and off-highway applications, most food manufacturing occurs in controlled conditions of temperature and low-temperature properties are not as critical. However, from the time of writing the book chapter for the first edition, there are now NSF HX-1-registered pour point depressants. These are typically maleic anhydride–styrene copolymers and, as seen in Figure 27.9, they are highly effective in lowering the pour point of technical white mineral oils.

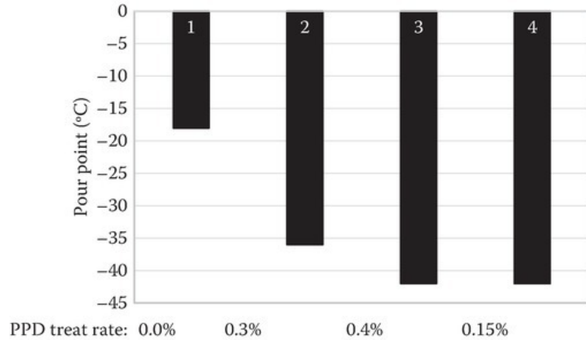
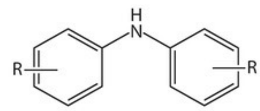


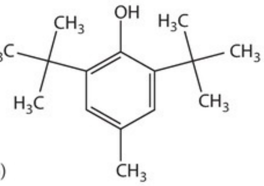
FIGURE 27.9 Commercial HX-1 registered pour point depressant in H1 registered white mineral oils. *Note:* Base oil kinematic viscosity at 40°C = 20 cSt.

27.4.1.1.2.4 Antioxidants

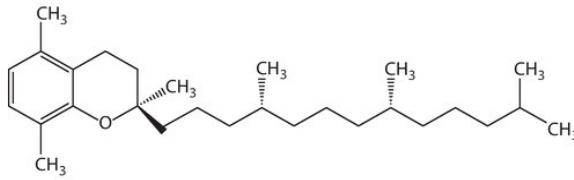
Incidental food contact lubricants are used in applications, including hydraulic fluids, gear oils, compressor oils, chain oils, and other lubricants and fluids. These lubricants are subject to oxidative stresses much like conventional lubricants but present additional challenges. First, the approved hydrocarbon base oils have very low polarity and solubilizing power due to the removal of the aromatic content in the oil. As a result, by-products of oxidation such as sludge are not easily solubilized and this can affect equipment performance. Second, these lubricants can be subject to temperatures as high as 350°F in oven chain oils and bearing grease. Finally, only a limited choice of approved antioxidants is available. Fortunately, Group II base oils and technical white mineral oils and PAOs, which are commonly used base oils in these applications, respond well to antioxidants due to the fact that they have very low unsaturation. Many antioxidants are available for incidental food contact lubricants. These include hindered phenols to substituted amine antioxidants. Some natural antioxidants such as tocopherols may also be used. The structures of some of these antioxidants are shown in Figure 27.10.



(a)



(b)



(c)

FIGURE 27.10 Chemical structures of antioxidants: (a) substituted diphenyl amine, (b) butylated hydroxyl toluene (BHT), (c) tocopherol E.

Substituted amine antioxidants are very effective in mineral oils although some darkening may be expected. Hindered phenols such as butylated hydroxyl toluene (BHT) are also very effective and may not cause as much discoloration. However, BHT may be difficult to solubilize in a blend and therefore there is a clear need for more soluble antioxidants.

The introduction of an antioxidant package, at the time of printing of the first edition, offers a product that is in liquid form and is highly effective in a variety of oils. The results of this package in technical white mineral oil are shown in Figure 27.11.[17]

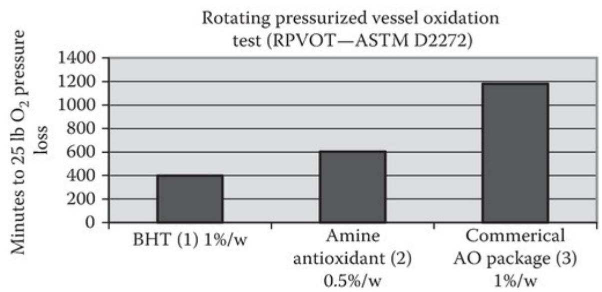


FIGURE 27.11 Performance of a commercial antioxidant package. (1) Shown at treat level comparable to the commercial antioxidant package, (2) shown at maximum permitted level, (3) shown at half the maximum permitted treat level. (From Raghaven, G.S.V. et al., Controlled atmosphere storage, in D. Heldman (ed.), *Encyclopedia of Agriculture, Food, and Biological Engineering*, CRC Press, 2003, pp. 148–150. United Nations Industrial Development Organization (UNIDO), Controlled atmosphere storage, paper 20, Retrieved from http://www.unido.org/fileadmin/32113_20ControlledAtmosphereStorage.2.pdf.)

