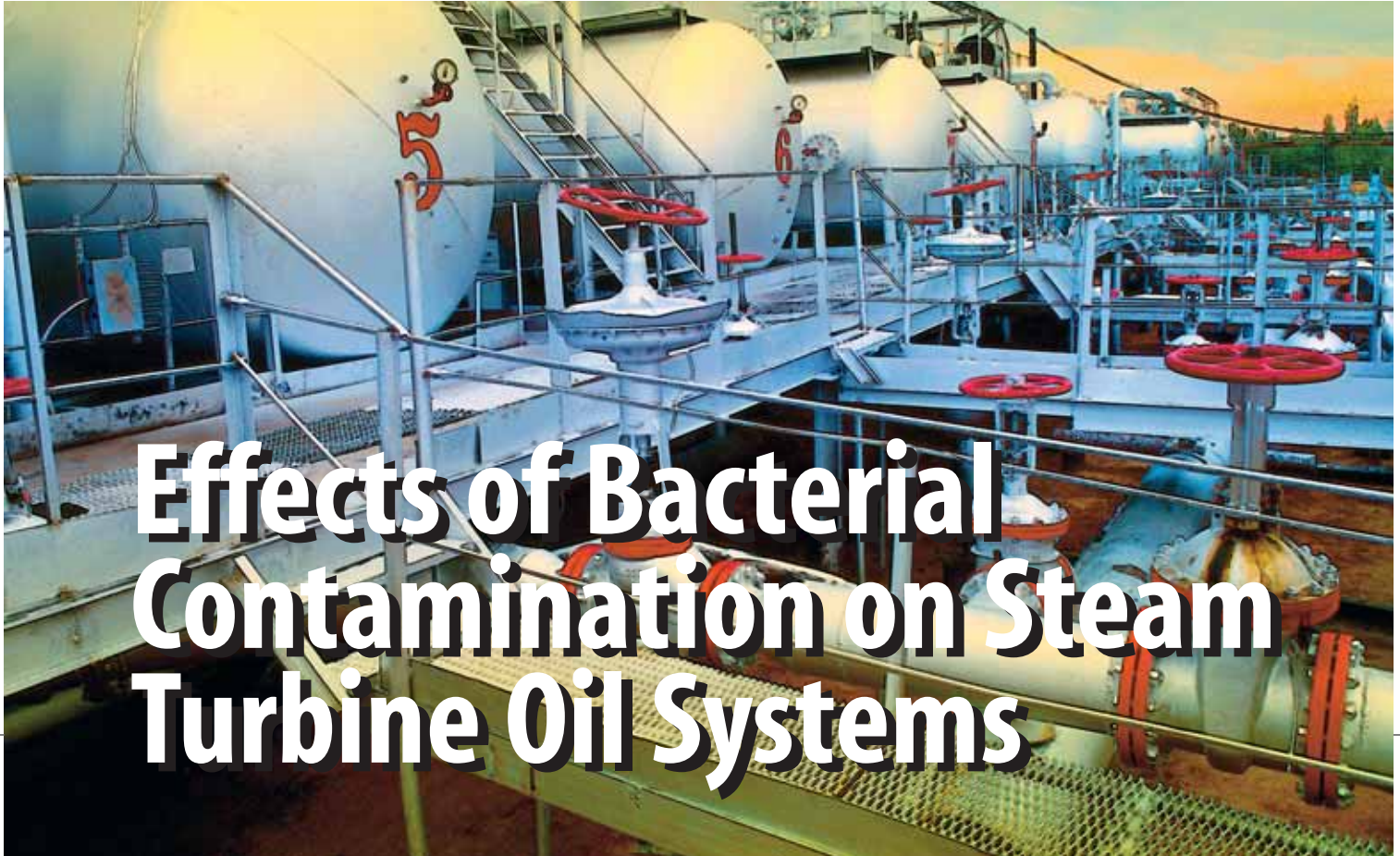


## Practical Applications



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### Introduction

Bacterial contamination of large circulating oil systems in steam turbines, paper machines and similar systems is a growing and expensive problem. The bacterial colonies, once established, clog control systems, quickly degrade oil quality and oil performance and produce corrosive byproducts. If not detected early, the problem will manifest itself into expensive repairs, extended downtime and a significant expenditure of scarce resources. As the U.S. steam turbine fleet ages and maintenance intervals are stretched, the problem is growing. Since steam turbines generate approximately 60% of the U.S. electrical power demand, the potential problem is significant.

