LUBRICATION OF GEARS

INTRODUCTION

• The use of gears for power transmission dates back several hundred years. Before the age of iron and steel, gears consisted of circular wooden wheels with wooden pegs fastened to the rims to serve as teeth. The power used in operating these mechanisms was provided either by man, animal, water or wind. Wear was not too much of a problem with the crude wood-tooth gears, but later, when cast iron gears came into usage, some form of lubrication became necessary; lubrication also reduced some of the noise.

In those early days it was known that a greasy material would reduce noise. Animal fats were about the only lubricants available, so they were used. They served the purpose satisfactorily because speeds and loads were low and mechanical wear on the teeth was not too serious. Broken teeth could be replaced without too much trouble.

However, by the time the steam engine was invented, gears were made of iron, which would withstand greater loads and speeds. Later, as the machine age continued to develop, gears of greater precision were required. At first spur and straight bevel gears were satisfactory, but with the advent of the steam turbine and electric motor, gear design became more of a science and the herringbone type was perfected. Then the process of gear cutting really became an art because precision and strength of metal had to be coordinated.

Other types of tooth design which accompanied the development of automotive transportation and built-in transmission units involved the helical, spiral bevel and worm. They paved the way for the hypoid gear which is virtually standard in automotive equipment today. The objectives of the designers were smooth running, quiet meshing and uniform hardness of the gear teeth to withstand wear. These objectives only can be assured, however, with effective lubrication.

Modern industry today demands greater power and speed than ever before to satisfy the increasing demand for more and more production. At the same time the turbines and engines that produce this power require gears that have greater toughness and higher precision than ever before. Only then can power be transmitted dependably into useful channels.

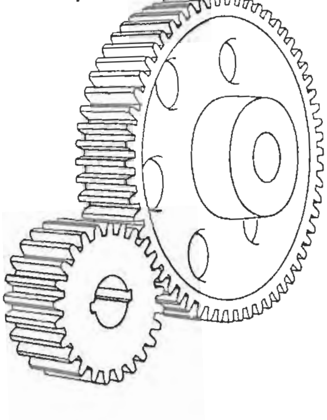
This question of gear tooth structure is all the more important due to the common practice of deliberately overloading gears two or three times beyond their rated capacity in order to increase production. This demand for ever-increasing production has placed a heavier load on the gears than perhaps on any other type of mechanism.

Obviously, overloading in this manner will shorten the life of the gears, although it can be counteracted to a certain extent, but not completely, by the use of heavy-duty-type lubricants. The increased cost of gear replacement is felt by many to be justified by increase in volume of goods produced.

TYPES OF GEARS
(FIGURE 1)

Figures 1 and 2 show illustrations and brief descriptions of the nine basic types of gears which are found in industrial use today, namely:

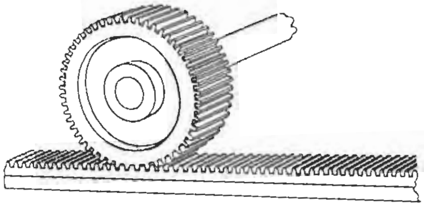
Spur	Spiral Bevel	Herringbone
Rack and Pinion	Internal Spur and Pinion	Worm
Straight Bevel	Helical	Hypoid



Spur Gear

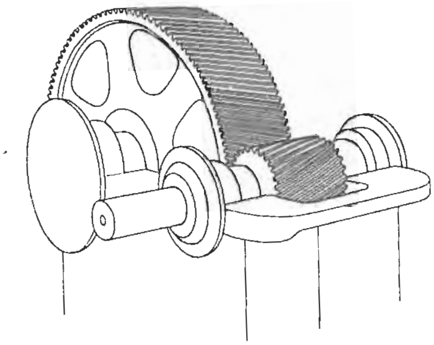
A spur gear is a cylinder, wheel, or disk on the surface of which are cut parallel teeth, each in a common plane with the axis. Spur gears are most commonly found on industrial machines, working under ordinary conditions, at moderate speeds and with medium pressures exerted upon the teeth.

There are also several specialized variations of the spur gear, such as eliptical gears, which impart a rhythmic motion to the driven shaft, and intermittent gears, in which the driver and driven gears have corresponding blank spaces where the motion of the driven gear stops momentarily.



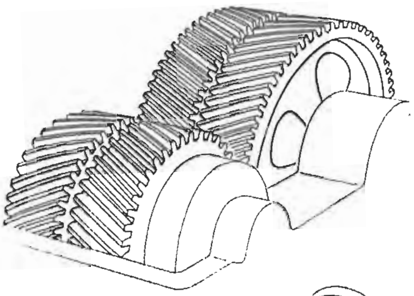
Rack and Pinion Gear

This is a specialized form of spur gear where the spur meshes with gear teeth on a flat rack. The function of this device is to bring about a reciprocating motion.



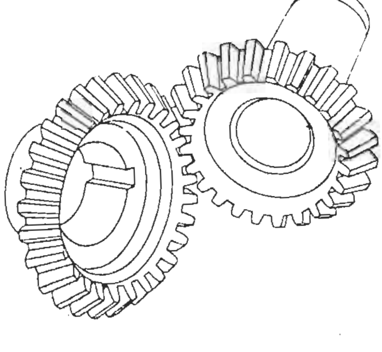
Helical Gear

The helical gear resembles the spur gear in that the teeth are cut on a cylindrical body, but it differs from the spur gear in that the teeth are spiraled around the body, rather than formed parallel to the axis of the gear body. Spiraling the teeth provides smoothness of operation.



Herringbone Gear

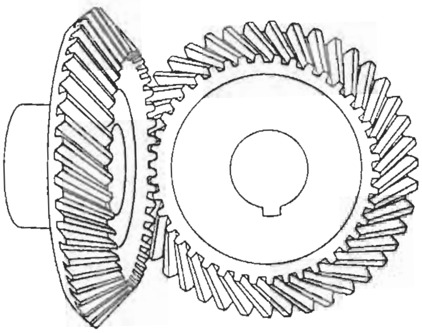
The herringbone gear resembles the helical gears having reversed directions of spiral, placed side by side, so that the teeth come together to form a chevron pattern. In general, helical or herringbone gears are used with parallel shafts. In the herringbone design, spiraling the teeth in both directions neutralizes end thrust. Herringbone gearing is generally used in enclosed drives, where fluid lubricants can be employed.



Straight Bevel Gear

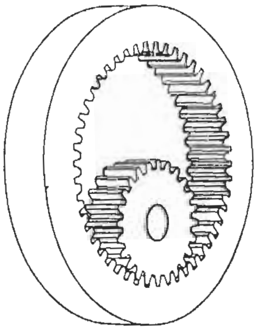
The teeth of the straight bevel gear are cut on an angular surface such as would be represented by a truncated cone. This gear is used for transmission of motion between shafts with intersecting center lines to form an angle between each other. This is usually a full 90-degree angle with the shafts positioned at right angles to each other.

TYPES OF GEARS *continued*
(FIGURE 2)



Spiral Bevel Gear

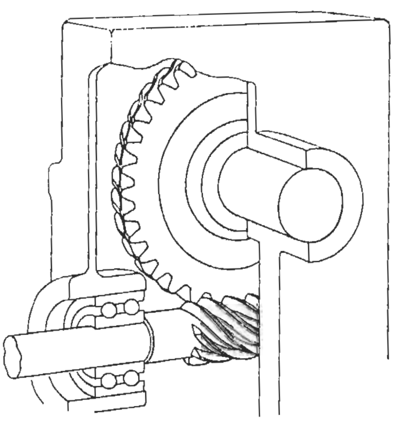
This gear is also adaptable to non-parallel shafting. It approaches the appearance of the straight spiral type of tooth.



Internal Spur Gear and Pinion

The annular gear has parallel teeth similar to the spur gear but cut on the inside rim of the ring. The companion pinion, however, is a standard gear. The main driving element on certain types of tractors is a typical example of the use of gears of this type.

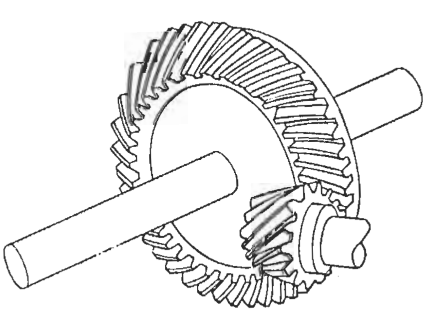
Worm Gear



This figure shows the two members of a worm gear set which are known as the worm and the worm wheel, or gear. The worm resembles a screw, although it is really a special form of helical gear, and its teeth are referred to as threads.

The worm is usually made of a hard, wear-resistant steel; the worm wheel, which resembles a helical gear (except that it is throated, or curved on the face to envelop the worm partially), is preferably made of a grade of bronze having good bearing properties. The worm is normally the driver, and the action of the worm gear is quite similar to the action of a screw on a nut. Due to the wedge-like action of the worm thread on the gear tooth, it is relatively easy to obtain quiet operation with this type of gearing; it also provides a very wide range of speed reductions.

Hypoid Gear and Pinion



This gear is used for transmitting power between shafts at right angles to each other but on different planes. The teeth have hyperbolic contours.

In contrast to the conventional spiral bevel gear, where motion is largely of a rolling nature, the hypoid develops a longitudinal sliding motion between the teeth of the pinion and the ring gear. This greater sliding action between the teeth of a set of hypoid gears creates a wiping effect which, combined with high tooth pressure may rupture the lubricating film unless the lubricant is manufactured to develop high load-carrying capacity.

All these types have one thing in common; the contacting teeth have pure rolling action at the pitch line but in any other position they slide on one another. This is most important since the amount and nature of this sliding has a great effect on the gear's lubrication requirements. For example, it is well-known that the amount of sliding with hypoid gears is considerably greater than with spiral bevel gears and that the lubrication requirements for hypoid gears are therefore more severe than those of spiral bevel gears.

Sliding motion occurs most actively when the teeth first come into contact. As they become disengaged, the points of the respective elements develop a certain amount of scraping action on the sides of the adjacent teeth. Both a wiping action and squeezing will be apt to occur at these times. As the teeth become more and more engaged, however, rolling contact becomes more pronounced. Wiping or scraping off of the lubricant is less apt to occur under these conditions but the squeezing-out action still is possible, especially since maximum contact pressures are encountered during the time the teeth are so engaged. Wear will occur more rapidly at the points and roots of the teeth due to the sliding friction involved; whereas, the intermediate tooth surfaces adjacent to the pitch line, being subject to rolling action, will resist wear more effectively.

TYPES OF LUBRICANTS AND THEIR APPLICATION

Due to the complexity of modern industrial operations, scores of lubricants are required to give proper lubrication and protection. In recent years, there has been a trend towards consolidation of these products and elimination of many of the unnecessary specialty products. Most lubricant manufacturers are giving wholehearted cooperation in this consolidation program.

Types of Gear Lubricants

Due to the variations in operating conditions, several varieties of gear oils are required to provide adequate lubrication. The following types are generally used:

1. Heavy Adhesive Residual Types (For Open Gears)

There are four varieties of this type of lubricant, namely:

a. Residual (Straight Mineral)

The first of the petroleum gear oils consisted of heavy, sticky residual products. These straight mineral oils represented the residue left in stills after distillation of lighter fractions from certain types of crudes.

They are still used widely on spur gears on comparatively slow-speed machines in steel, cement, rubber and other mills where speeds are under 100 RPM.

These products vary in viscosity from 200 up to 10,000 seconds (Saybolt Universal) at 210°F.

The heavier varieties have to be heated to be applied (usually by paddle).

They are very sticky and represent the most adhesive of all the gear lubricants.

This type product gives a thick film on gear teeth. The film separates tooth contact areas completely and the oil supports the load entirely by hydraulic action.

b. Residual (Compounded)

The straight mineral type is often blended with fatty or other polar material to provide improved film strength and to provide adequate lubrication under bad water conditions.

c. Residual (Cutback with Solvent)

The above types are sometimes cut back with a solvent to provide ease of application. After the solvent evaporates, the heavy material remains. *The cut-back lubricants should be used only where there is ample ventilation. If chlorinated solvents are used, they may have a toxic effect on personnel, and if petroleum-type solvents are used, they will present a flammability or explosive hazard.*

d. Residual (Extreme Pressure)

In recent years heavy, adhesive residual products with EP additives have been developed for steel mill and other very-heavy-duty gears where extreme pressure qualities are desired. The products can be sprayed on gears and also on bearings where severe water conditions exist. These compounds are also sometimes cut back with solvent to provide ease of application.

2. Greases (For Open and Enclosed Gears)

Adhesive greases of NLGI 0, 1 or 2 consistency are sometimes used on open gears where high temperature conditions prevail or where leakage of a thinner lubricant might contaminate materials being processed. EP or non-EP greases can be used and application is made by brush, paddle or pressure gun.

