

## VACUUM DISTILLATION METHODS FOR LUBE OILS INCREASE TURBOMACHINERY RELIABILITY

by

**Mark A. Adams**

Rotating Equipment Engineer

Amoco Oil Company

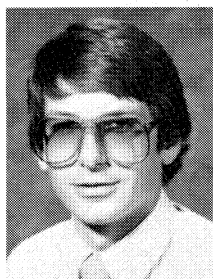
Texas City, Texas

and

**Heinz P. Bloch**

Consulting Engineer

Baytown, Texas



Mark A. Adams is a Rotating Equipment Engineer in the Central Maintenance Division of Amoco Oil Company's Texas City, Texas, refinery where he is responsible for providing technical support to the Field Machinist Group.

He received his B.S. degree in Mechanical Engineering from Michigan Technological University, and has served internships with Caterpillar Tractor Company's Hydraulics Division and in the Components

Technology Division at Argonne National Laboratory. While at Argonne he published work on acoustic imaging in breeder reactor steam generators.

He has been a Project Engineer and a Maintenance Engineer for Amoco Oil Company at the Texas City Refinery. Mr. Adams is a member of the ASME, the Vibration Institute, and Phi Kappa Phi National Honor Society.



Heinz P. Bloch is a Licensed Consulting Engineer specializing in machinery reliability improvement.

He holds B.S. and M.S. degrees in Mechanical Engineering from the New Jersey Institute of Technology and was employed by Exxon for more than two decades as a Machinery Specialist. The primary focus of his technical consulting is in the areas of maintenance cost reduction and machinery reliability improvement.

The depth of Mr. Bloch's involvement in all phases of this work is indicated in over 40 technical society papers and publications.

In addition, he has authored or co-authored six books and holds four United States Patents relating to high-speed machinery improvements.

Mr. Bloch has been elected to three national honor societies, is a member of STLE and ASME, and he now serves a broad range of clients with in depth consultation on reliable and efficient operation of high-speed machinery. He is a member of the International Pump Users Symposium Advisory Committee, sponsored by the Turbomachinery Laboratory.

### ABSTRACT

The lube oils in self-contained reservoirs for turbomachinery in hydrocarbon processing plants are subject to contamination and deterioration from airborne dust, component debris, system corrosion, heat, and water. Oil supplies associated with certain gas compression sealing systems are further exposed to potential dilution with lighter hydrocarbons, and gaseous diluents such as  $H_2S$ . Excess water and acquired hydrocarbon constituents which adversely influence the viscosity and other characteristics of turbomachinery lube oils must be removed periodically, if machinery distress is to be avoided.

As part of a determined effort to maintain the reliability of critically important turbomachinery, a major petrochemical complex has implemented a lube oil quality assurance program. Vacuum distillation equipment is used for oil purification, and periodic analysis of 36 reservoirs is employed to quantify lube oil condition. A major refinery in the same geographic area is developing a program with similar goals.

The relevant experience accrued at both facilities is described. What is required to have consistently good results and to obtain the maximum economic benefits is illustrated. This can be achieved by evaluating and selecting an appropriately designed vacuum oil purifier and following up by implementing a rigorous analysis program.

### INTRODUCTION

Lube oils in self-contained reservoirs at refineries, petrochemical and gas compression facilities are subject to contamination and deterioration from dust, system corrosion, heat, and water. In addition, some of the oils in compressor shaft sealing service may risk being diluted with lighter hydrocarbons and hydrogen sulfide gas. These contaminants adversely affect the viscosity, flash point, acidity, and other properties of lube oils and can lead to higher maintenance requirements, frequent oil changes, or even machinery failures. Studies have shown that free or dissolved water in lube oil can significantly reduce the fatigue life of steel parts [1]. A water content of 0.01 percent can reduce the fatigue life of antifriction bearings by as much as 50 percent. Industry experience similarly corroborates the deleterious effects of water in lube oil on turbomachinery reliability and component condition [2].

These facts and observations strongly support the contention that reclamation, oil conditioning, or onstream purification of turbomachinery lube oils makes economic sense for the overwhelming majority of self-contained lube oil systems found in

typical hydrocarbon processing facilities, utilities and other process plants.

### PRINCIPAL LUBE OIL PURIFICATION METHODS EXAMINED

Three principal methods of purifying or reclaiming lube oils, centrifuging, coalescing and vacuum distillation are typically found in process plants and utilities in the industrialized countries. Centrifuging and coalescing can remove almost all traces of free water, but cannot separate emulsified water, dissolved water, light hydrocarbons or harmful gases such as  $H_2S$ . The latter is capable of leaching copper out of Babbitt bearings and certain Babbitted oil film seals. Copper backed shoes of tilting pad bearings are especially susceptible to  $H_2S$  corrosion. A coating of copper sulfide forms as the copper corrodes, limiting the heat transfer properties of the bearings.

Centrifuging consists of separating the high specific gravity component (water) from the low specific gravity component (oil). The configuration of the centrifuge bowl must be such that the overflow port is at the exact level, for a given specific gravity of lube oil, at which there is no carryover of water into the reclaimed oil or loss of centrifuged oil into the free water being removed. Experience shows that the complete removal of free water is rarely achieved by even the best of centrifuges, which sometimes create a tight oil/water emulsion. While it has been claimed that with close control of specific gravity almost all free water could be removed, such close control appears nearly impossible in compressor installations which use the lubricant as a seal oil and thus experience absorption of gas [3].