27.4.1.1.2.5 Antiwear and Extreme-Pressure Agents

Antiwear agents are a crucial component of a lubricant. One of the most commonly used antiwear agents in incidental food contact lubricants is an amine phosphate salt shown in Figure 27.12. The amine phosphate salt also provides a degree of rust protection.

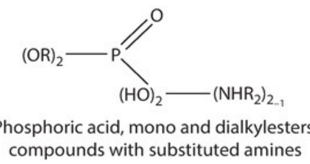


FIGURE 27.12 Chemical structure of a commonly used antiwear agent.

Other antiwear agents include glyceryl esters as well as certain fatty acids.

A limited number of extreme-pressure (EP) agents is available. One of the most commonly used EP components is triphenylphosphorothiorane (TPPT), which is a white crystalline solid (Figure 27.13). This does not contain "active sulfur" like conventional EP agents that are not HX-1-registered. While the approval of ingredients with active sulfur is desirable to obtain the EP performance of conventional EP agents (typical Timken OK loads in the range of 60+ lb), it appears that the industry has quite successfully managed with the use of EP agents shown in Figure 27.13. Very often, Timken OK load values obtained for mineral oil and PAO-based incidental food contact lubricants treated with TPPT are in the 15–25 lb range. Soluble versions of this EP agent containing alkyl substitutions on the aromatic rings are also available.

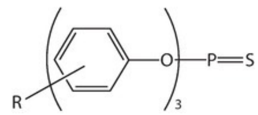


FIGURE 27.13 Chemical structures of commonly used EP agents—structure of triphenylphosphorothiorane (TPPT). R = H (solid), R = t-butyl; or nonyl (liquid).

27.4.1.1.2.6 Rust and Corrosion Inhibitors and Metal Passivators

Incidental food contact lubricants can be exposed to high-moisture conditions, which means that it is important that the lubricants have adequate rust and corrosion protection. Oleyl sarcosine is commonly used and is highly effective in mineral oils, PAO, and vegetable oils (Figure 27.14). A consistent pass test result can be obtained with this additive in both parts of the ASTM D665 rust test. The maximum treat rate permitted for this additive is 0.5% by weight. Substituted imidazolines are metal passivators (deactivator) (Figure 27.14).

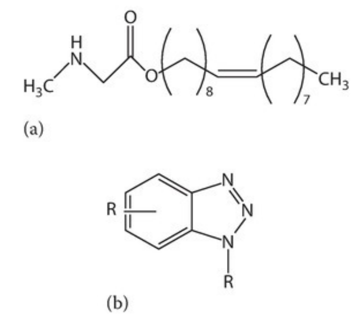


FIGURE 27.14 Chemical structures of rust inhibitors and metal deactivators. (a) N-methyl-N-(1-oxo-9-octadecynyl) glycine—oleyl sarcosine, (b) substituted imidazoline.

27.4.1.1.3 Defoamers

Defoamers are used to prevent excessive foaming. Silicon defoamers are approved for use in incidental food contact lubricants as long as the molecular weight of the defoamers is >2000 (Figure 27.15). They are highly effective in all approved base oils for this application.

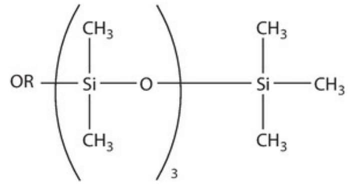


FIGURE 27.15 Chemical structure of a dimethylpolysiloxane defoamer.