This article presents a brief description of circulating oil bacterial contamination, problem recognition, types of lubricants and conditions that appear to be most susceptible, methods of treatment and known methods to clean up and prevent bacterial contamination. Also, a brief case history is included.

### Bacterial Contamination in Oil — What is it?

Bacterial contamination in crude oil and refined petroleum products has been well documented since the 1970s. The problem of bacterial contamination in steam turbine lube oil systems is significant and increasing. Three classifications or types of bacteria

that are typically encountered in petroleum products include the following:

- **Sulfate Reducing Bacteria (SRB).** This classification of bacteria metabolizes sulfate and is anaerobic in nature.
- **Acid Producing Bacteria (APB).** This classification of bacteria ferments sugars to acids (typically light organic acids) and is anaerobic in nature.
- **General Aerobic Bacteria (GAB).** This classification of bacteria requires oxygen.

These three classification types of bacteria are prevalent in nature. With respect to human health and safety, *pseudomonas sp.* are common aerobic bacteria that get into industrial fluids, and much is known about the health problems these can cause, especially in immuno-compromised individuals. It's unknown if this strain is present in bacteria-contaminated turbine lube oil. It's possible, but not likely, that the GAB classification of bacterium could produce other bacteria strains that might prove pathogenic to a portion of the human population.

The following conditions promote the bacteria growth in petroleum products:

- **Water mixed into the oil.** 500 ppm is sufficient (.5 ml of water per liter of turbine oil).<sup>(4)</sup>
- **Organic material.** Organic material such as hydrocarbons, which are the main ingredients in turbine oils, along with other nutrients that might be present as natural constituents or included in the additive package, such as nitrogen, phosphorus and sulfur.<sup>(4)</sup>
- **Oxygen.** Oxygen accelerates bacteria growth on hydrocarbons, but growth also can occur in the absence of oxygen.<sup>(6)</sup>
- **Optimum temperature.** Optimum temperature is 24 C (75 F) to 49 C (120 F), although growth at temperatures as high as 113 C (235 F) have been reported. 49 C (120 F) is the normal operating temperature for turbine lube oil systems.<sup>(3)</sup>
- **Stagnant/low flow conditions.** Stagnant or low-flow conditions, in either the presence or absence of light. Turbine lube oil systems abound with

these types of protected locations.

- **Suspended particulates.** Suspended particulates provide surface areas for concentration of bacteria and nutrients. Bacteria thrive at interfaces and coalescent sites.
- **Oil emulsification.** Molecular water (i.e., emulsification, is needed to facilitate the bacteria life cycle).

Avoiding the above conditions will lessen the risk of bacterial growth. Obviously, the easiest environmental factor for operations and maintenance staff to influence is the water concentration in the oil.

### **Bacterial Contamination in Oil: Operational Risks, Signs, and Symptoms**

**Operational Risks.** Power generation steam turbines operate at either 3,600 rpm (fossil power plants) or 1,800 rpm (nuclear power plants), while boiler feed pump turbines may turn as fast as 6,000 rpm. Electrical power generation output can range from one megawatt (1,340 hp equivalent) to 1,300 megawatts (1,742,000 hp equivalent).

Design radial operating clearances between the blade tips and casing seal strips and shaft packing can be .020 inch to 0.30 inch or, in some cases, tighter. Shaft diameters of 14 inch to 20 inch (or larger) in power generation units are common with radial shaft to bearing clearances of .020 inch to .030 inch. Shaft bearing loading can be as high as 50,000 lbf per shaft journal section—it's dependent upon the manufacturer's design, dynamic loading, unit condition, etc. Some journal bearings are segmented, elliptical shaped or segmented tilting pad in design. Axial shaft movement is controlled by a Kingsbury style or tilting pad thrust bearing and is typically limited in the range of .050 inch to .100 inch.