Coalescers are successfully used at many airport installations to dehydrate jet fuel and other aviation fuels, because they are subject to extremely close quality control and fuel properties deviate very little, if at all, from specifications. Free water is the only contaminant, which makes it possible to have the precise coalescer cartridge configuration for efficient water removal. The fibers to which the water clings can be woven and the configuration designed for optimum water separation. Both components to be separated, water and fuel, remain constant in properties.

Because the oil rarely exhibits constant properties, an investigation of purification methods for lube oils in hydrocarbon processing plants will quickly lead to vacuum distillation, also called vacuum purification. This purification method is the most suitable for a wide range of process plant applications since it is capable of removing free, emulsified and dissolved water, entrained air,  $H_2S$  and other gases, and light hydrocarbon fractions up to  $C_{12}$  chains. Specific gravity has no effect on separation using this method. At the chemical plant under study, two identical vacuum oil purifier (or oil conditioner) units have been used regularly in this service since the plant was commissioned in the late 1970s [4].

### VACUUM PURIFICATION PRINCIPLE AND EQUIPMENT DESIGN OPTIONS

Vacuum oil purifiers work on the principle of simultaneous application of vacuum and heat to cause vaporization of contaminants. A typical vacuum oil purifier is shown in Figures 1 and 2 and schematic diagrams are given in Figures 3 through 9. The approach taken by the first plant, which will be called the chemical plant is represented in Figures 1, 2, and 3.

In Figure 3, which also illustrates the operating principle of the equipment shown in Figures 1 and 2, the contaminated lube oil entering the vacuum vessel is controlled by a solenoid valve which allows a falling thin film and a standing reservoir in the vacuum vessel. In this particular model, the fluid is exposed to

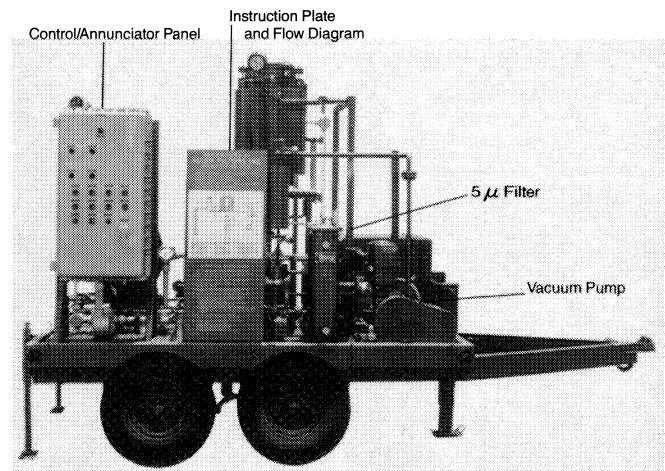


Figure 1. Vacuum Oil Purifier, Front View (Courtesy Allen Filters).

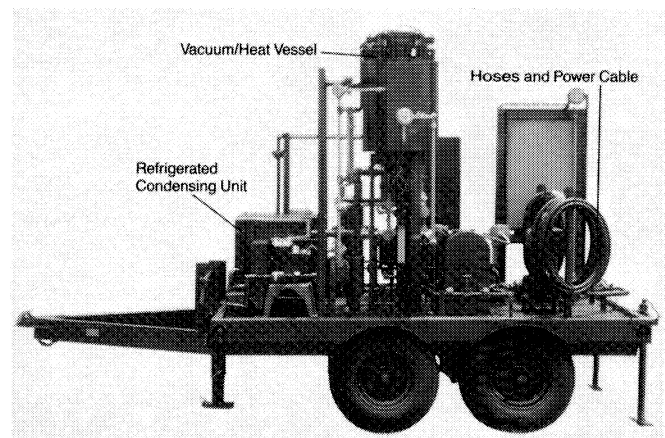
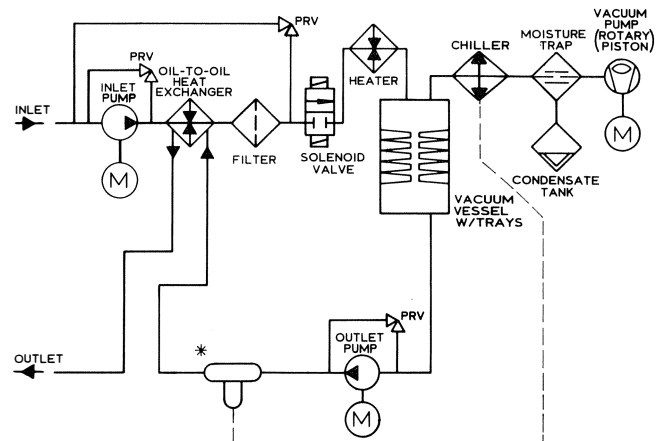


Figure 2. Vacuum Oil Purifier, Rear View (Courtesy Allen Filters).



\* FLOW REDUCING VALVE CONTROLLED BY FREON PRESSURE PRECLUDES COMPRESSOR OVERLOAD WHEN CONTAMINANTS EXCEED DESIGN PARAMETERS.

Figure 3. Schematic Diagram of Vacuum Oil Purifier Employing Baffled Aluminum Trays.

70-80°C (160-180°F) temperature and 1.0 to 25 mm Hg pressure (29.88 to 28 in Hg vacuum) in a tank-like vessel, while flowing over baffled, inclined, aluminum trays. As the fluid flows over the trays, dehydration, deaeration, and degasification are ac-

completed. The vapors are drawn from the vacuum vessel through a refrigerated condenser (evaporator) by a high vacuum pump. The condensed vapors settle in a distillate collection tank, which is drained intermittently, by automatic means. The non-condensibles are discharged through the vacuum pump exhaust, either to atmosphere or to a low pressure flare line.