Greases softer than NLGI No. 0 consistency are being used in enclosed gear sets, particularly in coal mining machinery, where high operating temperature and leakage are factors. Application is usually made by pressure gun.

3. Intermediate Viscosity Oils (For Enclosed Gears)

a. Straight Mineral Oil

Lower viscosity mineral oils of turbine or cylinder oil types are very well suited for enclosed high-speed single helical and herringbone reduction gear sets where pinion speeds may run up to several thousand RPM. These oils should be very resistant to deterioration in the presence of heat, which often develops during operation.

Viscosities of these oils may range from 300 seconds (SU) at 100°F. to 250 seconds (SU) at 210°F.

These lubricants are suitable for general lubrication of all type gears (except hypoid) operating under comparatively low loads and high speeds.

b. Mineral Oil with Oiliness or Polar Additives

Straight mineral oil of intermediate viscosity is often blended with a small amount of fatty or other polar material to provide improved lubrication to gears operating under partial boundary conditions where an EP product is not required.

Theory of Polar Lubrication

Partial boundary lubrication exists where operating conditions are severe and the mineral oil film is too thin to separate teeth or bearing surfaces completely.

It has long been known that certain materials, such as fatty acids or other oiliness agents are effective in reducing friction under partial-boundary lubrication conditions. These materials are high molecular weight organic compounds, containing carbon, hydrogen and oxygen, as compared to lubricating oils which contain only carbon and hydrogen. The fatty molecule which has the property of thin film oiliness, differs from the lubricating oil molecule in one other important respect, namely, that one end is highly reactive and has the property of forming a powerful bond with the metal surface. It is called a "polar" molecule, and it is attracted to a metal surface much the same as iron filings are attracted to a magnet. It is "adsorbed" to the surfaces so powerfully that the last traces in some cases can be removed by nothing short of machining. These polar molecules, when they are attached to a surface, can be described as long molecules sticking out like the flexible bristles of a brush. Physical measurements have shown that polar molecules act in this way and the length of the molecule has been measured.

Recent research work has shown that under operating conditions the polar materials react with contacting metals, forming a small amount of metallic soap. This adds to the good lubricating qualities of the polar materials.

In cases where heavy loads, low speeds or intermittent operation prevent formation of a thick film, an oiliness or polar-type lubricant is very desirable. Animal and vegetable oils and fatty acids possess great oiliness.

These oils are suitable for bronze-on-steel worm gears and for all types of steel-on-steel gears (except hypoid) where thin film lubricating conditions exist.

c. Extreme Pressure Oil (Mild Type)

Under conditions of very heavy loads where boundary lubrication exists and where straight mineral and the polar type oils are not effective, Extreme Pressure-type lubricants are recommended.

These oils are usually available in a series of several grades which may range in viscosity from 300 seconds at 100°F. to 1000 seconds at 210°F.

EP additives in these oils usually contain lead compounds in the milder forms and chlorine, sulfur or phosphorus compounds, sometimes in combination with lead compounds in the more active types.

d. Extreme Pressure Oil (Active Type)

Active-type EP oils are used primarily for automotive factory fill on hypoid gears only. In automotive gears a mild EP oil is often used for make-up.

Active EP oils usually contain lead soap and active-type sulfur. They are corrosive to copper while the milder EP oils are not corrosive.

Active-type EP oils are designed only for hypoid break-in and should not be used on other types of industrial gears.

Theory of EP Lubrication

When steel-on-steel bearing surfaces rub against each other, such as in gears or antifriction bearings, the local high spots develop a very high temperature due to friction. The purpose of an EP additive is to prevent welding of the high spots.

The theory is that at these high temperatures, there is a chemical reaction between the additives and iron. Compounds such as iron sulfide, iron chloride, or an iron phosphorus alloy are formed. When a combination of sulfur- and lead-type additives is used, there is believed to be a side reaction between the lead and sulfur compounds to form lead sulfide, which adheres to the metal surfaces.

These compounds are softer than iron, and they provide lubrication. This prevents welding and further tearing, and the gears can operate without accelerated failure rate.

EP additives are especially effective where steel-on-steel bearing surfaces are involved and where spot temperatures get high enough for the chemical reaction to take place.

It is believed, however, that EP agents are not particularly effective with steel in contact with softer metals such as brass, bronze, Babbitt, cadmium or aluminum. Under heavy load, these metals deform slightly and temperatures do not get high enough for the EP reaction to take place. EP gear oils often contain additives of polar nature. These are beneficial with steel against steel as well as steel against softer non-ferrous metals, since they usually provide cooler operation.

When an Extreme Pressure lubricant is used under light-duty conditions, the Extreme Pressure additive will not be depleted, but it is available for use if heavy pressure or shock load are encountered. For this reason many operators use EP lubricants as insurance against sudden adverse conditions.

Under heavy-duty loads, the EP additive will be depleted gradually and replenishment is desired. Usually the normal make-up of fresh oil will provide sufficient additional additive to give suitable operation. In many instances EP gear lubricants have been used for many years without appreciable change in EP characteristics.

After long-time service, especially if operating temperatures are higher than normal, there will be a gradual increase in viscosity due to oxidation. In such a case a lower viscosity EP lubricant can be used as make-up to bring the viscosity down to the desired level.

Lead naphthenate-sulfur type mild EP lubricants are almost universally used in steel mills for several reasons:

a. Lead naphthenate contributes to EP activity by combining with sulfur, forming a lead sulfide film on metal.

b. Lead naphthenate is easily soluble in mineral oils and does not separate under normal storage or operating conditions.

c. It is also polar in nature and provides lubrication under boundary conditions.

d. It gives "body" and adhesiveness to a lubricant, providing a cushioning effect and minimizing noise of gear operation, particularly in heavy-duty steel mill service.

Other types of Mild EP Gear Oils (some containing sulfur or sulfur-chlorine or sulfur-chlorine-lead combinations), are used for aircraft gears and for some automotive transmissions, differentials, steering gears, universal joints and hypoid gears.

If pressures or shock loads are extremely high, there is a point at which even EP agents can no longer be effective, and excessive wear and pitting are apt to take place. Where gears are continually operated at overload conditions, or where gear metallurgy is inadequate for the job, the use of EP lubricants will merely postpone the evil day when failure will take place. They cannot influence the effect of metal fatigue.

With this same idea in mind, the following quote from an article in the magazine LUBRICATION ENGINEER, December, 1957, by Mr. A. E. Cichelli of Bethlehem Steel, titled "A Lubrication Engineer Surveys Steel Mill Gearing," stresses the major importance of metallurgy in gear performance.

> "Lubrication of steel mill gears is only one of the factors affecting steel mill gear performance—in many cases it is minor. It has been demonstrated that even the best lubricants are inadequate when gear metallurgy and geometry are below standard for the job. We know of no lubricant that can substitute for toughness and hardness when these two factors are demanded."

The following summarizes briefly the discussion on EP gear lubricants.

1. EP lubricants are not necessary on any types of gears where thick film lubricating conditions exist; however, some operators want to use EP lubricants as insurance against possible adverse conditions.

2. EP lubricants are definitely advantageous on gears where speed and load conditions are very adverse.

3. EP lubricants should not be used indiscriminately, but should be wisely placed only in equipment where needed.

4. EP lubricants are not a cure-all for all ills of lubrication. They cannot cover up faulty mechanical or metallurgical conditions indefinitely.

EP Gear Lubricant Additives

In addition to the *fatty or polar compounds* which are added to reduce friction and the *EP additives* containing chlorine, phosphorus, sulfur or lead compounds to prevent welding of metal surfaces, there are also several other types of additives that are often used in gear oils:

1. *Pour Depressants* — To reduce the pour point or channel point of the lubricant so that it will flow freely at low temperatures.

2. *Viscosity Index improvers* — To improve the viscosity-temperature relationship of the lubricant and to minimize the viscosity spread over the operating temperature range.

3. *Foam Depressants* — To prevent foam formation or to accelerate foam collapse and thus minimize loss of lubricant due to foaming in service.

4. *Oxidation Inhibitors* — To prevent undue thickening due to oxidation and to give longer life to the lubricant.

5. *Corrosion Inhibitors* — To minimize attack of water and other corrosive material on metal surfaces.

Laboratory EP Tests

Several types of EP tests have been developed for evaluating EP gears oils. The more prominent are listed below:

The Almen Test

Falex EP Test

The 4-Ball EP Test

The SAE EP Test

The Timken Test

Some of these tests were originally developed for automotive lubricants and others for industrial lubricants. Unfortunately there is no correlation between the results of the various methods. One test may give a sulfur-bearing oil a high rating and another will rate a chlorine-bearing oil higher than the others.

In some of these tests the reproducibility is not good and they do not rate a series of oils in the same comparative order of EP values. Two reasons are shown below:

1. Most of these tests were originally de-

signed to differentiate only between EP and non-EP oils. Most of the machines and procedures are not accurate enough to measure the various levels of EP characteristics.

2. There are many variables, such as the following, which, if not carefully controlled, will give erratic EP results:

Kinds of metal used in the test	Temperature of oil
	Rubbing speed
Surface finish	Ambient temperature
Metal hardness	Method of applying load

Any single EP test may duplicate one or two service conditions, and may be used as a screening test but should not be used to replace a full-scale or simulated service test for rating the lubricant for specific application. Correlation of EP tests with service performance in a given piece of equipment is difficult and predicting performance on the basis of EP tests alone is not possible.

Many EP lubricants, in addition to EP or "anti-weld" materials, also contain polar agents, sometimes referred to as oiliness additives. The latter additives are desirable and useful supplements to EP additives since they provide protection to metal surfaces during boundary conditions existing prior to abnormal conditions which will bring the EP additives into action.

The following table shows the approximate range of values for straight mineral, mild EP and high EP lubricants when tested on various machines:

Almen Test	**Load in Pounds**	**Reproducibility**
Straight Mineral Oil	4 to 11	Not sufficiently precise or reproducible to distinguish between levels of EP characteristics. Suitable for screening straight mineral oils from EP oils.
EP Lubricant	15 to 35	
Falex EP Test	**Pop-Up in Pounds**	**Reproducibility**
Straight Mineral Oil	Below 750	Not precise or reproducible enough to distinguish between levels of EP within a given grade. Suitable for screening straight mineral oils from EP oils.
EP Lubricant	750 to 4500	
4-Ball EP Test	**Typical Mean Hertz Load Ranges in KG**	**Reproducibility**
Straight Mineral Oil	7 to 25	Values usually check within ±10%. Precision is better than with most other methods.
Mild EP Lubricant	30 to 45	Suitable for screening straight mineral oils from EP oils and for indicating levels of EP values.
High EP Lubricant	50 to 70	
SAE — EP Test	**Typical SAE Tests in Pounds**	**Reproducibility**
Straight Mineral Oil	Below 125	Values usually check within ±16%. Suitable for screening straight mineral oils from EP oils. Not suitable for distinguishing levels of EP value.
EP Lubricant	125 to 550	
Timken EP Test	**Typical Timken EP Tests in Pounds**	**Reproducibility**
Straight Mineral Oil	0 to 20	Approximate reproducibility for the 3 types of oils are ±10, ±15 and ±20 pounds, respectively. Suitable for differentiating between straight mineral and EP oils but questionable for use in evaluating levels of EP.
Mild EP Lubricant	20 to 60	
High EP Lubricant	60 and above	

Conclusions

The following conclusions can be drawn on the basis of the above evaluations:

1. None of these are entirely satisfactory because of many variables which cannot be controlled.
2. These EP tests are useful in determining whether or not a lubricant has EP properties, but with the exception of Mean Hertz Load, should not be used to distinguish between levels of EP value.
3. In normal operations the occasional addition of fresh lubricant is sufficient to keep the EP characteristics high enough to give suitable protection.
4. EP tests alone cannot be used to predict field performance reliably.

Examination of Used EP Gear Oils

The following tests are often used to determine the suitability of used EP gear oil for continued use.

Viscosity

If the viscosity has increased to that of the next higher grade some oxidation has probably taken place, or there may have been contamination with a higher viscosity oil. Addition of a lower viscosity grade will bring the viscosity down to the desired level.

If the viscosity has decreased, it is probably due to contamination with a lighter product. If excessive, a higher viscosity grade can be added as make-up to raise the viscosity to the desired level.

Sediment by Centrifuge at 160°F.

This will determine the total amount of dirt, oxidation sludge, bearing wear or water which may be present as contaminants. If this is excessive, the oil should be cleaned up by centrifuging, filtering or settling.

This test is run on a representative sample of the used oil without using any diluent such as precipitation naphtha. The latter solvent will usually cause erroneous results.

Lead, Sulfur or Other EP Additive

Tests will determine the amount of available additive present. If it is very low, it may indicate contamination with a straight mineral oil or reduction of additive due to usage.

EP Test

Tests such as Timken or Mean Hertz Load will indicate whether depletion of EP characteristics is excessive and if correction is necessary.