Most turbine manufacturers design their turbine shafts and bearing journals to establish and maintain dynamic shaft stability by forming a hydrodynamic oil wedge in the journal bearing. This hydrodynamic wedge is formed due to the shape of the journal and the rotating action of the turbine generator shaft. As can be seen, a stable, high quality oil film is required to maintain continuous

**Most turbine manufacturers design their turbine shafts and bearing journals to establish and maintain dynamic shaft stability by forming a hydrodynamic oil wedge in the journal bearing.**

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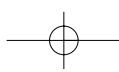


Figure 1.



Note the following in the sight glass from top to bottom: emulsified oil, oil water boundary, water layer and bacteria biomass. This colony tested to be primarily GAB.

Figure 2.



This view was taken looking into a boiler feed pump turbine oil reservoir. Note rust buildup from the bacteria colonies. The lower right hand corner of the picture shows a cleaned tank surface.

Figure 3.



The interior of a filtration unit that has been subject to heavy bacterial contamination and turbine oil with prolonged elevated water content.

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operation of these units.

Operation of steam turbines with bacterially contaminated lube oil introduces significant risks in the following areas:

**Lubricating qualities reduced due to water retention.** The bacteria contaminated oil will retain water instead of readily separating. The ability of steam turbine oil to readily separate from water is one of its primary performance requirements. The retained water will alter the lubrication and heat removal characteristics of the turbine oil. If this retained water is carried over to the bearings and/or control the system, the results will be:

1. Reduced shaft dynamic stability.
2. Inability to properly control the unit.
3. Reduced journal bearing load-carrying capabilities.

**Turbine oil foaming.** Bacterially contaminated turbine oil will have a tendency to foam excessively. If the foaming oil is pumped to the journal bearing, the hydrodynamic wedge will not properly form and dynamically lock the shaft in the journal bearing. Excessive vibration will result; oil whirl has been observed by the authors in this situation. If the vibration is severe enough, the critical steam seal clearances will be destroyed, and bearing journals may be damaged. If the turbine oil is also used as the hydraulic control oil, the introduction of foaming oil into the control system will result in loss of control. Loss of turbine control could mean inability to stay synchronized to the grid, failure to control speed during startup or failure to respond to protective trip functions (over-speed, high vacuum, high vibration, etc.)

**Turbine oil emulsification.** Bacterially contaminated turbine oil will form emulsifications as part of the bacteria life process. The emulsifications don't provide adequate lubrication qualities and will serve to gum up control systems. The emulsifica-

tions may also assist in spreading the bacteria throughout the turbine lube oil system.

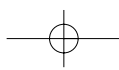
**Corrosive byproducts formation.** As part of the bacteria life cycle process, corrosive byproducts (chemical compounds) are produced. These chemicals will attack and corrode internal components of the turbine generator that are exposed to the turbine lube oil system. This corrosive attack will result in premature parts replacement, failure of critical components in the controls systems and extended repair periods to correct.

**Signs and Symptoms.** Bacterial contamination can only be positively confirmed by laboratory analysis. However, multiple signs and symptoms for operations and maintenance personnel are available. As the bacteria grow, they produce visible growth of biomass. This biomass has approximately the same color as clear silicone RTV and is gelatinous in appearance. One location where this biomass can be easily viewed is in the sight glass of an oil filtration skid such as the one shown in Figure 1.

Additional symptoms of bacterial contamination in a turbine lube oil system:

- Frequent plugging of filters with a jelly-like substance.
- Sluggish or inadequate controls response—possibly resulting in a unit trip.
- Plugging of control orifices or lines with a gooey, jelly-like substance.
- Prolonged operation with water levels > 500 ml.
- Emulsified oil or an oily water mixture that will not readily separate.
- Failure of the water demulsification test (ASTM D 1401).
- Failure of the turbine oil foaming characteristics test (ASTM D 892).
- Relatively rapid turbine oil oxi-

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# Case History:

During the summer of 2003, PacifiCorp. suspected bacterial contamination in the turbine lube oil systems of the Naughton Unit 3 Boiler Feed Pump Turbines (BFPT). These 5,000 horsepower steam turbines drive the boiler feed pumps (2,750 psi discharge pressure @ 1 x 10E6 lbm/hour). Their operation is critical for maintaining 100% power production. Each BFPT's 1,200 gallon turbine oil system could also be cross connected to any one of the turbine generator reservoirs. Therefore, it was vital to determine if bacterial contamination was present in the boiler feed pump turbines and to prevent spreading to the other turbine reservoirs.