Experience to date with the vacuum oil purifier depicted in Figures 1 through 3 has shown it to be efficient and generally low in maintenance. Overall, it incorporates a minimum number of parts and features nonexpendable baffled trays within the vacuum vessel. Reliability and energy efficiency are achieved in this model with refrigerated condensing, electric oil heaters which do not contact the oil, and, if economics warrant, heat exchange between the cooler incoming oil and the warmer discharging oil. This single-stage vacuum design is typically equipped with a programmable logic controller and annunciator system.

At the second plant, which we will call the refinery, the vacuum oil purifiers used are represented by Figure 4. These units typically consist of an immersion-type electric heater, vacuum vessel and dispersion elements for surface area extension. The oil level inside the vacuum vessel is maintained by a float operated valve which allows the vacuum system to draw oil in as required. An outlet oil pump returns reclaimed oil from the vacuum vessel to the reservoir. Vacuum is maintained by an eductor system which uses water from a closed loop system as the motive fluid. Equipment required for the vacuum system are a water pump, reservoir, eductor and piping. Light hydrocarbon or water vapors which are removed from the vacuum vessel are entrained with the water passing through the eductor and are condensed or vented off from the circulating water reservoir. An ambient temperature water condenser is located between the vacuum vessel and the eductor to condense a portion of the hydrocarbon vapors and water, thereby reducing the vapor loading on the eductor. These units were chosen primarily for their low initial cost, minimal number of components, and apparent simplicity.

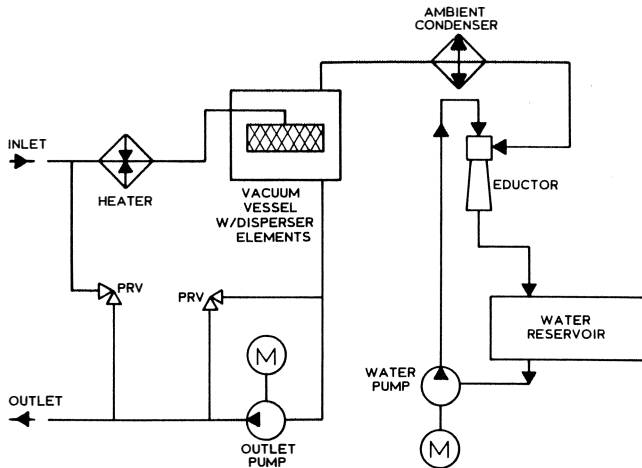


Figure 4. Vacuum Oil Purifier Used at the Study Refinery.

With an increasing number of users opting for vacuum oil purifiers to reclaim lube oils, a number of manufacturers are entering the marketplace with competing executions and configurations. Each of these may offer certain advantages and/or disadvantages. An engineering appraisal of several configurations is presented here. Potential users similarly must evaluate the advantages and disadvantages of all systems under consideration.

A variety of designs (Figures 5, 6, 7, 8, and 9) illustrate proposals for a specific user's application [5]. A Roots (lobe-type) vacuum pump (shown in Figure 5) upstream of the condensing chiller, could have a negative impact on initial cost and maintenance. The design also requires an additional vacuum pump and driver. The dispersion (coalescer) cartridges within the vacuum vessel may require frequent replacement and sometimes limit the

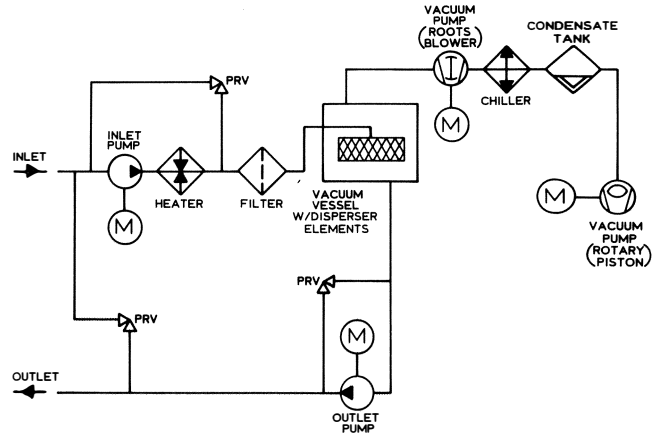


Figure 5. Vacuum Oil Purifier Incorporating Blower Pump Upstream of Chiller.

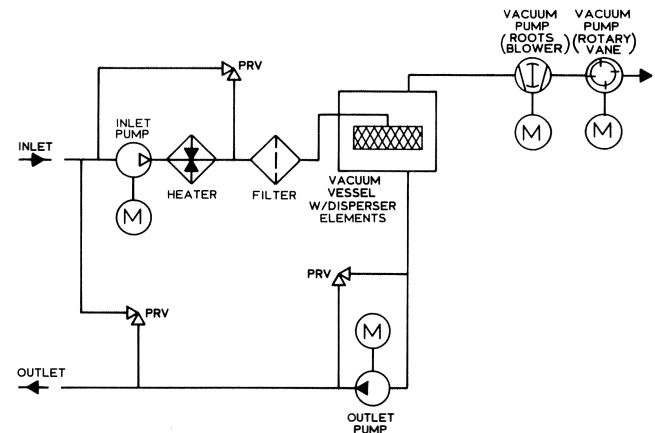


Figure 6. Vacuum Oil Purifier Without Condenser.