Methods of Application to Gears

Due to the numerous varieties, sizes, and locations of gear assemblies in a steel mill, several methods are employed for application of lubricant to the gears, including the following:

1. *By Paddle* — Heavy residual oils are often applied to open gears by paddle. Too much is usually applied and the excess is thrown off into the surrounding area.
   This, of course, is very wasteful, and presents a poor appearance in the surrounding area.
2. *By Hand* — Residual-type lubricants are sometimes formed into a ball by hand and dropped into the gear mesh. This method has been improved, and the lubricant is now often marketed in small plastic bags. These are dropped through the lubricant opening, and the bags are eventually chewed to bits by the gears. This is a much cleaner operation and is preferred by operators.
3. *By Drip* — In some gear sets, the more fluid types of lubricant, including the cutback variety are dripped slowly onto the gears, as shown in Figure 3.

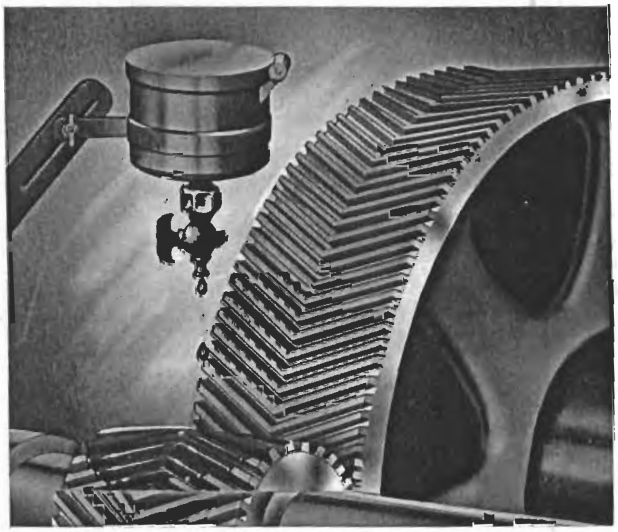


FIGURE 3 — Drip Application

4. *By Brush* — In many cases, as illustrated in Figure 4, fluid-type lubricants are applied by an ordinary paint brush.

5. *By Pouring* — In some cases the lubricant is poured at intervals from a container onto the gears. The heavier varieties of residual oil must be heated before they will pour easily.

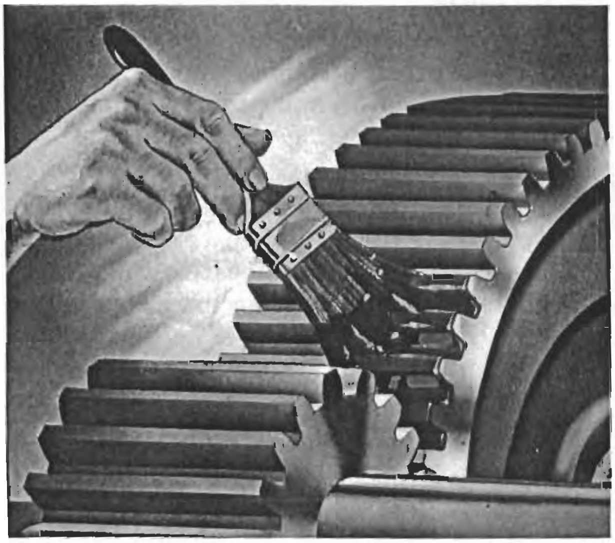
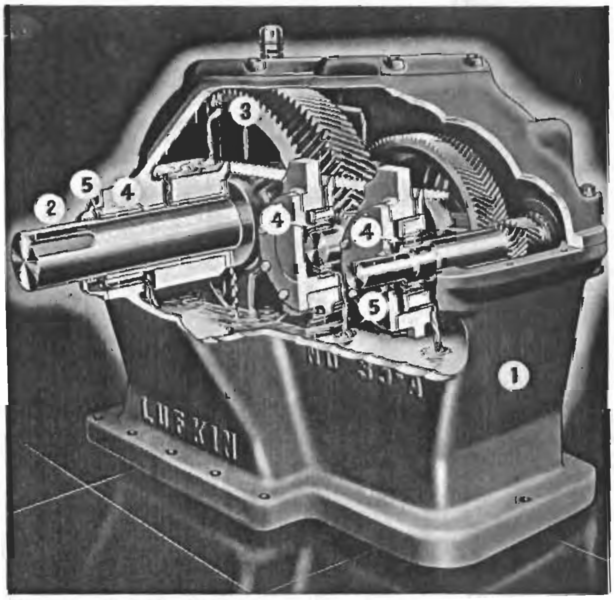


FIGURE 4 — Brush Application



(Courtesy of Lufkin Foundry and Machine Co.)

FIGURE 4A — Gearbox showing Bath Lubrication System 1 — gear reducer housing 2 — forged alloy steel shaft 3 — Precision-cut herringbone gears 4 — Bronzoid crankshaft bearing 5 — Patented oil seals — main crankshaft is equipped with collar oil slingers and annular grooved drain covers

6. *By Bath* — The fluid-type lubricants are often placed in a sump or bath in the bottom of the enclosed gear set. One of the gears dips into it and lubricant is transferred to the contacting gears. The excess is thrown against the housing and is guided by means of troughs into the bearings or back to the sump. (See Figure 4-A.)

7. *By Idler Gear* — In many instances on slow-moving gear assemblies, an idler gear dips into a sump and transfers its lubricant to the other contacting gears.

8. *By Circulating System* — In systems such as runout tables involving numerous gears, lubricant is pumped from underground tanks to the gear sets and then returns to the tanks. Lubricants used in these systems are occasionally contaminated with water and mill scale and have to be reclaimed by settling, filtering and centrifuging.

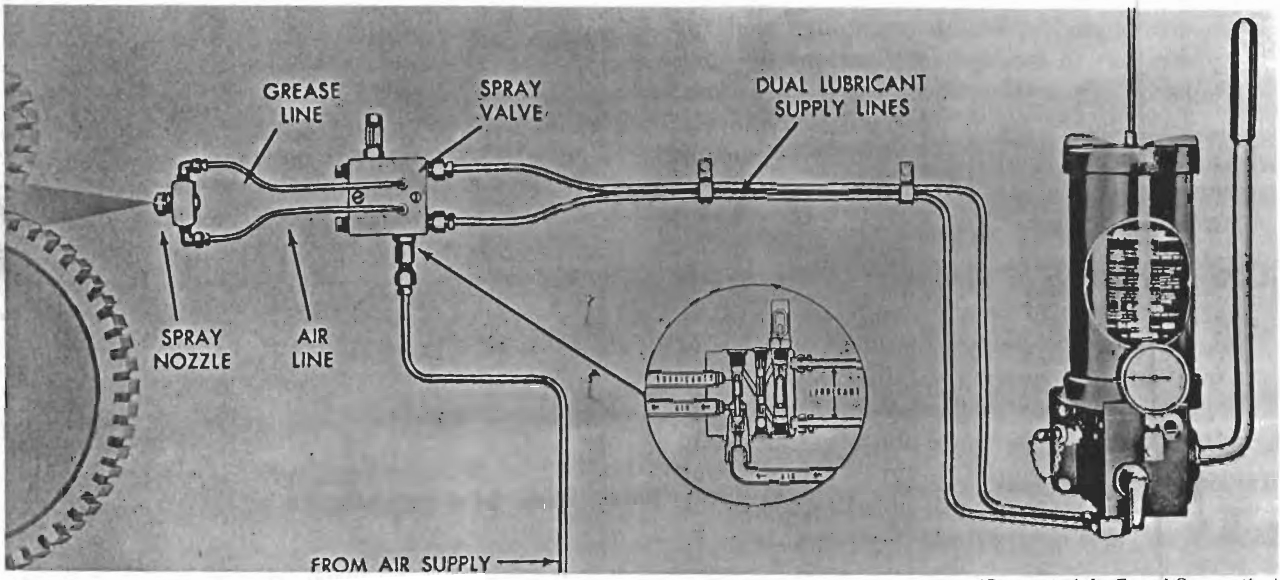
9. *By Spray* — During the last decade automatic spray application on open gears has gained considerable prominence.

   A controlled amount of lubricant can be sprayed over the gear surface at desired intervals, and the cycles can be controlled automatically or manually, as illustrated in Figures 6 and 8.

   Size and shape of spray patterns can be controlled by use of various types of nozzles, distance from nozzle to target, pressure and temperature of lubricant.

   The spray is usually applied on the pressure side of the gears prior to meshing. It has been found that application directly at the point of mesh is often faulty, due to air turbulence at that location.

   Heavy lubricants are usually applied manually on open gearing, but experience has shown that in addition to other methods, some of them can also be applied by spray without difficulty. The limiting factor is the pumpability of the lubricant at the temperature of application. The use of solvent as a cutback for the very heavy residual type provides greater ease of



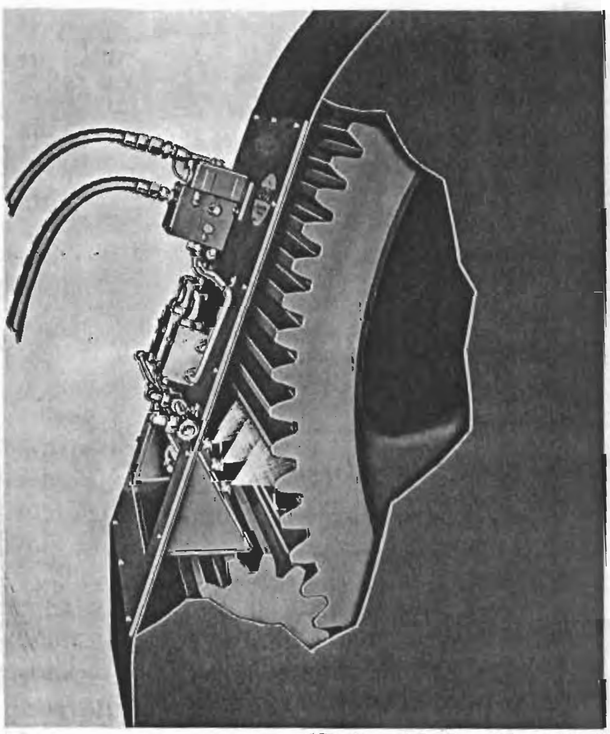
(Courtesy of the Farval Corporation)

FIGURE 6 — Schematic sketch of spray lubrication system

application, especially for spraying. Spray application places lubricant at the point where it is needed and effects a great saving in amount used over the old hand-packing or paddle applications. These savings will often pay for the spray installation in a comparatively short time.

The following types of dispensing equipment are available for spray application:

A. *Completely Portable Equipment* — This resembles a paint spray gun with a one- or two-quart capacity. (See Figure 5.) It is actuated by air supplied through a hose at



(Courtesy of the Farval Corporation)

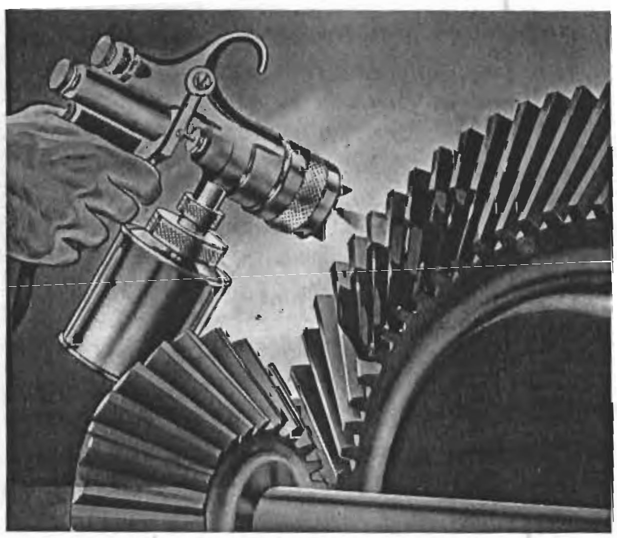


FIGURE 5 — Hand Spray Application

FIGURE 8 — Schematic cutaway showing automatic spray panel on a typical gear and pinion installation.

about 35 PSI. This equipment is the least expensive and is suited especially well for application to isolated applications on open gears on track wheels of overhead cranes, presses, shears, steam derricks, and shovels. It is also practical for open mitre gears on conveyor tables and for coating wire rope on hoist drums.

B. *Semi-Portable Equipment* — This equipment consists of conventional air-operated, barrel-type grease gun installed on a 35- or 100-pound lubricant container mounted on a two-wheeled dolly. Compressed air is supplied through a 3/8″ hose and a 3/4″ lubricant line to a spray gun. This type of application is practical where the floor is in good condition and not obstructed.

C. *Stationary Equipment* — Stationary or permanent units are often used when a large number of open gears operate in a limited area. These units usually employ a barrel-type grease pump installed in a 100- or 400-pound drum.