Oil and suspected biomass samples were obtained from the following locations:

- BFPT Kaydon filter sight glass drains.
- Boiler feed pump bearing drain lines.
- BFPT filter effluent sample ports.

The following bacteria contamination report for these samples was provided to PacifiCorp.'s Naughton Power Plant. Bacteria contamination was suspected based on "operational symptoms" but had not been confirmed by laboratory analysis.

**General description.** Four samples of contaminated turbine oil were received on July 22, 2003. Two of the samples were labeled "Centrifuge Boiler Feed Water" (CBFW) and the other two were labeled "Conoco Turbine Oil 32" (CTO). The CBFW samples contained a thin layer of yellowish scum (presumably oil or emulsified oil/water) on the top while the CTO samples contained only a few milliliters of water in the bottom of the bottles with the rest being dark amber oil. At the oil/water interface of the CTO samples, there was a thin film or "rag" layer. A dark particulate material was present in the bottom

**Table 1. Estimate of Viable Bacteria Contained in Turbine Oil Samples**

Sample	Bacteria/mL*		
	GAB	APB	SRB
CBFW	690 – 145,000	1 – 145	690 – 145,000
CTO	690,000 – 145,000,000	7 – 1,450	1 – 145

\* Estimated range of bacteria concentration based on a single serial dilution.<sup>(5)</sup>

of the CTO bottles.

**Microscopic analysis.** A small sample from the interface layer of the CTO sample was centrifuged resulting in an organic layer on top, a thin layer in the middle (emulsion) and a clear aqueous phase on the bottom. There was also a diffuse, dark pellet that adhered to the sidewall of the centrifuge tube. Microscopic examination of the interface layer revealed numerous blobs of oil surrounded by clumps of amorphous particles (unidentified suspended solids). Bacteria could also be seen attached to these particulates and moving about in the bulk aqueous phase. A 100-ml sample of water from each sample was then diluted in sterile water, filtered, stained with acridine orange and examined under a fluorescent light source. Acridine Orange complexes with DNA and RNA contained in all microbial cells and allows for their direct counting (total viable and non-viable cells). The total bacteria count in the CBFW sample was 1.0 x 10<sup>7</sup> bacteria/mL and in the CTO sample it was 2.6 x 10<sup>7</sup> bacteria/mL.

**Bottle counts.** To estimate the viable numbers of bacteria in these samples, an aqueous fraction from each sample was inoculated into three sets of bottles containing three different growth media. The three growth media included API aerobic broth for general aerobic bacteria (GAB); APB broth (anaerobic) for acid producing bacteria (APB); and API RP38 medium for sulfate reducing bacteria (SRB) (C&S Laboratories, Tulsa, Okla.). A single 10-fold serial dilution series of each medium was run on both water samples. The

bottles were incubated at room temperature and the results after one-week incubation are listed in Table 1.

All seven GAB bottles for the CTO sample were fully developed within two days incubation suggesting a very active bacterial population was present. The concentration of anaerobes (APB and SRB) is smaller, but since these typically grow at a slower rate, they may increase in number with more incubation time.

**Conclusions and recommendations.** Significant concentrations of viable bacteria were present in both samples. The fact that a very active, high concentration of aerobic bacteria was found in the CTO sample suggests these bacteria are feeding off the turbine oil as a food source. This is also supported by the observation that an emulsified layer of oil and water was visible in the CTO sample. Emulsions are often associated with oil-degrading bacteria since they have to solubilize the oil for cellular uptake. However, these samples were at least five days old when received and weren't preserved (e.g., refrigerated), so they can't be relied upon to provide an accurate concentration of bacteria in the system at the time they were collected. Bacteria concentrations can either increase or decrease within a few hours after collection and thus samples should be either processed on-site or preserved prior to shipping. However, the results suggest there is a good potential that these turbine oils are populated with significant concentrations of viable bacteria growing at the expense of the turbine oil. <<

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dation as measured by the RPVOT test (ASTM D 2272), especially if the oil hasn't been overheated. (See Appendix 2)

- Isolated, concentrated rust spots on filter element metal ends, turbine bearing components, etc.
- Rotten egg smell upon opening of centrifuges or filtration systems.