27.4.1.1.4 Additive Packages for Incidental Food Contact Lubricants

As in conventional lubricants, additive packages simplify operation and can cut development time. One of the challenges in offering additive packages is to ensure that the limits specified for components must be adhered to. Hydraulic fluid additive packages are now offered by two leading additive suppliers. One of the suppliers offers a product that may be used in hydraulic oils as well as gear oils, thereby providing additional logistics simplicity. Key performance results for this additive package are shown in Table 27.7 and pump performance tests are shown in Table 27.8.[17]

TABLE 27.7
Performance of a Commercial Hydraulic and Gear Oil Additive Package

Test Method	Test Method ASTM or Other	ISO46 Hydraulic Fluid Typical Result	ISO 220 Gear Oil Typical Result
Performance tests			
Air release @ 50°C	D3427		
Air bubble separation in minutes		2.5	
Oxidation and seal performance			
RBOT (minutes to 25 lb oxygen pressure loss)	D2272	571	623
Seals 168 h/100°C	Hydraulic SRE-NBR28		
%Volume/hardness change			4.8/−5
%Tensile strength/elongation decrease			1.3/−4
Corrosion and wear performance			
Copper strip	D130		
3 h at 100°C		1B	1A
3 h at 121°C			1B
Rust test—part A/part B	D665	Pass/pass	Pass/pass
4-Ball wear test (167°F, 1200 rpm, 20 kg)			
Scar diameter (mm)		0.30	
Average friction coefficient		0.108	
4-Ball wear test (167°F, 1200 rpm, 40 kg)	D4172		
Scar diameter (mm)		0.37	0.37
Average friction coefficient		0.113	0.117

TABLE 27.8
Pump Test Performance of a Commercial Hydraulic and Gear Oil Package

Test Method	Initial/Final Flow (gpm)	Total Ring and Vane Weight Loss (mg)[a]	Ring Weight Loss (mg)[a]	Vane Weight Loss (mg)[a]
Eaton-Vickers V104-C 100 h at 150°F Conestoga	5.3/5.3	42	39	3
Eaton-Vickers 35VQ (50 h)		52	45	7

[a] The values indicated in the table are typical results and are not intended to be specifications.

27.4.1.2 Formulation Challenges for Incidental Food Contact Lubricants

The formulation of incidental food contact lubricants is challenging because the formulator has to abide by many restrictions and yet is often expected to deliver the same performance that is expected from conventional lubricants.[20] These include the following:

- Limited list of approved ingredients compared to conventional lubricants—this can also create product differentiation challenges since all suppliers have the same list of ingredients to draw from
- Limitations on the amount of additive that can be used
- Limited solubility of additives in technical white mineral oil and PAO

An article summarizing the challenges that was published almost 8 years ago still continues to be valid.[12]

27.4.2 Formulation Considerations for Other Fluids Used in the Food Industry

27.4.2.1 Heat Transfer Fluids

Heat transfer fluids are often the highest-volume fluid used in a food plant, and their usage can account for tens of thousands of gallons for a single plant since these are circulated to various locations in a plant. For a high-quality fluid, when temperature range limits are monitored and followed, and oil condition is monitored, the initial fill can last for a decade. Replenishment is not common unless leaks or other reasons require a changeover. Typical off-cycle fill of heat transfer fluids often stems from system leaks and fires. Some years ago, frying processes utilized direct fired frying kettles. However, with certain unfortunate accidents and the industry's attention to safety, most of these systems now utilize high-temperature heat transfer fluids. High-temperature heat transfer fluids are mostly used for frying chicken and potato chips. Instead of direct fire, specialized heaters (supplied by specific OEMs), often fired by natural gas, are used to heat the heat transfer fluid, which is then circulated to its point of use in the plant.

Heat transfer fluids are one of the most commonly used fluids in this category aside from ammonia refrigeration oils. Heat transfer fluids may be classified by the chemistry or temperature-operating range (Figure 27.16).

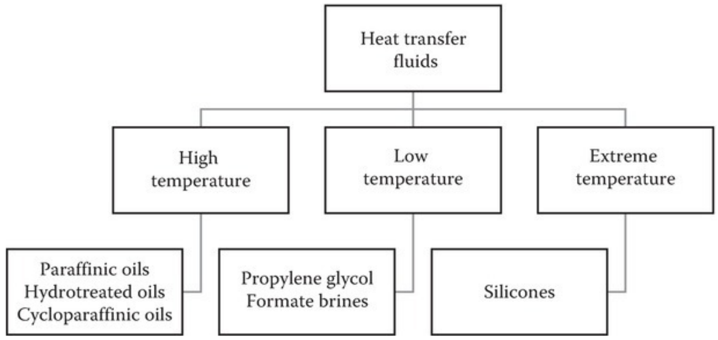


FIGURE 27.16 Heat transfer fluids used in the food industry.

The high temperature range within which a heat transfer fluid operates is often dictated by the chemistry—conventional paraffinic oils have the lowest high-temperature limit while silicones have the highest.