Lubricant from the grease gun is piped to all the units through 3/4″ or 1″ standard pipe. A 1/2″ air line parallels the lubricant line and supplies compressed air at pressures of 40 PSI or higher for atomizing lubricant through nozzles.

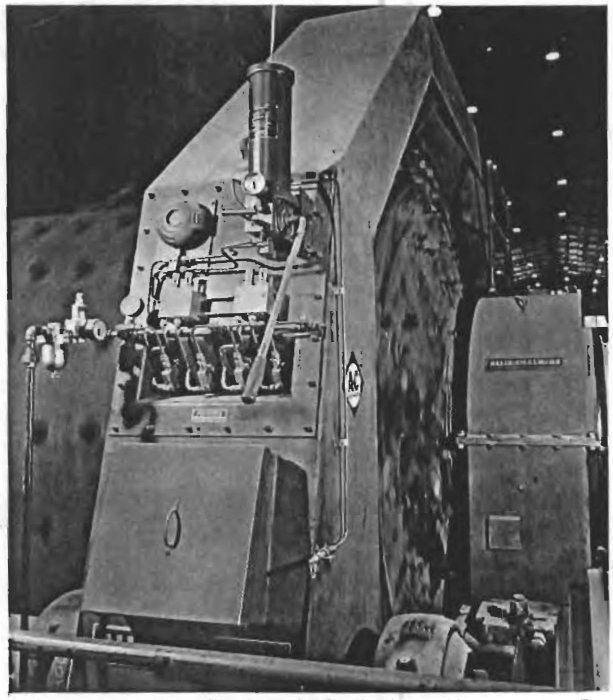
Various types of hand- or motor-operated spray equipment are depicted in Figures 6, 7, 8 and 9.

D. *Measured Quantity Centralized Systems* — These systems are used when it is desirable to spray a measured quantity (which may vary for each set of gears) at definite intervals. They consist of a hand-operated or time clock-operated lubricant pump which dispenses lubricant through lines to any required number of metering spray nozzles of various capacities.

They require compressed air for atomization of the lubricant and the lubricant acts as a hydraulic medium for the operation of the measuring valve.

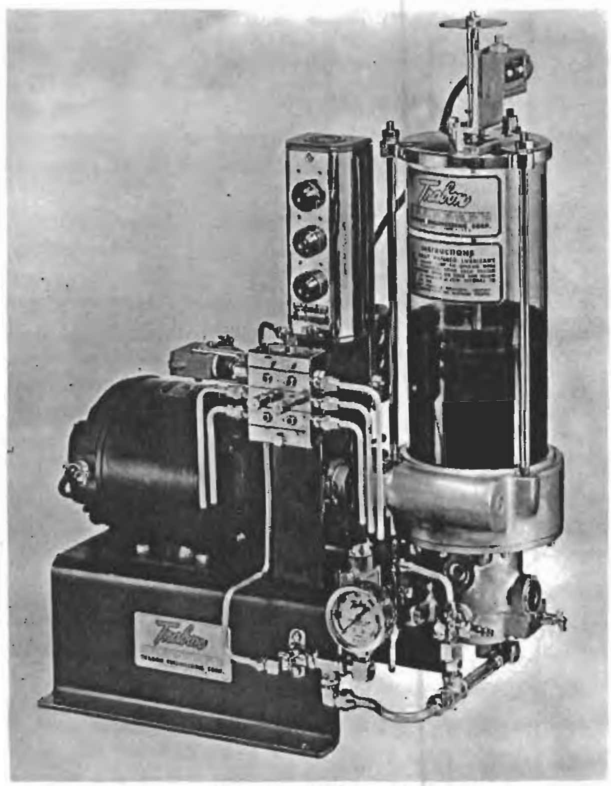
These systems are quite new and usually more expensive than other types of spray applicators.

In comparison with manual methods of application, the spray method is claimed to have



(Courtesy of Allis-Chalmers Manufacturing Co.)

FIGURE 7 — Manual lubricating system on a ball mill



(Courtesy of Trabon Engineering Corporation)

FIGURE 9 — Motor-driven automatic pump and reservoir assembly

the following advantages:

a. Minimizes waste and contamination.

b. Saves man-hours in application.

c. Eliminates accident hazards, particularly on open gears.

d. Provides smooth, even coating.

e. Minimizes spoilage due to drippage on material being processed.

f. Provides ease of application to difficult locations.

(Courtesy of Alemite Division of Stewart-Warner Corporation)

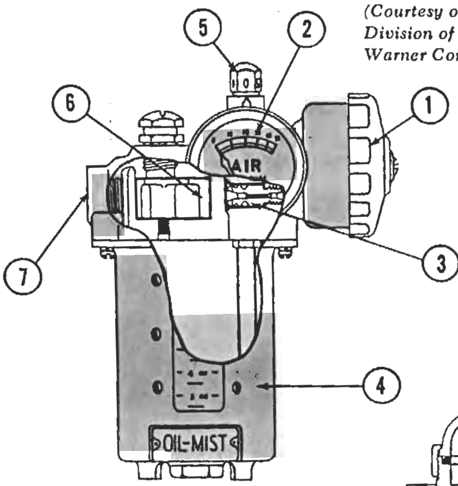


FIGURE 10
1 — Air regulator
2 — Air gauge
3 — Venturi
4 — Oil reservoir
5 — Air flow knob
6 — Oil flow knob
7 — Mist outlet

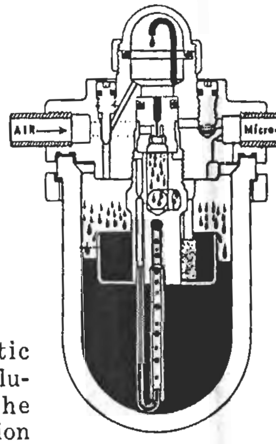


FIGURE 11 — Schematic cutaway of a micro-fog lubricator illustrating the principle of oil atomization

(Courtesy of C. A. Norgren Company)

10. *Airborne* — Work with oil mist or fog lubrication of gears and bearings has been going on for a number of years in many plants. At first only the light-duty machines were lubricated in this way but later it was found that many pieces of heavy-duty equipment could also be successfully lubricated in this manner.

The mist lubrication system as illustrated in Figures 10 and 11 employs an oil reservoir with capacity up to three gallons. The oil is atomized to a mist or fog by the use of compressed air. After passing a baffle, only the microscopic particles are blown into the delivery tubes which carry the mist to gears, bearings or other moving parts.

The theory of this type of lubrication is that the mist will flow through straight pipes and around bends without any appreciable condensation, but oil droplets will condense on fast-moving parts at locations where the lubricant is needed. The low-pressure flow of air (usually below 5 PSI) on the bearings also provides some cooling effect.

The mist can be applied to gears, bearings and other parts through fittings which will deliver it in the form of mist, fine oil spray or oil droplets.

The chief advantages are for application where drippage from conventional lubricants would contaminate the material being processed and for lubrication in hard-to-get-at or dangerous locations unsuitable for other means of application.

Straight mineral oils with viscosities up to 1000 seconds (SU) at 100°F. can be handled easily in the airborne systems. The lower viscosity oils will atomize at a faster rate than those of higher viscosity. EP gear lubricants below the 1000 second (SU) viscosity range are often used where heavy-duty lubricant is required. The choice of viscosity and type of oil will depend on the severity of service and the viscosity required for proper lubrication of the parts. By use of heated air, oils of considerably higher viscosity may be used.

Gear Lubrication in Heavy Industrial Equipment

All industrial operations involve the use of gears of one type or another. Some perform comparatively light service but in most of the heavy industrial operations the gears as well as the lubricants must be very rugged so as to stand up under all sorts of adverse operating conditions. These may include high load, high speed, shock loading, high and low temperature and contamination with water and abrasive materials. Several types of heavy industrial equipment are listed on page 18:

EARTH-HANDLING EQUIPMENT

The operating parts of earth-handling equipment such as shovels, draglines, backhoes and cranes are usually exposed to contamination with water as well as abrasive dust and dirt. Very adhesive type lubricants are usually used on the gears and dipper sticks to provide a thick coating of oil which will minimize the effect of abrasive material as well as water washing and rusting. This type of lubricant also assures efficient lubrication for a long period of time and, due to its thick, clinging film, provides quiet operation. It also gives good lubrication to equip-

(Courtesy of Bucyrus-Erie Company)

FIGURE 12 — 1650-B stripping shovel

(Courtesy of Koehring Company)

FIGURE 13 — 205 excavator

(Courtesy of Baldwin-Lima-Hamilton Corporation)

FIGURE 14 — Diesel-powered shovel with 6-cu.-yd. bucket

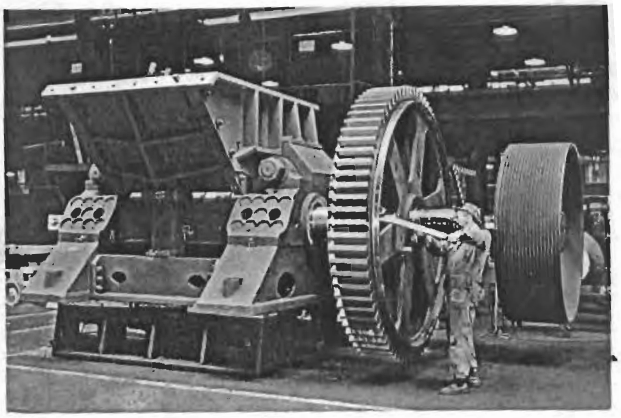
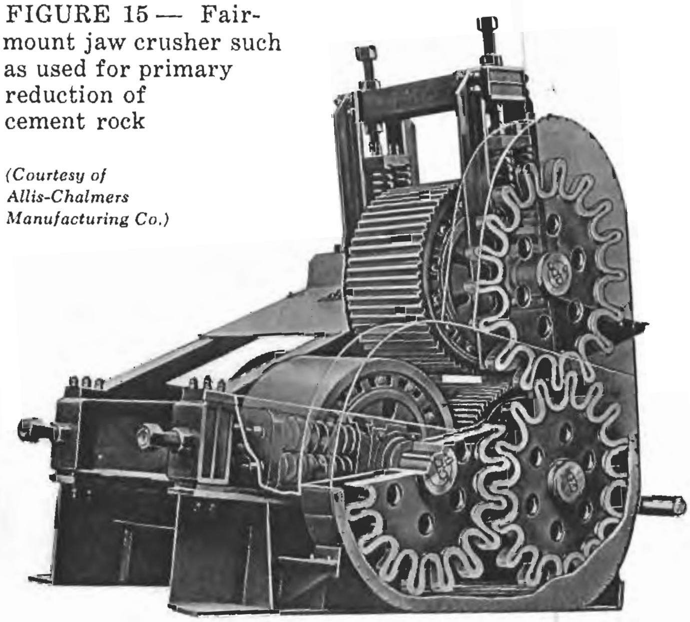


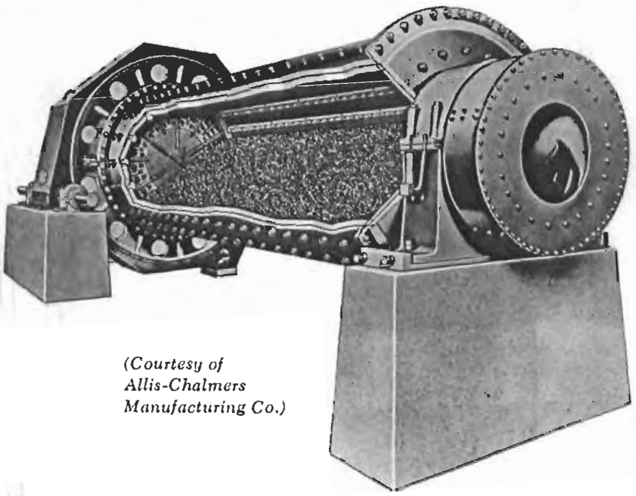
FIGURE 15 — Fairmount jaw crusher such as used for primary reduction of cement rock

(Courtesy of Allis-Chalmers Manufacturing Co.)



(Courtesy of Pioneer Engineering Division of Poor and Co., Inc.)

FIGURE 16 — Cutaway of pioneer 54 x 24 triple roll crusher



(Courtesy of Allis-Chalmers Manufacturing Co.)

FIGURE 17 — Ballpeb grinding mill used for secondary grinding to produce finished cement

ment operating on uneven terrain where considerable shock loading exists. Figures 12, 13 and 14 depict the heavy-duty service and the contaminating influences under which gears in earth-handling equipment must operate.

CEMENT MILLS

Crushers

Three types of crushers — roll, jaw or gyratory are used for crushing rock in cement making or for other purposes.

Rock is received in varying sizes up to 3 or 4 feet in length and primary crushing reduces the size to 4 inches or less. Pressures in these mechanisms are tremendous and a great deal of heat is developed.

The gears as well as bearings are subjected to very heavy shock loads, extreme temperature and considerable dust and grit.

