MPR ASSOCIATES INC. ENGINEERS

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Use of Low and Ultra-Low Sulfur Fuel in Cooper-Bessemer Model KSV EDGs

Purpose

The purpose of this white paper is to discuss the potential issues associated with the use of low sulfur and ultra-low sulfur diesel fuel in Cooper-Bessemer Model KSV emergency diesel generators (EDGs) in U.S. nuclear power plants.

Background

Regulations

In an effort to reduce harmful emissions from diesel engines, the U.S. Environmental Protection Agency (EPA) has passed or proposed regulations that impact the formulation of diesel fuel. In 1993, EPA regulations (Reference 1) that require the use of low sulfur (<0.05 wt. % or 500 ppm) fuel oil in diesel engines for highway use took effect. In addition, these regulations limited the aromatic content of highway diesel fuels to 35 percent by volume or required the fuels to have a minimum cetane index of 40. Fuels which meet these requirements are commonly referred to as *low sulfur* or *EPA fuels*. Fuels with greater than 0.05 weight percent sulfur are referred to as *high sulfur fuels* and are dyed red. Under the 1993 regulations, non-highway diesel engines are permitted to use high sulfur fuel.

In 2001, the U.S. EPA published a rule (Reference 2) which specifies that beginning June 1, 2006 refiners must begin producing highway diesel fuel with a maximum sulfur content of 0.015 weight percent (15 ppm). These fuels are referred to as *ultra-low sulfur fuels*. Legislation has since been passed that requires that sulfur levels for non-road diesel fuel be reduced to 0.05 weight percent (500 ppm) in 2007 and to 0.015 weight percent (15 ppm) in 2010 (locomotive and marine diesel engines would be excluded from the 2010 reduction).

Diesel Fuel and Its Production

Diesel fuel is produced from crude oil. Finished diesel fuel consists of a mixture of four types of hydrocarbon molecules (paraffins, olefins, cycloparaffins, and aromatics) and impurities such as oxygen, nitrogen, and sulfur. Low sulfur and ultra-low sulfur fuels are manufactured by severely hydrotreating the diesel fuel to replace the impurities with hydrogen. Hydrotreating also breaks up a portion of the aromatic hydrocarbons in the fuel, lowering the aromatic content.

Discussion

The potential concerns associated with the use of low and ultra-low sulfur fuels include:

- reduced lubricity
- elastomeric seal leaks
- fuel oil – lube oil incompatibility,
- decreased heat content,
- cloud point elevation,
- decreased conductivity,
- decreased storage stability,
- increased cetane number, and
- fuel oil – tank liner incompatibility

The first four are the most important concerns and are discussed in detail below. The remaining concerns are briefly covered.

Fuel Lubricity

The lubricating ability of a fuel is referred to as its lubricity. The hydrotreatment process used to remove sulfur from diesel fuel also removes the constituents responsible for good lubricating properties. Diesel engine fuel injection pumps and nozzles have extremely tight clearances and rely on the fuel for lubrication and cooling. If the lubricating properties of the fuel are decreased, these components may experience increased wear or failure rates. Two lubricity test methods (Scuffing Load Ball on Cylinder Lubricity Evaluator, or SL-BOCLE, and High Frequency Reciprocating Rig test, or HFRR) have been developed and issued by the American Society for Testing and Materials (ASTM) (References 3 and 4)

The ASTM has been working for several years to develop a lubricity specification for ASTM Specification D975 (Reference 5), the specification for diesel fuel, but has been unable to reach a consensus. The latest version of D975 includes a non-mandatory section on lubricity which provides some guidance on acceptable lubricity levels. Discussions with fuel manufacturers indicate that most are targeting to exceed ranges recommended in D975 (2000 to 3100 grams on SL-BOCLE or 600 to 450 microns on HFRR). Haynes Corporation, which manufacturers the fuel injection equipment used on Cooper-Bessemer Model KSV engines, has not established lubricity limits for use with its equipment. Several U.S. nuclear utilities, including several CBOG member stations, have been using low sulfur diesel fuels in the EDGs for a number of years with no reported lubricity problems.

The lubricity problems that have been reported have primarily been with small distributor-type (supplying more than one cylinder) fuel injection pumps which are used on trucks rather than with the large jerk pumps (supplying only one cylinder) that are used on EDG engines. However, fuels with less than acceptable lubricity have been identified in the U.S. The lack of lubricity problems has been attributed to inadvertent mixing of good and poor lubricity fuels, which results in acceptable lubricity blends. Consumers who depend on a single fuel source could be vulnerable to low lubricity fuel.

Lubricity problems could be avoided through the use of lubricity additives, replacement of fuel injection equipment with materials more resistant to the type of wear caused by poor low lubricity or through the addition of a minimum lubricity requirement to fuel purchase specifications.

Elastomeric Seal Leaks

Elastomeric seals which are immersed in a fluid typically absorb some of the fluid, resulting in an increase in seal volume or swelling of the seal. This swell aids in forming an effective seal. Nitrile rubber (Buna-N) seals swell in the presence of diesel fuel, with the amount of swelling increasing directly with the aromatic content of the fuel. When exposed to a low aromatic content fuel following exposure to a high aromatic content fuel, nitrile rubber seals experience a negative volume change. For some older seals, which may have lost their flexibility or taken on a compression set, this may result in leaks. In most cases, replacement of the nitrile rubber seals will solve the problem. Fluorocarbon (Viton) seals exhibit significantly less volume change when exposed to diesel fuel and the amount of swell does not correlate with aromatic content. As a result, fluorocarbon seals are much less susceptible to leakage following a change from high sulfur fuel to low or ultra-low sulfur fuel.