For high-temperature heat transfer fluids used at >450°F operating temperatures, NSF HT-1-registered paraffinic oils are widely promoted. However, despite claims, these often rapidly degrade as temperatures exceed 500°F. At temperatures exceeding 500°F, highly refined and custom-produced NSF HT-1-registered cycloparaffinic oils are a prudent choice that offers a very high cost/benefit ratio with outstanding thermal stability to 625°F. A comparison of key operational benefits of cycloparaffinic base oils versus paraffinic base oils is shown in Figure 27.17.[21]

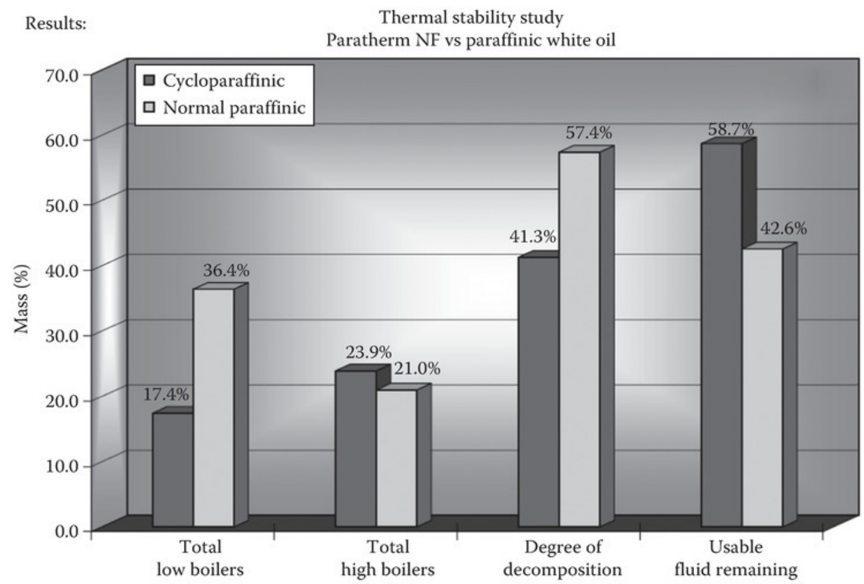


FIGURE 27.17 Comparison of thermal stability of heat transfer fluids. *Notes:* Value for *Total Low Boilers* includes gaseous decomposition products. Value for *Total High Boilers* includes residual materials not vaporized.

For low-temperature applications, propylene glycol (PG)–based heat transfer fluids are the staple of most food plants. They are low cost and NSF HT1-registered. The low-temperature properties are simply modified by using deionized water—each dilution leads to a progressively higher operating temperature for the fluid (higher pour points or worse low-temperature behavior). Typically, the fluid contains an inhibitor package to prevent corrosion. Formate-based brines are a very good alternative offering much better operational viscosity at lower temperatures than glycols.[22] Care must be taken for glycols and the formate brines (especially the brines) that deionized water is used and *all* materials of construction are compatible to avoid corrosion. Silicones are the most expensive option with a wide temperature range.

27.4.2.2 Refrigeration Oils

Refrigeration is a very common operation in the food industry. It can be used to cool secondary fluids or a space or a process. Ammonia-based refrigeration systems are widely used; CO_2 systems used independently or more often as cascade systems with ammonia are common.[23] Both these systems are common for plant-wide operations, and you can have several miles of ammonia piped in a large food plant. Finally, hydrofluorocarbon (HFC)-based systems are also used but generally in more localized cooling applications and rarely piped through an entire operation. Each gas poses its own benefits and challenges. With certain regulations on the volume of ammonia in a plant, it is common to use a secondary loop heat transfer fluid that is cooled by ammonia.

All refrigeration systems use compressors and these require lubrication. Screw compressors are very common. Ammonia systems can use mineral oil or synthetic PAO but never polyolester (POE) refrigeration oils. Ammonia–CO_2 cascade systems[24] additionally use POE-based lubricants, but strictly on the CO_2 side of the cascade. HFC refrigeration gases utilize POE-based lubricants.