In many of the crushers lubrication of gears is handled by a circulating system consisting of a pump, sump tank, a filter to remove grit and a cooler to keep the oil temperature below 130°F. A mild EP gear oil in the viscosity range of 300-500 seconds at 100°F. is usually used.

Figures 15 and 16 illustrate the jaw- and roll-type crushers.

Grinders

Cement and other similar industries employ ball, pebble and rod mills for grinding rock to very fine sizes. The mill usually contains 43 to 45% by volume of steel balls or rods and the cylinder revolves horizontally on its axis.

The mill is revolved by means of a ring gear around the circumference at one end. It is usually protected by a guard to safeguard personnel and to keep out extraneous material as much as possible. An adhesive residual gear oil with mild EP characteristics is usually used as a lubricant. Figure 17 illustrates one type of grinding mill.

Kilns and Dryers

Many industries, including cement, utilize cylindrical kilns and dryers for calcining or dehydrating various materials. Some of these are 10 feet or more in diameter and 200 to 400 feet in length. They are installed in a horizontal position, usually with a slight slope, to allow the contents to move slowly towards the exit end.

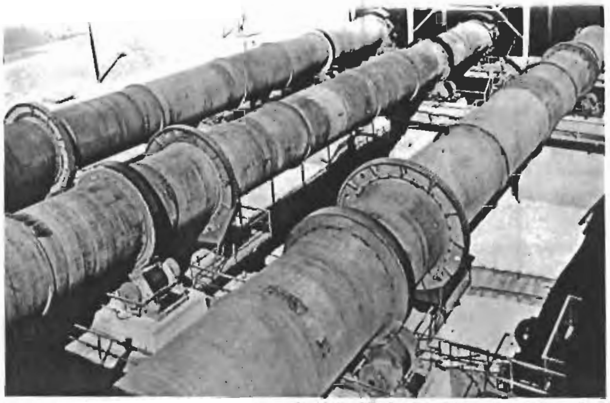
They rotate about 1 RPM and the motion is actuated by a motor operating through a speed reducer and a pinion gear which turns the large girth gear. The latter is lubricated by dipping into a reservoir or by means of an idler gear. Heavy cylinder oil or mild EP type lubricants are satisfactory.

The lubricant must operate under high heat conditions.

Cement kilns have an internal temperature of approximately 2700°F. so the lubricant must be resistant to oxidation. Other adverse conditions include contamination with dust, and at times water washing, since many of the girth gears are exposed to outside atmospheric conditions.

Figures 18 and 19 show girth gears on several kilns and dryers.

Other gear-operated machinery used in cement manufacture include cranes, conveyors, elevators, shovels, pumps, pulverizers, centrifuges, and thickeners.



(Courtesy of Allis-Chalmers Manufacturing Co.)

FIGURE 18 — Rotary kilns for pyrochemical processing

(Courtesy of Allis-Chalmers Manufacturing Co.)

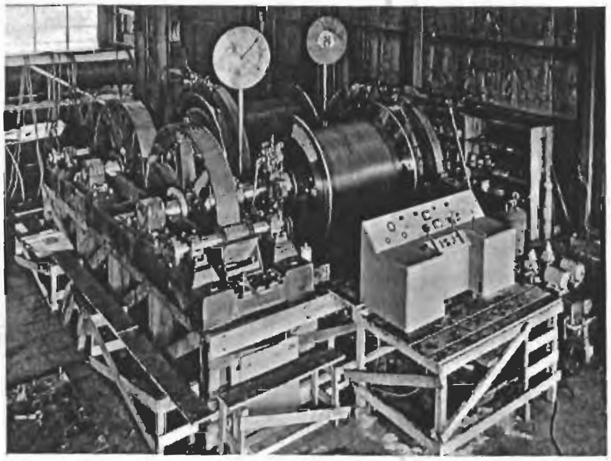
FIGURE 19 — 9½ x 300 ft. rotary cement kiln, showing girth gear drive mechanism and riding ring with roller

MINING

Hoists

The gears used in operating a mine hoist are among the largest used in a mining operation. If the gears are open they can be lubricated with a residual-type oil but if they are closed they are usually lubricated by dipping into a reservoir of mild EP type gear oil or a heavy cylinder oil. These gears are housed in a building so there is no serious contamination problem.

Figure 20 shows the gear arrangement in double drum mine hoists.



(Courtesy of Vulcan Iron Works Co.)

FIGURE 20 — Double drum mine hoists

Mining Machines

Modern underground mining machines have many enclosed gear cases, including transmission and gathering head. If gear cases are tight they can be satisfactorily

(Courtesy of Joy Manufacturing Company)

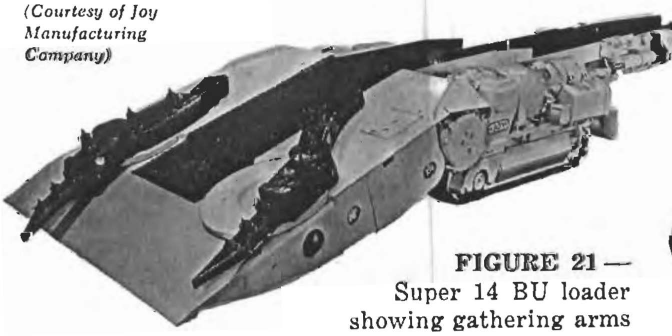


FIGURE 21 — Super 14 BU loader showing gathering arms

lubricated with straight mineral oil, cylinder oil containing polar material or mild EP gear oil. Some machine manufacturers object to the use of EP oils in gear sets containing friction clutches because of possible slippage. Other manufacturers do not object. Where leakage is a factor, special greases, softer than NLGI 0 Grade, are being used with considerable success.

High temperature and contamination with water and large amounts of coal dust are often experienced in mining machine lubrication.

Figure 21 illustrates a modern miner and loader used in underground coal mines.

Other mining machinery operated by gears includes loaders, shuttle cars, cutters, hoists, locomotives, crushers, jigs, shaking screens and conveyors.

STEEL MILLS

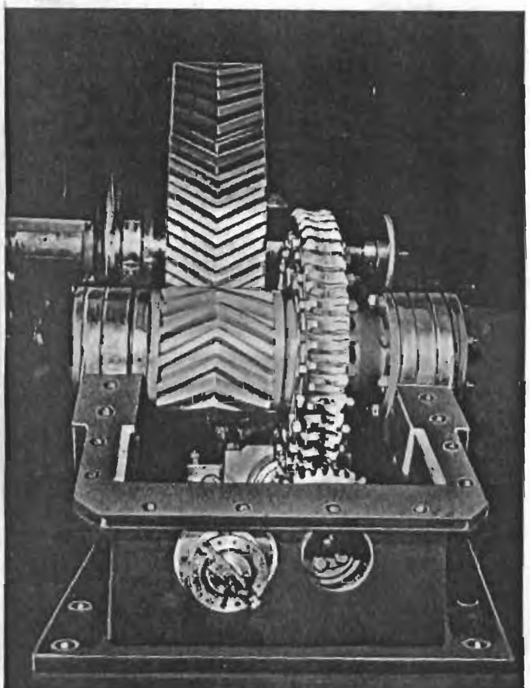
Steel mill gears often operate at high speeds, under heavy loads and subject to high heat radiated from hot steel being processed. In addition, the gear lubricants in service are apt to become contaminated with fine mill scale and water.

Open gears, which are normally lubricated with heavy residual lubricants, are being gradually replaced with enclosed gears. These are lubricated with straight mineral oils, compounded oil or mild EP lubricants.

Figures 22, 23, 24, 25 and 25-A illustrate a few types of steel mill gears. The following list shows a few examples of equipment actuated by gears:

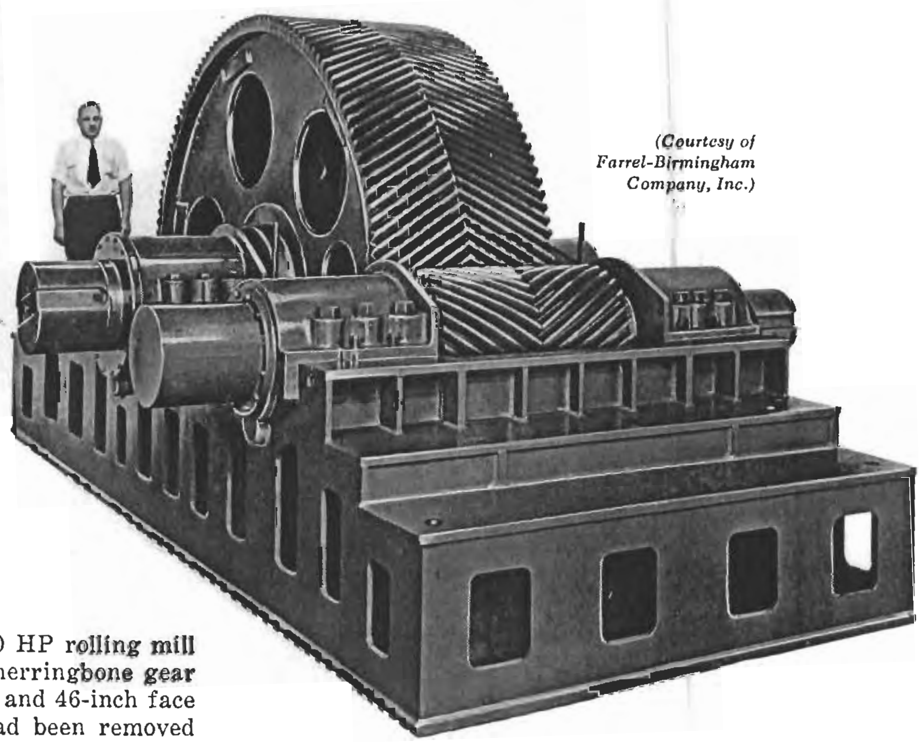
Ore Bridges	Ladle Cranes
Hoisting Equipment	Ingot Buggies
Gas Producers	Overhead Cranes
Mixers	Rolling Mills
Hot-Metal Cars	Screw Downs
Pig Machines	Tables
Furnace Tops	Conveyors
Oxygen Converters	Transfer Cars
Electric Furnaces	Shears
Charging Machines	Reheating Furnaces
	Manipulators

Open Hearth and Bessemer Converters



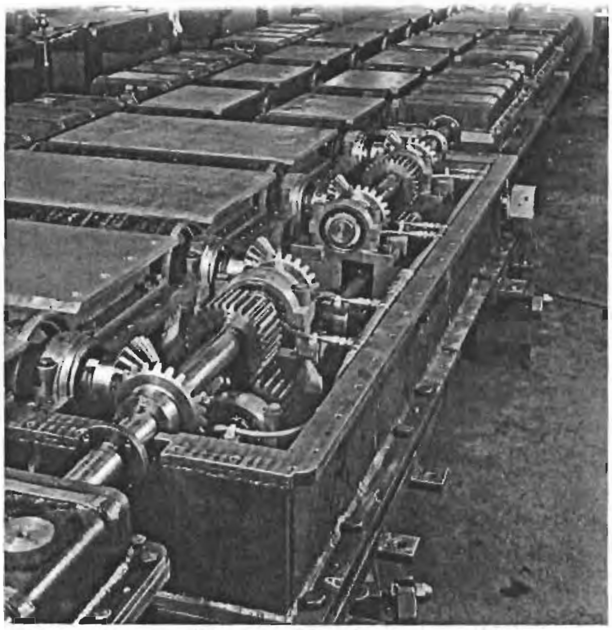
(Courtesy of Jones and Laughlin Steel Corp.)

FIGURE 22 — Reduction gear set which actuates tilting of the basic oxygen converter



(Courtesy of Farrel-Birmingham Company, Inc.)

FIGURE 23 — 5500 HP rolling mill drive with continuous tooth herringbone gear 144 inches in diameter and 46-inch face width. Cover had been removed



(Courtesy of Farrel-Birmingham Company, Inc.)

FIGURE 24 — Mill entry table for 30" x 36" cold breakdown mill. Cover of one drive removed to show arrangement of spur and bevel gearing

FIGURE 25A — Edging mill bevel gear

(Courtesy of The Tool Steel Gear and Pinion Co.)

SUGAR MILLS

Grinders

Sugar mill gears operating the grinders are quite heavily loaded and some initial pitting of new gears may take place but it usually subsides after the gears are sufficiently broken in.

Some of the older mills have completely open gearing with no slush pans. They are lubricated with heavy residual-type lubricant applied manually.

The more modern mills are equipped with enclosed gear cases with oil slush pans into which the gears dip. A less viscous type of gear oil in the pans enables the gears to be self-lubricating.

Great care is taken in sugar mills or other food-processing plants to make sure that the lubricants do not contain materials that would be toxic if accidental contamination should take place.

Figure 26 shows a view of the gear train in a modern sugar mill.

