The History and Use of Fire Resistant Fluids in Gas Turbines

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This paper examines the three important developments of the trend toward increased use of phosphate esters, and provides a look at what can be expected in the next several years. Phosphate ester fire-resistant fluids offer three significant improvements in fire safety, when compared to petroleum products: (a) increased auto ignition and hot manifold ignition temperatures, (b) non-propagation of a flame, and (c) higher compression/ignition ratio. The use of fire-resistant phosphate ester fluids has increased significantly during the last ten years as a direct result of experience generated and problems being solved.

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INTRODUCTION

During the last four years, the interest in using phosphate ester fire-resistant fluids as lubricants in gas turbines, has increased significantly. The gas transmission and utility industries have made commitments to use phosphate ester in a large number of new installations, and in a few cases have made studies to determine the cost of converting equipment from petroleum lubricants. At the same time, the steel industry, die casting operations, mining, and non-ferrous metal production have also increased their usage of phosphate esters.

The trend toward the increased use of phosphate esters can be related to three important developments, involving:

1. An attitude to examine and improve all aspects of operating safety
2. A greater emphasis to improve operating efficiency and reliability, primarily to offset rapidly increasing fuel, raw material and labor costs
3. A better understanding of the characteristics of phosphate esters, and increasing confidence in their use in specific applications such as gas turbines.

This paper will examine each of these three developments, and provide a look at what we can expect in the next several years.

INCREASED OPERATING SAFETY

Activity by both government and private industry have been placing an increased emphasis on improving plant operating conditions. Noise levels, air quality, hazardous operating situations, and operating techniques have been monitored with the intent of improved employee well being. Little or no governmental activity, outside of mine legislation, has involved the specific types of lubricants and hydraulic fluids to be used in hazardous applications. Yet a responsible industry management and the continuing concern of labor groups have examined the use of petroleum products in a number of systems, and decided they should be replaced by fire-resistant fluids. In addition, many new systems being built for future installations will be designed to use phosphate ester fluids.

Phosphate ester fire-resistant fluids offer three significant improvements in fire safety, when compared to petroleum products:

1. Increased Auto Ignition and Hot Manifold Ignition Temperatures
2. Non-propagation of a flame
3. Higher compression/ignition ratio.

The auto ignition temperature of a fluid is defined as that point at which any number of drops of that fluid will ignite when introduced by pipette into a standard 125-ml flask, heated by either electrical or molten metal methods, but at 5 °C below which ignition fails to take place. It is a measure of the temperature required to ignite a fluid without the presence of a direct flame.

The hot manifold test more closely simulates the conditions found in the vicinity of hot metal surfaces. For this test the fluid is dripped onto the surface in a manner simulating fluid spillage or leakage. For both the auto ignition test and hot manifold test, the temperatures required for ignition of the phosphate esters are approximately 400 °F higher than for similar petroleum products. These results do not imply that the phosphate esters are non-flammable, but that they provide protection from ignition at much higher temperatures than petroleum oil.

Another characteristic of phosphate esters is that they will not propagate a flame. This means that fluid which has been ignited will self-extinguish when the ignition source is removed, as when fluid spillage or leakage drips off of a hot or molten metal surface. This
characteristic keeps any ignition localized in
the area of the flame or high temperature, and
does not permit the fire to spread to surrounding
areas. Petroleum based fluids will propagate a
flame and can cause severe and widespread damage
once they are ignited and allowed to flow freely.
With modern lubrication systems using between
500 and 2000 gal of fluid, this can mean the
spread of an ignition to a considerably large
area, should a line break or leak excessively.

A third property of the phosphate esters
which contributes to increased safety is the
higher compression ignition ratio. The rapid
compression of any fluid will increase the
temperature and can eventually result in an
ignition. Research data has indicated that
petroleum oils can be ignited when they are
compressed by a 10:1 ratio in a compression/
ignition device. In the same device, a com-
pression/ignition ratio in excess of 40:1 has
been routinely noted for the phosphate ester
fluids. This property has been a significant
factor in the widespread use of phosphate esters
in air and natural gas compressors, with partic-
ular usage in reciprocating compressors.