The bacterial contamination may also be visible as biomass in the bottom of drained turbine oil reservoirs as shown in Figure 2 (see page 28) and the inside of filter housings as shown in Figure 3 (see page 28).

### Bacterial Buildup in Turbine Oil: Laboratory Confirmation

Turbine oil bacterial contamination in the transfer lines, storage tanks and the turbine reservoir is a major concern of the power generation companies. If left untreated, it can lead to disastrous control and synchronization problems, extensive downtime and costly repairs.

Turbine oil bacterial detection and correction can be quite exhaustive and detailed in nature. Most commercial oil analysis laboratories don't have this capability or technical

expertise. However, major petroleum refiners and marketers employ this type of technical expertise on staff. Bacteria can be positively confirmed by a microbiologist conducting detailed analyses, which consist of attempting to incubate and culture the bacteria in different types of nutrient media and then analyzing for their activity. This method also can be used to get a rough estimate of the number of viable bacteria contained in the oil and belonging to a certain physiological group (e.g., SRB, APB and GAB). Direct examination for total bacteria (growing and non-growing) in oil can be made using phase contrast microscopy or epifluorescent microscopy of bacterial cells after staining with Acridine orange that binds to RNA and DNA found in bacterial cells.<sup>(2)</sup>

It's very important to establish a dialogue with your lubricant supplier and microbiologist to determine the best types of samples to obtain, sample preservation requirements, sampling locations, etc. Complying with their recommendations provides optimal analytical results.

A thorough bacterial/microbiological analysis of turbine oil that is suspected to be contaminated with bacteria will consist of the following:

1. General description and recording of visual observations of the samples. Bacteria-contaminated turbine lube oil will present with emulsion layers, visible water, and, quite often, biomass.
2. Microscopic analysis of the samples utilizing standard microbiological analytical techniques.
3. Viability determination to determine if observed bacteria are viable strains. API or NACE standard growth media should be utilized for determination of aerobic, anaerobic and sulfate reducing bacteria.<sup>(1), (5)</sup>

### Cleanup and Treatment Methodology

Once bacterial contamination has established itself in the system, eradication can be very difficult. The most effective method involves the following sequential steps:

1. **Remove the bacterially-contaminated oil and send it off-site for use as fuel oil.** It is important that in-plant transfer piping not be used during the removal of the contaminated oil. This will minimize the potential for spreading the problem to other components.
2. **Inspect and clean the lube oil system.** This involves disassembly and cleaning of major components. Specific attention should be paid to oil storage tanks, reservoirs, coolers and filter housings.
3. **High volume/high temperature oil flush.** Always use new flush oil (don't use the old oil as flush oil) recommended by your lubricant supplier and perform a high volume/high temperature flush. The flush oil used at PacifiCorp. is an ISO 22 mineral oil formulated with Group II base oils, as shown in Figure 5. The oil tem-



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perature should be maintained at 71 C (160 F) minimum for 30 to 45 minutes, and flow rate should exceed 2,000 gpm for a 4,000-gallon turbine lube oil system. After the flush is complete, dispose of the flush oil as in Step 1 above. This flush should also use high quality, full flow filtration capable of at least 5  $\mu\text{m}$  @ Beta>200. Figure 5 illustrates the cleaning that can be accomplished before and after flush.

4. **Perform a final inspection and cleaning of the reservoir and any other accessible components.** Cleaning should follow the lubricant supplier instructions — the use of cleaning solvents or detergents is generally not recommended.
5. **Filtration.** When refilling, use new hoses and fill directly to the reservoir from the transport unless the plant transfer piping is known to be clean and free of bacteria. Install new filter elements and place all filtration components in service. Ensure that the new oil is “dry,” less than 500 ppm water content. Use a desiccant if necessary.
6. **Refill with high quality new turbine oil.** At PacifiCorp.’s Naughton Generating Plant, the turbine oil of choice is a premium quality, rust and oxidation inhibited, gas and steam turbine oil formulated with Group II base oil for extended service life. Typical inspection properties are shown in Table 3 (see page 34).
7. **Add a recommended biocide to the turbine oil.** Consult with your lubricant supplier for the best application. Test the new oil doped to the recommended biocide level to determine baseline data for: RPVOT, TAN (Total Acid No.), Demulsibility, Foaming, Viscosity and Color.