Other types of sugar mill machines include the following:

- Tractors
- Harvesters
- Elevators
- Conveyors
- Cane Carriers
- Cane Crushers or Grinders
- Granulators
- Dryers

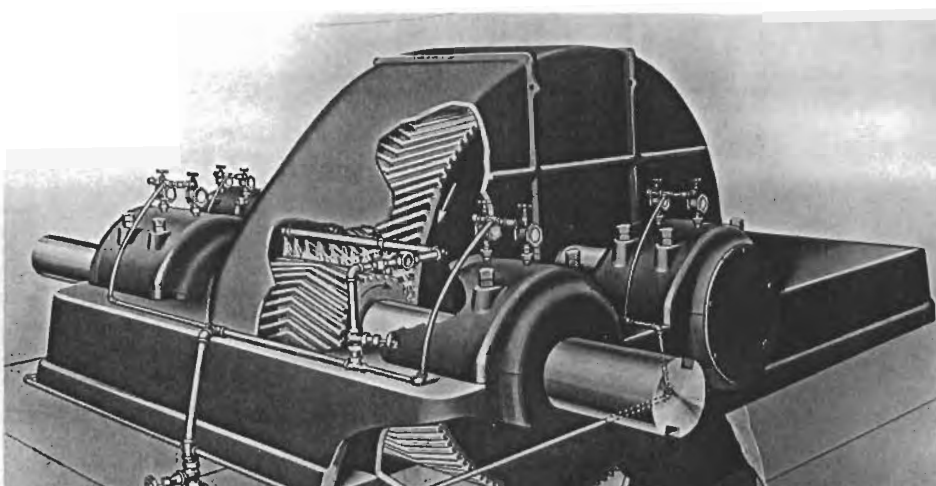


FIGURE 25 — Herringbone gear reduction set showing arrangement for spray lubrication

(Courtesy of Bowser, Inc.)

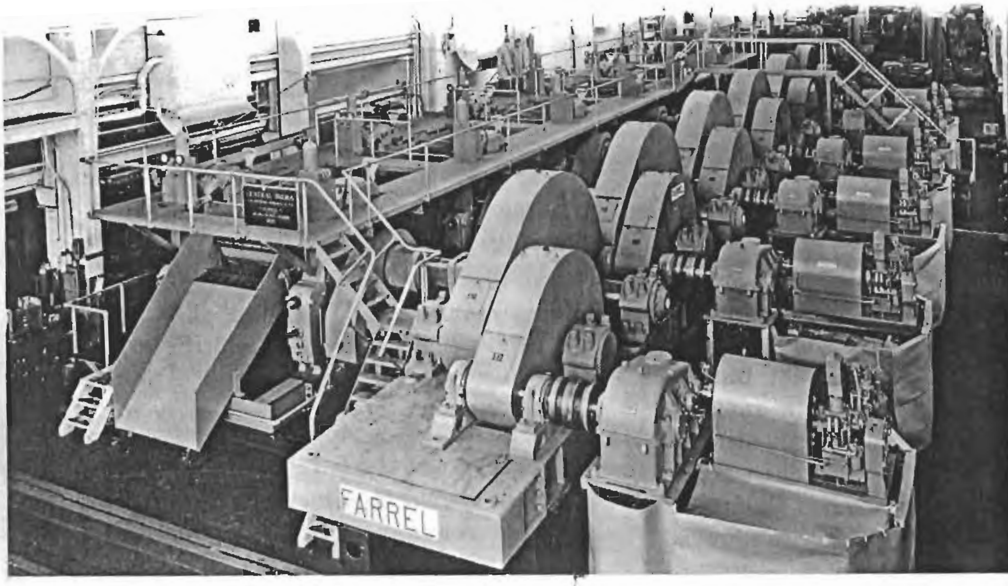


FIGURE 26 — Tandem sugar mill consisting of six three-roll mills, each with its own turbine drive. Grinding capacity is 5000 tons of cane per day. Enclosed reduction gears are closed herringbone type

(Courtesy of Farrel-Birmingham Company, Inc.)

OTHER TYPES OF EQUIPMENT

In addition to the above types of heavy industrial equipment the following list shows other types of industrial machinery in which gear lubrication is very important.

The choice of lubricant for these machines will depend on many factors such as whether open or enclosed gears are involved, speed, temperature, pressure, and if there is contamination with dirt, abrasives or water.

Baking Machinery

Mixers, flour handling, dividers, rounders, moulders and traveling type ovens.

Boiler Plant Machinery

Economizers, coal- and ash-handling conveyors.

Bottling Machinery

Clay Products Industry

Skip hoists, rolls, disintegrators, granulators
Pug mills, augers, grinders
Brick and tile cutters and pressing machines
Clay-distributing equipment
Plungers, screens and ball mills

Coke Ovens

Exhausters, blowers, pumps
Coal- and coke-handling equipment
Charging machines, door extractors
Pushing machines, electric locomotives

Concrete Mixers

Distilling and Brewing Equipment

Power-transmission equipment, bottling machines

Dredges

Elevators and Escalators

Glass Making

Polishing and grinding machines, overhead cranes
Bottle machines, pressing machines, Lehr furnaces, mixing equipment
Gas producers

Grain Elevators

Gravel Handling and Washing

Laundry Machinery

Washing machines, ironers, extractors
Driers, starch mixers, dampeners

Machine Tools

Marine Machinery

Jacking engines, telemotors, windlasses
Capstans, deck winches, steering engines

Materials-Handling and Hoisting Equipment

Cranes, ore bridges, unloaders, car dumpers

Metal-Forming Machinery

Paper Mills

Chemical mixers, digesters, agitators, pumps, dryers

Pneumatic Machinery

Air hoists

Printing and Binding Machinery

Web presses, bed presses, platen presses
Paper feeders, folders and cutters
Binding and composing room machinery

Pumps

Road-Building Machinery

Scarifiers, graders, surfacing and finishing machines
Pavers

Rock Products Machines

Scarifiers, graders, ball mills, tube mills, Rotary screens

Rubber Machinery

Crackers, washers, mixers, calenders

Textile Machinery

Cotton, silk and woolen mills
Printing and knitting machines

Wood-Working Machinery

Power plant and mill machines

American Gear Manufacturers Association Activities

For many years the AGMA has recommended straight mineral gear oils and a few compounded with fatty oils for various types of industrial gears. Nearly all of the gear manufacturers adhere strictly to the AGMA specifications. A brief extract of the "AGMA Standard Specification for Lubrication of Industrial Enclosed Gearing" AGMA — 250.02 Dec. 1955 is shown on page 30.

However, in recent years there has been a trend in industry towards the use of mild EP lubricants where heavy-duty conditions require such products. These EP lubricants have performed well.

Recently AGMA has developed a new specification which recommends the use of mild EP type gear lubricants for certain applications. An abstract of this new specification "Tentative AGMA Standard 252.01 Mild EP Lubricants for Industrial Enclosed Gearing" May 1959 is shown on page 31.

The AGMA is to be complimented on their efforts over the years to standardize the types of lubricants best suited for all varieties of gears.

Gear Manufacturers Activities

Since the general trend in industry is towards greater loads, higher speeds and force-feed lubrication, the gear manufacturer is continually cooperating to improve gear performance. Following are some of the procedures:

1. Improved steels and heat treatments are being used. These are restricted to some extent by limitations of machinability.
2. Accuracy of manufacture is stressed. Accurate tooth spacing is especially important with high-speed gears. Inaccuracies will result in lubricant failure as well as gear tooth failure and will cause loss of power transmitted. Tooth surface finish also is important. Rough finishes usually result in high operating temperatures, which are apt to cause deterioration of gear teeth as well as lubricant.
3. Special attention also is being given to mounting of gears to prevent damage to teeth and to make sure there is no misalignment.
4. Improved guards are being provided to keep oil in the housings and to prevent contamination.
5. The use of welded steel gears to replace cast gears is being extended. This provides gear teeth with greater strength and resistance to wear and reduces the possibility of hidden defects within the gears.
6. Manufacturers are continually modernizing and redesigning units and at the same time incorporating the latest methods of heat treatment and other metallurgical and manufacturing improvements. By taking advantage of newest techniques gear units can be made to closer tolerances, and this provides increased capacity ratings as compared to older styles.

Choosing a Gear Lubricant

Although a great deal of research has been carried out, a formula for computing the proper viscosity and type of gear lubricant has never been developed, due to the complexity of factors involved. Usual practice is to select the lubricant on the basis of previous practical field experience with gear operation under various conditions.

One investigator[1] has presented the following formula which, it is claimed, will aid in predicting loads at which scoring will take place, using speed of the pinion, viscosity of lubricant and bulk oil temperature values.

$$W = (aZ^{1/2} - bT)/N^{2/3} \text{ where}$$

W = Scoring load

N = Rotational Speed of Pinion

Z = Nominal viscosity

T = Bulk oil temperature

a and b = Constants for the machine

This investigator further states, "Though the practical problem of selecting the right

[1] E. T. Hutt in "Lubrication Engineering," Aug., 1952.

lubricant for a specific application can usually be solved by reference to the immense body of practical experience that has been accumulated in this field, the final choice is essentially an empirical one and the theoretical justification for it is not always clear. However, the progress achieved in recent years encourages the belief that a full solution of the important problem of predicting the performance of gears of all kinds is not indefinitely remote." Other investigators[1] have shown that the viscosity of a gear lubricant is an important factor in the power-transmitting capacity of gears. They have presented the following formula (which is an adaptation of Lewis' original equation for predicting maximum gear tooth loads).

$$W = Spby \left(\frac{ZK}{2K + ZV}\right), \text{ where}$$

W = Tooth load — pounds

S = Safe static stress — PSI

p = Circular pitch — inches

b = Width of face — inches

y = Tooth form factor

Z = Absolute viscosity in lb/min. ft.

K = Constant assumed by manufacturer

V = Pitch line velocity — fpm

Based on this modified Lewis formula, Figure 27 shows the effect of viscosity on transmitted power for gears on a test apparatus at one speed — 3000 RPM.

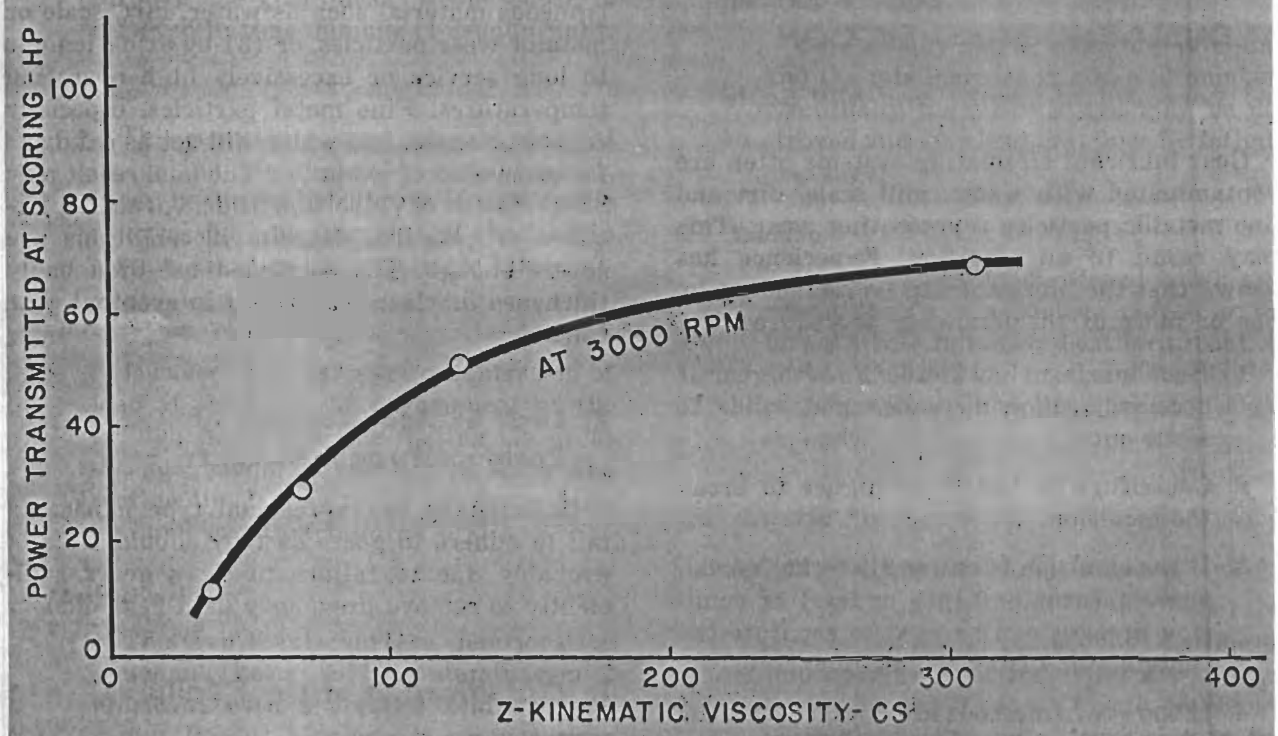
Since it is difficult to predict types of lubricants required for various types of gears it is usually necessary to actually run laboratory tests using the specific gears involved. The following types are being used in a large petroleum laboratory testing program.