Perhaps the most important consideration
for the phosphate esters is that their fire-
resistance is permanent. It is fire protection
that is built in, not added on. The phosphate
esters prevent many kinds of ignitions, and
significantly reduce the effects of others.
Certainly, when plant and personnel safety are
being reviewed, the use of phosphate ester fluids
and lubricants are being discussed.

IMPROVED OPERATING EFFICIENCY

The present domestic and international
economic situation has required all phases of
business to examine their production techniques,
and return on investment, not only to maintain
adequate profitability but to insure production
in a period of shortages. Inflated sales prices
often give an erroneous picture of the success
of an operation, where raw material costs and
labor have also increased significantly. Pro-
duction managers advise that equipment downtime
must be kept to a minimum, and maintenance costs
reduced.

The phosphate esters as gas turbine
lubricants can provide a reduction in system
downtime and operating costs in several important
areas:

1 Fire-resistance
2 Oxidative stability
3 Reclaimability
4 Deposit formation.

Previously, we discussed the fire-resistant
characteristics of the phosphate esters, and
found them to reduce the probability of an igni-
tion should operating fluid leak or spill onto
a hot surface. The possibility of fluid leakage
in bearing areas on gas turbines has been well
documented by both equipment manufacturers and
turbine operators. These areas are usually
protected by heat and fire detection devices
which are activated when an ignition occurs.
Such activation will trip the unit off of the
line and cause a forced outage until any minor
damage is repaired, and the fire suppression
devices recharged. In addition to the cost and
time to repair damage and recharge the fire-
suppression devices, the turbine outage requires
supplemental power to be purchased or alternate
units to be started up, to maintain production
schedules. It has also been documented that
increased numbers of turbine start-ups and
shutdowns can result in higher maintenance costs,
and shorter turbine life. Therefore, operating
on a phosphate ester fire-resistant fluid can
improve efficiency and reduce some maintenance
costs by eliminating or reducing the potential
of forced outages due to the ignition of the
lubricant.

The phosphate esters have also been
produced to provide equal or better thermal
stability than petroleum lubricants. Pure
phosphate esters have been improved in recent
years to include rust and oxidation inhibitors
which give extended service life, and therefore
reduce fluid changeout and makeup costs. Within
the last year an advanced design phosphate ester
has been installed in several industrial gas
turbines, with the promise of even longer service
life. This latest product development achieves
its oxidative stability from the phosphate ester
itself, rather than the presence of inhibitors,
and, therefore, is not expected to be affected
by additive depletion in service. Should the
environment of a particular gas turbine cause
an extreme stress on the fluid, the degradation
products may be removed by Fuller's Earth Filtra-
tion, and no fluid changeout would be required.
Standard petroleum lubricants contain additive
packages which are removed in Fuller's Earth
Treatment, and these additives must be put back
into the lubricant in the proper amounts to
continue to provide adequate service. The
result of the improved oxidative stability of the
phosphate esters and ease of removal of degrada-
tion products, provides the turbine operator
with a method to reduce fluid makeup and change-out costs.

In addition to the ease of removing acidic degradation products, the phosphate esters lend themselves to other aspects of reclamation. The non-additive nature of most phosphate esters permits the use of 1/2 micron filtration to remove solids, without fear of removing important additives, such as viscosity index improvers. The phosphate esters can also have water easily removed by vacuum dehydration, or centrifuge, as long as the higher density of the ester is recognized. Reclaiming the phosphate esters only once reduces the net fluid cost in half, and with care the turbine lubricant system can be operated without changeout, through 40,000-100,000 hr intervals.

When the gas turbine does come down for overhaul, the phosphate ester can provide one additional area of cost savings. The latest phosphate ester products provide a significant decrease in sludge and deposit formation, when compared to conventional petroleum products. Tests by the National Research Council of Canada, have recently confirmed these results, with the conclusion that the new phosphate esters outperform petroleum products with a reduction of deposit rating of over 90 percent.

The increased emphasis on a reduction in forced outages; and increase in service life, both for the equipment and the lubricants; and a reduction of routine maintenance costs; has resulted in a greater consideration and application of phosphate esters as lubricants for industrial gas turbines.