No U.S. nuclear plant has reported seal leaks resulting from a change from high sulfur fuel to low sulfur fuel. Some plants are known to have replaced nitrile rubber seals prior to changing fuels, but it is likely that some plants did not.

Fuel Oil – Lube Oil Incompatibility

In 1996 Calvert Cliffs Nuclear Power Plant reported the discovery of cylinder liner scuffing in two SACM Model UD45 diesel generators due to excessive combustion chamber deposits. A similar event was reported at Prairie Island in 2001. In both cases root cause investigations concluded that the excessive deposits were due to an incompatibility between the low sulfur diesel fuel and high ash content/high total base number lube oils used in these engines.

MPR wrote a white paper on these events on behalf of the ALCO and Cooper-Bessemer Owners' Groups (Reference 5). The white paper concluded that in both cases, the root cause of the combustion chamber deposits and cylinder liner scuffing was a high lube oil consumption rate during the break-in period. Both stations reported high lube oil consumption rates prior to discovery of the excessive deposits. Use of high ash content lube oil in an engine with high lube oil consumption rates will lead to excessive deposit formation, stuck piston rings and cylinder liner scuffing.

Many U.S. nuclear stations with other makes and models of EDGs (including at least one station with Cooper-Bessemer KSV EDGs) have used low sulfur fuel and high ash content lube oils for many years without experiencing excessive combustion chamber deposits. While use of low or ultra-low sulfur fuel would suggest the use of low ash content lube oil, as long as lube oil consumption rates remain acceptably low, there should be no problem with excessive combustion chamber deposits.

Decreased Fuel Heat Content

Fuels with higher aromatic content have higher densities and higher heat content per unit volume. Hydrotreatment reduces the aromatic content of diesel fuel, resulting in lower heat content per unit volume. Low sulfur fuels have been found to have heat contents approximately 0.5 percent lower than high sulfur fuels. Ultra-low sulfur fuels have been found to have heat contents approximately 3 percent lower than high sulfur fuels.

The decreased heat content results in increased fuel flow rates to supply the same load. As a result, the fuel rack position at a given generator load will be higher with low or ultra-low sulfur fuel than with high sulfur fuel. As long as sufficient fuel rack margin exists, the governor will adjust fuel rack position to carry the demanded load. Cooper-Bessemer Model KSV EDGs have significant fuel rack margin at full load (full load rack position of approximately 35 mm versus approximately 54 mm maximum position).

The decreased heat content and resulting higher fuel consumption rate also result in larger required fuel oil storage volumes to meet Technical Specification requirements. Depending on the assumptions in the fuel oil storage volume calculation, the calculation may need to be revised to account for the lower heating values.

Cloud Point Elevation

The removal of aromatics from diesel fuel may raise the cloud point of the fuel. Fuel purchase specifications should contain cloud point requirements to ensure that low temperature operability is not affected.

Decreased Conductivity

The decreased sulfur content of low and ultra-low sulfur fuels may decrease fuel conductivity, making the fuel more susceptible to ignition by a static electricity arc. However, conductivity is controlled through the use of additives and conductivity changes in low and ultra-low sulfur fuels are anticipated to be insignificant.

Decreased Storage Stability

Low sulfur diesel fuels tend to have greater storage stability that high sulfur fuels because the hydrotreatment process destroys organic particulate precursors. However, hydrotreatment also removes naturally occurring anti-oxidants in the fuel which could reduce the storage stability.

The usual fuel sampling and trending programs at nuclear power plants should identify degradation when it occurs, but the use of storage stability additives is recommended.

Increased Cetane Number

The reduction in aromatic content increases the fuel's cetane number. Cetane number represents the ease with which a fuel ignites. An increased cetane number results in shorter fuel ignition delay and earlier start of combustion. This is the same effect as advancing fuel injection timing. Neither ASTM D975 nor most plant's Technical Specifications establish maximum cetane numbers for diesel fuel. If a fuel with a significantly higher cetane number is burned in an engine, engine signature analysis should be conducted to determine if fuel injection timing changes are needed to improve combustion performance.

Fuel Oil – Tank Liner Incompatibility

The compatibility of some epoxy fuel tank lining systems with low or ultra-low sulfur fuels may not have been established or may not be guaranteed by the manufacturer. Testing may be necessary to establish compatibility.

References

1. Code of Federal Regulations, Title 40, Section 80.29, January 22, 1996.

2. Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements. Federal Register: January 18, 2001 (Volume 66, Number 12) Pages 5001-5134.

3. ASTM Standard D6078-04, "Standard Test Method for Evaluating Lubricity of Diesel Fuel by the Scuffing Load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE)."

4. ASTM Standard D6079-04, "Standard Test Method for Evaluating Lubricity of Diesel Fuel by the High-Frequency Reciprocating Rig (HFRR)."

5. MPR White Paper, "Fuel Oil / Lube Oil Incompatibility," April 2, 2003.