Traction Motor Gears

Open Gears

[1] Borsoff, Accinelli and Cattaneo, "ASME Transactions, 1951."

FIGURE 27



High-Speed Aircraft Gears

Hypoid Gears

Since at the present time there is no suitable formula for arriving at the proper lubricant to use on specific gears, the choice is usually made after consultation with various groups interested in the lubrication problem.

1. The gear manufacturer usually depends on previous experience with certain types of lubricants; he prefers those which he knows have performed well in similar service in the past.
2. The manufacturer of equipment in which the gears are used also is usually consulted.
3. The user of the gears, of course, can apply whatever lubricant he wishes, (after the guarantee period), but it is of utmost importance to have the right lubricant in his equipment.
4. The lubricant supplier likewise, on basis of field experience has definite ideas as to the best lubricant to use; however, his recommendation should be tempered by the desires of the other people involved.

TROUBLE-SHOOTING SECTION

A. Removal of Water and Mill Scale

Gear lubricant circulating systems often are contaminated with water, mill scale, dirt and fine metallic particles representing wear. This may result in an emulsion. Experience has shown that the lubricant can be cleaned up by one or more of the following procedures.

1. Heat lubricant up to 160°F. or higher if necessary, allowing water and solids to settle out.
2. Centrifuge at 160°F. or higher to break the emulsion.
3. If the emulsion is extremely tight, a small amount (usually 0.10% or less) of emulsion breaker can be used to separate the contaminants from the oil.
4. If the above methods are not effective, the oil tank can be heated below the foaming point and water removed by boiling off.

B. Noisy Operation

This condition can develop because of improper design, faulty installation, faulty operation, development of misalignment or worn-out gears. Excessive noise should be investigated promptly.

C. Foaming

Foaming in a gear box may occur for one of the following reasons:

1. Oil level too high, resulting in excessive churning.
2. Certain types of additives may cause foaming.
3. Water in the oil may cause foam, especially if operating temperature is high.

Foaming is objectionable since it may cause oil starvation on the gear teeth as well as leakage from the box.

D. Lubricant Thickening

This can be caused by (1) contamination with a heavier oil, (2) contamination with extraneous material such as water, dirt, scale or metallic wear particles, or (3) by oxidation due to long service or excessively high operating temperatures. Fine metal particles, especially copper or brass, and water will act as catalysts for promotion of oxidation. The final result may be formation of petroleum acids, varnishes, lacquers or coke-like deposits if conditions are severe enough. The continued use of a badly thickened lubricant can result in eventual gear failure.

E. Lack of Adhesiveness of Residual Type Lubricants

Occasionally heavy residual type lubricants fail to adhere to gears as they should. This is probably due to failure to clean gears sufficiently to remove previously used gear oils.

F. Classification of Gear Failures

Years of field experience with gear operation have shown that many types of failure are likely to occur. These can be charged chiefly to faulty operating or mechanical conditions. The lubricant is very seldom at fault if the proper type and amount is applied and if there is no excessive contamination. Brief descriptions of the various types of failures are tabulated below:

1. *Wear*

Normal Wear or Polishing

Slow loss of metal from gear surface that will not affect the expected life of the gears.

Destructive Wear

Heavy wear causing change in tooth shape, resulting in shortened life and noisy action.

Abrasive Wear

Injury caused by metal or other abrasive particles passing through the gear mesh.

Scratching

Is a severe form of abrasive wear caused by hard foreign pieces passing through the gear mesh. If the cause is removed in time damage is usually light.

Scoring

This represents rapid removal of metal by tearing due to metal-to-metal contact. It can be caused by rupture of oil film due to excessive concentration of the load in certain areas or an unsuitable lubricant.

Interference Wear

Is caused by improper concentration of load at the point of engagement of the driving flank with the mating tip or at disengagement of the driven flank and mating tip. It may result in severe damage and eventual failure.

Corrosive Wear

This represents surface deterioration which may be caused by contamination of lubricant with a foreign acid or with water. It can also occur if an overactive Extreme Pressure lubricant is used.

Flaking

Occurs when thin flakes of metal are removed from gear teeth. It can be caused by surface fatigue or as a result of tensile yielding under combined rolling and sliding action. It is usually associated with softer steels or with bronzes. Ordinarily this only occurs during the initial period of operation and is usually not serious.

Burning

This is the result of excessive temperature either from external sources or as a result of friction due to high loads or speed or inadequate lubrication. It is characterized by temperature discoloration of the contacting or adjacent surfaces.

2. *Surface Fatigue*

Initial Pitting

Involves light pitting, usually occurring at the beginning of operation and diminishing when high spots are worn down. It usually occurs in a narrow band near the pitchline. It is not serious and usually corrects itself.

Destructive Pitting

This usually starts below the pitchline and the pits increase in size and number. Eventually the tooth shape may be destroyed and may lead to failure by fatigue breakage.

Spalling

Often occurs in hardened steel and originates from a surface defect or internal stress following heat treatment. It is characterized by large particles flaking out of tooth surfaces, usually on top edges or ends.

3. *Plastic Flow*

Rolling and Peening

Are caused by sliding action under excessive loads and impact loading due to improper tooth action. They are characterized by fins at edges of teeth, by rounded tooth tips, or by a depression in the surface of the driving gear and a raised ridge near the pitchline of the driven gear. Tooth profiles become badly deformed before complete failure.

Rippling

This is a wave-like formation on the surface at right angles to the direction of sliding. It has a fish-scale appearance and occurs on case-hardened hypoid pinions. It is not serious unless allowed to continue.

It can be caused by friction due to insufficient lubrication, heavy loads or vibration.

Ridging

This occurs on tooth surface of case-hardened hypoid pinions and bronze worm gears. It may appear as diagonal ridges or as a herringbone pattern occurring in the direction of sliding. This is usually associated with excessive loads or insufficient lubrication and may result in complete failure.

4. *Breakage*

Fatigue Breakage

This results from bending stresses beyond the limit of the metal. These stresses can originate from poor design, overload, misalignment or surface defects. Breakage usually starts as a crack on the loaded side.

Breakage from Heavy Wear

Severe pitting, spalling or abrasion can remove enough metal to reduce the strength of the tooth to its breaking point.

Overload Breakage

Results from sudden shock overload and does not show progression from a crack as in fatigue. Harder materials have a silky appearance and ductile metals have a fibrous or torn appearance. Misalignment or entrance of a large piece of foreign matter in the mesh may be contributing causes.

Quenching Cracks

These cracks originate from internal stresses developed during heat treatment and are visible as hairline cracks. They often are the focal points for fatigue breakage or overload breakage.

Grinding Cracks

These fine surface cracks are developed by improper grinding technique or heat treatment. Often they do not appear until the gear has been subjected to load. Cracks are originating points for fatigue breakage or surface spalling.

SAE CLASSIFICATION VISCOSITY RANGES

Motor Oil SAE Vis. No.	Viscosity Range, SUS, (Oct. 3, 1950)			
	at 0°F.		at 210°F.	
	Minimum	Maximum	Minimum*	Maximum
5W	—	4,000	—	—
10W	6,000 (A)	Below 12,000	—	—
20W	12,000 (B)	48,000	—	—
20	—	—	45	Below 58
30	—	—	58	Below 70
40	—	—	70	Below 85
50	—	—	85	110

A—Can waive min. vis. at 0°F. if 210°F. vis. is above 40 SUS.
B—Can waive min. vis. at 0°F. if 210°F. vis. is above 45 SUS.
*—Crankcase oils must have viscosity not less than 39 SUS at 210°F.

Gear Oil SAE Vis. No.	Viscosity Range, SUS, (Jan., 1953)			
	at 0°F.		at 210°F.	
	Minimum	Maximum	Minimum*	Maximum
75	—	15,000	—	—
80	15,000 (A)	100,000	—	—
90	—	—	75	120 (B)
140	—	—	120	200
250	—	—	200	—

A—Can waive min. vis. at 0°F. if 210°F. vis. is above 48 SUS.
B—Can waive max. vis. at 210°F. if 0°F. vis. is below 750,000 SUS. (Extrapolated.)
*—Trans. and axle lubes must have vis. not less than 40 SUS at 210°F.

NLGI GREASE CLASSIFICATION

NLGI Grade No.	ASTM Worked Penetration 77°F. Min.	Max.
000	445	475
00	400	430
0	355	385
1	310	340
2	265	295
3	220	250
4	175	205
5	130	160
6	85	115

AGMA STANDARD SPECIFICATION FOR LUBRICATION OF INDUSTRIAL ENCLOSED GEARING

AGMA 250.02 — DECEMBER 1955

TYPE OF OIL

a. Shall be high quality, well refined, petroleum oil.

b. Shall be noncorrosive to gears, to ball, roller and sleeve bearings.

c. Shall be neutral in reaction, free from grit or abrasiveness, have good defoaming properties and good oxidation resistance.

d. Shall be straight mineral oil with following exceptions:
   (1) For worm gears, addition of 3 to 10% animal fat such as acidless tallow, is desirable.

   (2) Special additives are permitted in applications where speeds, loads or temperatures are abnormal.

VISCOSITY

a. Viscosity Index (Dean & Davis) of 30 minimum is allowed for ordinary applications. Where operating temperatures vary more than 80°F., a viscosity index of 60 minimum is desired. Oils meeting AGMA 7 comp, 8 comp and 8A comp must have a minimum viscosity index of 90.

b. Viscosity must be within the ranges shown below:

VISCOSITY RANGE FOR VARIOUS AGMA LUBRICANTS

AGMA Number	Viscosity Range SUV Seconds at 100°F.	at 210°F.
1	180 to 240	
2	280 to 360	
3	490 to 700	
4	700 to 1000	
5		80 to 105
6		105 to 125
7 comp*		125 to 150
8 comp*		150 to 190
8A comp*		190 to 250

* To be compounded with 3 to 10% animal fat such as acidless tallow.

TENTATIVE AGMA STANDARD SPECIFICATION MILD EXTREME PRESSURE LUBRICANTS FOR INDUSTRIAL ENCLOSED GEARING

AGMA 252.01 —— MAY 1959

SCOPE

a. Applicable to following types of gearing.
Helical · Herringbone · Straight Bevel · Spiral Bevel · Spur

b. Not applicable to worm gearing (consult manufacturers).

TYPE OF OIL

Shall be a mild Extreme Pressure oil with following characteristics.

a. No separation of oil and additive.

b. Have maximum resistance to foaming under normal operating moisture conditions.

c. Non-corrosive to metals encountered even in presence of moisture.

d. Have minimum Timken EP test of OK 30 pounds load.

e. Contain no dirt, abrasive or other deleterious materials.

f. Sufficiently stable to give normal service life in AGMA standard gears operating at temperatures up to 160°F.

VISCOSITY

a. Have minimum Viscosity Index of 60. (Dean & Davis)

b. Viscosity of various grades must be within the ranges shown below.

VISCOSITY RANGE OF AGMA LUBRICANTS

Lubricant Number	Viscosity Ranges at 100°F.	SUV Seconds at 210°F.
2 EP	280- 400	
3 EP	400- 700	
4 EP	700-1000	
5 EP		80-105
6 EP		105-125
7 EP		125-150
8 EP		150-190

VISCOSITY SYSTEM FOR INDUSTRIAL FLUID LUBRICANTS

ASTM D-2422-65T

In recent years, there has been considerable interest on the part of users of industrial lubricants in a viscosity classification system which will be adaptable to electronic data processing machines for statistical listing. This is especially needed by companies who may purchase a variety of lubricants from various petroleum suppliers.

The ASTM-ASLE Viscosity System is in process of adoption by industry. Its purpose is to standardize and simplify viscosity classifications of industrial lubricants. Only 16 different viscosities are used, with a uniform viscosity tolerance of ± 10% for all grades. All viscosities are based on a temperature of 100°F.

This System simply groups industrial lubricants by viscosity ranges. It is similar to the SAE numbers used to designate automotive lubricant viscosities. Neither system evaluates lubricant quality.