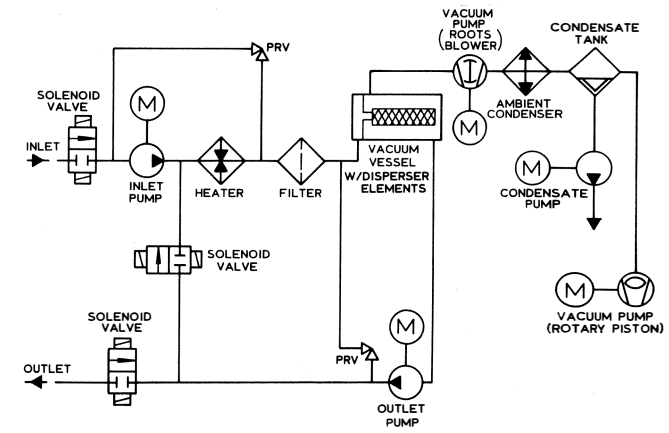


Figure 7. Design With Ambient Condenser Downstream of Blower Pump.

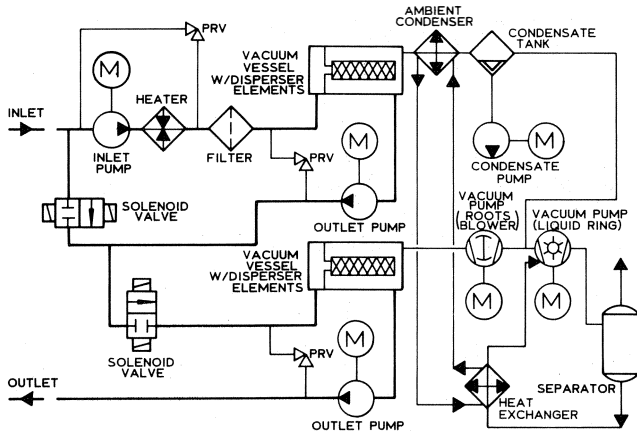


Figure 8. Two-Stage Vacuum Oil Purifier Diagram.

range of oils which may be processed. European and North American users have reported instances of additive depletion when using dispersion cartridges in vacuum service on compressor sour seal oils. Some of these users noted an emulsion gradually forming and collecting on the outer surface of the cartridge through which the oil had passed.

It is suspected that there might be a direct relationship between emulsion formation and additive depletion. No additive depletion has been experienced by the chemical plant in nine years of using baffled tray-type vacuum oil purifiers, however, at vacuum levels of 1.0-10 mm Hg and temperatures of 80 to 85°C. This is of interest because a concern is raised occasionally that high vacuum oil purifiers may remove additives by vaporizing them with the contaminants.

Immersion heaters located upstream of the filter may have shortened life due to contaminants or lube oil constituents carbonizing on the surface of the elements. Additionally, high surface temperatures (or hot spots) on the elements tend to oxidize the oil on contact.

The execution shown in Figure 6 lacks either a chiller or ambient condenser—the subject of discussion later. The reader may recognize it to be a lower-cost version of the earlier Figure 5, and the same comments would apply. It is also noteworthy that the rotary vane vacuum pump used here may require frequent vane replacement, due to wear and degradation by some types of contaminants, and deserves the attention of personnel involved in selecting this equipment.

The design depicted in Figure 7 places the condensing components downstream of the primary vacuum pump. This makes the vacuum pump unnecessarily large and subjects the pump internals to potentially harmful degradation from water droplets and other carryover. Note the ambient condenser to be discussed later, and a condensate purge design which requires an additional pump and driver.

Examining Figure 8, find a two-stage configuration requiring a total of seven pumps and drivers which could prove both expensive and complex. Thermodynamics considerations with a single closed-loop cooling system used here both as an ambient condenser and as a sealing fluid for the liquid ring vacuum pump would require close investigation. Again, the user's review effort would have to focus on these issues, since reliability and maintainability weigh heavily in a modern plant environment.

Finally, the reviewer would have to consider that Figure 9 might have the potential drawbacks described in the earlier discussions of rotary vane vacuum pumps and immersion heaters, although here the heaters are preceded by a filter. The crinkled wire mesh used in this execution creates a pressure drop across the vacuum vessel which the reviewer must ensure will not be

detrimental at his operating conditions. A high pressure drop could allow the oil to accumulate in the vapor space in the top of the vessel, and subsequently carry over into the vacuum line. The screw type discharge pump in this execution would be subject to cavitation under high vacuum conditions even with low to moderate water contamination.

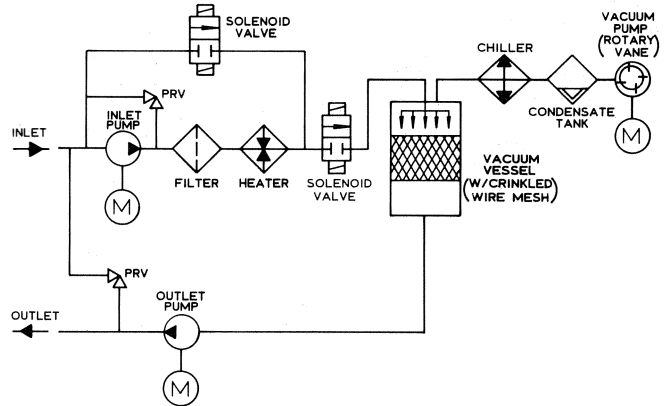


Figure 9. Design Using Crinkled Wire Mesh.

## REMOVING GASES BY VACUUM DISTILLATION METHODS

Sour seal oil contaminated with  $C_1$  to  $C_{12}$  hydrocarbons, hydrogen,  $H_2S$ , and  $HCl$  can be very effectively degassed by vacuum methods that are an inherent feature of vacuum purification units. As illustrated earlier, oil entering the system is brought to optimum temperature and reduced in viscosity to promote thin-film flow across the fibrous media contained in the dispersion cartridge or, for reduced maintenance, over slanted baffles or trays. As the thin film of oil flows through the vessel, water, light hydrocarbons and other volatile contaminants are thus distilled, removed by the vacuum equipment and recondensed for disposal. The filtered, degassed and dehydrated oil is then returned to the lubrication or seal oil system via the discharge pump.