At this point some very important “do’s and don’ts” need to be considered:

1. **Do not** add biocide to the oil without performing any of the other activities. The biocide will kill the bacteria and release a tremendous biomass that will plug filters, control lines, etc. The plugging may be so complete that removal by flushing will be almost impossible.
2. **Do not** use the lowest price oil flush contractor to perform the high volume/high temperature turbine lube oil flush.
3. **Do not** cross contaminate other plant systems with bacterially infected oil. Think medical contamination control. Utilize your microbiologist/laboratory to provide basic instructions in this concept.
4. **Do** add biocide to the oil when the system is operational and after the system has been thoroughly cleaned, flushed and filled with new oil. Read and follow all precautions.
5. **Do** use an oil flush contractor that has state-of-the-art, engineered, high volume pumping and filtration equipment. During the flushing process, it is important for the biomass and other contaminants that the bacteria live on be kept in suspension and captured by the filtration equipment.
6. **Do** write a detailed specification and contractual document for the high volume/high temperature flush.
7. **Do** assume that other plant lubrication systems are contaminated with bacteria and treat with biocide. Ensure that the biocide is compatible with these oil types.
8. **Do** dispose of the waste oil

according to state and local regulations.

### Turbine oil sampling

All turbine oil samples should be taken while the oil system is in full circulation and operating at normal temperature. If oil cleanliness testing is desired, then particle counts are to be performed using ISO 4406:1999 test method, and samples should be taken on the main flow return lines and upstream of the oil filters. These locations offer more accurate measurement of the representative wear metals and particles present in the oil prior to filtration.

New, clean, unopened and sealed bottles should always be used for best results. Purge a quart of oil through the port or valve from which the sample is taken to insure a clean sample. For optimum results, the bottle should be purged as well by opening the bottle just prior to filling. Fill it halfway, install the cap and shake. Empty the bottle and take a representative sample by filling the bottle to three-quarters of its total volume.

If sampling from a reservoir, take oil samples from the lowest possible point and at mid-point, either via a sampling gun with new tubing or via a drain valve to assure accuracy of overall contents and follow the previous purging procedure. Prepare the label to list the following: unit make and model, sample date, brand and type of oil, total operating hours of the unit and the hours that the oil has been in-service. Send the sample immediately to the lab to be analyzed so that you will get the most accurate results. Don’t set the sample in direct sunlight for it can alter the color of the oil. The color is measured as part of the analytical testing. If bacterial contamination is suspected, the sample should be packaged in an insulated container and sent to the lab right away for further testing.

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# Conditions that Favor Bacterial Growth

The following conditions provide optimal conditions for bacterial colony growth:

- Prolonged water content greater than 500 ppm.** Water is the required medium for the bacteria to live and grow, even though their food source is the organic material in the turbine oil.

- Relatively constant turbine lube oil temperatures over a prolonged period.** As in food safety, bacteria growth can be inhibited by heating to elevated temperatures or storage at low temperatures.

- Group I, solvent neutral base oils.** The American Petroleum Institute (API) established guidelines for base oils used in finished lubricants. Their classification is shown in Table 1. Group I solvent neutral base oils are highly branched which tend to support more bacteria growth, and render their compounds less inherently biodegradable than Group II or Group III hydroprocessed base oils because (1.) they contain higher aromatic and sulfur compounds which have affinity for water, (2.) their molecular structure and molecular weights are different and (3.) the sulfur in Group I base oils enhances bacteria growth. Furthermore, Group I base oils have a tendency to tie-up water, which in steam turbines often enters the turbine oil through the steam seals and promotes bacteria growth.

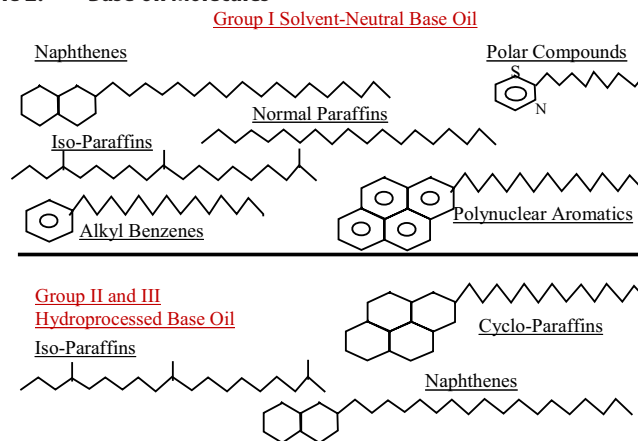
As shown in Table 2, Group II and Group III base oils contain iso-paraffins, cyclo-paraffins and naphthenes. They are free of aromatics and sulfur, which minimizes food for bacteria growth. They separate water faster than Group I base oils, which also minimizes bacteria growth (see Figure