VISCOSITY CLASSIFICATION

Viscosity Grade Number, SUS at 100°F.	Kinematic Equivalent cs at 100°F.
7000	1515
4650	1000
3150	682
2150	464
1500	324
1000	216
700	151
465	100
315	68.0
215	46.3
150	32.0
105	21.7
75	14.4
60	10.3
40	4.27
32	1.83

TEXACO

LUBRICATION CHART

FOR

GEARS

TYPES OF GEAR LUBRICANTS

1. *Heavy Adhesive Residual Type (For Open Gears)*

a. Residual (Straight Mineral)
   Texaco Crater 00, 0, 1, 2, 3, 5

b. Residual (Compounded)
   Texaco Crater A, 1X, 2X, 5X, 10X

c. Residual (Cutback with Solvent)
   Texaco Crater 2X Fluid and 5X Fluid

2. *Greases (For Open and Enclosed Gears)*

Texaco Marfak 00, 0 and 1

Texaco Marfak Heavy Duty 2 and 3

Texaco Thermatex 000

Texclad 1 and 2 (For Open Gears)

3. *Intermediate Viscosity Oils (For Enclosed Gears)*

a. Straight Mineral Oil
   Texaco Thuban 80, 90, 140 and 250
   Texaco Regal Oils PC-R&O, PE-R&O, F-R&O, G-R&O, H-R&O

b. Mineral Oil With Oiliness or Polar Additive
   Texaco Honor Cylinder Oil
   Texaco 650T Cylinder Oil

4. *Extreme Pressure Oil (Mild Type)*

Texaco Meropa Lubricants 1, 2, 3, 4, 5, 6, 7, 7H, 8 and 10
Texaco Universal Gear Lubricants HD 80, 90 and 140

5. *Extreme Pressure Oil (2105B Type)*

Texaco Multigear Lubricants EP (Where required to meet Military Specification MIL-L-2105B)

TEXACO RECOMMENDATIONS FOR GENERAL INDUSTRIAL GEAR LUBRICANTS

Type of Gear	Description	Ambient Temperatures	Normal Operation	Heavy Duty, Where Extreme Pressure Lubrication Required	In Presence of Water or Chemicals
Spur, Bevel, Spiral Bevel, Annular or Internal	Gears enclosed, casings oil tight, bearings separately lubricated.	Below 40° F.	Thuban 80 Regal Oil PC R&O	Meropa Lubricant—1	
		40° to 100° F.	Thuban 90 Regal Oil G R&O	Meropa Lubricant—3	
		Above 100° F.	Thuban 140	Meropa Lubricant—6	
	Gears enclosed, casings oil tight, gear lubricant to serve bearings as well.	Below 40° F.	Regal Oil F R&O Algol Oil	Meropa Lubricant—1	
		40° to 100° F.	Regal Oil G R&O Thuban 90	Meropa Lubricant—2 or 3	
		Above 100° F.	Regal Oil H R&O Thuban 90	Meropa Lubricant—3	
	Gears entirely exposed, hand lubricated.	Below 40° F.	Crater 1 or 2X Fluid Texclad 1	Meropa Lubricant—2 or 3	Crater 1X
		40° to 100° F.	Crater 1, 2 or 2X Fluid Texclad 2	Meropa Lubricant—3 or 4	Crater 1X, 2X or 2X Fluid
		Above 100° F.	Crater 3 or 5X Fluid Texclad 2	Meropa Lubricant—6	Crater 2X or 2X Fluid
	Gears exposed, bath lubricated.	Below 40° F.	Regal Oil G R&O Thuban 90	Meropa Lubricant—3	
		40° to 100° F.	Thuban 140 or 250 Crater 00, 0 or 2X Fluid Higra	Meropa Lubricant—6 or 8	Crater 1X
		Above 100° F.	Thuban 250 Crater 0, 1, 2 or 2X Fluid Higra	Meropa Lubricant—8	Crater 1X or 2X Fluid
Helical or Herringbone	Gears enclosed, casings oil tight, bearings separately lubricated.	Below 40° F.	Regal Oil G R&O Thuban 90	Meropa Lubricant—3	
		40° to 100° F.	Regal Oil G R&O Thuban 90 or 140	Meropa Lubricant—3 or 6	
		Above 100° F.	Thuban 140	Meropa Lubricant—6	
	Gears enclosed, casings oil tight, gear lubricant to serve bearings as well.	Below 40° F.	Regal Oil PE R&O Algol	Meropa Lubricant—1	
		40° to 100° F.	Regal Oil F R&O Thuban 90	Meropa Lubricant—1 or 2	
		Above 100° F.	Regal Oil G R&O Thuban 90	Meropa Lubricant—3	
	Gears entirely exposed, hand lubricated.	Below 40° F.	Crater 0, 1 or 2X Fluid Texclad 1	Meropa Lubricant—3	Crater 1X or 2X Fluid
		40° to 100° F.	Crater 1, 2 or 2X Fluid Texclad 2	Meropa Lubricant—6 or 8	Crater 1X, 2X or 2X Fluid
		Above 100° F.	Crater 1, 2 or 2X Fluid Texclad 2	Meropa Lubricant—8	Crater 1X, 2X or 2X Fluid
	Gears exposed, bath lubricated.	Below 40° F.	Regal Oil G R&O Thuban 90	Meropa Lubricant—3	Crater 1X
		40° to 100° F.	Thuban 140 or 250 Crater 00, 0 or 2X Fluid Higra	Meropa Lubricant—6 or 8	
		Above 100° F.	Thuban 250 Crater 00, 0 or 2X Fluid Higra	Meropa Lubricant—8	

TEXACO RECOMMENDATIONS FOR GENERAL INDUSTRIAL GEAR LUBRICANTS

Type of Gear	Description	Ambient Temperatures	Normal Operation	Heavy Duty, Where Extreme Pressure Lubrication Required	In Presence of Water or Chemicals
Worm	Gears enclosed, casings oil tight, bearings separately lubricated.	Below 40° F.	Regal Oil PC R&O Thuban 80	Meropa Lubricant—1	
		40° to 100° F.	Honor Cylinder Oil Thuban 90 Regal Oil G R&O	Meropa Lubricant—3	
		Above 100° F.	Honor Cylinder Oil 650T Cylinder Oil Thuban 140	Meropa Lubricant—6	
	Gears enclosed, casings oil tight, gear lubricant to serve bearings as well.	Below 40° F.	Regal Oil PC R&O Thuban 80 or 90	Meropa Lubricant—1 or 3	
		40° to 100° F.	Honor Cylinder Oil Thuban 90 Regal Oil G R&O	Meropa Lubricant—3	
		Above 100° F.	Honor Cylinder Oil 650T Cylinder Oil Thuban 140	Meropa Lubricant—6	
	Gears entirely exposed, hand lubricated.	Below 40° F.	Regal Oil G R&O Thuban 90 Texclad 1	Meropa Lubricant—3	
		40° to 100° F.	Thuban 140 Texclad 2	Meropa Lubricant—6	Crater 1X or 2X Fluid
		Above 100° F.	Thuban 140 Crater 0, 1 or 2X Fluid Texclad 2	Meropa Lubricant—6	Crater 1X or 2X Fluid
Rack and Pinion	Gears exposed, bath lubricated.	Below 40° F.	Regal Oil G R&O Thuban 90	Meropa Lubricant—3	
		40° to 100° F.	Thuban 140 Higra	Meropa Lubricant—6	Crater 1X
		Above 100° F.	Thuban 140 or 250 Higra	Meropa Lubricant—6 or 8	Crater 1X
	Teeth entirely exposed, hand lubricated.	Below 40° F.	Crater 00, 0, 1 or 2X Fluid Texclad 1	Meropa Lubricant—6	Crater 1X or 2X Fluid
		40° to 100° F.	Crater 1, 2 or 2X Fluid Texclad 2	Meropa Lubricant—6 or 8	Crater 1X, 2X or 2X Fluid
		Above 100° F.	Crater 3 or 5X Fluid Texclad 2	Meropa Lubricant—8 or 10	Crater 2X, 5X or 2X or 5X Fluid
	Teeth exposed, bath lubricated.	Below 40° F.	Regal Oil G R&O Thuban 90 Crater 00 or 2X Fluid	Meropa Lubricant—3	Crater 1X
		40° to 100° F.	Thuban 140 Crater 00, 0 or 2X Fluid	Meropa Lubricant—6	Crater 1X or 2X Fluid
		Above 100° F.	Thuban 140 or 250 Crater 0 or 2X Fluid	Meropa Lubricant—6 or 8	Crater 1X or 2X Fluid

NOTES: The above recommendations naturally are more or less general, based on average pressures and for small to medium sized gears:

1. In case of light loads or high speeds: Use next lighter grade of gear lubricant.
2. If gears are very large: Use somewhat heavier grade than that recommended above.
3. Meropa Lubricants are highly resistant to water and should be recommended where both a water resistant and an EP lubricant is desired.
4. For cast gears: Use the next heavier grade of gear lubricant recommended.
5. Texaco Craters under certain conditions are recommended for enclosed gears and exposed worm gears.
6. Should ambient temperatures be extremely low or high or should any uncertainty exist as to the correct lubricant recommended for a specific application, consult your local Texaco Lubrication Engineer.

* * *

NOTE: It is very important that there be adequate ventilation, due to the nature of the solvent, when Crater Fluid is applied, in order to carry away vapors and speed up the evaporation. The solvent does not burn.

AGMA STANDARD SPECIFICATION FOR LUBRICATION OF INDUSTRIAL ENCLOSED GEARING

AGMA 250.02 — DEC. 1955

TYPE OF OIL: — a. Shall be high-quality, well-refined, petroleum oil.

b. Shall be noncorrosive to gears, to ball, roller and sleeve bearings.

c. Shall be neutral in reaction, free from grit or abrasiveness, have good defoaming properties and good oxidation resistance.

d. Shall be straight mineral oil with following exceptions:

(1) For worm gears, addition of 3% to 10% animal fat such as acidless tallow, is desirable.

(2) Special additives are permitted in applications where speeds, loads or temperatures are abnormal.

VISCOSITY: — a. Viscosity Index (Dean & Davis) of 30 minimum is allowed for ordinary applications. Where operating temperatures vary more than 80°F., a viscosity index of 60 minimum is desired. Oils meeting AGMA 7 comp and 8 comp must have a minimum viscosity index of 90.

b. Viscosity must be within the ranges shown below:

VISCOSITY RANGE FOR VARIOUS AGMA LUBRICANTS

AGMA Number	Viscosity Range SUV Seconds at 100°F.	Viscosity Range SUV Seconds at 210°F.	Texaco Oils Recommended Against This Specification
1	180 to 240		Regal B R&O
2	280 to 360		Regal PC R&O
3	490 to 700		Regal F R&O
4	700 to 1000		Regal G R&O
5		80 to 105	Regal H R&O
6		105 to 125	Regal J R&O
7 comp*		125 to 150	Honor Cylinder Oil
8 comp*		150 to 190	650T Cylinder Oil

* To be compounded with 3% to 10% animal fat such as acidless tallow.

TENTATIVE AGMA STANDARD SPECIFICATION
MILD EXTREME PRESSURE LUBRICANTS FOR INDUSTRIAL ENCLOSED GEARING

AGMA 252.01 — MAY 1959

SCOPE: ——— a. Applicable to following types of gearing.

Helical
Herringbone
Straight Bevel
Spiral Bevel
Spur

b. Not applicable to worm gearing (Consult Manufacturers)

TYPE OF OIL: ——— Shall be a mild extreme pressure oil with following characteristics.

a. No separation of oil and additive.
b. Have maximum resistance to foaming under normal operating conditions.
c. Non-corrosive to metals encountered even in presence of moisture.
d. Have minimum Timken EP test of OK 30 pounds load.
e. Contain no dirt, abrasive or other deleterious materials.
f. Sufficiently stable to give normal service life in AGMA Standard Gears operating at temperatures up to 160°F.

VISCOSITY: ——— a. Have minimum Viscosity Index of 60.

b. Viscosity of various grades must be within the ranges shown below:

VISCOSITY RANGE OF AGMA LUBRICANTS

AGMA Mild EP Lubricant Number	Viscosity Ranges at 100°F.	SUV Seconds at 210°F.	Texaco Oils Meeting AGMA Standard 252.01
2 EP	280-400		Meropa Lubricant 1
3 EP	400-700		Blend Meropa 1 & 2
4 EP	700-1000		Meropa Lubricant 2
5 EP		80-105	Meropa Lubricant 3
6 EP		105-125	Meropa Lubricant 4
7 EP		125-150	Meropa Lubricant 5
8 EP		150-190	Meropa Lubricant 6

OTHER TEXACO GEAR LUBRICANTS

Greases

Greases such as *Texaco Marfak, Marfak HD* and *Multifak* are sometimes used on exposed gears where high temperatures prevail or where high leakage with fluid-type lubricant is encountered. Also soft grease such as *Texaco Thermatex 000* is used extensively in enclosed gear cases, particularly in underground mining machines. This grease minimizes leakage and lubricates well at high temperatures.

Universal Gear Lubricants HD 80, 90 and 140

These lubricants are often used to replace Meropa 2, 3 and 6.

Multigear Lubricants EP

Where customers require a product meeting Military Specification MIL-L-2105B.

Craters

These products are used for lubrication of open gears, enclosed gears and certain types of plain roll neck bearings. They were designed for use in steel mills and other heavy industries where water conditions and heavy loads are encountered and where economy and ease of application are required.