Just how well vacuum purification units will degas the oil depends on the vessel design, temperature, condensing efficiency and the degree of vacuum maintained in the vessel. Test and analysis data from the refinery, the chemical plant and from capable vendors show that units which effectively raise the temperature of the oil, create a sufficient vacuum, condense vapors at relatively cold temperatures and extend the surface area without promoting oil carryover will satisfactorily reclaim severely contaminated seal oil. In one test, a 19 liter (five gallon) sample of ISO Grade 43 lube oil containing 75 wppm of  $H_2S$  and two percent light hydrocarbons was processed, in a single pass, through a vacuum purifier unit operating at 26.92 in Hg (76.2 mm Hg). The reclaimed oil was analyzed and its residual  $H_2S$  concentration conservatively estimated at 0.03 wppm (the vapor in the sample bottle contained seven mppm of  $H_2S$ ). The amount of light hydrocarbons was reduced to 0.25 percent in the same purification step. A second sample processed through a vacuum purifier unit operating at approximately 29.8 in Hg (3 mm Hg) was degassed even more effectively, with the vapor containing a residual  $H_2S$  concentration of two mppm. Again, the amount of light hydrocarbons was reduced from two percent to 0.25 percent in one vacuum purification stage.

The refinery also reports interesting results. Here, the existing units are designed to operate with a vacuum of 28 in Hg (48.8

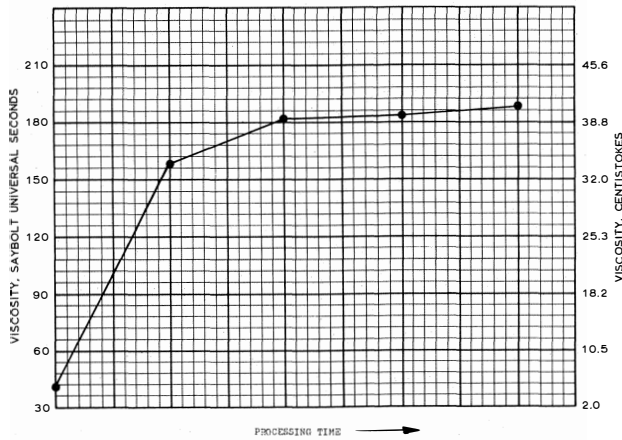


Figure 10. Viscosity Improvement During Processing Train A Oil.

mm Hg) and an inlet oil temperature of 71°C (160°F). In the field, vacua above 27 in Hg (74.2 mm Hg) are commonly achieved, though the vacuum in purifiers which process sour seal oil that has not been adequately degassed in degassing drums has been observed to deteriorate to 21 in Hg (226.6 mm Hg) or less. Inlet oil temperatures typically range from 60°C to 82°C (140°F to 180°F). The vapor pressure/temperature relationship of certain lube oil contaminants is such that high degrees of vacuum at reasonable temperatures are required for effective purification [6]. It did not, therefore, come as a surprise that with the lube oil contaminants in the C<sub>6</sub> to C<sub>10</sub> range, the more elementary vacuum purifiers could not give consistently good results. Therefore, batches of unprocessed sour seal oil were subjected to special testing.

A drum of sour seal oil was collected from each of three compressors for use in the test: a crude unit wet gas machine (Train A), an isomerization unit hydrogen machine (Train B), and a reformer recycle machine (Train C). Sour seal oil contaminants by weight percent were identified by gas chromatography in the C<sub>4</sub> to C<sub>10</sub> range in the Train A and Train B samples, and C<sub>3</sub> to C<sub>10</sub> in the Train C sample as shown in Table 1. Additionally, the Train A sample contained H<sub>2</sub>S gas, nitrogen and carbon dioxide. Marked improvements were noted in viscosity and total acid number of the test oils as they were processed by multi-pass circulation through the vacuum oil purifier. As shown in Figure 10, the viscosity of the Train A oil improved from 4.5 to 41.0 centistokes at 38°C (40.7 to 188.2 SUS at 100°F) after several passes. It was not possible to determine the exact number of passes, however, because the sample volume was drastically reduced from approximately 200 liters to 70 liters (55 gallons to 18 gal-

Table 1. Composition of Sour Oil from Three Process Compressors by Weight Percent.

Component Type	457-J Sour Oil Composition	J-1 Sour Oil Composition	412-J Sour Oil Composition
C <sub>3</sub>	0.0	0.0	0.13
C <sub>4</sub>	1.78	0.28	0.67
C <sub>5</sub>	22.20	3.39	2.55
C <sub>6</sub>	26.49	5.60	10.46
C <sub>7</sub>	10.73	4.90	3.78
C <sub>8</sub>	4.61	0.13	9.76
C <sub>9</sub>	0.24	0.01	1.48
C <sub>10</sub>	0.01	0.01	0.67
C <sub>11+</sub>	33.94	85.68	70.50

lons) as the light hydrocarbons were removed. Similarly, the viscosity of the Train B oil improved from 31.8 to 56.8 centistokes at 38°C (149.2 to 263.2 SUS at 100°F); and the Train C oil, from 4.1 to 28.9 centistokes at 38°C (39.3 to 136.6 SUS at 100°F). No comparison is made here to original oil specifications, since the testing was limited by time, and because the oil taken for testing from the Train A and Train B compressors was a mixture of two viscosity grade oils.