**Table 1. Base Oil Groups Per API Guidelines**

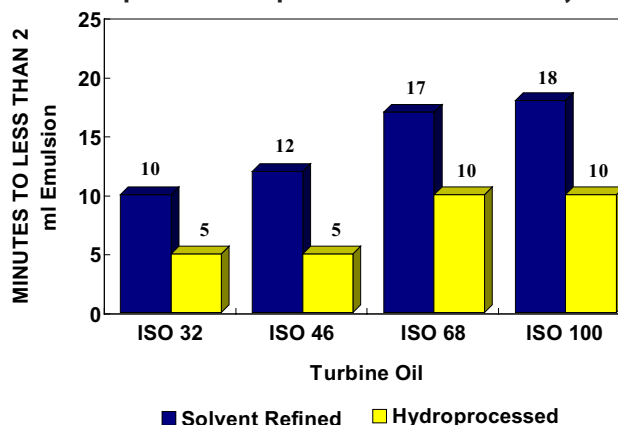
Group	Viscosity Index	Saturates* wt %	Sulfur wt %
I	80 – 119	< 90	> 0.03
II	80 – 119	90 min.	0.03 max.
II+	100 – 119	Not Defined	Not Defined
III	> 120	90 min.	0.03 max.
IV	All PAO Synthetics		
V	All Other Synthetics (Esters, Polyglycols, silicones, Fluor. ethers)		

\* Cyclo-Paraffins, Paraffins and Naphthenes

**Table 2. Base Oil Molecules**



**Figure 4. Superior Water Separation in Steam Turbines By ASTM D-1401**



4). The cyclo-paraffins and naphthenes in Group II and III base oils have an affinity for the metal surface, which tend to dislodge deposits built

up in storage tanks and pipes, resulting in periodic filter plugging. However, once the system is clean, filter plugging is eliminated. <<

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### Summary: Prevention of Bacterial Contamination

In summary, prevention of turbine oil bacterial contamination is relatively simple and straightforward:

#### Maintain water concentration in the oil to less than 500 ppm.

Additional measures or practices that will help prevent bacterial contamination:

1. Use premium quality, rust and oxidation inhibited turbine oil formulated with Group II or Group III base oils.
2. Minimize the formation of stagnant water, i.e., in separator sight glasses. Remove it immediately if it forms.
3. Maximize filtration and maintain low ISO Particle Counts. The bacteria need water to grow but the presence of particulates provides additional surface area for concentration of cells and nutrients.
4. Perform daily "clear and bright" inspections. (Note: Clear and

*bright* is a marine engineering term that means turbine oil is collected in a clear glass container and visually inspected. If it's clear and bright, then the water content is below visual and the filtration is providing adequate particle removal. It's not a substitute for laboratory testing, but it will alert the operators to changing conditions within the oil and the steam turbine itself).

5. Maintain an appropriate biocide dosage level if bacterial contamination has been identified and subsequently cleaned. <<

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### Table 3. Turbine Oil Typical Properties

ISO Grade	32
Specific Gravity @ 15.6 C	0.859
Density, lb/gal	7.16
Gravity, ° API	33.2
Color, ASTM	0.5
Flash Point, COC, C (F)	227 (441)
Pour Point, C (F)	-40 (-40)
Viscosity, ASTM D445:	
cSt @ 40 C	31.8
cSt @ 100 C	5.4
SUS @ 100 F	164
SUS @ 210 F	44
Viscosity Index,	
ASTM D 2270	102
Total Acid Number,	
ASTM D664	0.08
Copper Strip Corrosion,	
ASTM D130	1A
Demulsibility, ASTM D1401,	
minutes to pass	10
Foam Test, ASTM D892	Pass
Oxidation Stability, TOST,	
ASTM D943, hours	22,500
Rust Test, ASTM D665A & B	Pass

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