As stated earlier, ammonia gas (R-717) refrigeration systems are very common in food-manufacturing plants as well as in cold storage applications. This is because despite its toxicity, ammonia is a natural refrigerant, which is cheap, highly efficient, and has zero "global warming potential" (GWP). Ammonia systems can save as much as 10%–20% on electricity costs versus comparable HFC systems as per a reputed refrigeration system supplier.[25] While large distributed systems are common, low-charge ammonia systems in which a secondary cooling fluid is circulated are growing in use as they lower the total ammonia charge at a facility.[25,26] The design of closed-circuit ammonia refrigeration systems is covered by the new American National Standard, ANSI/IIAR 2-2014.[27]

For lubrication of ammonia refrigeration systems, the choice of base oils is critical for longevity and performance. Almost all of the systems utilize screw compressors and have an oil return system that is set up for immiscible oils. The ideal viscosity in most ammonia applications is ISO VG 68. Hydrotreated mineral oils (HTMOs) work best from a cost performance standpoint and can last up to 7000 h compared to naphthenic oils that last only a few thousand hours. Alkylbenzenes (ABs) are also used. PAO lubricants offer premium performance (7000+ h) coupled with excellent low-temperature properties and (like the other oils mentioned) are immiscible with ammonia (see PAO data in Figure 27.18). NSF H1-registered products are available only in the PAO category.

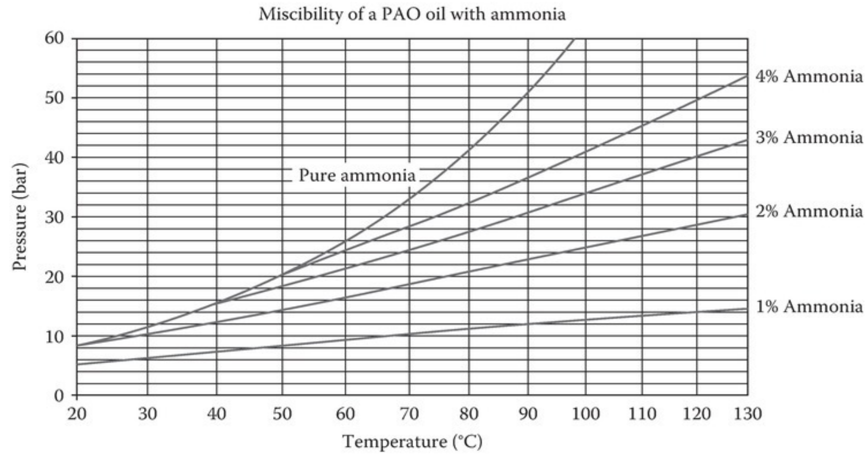


FIGURE 27.18 PAO-based ammonia oils make sense where immiscible oils are required.

PAGs are the fluids of choice for DX-style evaporators where a miscible oil is desirable (Figure 27.19).[28]

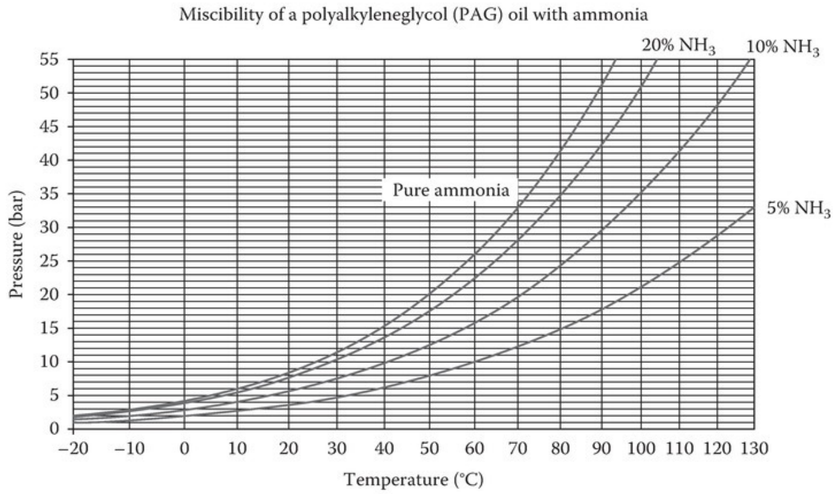


FIGURE 27.19 Why PAG-based ammonia oils make sense when miscibility is desired. *Note:* At typical operating temperatures of 60°C and pressures of 20–25 bar, PAG-based products will see a 20% dilution with ammonia resulting in a greatly reduced working viscosity making them unacceptable for use with regular ammonia systems. (Contrast that with a PAO lubricant shown in Figure 27.18.) PAG Oils are however used when a miscible oil is required as in DX style evaporators. At typical operating temperatures of 60°C and pressures of 20–25 bar, a PAO-based product will see a 2%–3% dilution with ammonia that provides a highly workable lubricant for ammonia systems. (Contrast that with a PAG lubricant shown in Figure 27.19.)