All the test oil samples showed a reduction in total acid number following purification. The most significant decline in total acid number occurred in the processing of the Train B oil: from 0.513 to 0.170 KOH mg/gm of oil.

The effectiveness with which contaminants are removed by vacuum purification is illustrated in Table 2, which is a comparison of C<sub>3</sub> C<sub>10</sub> contaminant content of the Train C test oil before and after purification. Table 3 was developed from a gas chromatograph of the distillate collected during the test. The C<sub>3</sub>, C<sub>4</sub> and most of the C<sub>5</sub> contaminants, as gases, were not in the distillate sample having been exhausted through the vacuum pump. However, as noted earlier, the C<sub>6</sub> to C<sub>10</sub> contaminants were effectively flashed off and recaptured for subsequent disposal due to the combination of high vacua, adequate temperature and refrigerated condensing during the test.

Table 2. Composition of Train C Sour Oil by Weight percent Before and After Purification.

Contaminant Type	Before	Final	Change
C <sub>3</sub>	0.13	0.0	0.13
C <sub>4</sub>	0.67	0.0	0.67
C <sub>5</sub>	2.55	0.0	2.55
C <sub>6</sub>	10.46	0.14	10.32
C <sub>7</sub>	3.78	0.16	3.62
C <sub>8</sub>	9.76	2.73	7.03
C <sub>9</sub>	1.48	0.83	0.65
C <sub>10</sub>	0.67	0.41	0.26

Table 3. Composition of Train C Distillate by Weight Percent.

Contaminant Type	Weight %
C <sub>5</sub>	0.02
C <sub>6</sub>	5.23
C <sub>7</sub>	11.91
C <sub>8</sub>	72.23
C <sub>9</sub>	9.53
C <sub>10</sub>	1.68
C <sub>11+</sub>	0.02

Test data from the refinery samples correlate positively with similar tests conducted by other refineries. Viscosity improvement indicated in Figure 11 is on an ISO VG 32 compressor seal oil from a wet gas compressor in another refinery, which had not been mixed with other oils. It shows viscosity improvement from 22.6 to 30.0 centistokes at 40°C (109 to 141.3 SUS at 100°F) after just 6 passes through a vacuum oil purifier at process conditions of 65°C to 78°C (150°F to 173°F) and 1.7 to 15 mm Hg. Flash point improved during the same test from 38°C to 204.5°C (100°F to 400°F).

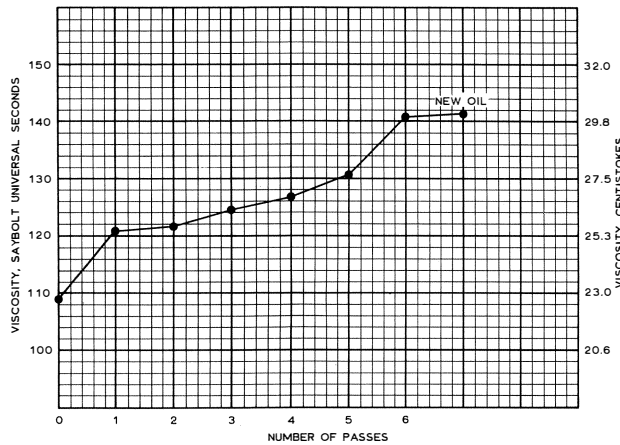


Figure 11. Viscosity Improvement During Processing ISO VG 32 Sour Seal Oil.

### CONSIDERATIONS FOR REFRIGERATED CONDENSING

Vacuum oil purifiers should, in most cases, incorporate refrigerated condensing means between vacuum vessel and vacuum pump. The refrigerated condensing system improves both the processing and energy efficiency of the vacuum purifier. Refrigerated condensing prevents large quantities of water from going through the vacuum pump. *It is absolutely necessary to have refrigeration condensing if there are any condensible hydrocarbons in the system.* The condensible hydrocarbons also dissolve in the vacuum pump lube oil and lower its viscosity. This causes rapid deterioration of lube oil which can lead to distress and failure of the vacuum pump.

As regards the degree of water removal achievable with vacuum oil purifiers operating at different levels of vacuum and temperature, Figure 12 will be of interest. With the final ppm of water in the lube oil calculated on the basis of Henry's law, it is clear from the figure that if the vacuum level is above 50 mm Hg, it is no longer possible to reduce water content in lube oil to within the desired 40 to 50 ppm range. These findings were corroborated by field experience reported by vacuum oil purifier users. There is no significant difference in overall dehydration efficiency if the system is operated at 10 to 25 mm Hg vs 2.0 to 10 mm Hg, but the higher vacua may be required for removal of light hydrocarbons above C<sub>8</sub> chains.

### REQUIRED PROCESSING TIME FOR WATER CONTAMINATED OIL CAN BE CALCULATED

In a typical turbomachinery lube oil reservoir, the bulk oil is contaminated with a combination of free, emulsified and dissolved water. Analytical studies and field experience show that even under the best circumstances, lube oil drain headers and reservoirs are saturated with moist air [1, 7]. The systems are usually vented to atmosphere. Temperature differences and cyclic variations in delta T between vent areas and ambient temperatures promote condensation. The possibility of ingesting wet or contaminated air exists also at the shaft seals. Large amounts of oil draining from the bearing area back to the reservoir are known to create suction effects or slightly lower pressure regions in the bearing housing. This promotes the inflow of ambient air through labyrinth seals and, together with condensation in reservoirs and vents, explains the fact that even motor-driven turbomachinery experiences lube oil contamination [3].