A Better Understanding of Phosphate Esters

Phosphate esters have been used in industrial and military applications for over 20 years. It was no wonder, therefore, that they would be carefully examined in the late 1950's for their possible use as steam and gas turbine lubricants. The requirement for fire-resistance resulted from operating experience indicating the relatively frequent leakage of lubricant, and the accompanying danger of a serious fire. History had recorded a number of serious oil related turbine fires resulting from cracked or broken oil lines which allowed oil to come in contact with hot metal surfaces. Of primary concern was the lubrication of turbines at unattended stations, but it was also felt that the increase in safety would be valuable at attended stations.

A major Canadian pipeline was the first to install phosphate esters in industrial gas turbines, with the first units operational in early 1960. With little field experience to draw on, a number of important considerations had to be made in order to operate successfully. All pumps, piping, and controls had to be checked and modified where necessary to accommodate the higher specific gravity of the phosphate esters. In addition, seal material, packings, filters, and paints were changed where necessary, in order to be compatible. Unfortunately not all conversions were made prior to system start-up, and this resulted in a number of seal and diaphragm failures, as well as some filter plugging due to dissolved paint from the piping. With a careful examination of each area, however, these problems were resolved, and it was concluded that with proper design and construction there were no problems in the use of phosphate esters that could not be resolved.

Experience in laboratory tests, and in several turbine trials in Europe indicated that the phosphate esters would exhibit poor performance if water, solids, and acidic degradation products were not removed during service. This poor performance was sometimes related to contamination from the previous petroleum lubricant, or from cooler or steam seal leakage. Subsequent experience indicated that regular filtration with fine micron filters (½ to 5 microns), care to prevent petroleum or gross water contamination, and regular treatment with Fullers Earth, eliminated most operating difficulties, and provided a reliable lubrication system. Low temperature operation was resolved through the use of reservoir heaters or turbine enclosures.

Service evaluations in boiler feed pump turbines were carried out successfully, and additional gas turbine units were started up in Canada on pure phosphate esters. By 1970, over 60 gas turbines from five different manufacturers had generated over 3,000,000 successful operating hours. This operating experience had concluded that the phosphate esters could be used quite successfully as gas turbine lubricants, and also provide the improved safety, especially for unattended stations.

The operating experience had provided several areas where improved performance was desirable. These included improved oxidative stability, lower pour point, a reduction in deposit formation characteristics and improved toxicology performance. The result of these efforts was the formulation of a rust and oxidation inhibited phosphate ester to be used in an industrial gas turbine operating In Kentucky for a gas transmission pipeline. The turbine was a new installation and was designed to be operated on a phosphate ester. Service began in 1971,
and to date the system has operated without incident for over 10,000 hr.

Shortly after the turbine was started up in Kentucky, another Southern gas transmission company decided to convert several gas turbines from a polychlorinated biphenyl fire-resistant fluid to a phosphate ester. The conversion was required due to the removal of the biphenyl product from the market for environmental reasons. Since 1972, a total of nine turbines have been converted to the rust and oxidation inhibited phosphate esters, and over 100,000 hr of service generated. Two turbines have experienced difficulty in controlling the acid number of the phosphate ester. The problem at one installation was eventually related to the manufacture of the ester, and improved production control has eliminated that problem from consideration. The second turbine has been converted to a developmental phosphate ester which should provide the increased stability required by that particular system. As of this time, over 70 gas turbine systems are operating on phosphate esters, with a total of over 5,000,000 operating hours having been generated. The use of phosphate esters as gas turbine lubricants has been so successful that a major turbine manufacturer now offers a fire-resistant lubricant system as a standard on one model of their new industrial turbines. Installation of eight of these turbines is expected in the first quarter of 1975, and subsequent turbine start-ups are expected for later in 1975.

The use of fire-resistant phosphate ester fluids has increased significantly during the last ten years as a direct result of experience generated and problems being solved. Low temperature problems can be resolved with the use of reservoir heaters or turbine enclosures. The improved stability of the rust and oxidation inhibited esters has increased service life significantly, and resulted in lower operating costs. Turbine manufacturers and operators are designing, manufacturing, and servicing the gas turbines so that material compatibility is insured. In addition, developmental phosphate esters are now available which offer further improvements in oxidative stability, lower pour points and elimination of toxicology problems. With the corresponding increase in plant and operator safety considerations, and a greater emphasis on improved system availability and efficiency, the next ten years should result in an even greater acceptance of phosphate ester fire-resistant fluids as main bearing lubricants in industrial gas turbine systems.