POE refrigeration oils, which are commonly used for HFC refrigeration, must *never* be used with ammonia oils as they result in the formation of solid amides (Figure 27.20).[28] This can be a very costly cleanup procedure in addition to leading to significant downtime in critical operations.

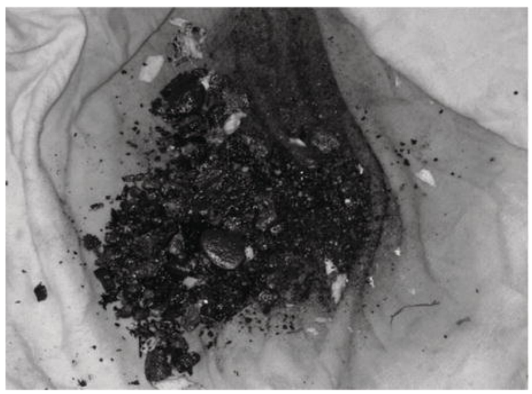


FIGURE 27.20 Formation of solid amides via the interaction of POE refrigeration oils with ammonia (R-717) refrigerant gas.

27.4.3 Application Considerations for Users in the Food Industry

There are many suppliers of lubricants and fluids for the food industry. However, one must be careful in choosing a supplier and the fluid. Here are some guidelines that ideal suppliers should possess:

- Supplier reputation and longevity in the lubricant business as well as their ability to develop new product versus copied-me-too products
- Facility certification such as ISO 9001 and ISO 21469 and RC 14001 and Kosher and Halal
- NSF registration of products in the appropriate NSF H categories
- Ability to invest in new technology and manufacturing capabilities
- Ability to provide full data sets with performance tests included
- Ability to offer oil condition monitoring services
- OEM approvals if available

From a product standpoint, it is extremely important to realize that none of the above criteria (except the last bullet) are associated with performance of the lubricant in an application. The suitability of using a product in an application must still be independently verified by the user. OEM-approved products, products recommended by OEMs, and products supplied by independent parties with full performance data sets will be most reliable. Coupling this with oil condition monitoring improves overall operational efficiency. Synthetic lubricants utilizing PAO, while seemingly expensive up front, generally provide the longest life, reduced downtime, and ultimately worry-free performance that translates into cost savings.

Finally, a very important point to note is that the presence of various additives and ingredients requires that global harmonized system (GHS) reporting guidelines are followed for the safety data sheets (SDS) for these products. Despite their incidental food contact status, the SDSs for these products can contain hazard labels, pictograms, signal words and risk phrases, as well as transportation, personal protection, and exposure guidelines.

27.5 OUTLOOK AND TRENDS

The growth of the food and beverage industry in the United States tracked at about 4.4% in 2014 and 4.1% in 2015.[29] Based on this, an approximately 4% growth may be anticipated in 2016. Developing countries constitute another avenue for growth and one can see sizable growth for manufactured and packaged food in many regions.[30] The industry continues to be under marginal pressures and therefore improved productivity is emphasized, and hence there is greater focus on compliance with regulations. This means that higher-performing lubricants and fluids that are also NSF-compliant are more often in demand. This is evidenced in the growth of NSF-registered products[2] as well as growth in ISO 21469-certified facilities; as per the NSF, 15 companies now have 21 ISO 21469-registered facilities (10 in Europe and 11 in North America) covering 684 products.[2]

Product performance continues to improve as previously unregistered components such as esters and pour point depressants as well as oil-soluble PAGs are registered under the HX1 category. This is giving formulators extra latitude to push the performance of their products higher.

As more H1 lubricants and HT1 heat transfer fluids continue to be registered, the H2 category is beginning to come under scrutiny. Most plants are moving to all H1/HT1-registered products, and the H2 category is thus becoming a source of confusion. Furthermore, the performance difference between H1 and H2 lubricants continues to diminish and many H1 lubricants do not perform as well as their H2 counterparts. The use of these lubricants in a food plant and the need for this category are thus becoming questionable.[2] This may lead to the discontinuance of this category in the future.

The growth in sales of fluids and lubricants that are NSF-registered is expected to track between 2% and 4%. Finally, mergers and acquisitions activity continues in the food- and beverage-manufacturing sector,[29] as well as in the lubricants and fluids sector.[31,32] This can lead to more consolidated buying of fluids and lubricants, requiring suppliers to meet the prevailing standards and offer improved products.

ACKNOWLEDGMENTS

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