While nitrogen blanketing is occasionally used in efforts to exclude atmospheric air, experience shows small quantities of

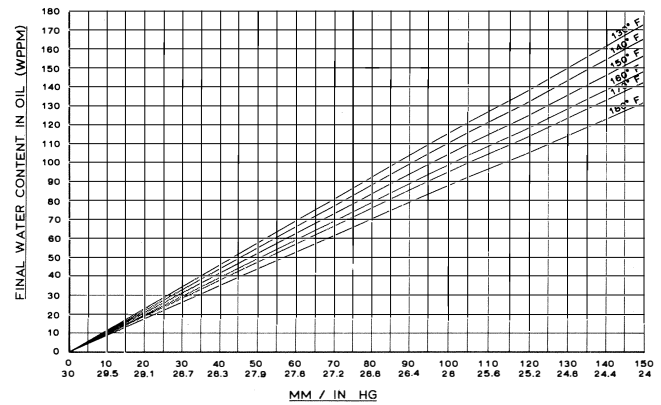


Figure 12. Effect of Vacuum Level on Performance at Different Temperatures.

nitrogen to be rather ineffective. It has often been noted that nitrogen blanketing can promote a false sense of security that water intrusion is eliminated, especially in high humidity locations. To be effective, large volumes of nitrogen would have to be used and the procedure would not be economically viable or justifiable.

A conservative rule of thumb developed at the Chemical Plant showed that for typical water concentrations in the vicinity of 1,000 to 10,000 wppm it would be possible to reduce the level of water contamination down to 40 wppm of dissolved water after perhaps five "turnovers." In this context, "turnover" would be calculated by dividing the contents of the lube oil reservoir (gallons) by the processing rate of the lube oil conditioner (gallons per hour). Thus, one would normally keep a 300 gph vacuum dehydrator hooked up to a 3,000 gallon reservoir for 50 hours:

$$\frac{3000 \text{ gallons}}{300 \text{ gallons/hr}} \times 5 = 50.$$

$$T = \frac{W}{Q} \ln \frac{i_w}{f_w},$$

Where

T = processing time, hours

W = contents of lube oil reservoir, gallons

Q = purifier capacity, gallons per hour

$i_w$  = initial water content, decimal expression

and  $f_w$  = final water content, decimal expression

Or, in our example

$$T = \frac{3000}{300} \frac{1000}{40} = 10 \ln 25 = 32 \text{ Hours}$$

This would assume a processing efficiency of 100 percent, whereas a more realistic, generally achievable efficiency would be 80 percent. Note, also, that the above equation does not take into account the small amount of water which theoretically continues to enter the reservoir from whatever source.

### LUBE OIL ANALYSIS PROGRAMS

Research efforts spearheaded years ago by the utilities industry have led to optimized lube oil analysis methods for steam turbine lube oils. An authoritative book on this subject recommends testing for color, foreign solids, neutralization number, viscosity and water content [8]. However, more recent studies



indicate that these tests alone are not sufficient for early determination, if oxidation has progressed to an undesirable degree [9]. Lube oil oxidation can result from prolonged exposure to atmospheric oxygen, high bearing and reservoir temperatures, or possibly even excessive heating during processing in vacuum oil purifiers with incorrect temperature settings.

The chemical plant opted for an analysis program which checks for appearance, water, flash point, viscosity, total acid number, and additive content. These tests are further described in the literature [10, 11].

#### PURIFICATION AND ANALYSIS: LONG TERM RESULTS

During the first full year of the onstream lube oil purification and analysis program, the chemical plant was primarily interested in establishing the "before *vs* after" results of analyses for dissolved water and oxidation inhibitor. The water check would demonstrate acceptable overall operation of the two vacuum oil purifiers, checking the oxidation inhibitor content would tell us if the lube oil had aged, or if, perhaps, the application of heat and vacuum in the unit had caused the phenolic oxidation inhibitor constituent to be removed from the lube oil.

Four turbine driven boiler fan lube oil systems were found to be typical of the water contamination analysis results. Each of these 2006 liter (530 gallon) reservoirs was purified during 12-hour shifts and showed "before *vs* after" water contents of 317/135, 138/11, 324/47, and 351/62 wppm, respectively. The reservoir with the 135 wppm residual water content was given another 12-hour purification treatment and all four subsequently earmarked for 18-hour conditioner hookups in the future.

Analyses for depletion of the phenolic oxidation inhibitor were made in similar "before *vs* after" fashion on all of the 36 lube oil reservoirs at the chemical plant and also by simultaneously withdrawing an oil sample from both inlet and outlet connections on the vacuum oil purifier. There were no significant differences in the levels of inhibitor concentrations in the sample streams. Also, no significant differences were found in the inlet *vs.* outlet samples when the vacuum oil purifier processing temperature was experimentally raised to 93°C (approximately 200°F). In fact, the oxidation inhibitor concentration level has never dropped below the minimum acceptable level of 0.2 per-

cent in any of the 36 lube oil reservoirs during almost nine years of operation! It can certainly be concluded that vacuum oil purification at the processing conditions given above does not result in the removal of desirable additives, at least not from turbine lube oils marketed by major lube oil refineries. No effort was made to define which academic values of temperature and vacuum would cause concern, but users who theorize that their oil additives may be highly volatile could perform a series of mass transfer calculations to establish "safe" vacuum oil purifier operating conditions.

At the chemical plant, oil leakage from compressor shaft seals is returned directly to the reservoirs. The authors are aware, however, of many user locations such as refineries and gas compression facilities onshore and offshore which collect large quantities of seal oil directly from the traps. These oils are then batch processed through vacuum oil purifiers at the same operating levels of vacuum and temperature as at the chemical plant with excellent results. One such skid mounted unit incorporating three 2,500 liter (660 gallon) batch process tanks and three vacuum oil purifiers is shown in Figure 13.

The chemical plant examined the restoration of flash point by comparing "before *vs* after" analyses with, values expressed in degrees Fahrenheit: 405/412, 412/426, 397/419, and 415/423. As expected, vacuum oil purification had resulted in the removal of light hydrocarbons. Very similar results can be reported for seal oil systems with oil charges that had occasionally been exposed to contact with H<sub>2</sub>S containing gas streams. In three years of observation by one of the writers, the oils continued to show flash point values around 210°C (410°F). In all of these cases, the accompanying change in lubricant viscosity was marginal and appeared to be within the anticipated error band for the kinematic viscosimeter which was used in this lube oil analysis.

Finally, the chemical plant was observing very minor upward changes in total acid number for oils after conditioning. However, all of the 36 reservoirs remained well within the specified allowable maximum TAN of 0.3 KOH mg/gm of oil during the entire nine year period from 1978 until 1988. In fact, the chemical plant is still using the original 83,500 liters (22,000 gallons) of lube oil which were loaded into the reservoirs when the facility was commissioned in 1978. The plant intends to have the same oil in place during the next decade.

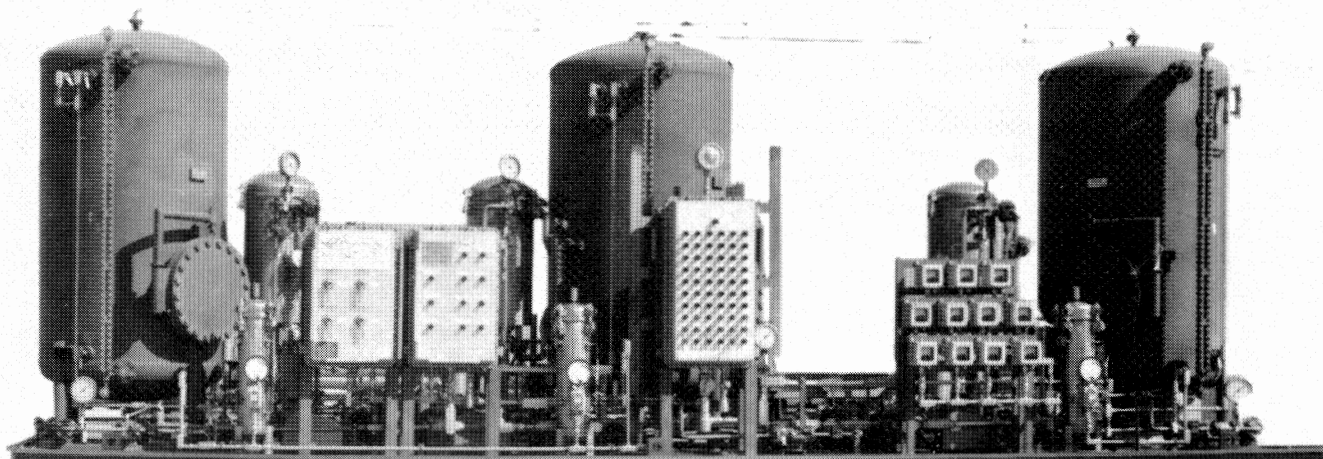


Figure 13. Batch Process Type Sour Seal Oil Reclaimer Package (Courtesy Allen Filters).

## BENEFIT-TO-COST RATIO CALCULATED

The benefits of on-stream reclamation or purification of lube oil have been described in numerous technical papers and other publications. Monetary gains are almost intuitively evident and additional documentation contained in Jacobson's and Sullivan's articles [12, 13], and others can be consulted by engineers interested in reliable plant operation.

Two hours of unscheduled downtime brought on by contaminated lube oil in a major turbocompressor would cost many plants more than the estimated purchase price which can typically range from \$30,000 to \$80,000 for small, fixed base to large, mobile vacuum oil purifiers. Although this fact alone should be sufficient justification for most programs, a detailed investigation was conducted of annual costs and savings for the inhouse analysis portion of plantwide turbomachinery lube oil reconditioning and analysis program performed at the chemical plant. These costs consisted of laboratory technician wages and expendables such as glassware and chemicals. Savings included avoidance of higher charges for outside contract laboratory work, and labor and electric power savings from the elimination of "precautionary reclamation" practiced in the many instances where delayed reporting or logistics problems deprived us of timely feedback. The net annual savings substantially exceeded the cost of acquiring supplemental laboratory instrumentation specifically required for inhouse analysis of lube oil, and not otherwise needed by the laboratory. The chemical plant achieved a benefit-to-cost ratio approaching 1.8, with discounted cash flow returns exceeding 100 percent.

Another way of calculating the approximate total savings at the Chemical Plant from 1979 until 1988 would be as follows:

### Costs

Collection and processing of samples, \$8,450/yr.	
Nine-Year Total:	\$ 76,000
Incremental analytical instruments:	6,000
Vacuum oil purifier initial cost:	60,000
Avoided cost for individual (dedicated) purifiers:	(68,000)
Vacuum dehydrator maintenance:	20,000
Vacuum dehydrator operating labor (160 hrs/hr):	36,000
Nine-Year Total:	\$130,000

### Avoided Costs—Method I

(frequent changes prevent machinery downtime)

Four complete oil changes, 4×22,000 @ \$2.49/gal	\$219,000
Two non-turnaround, scheduled, major turbo-train shutdowns for the purpose of changing lube/seal oil	300,000
Labor and disposal costs, 36 reservoirs, 4 exchange events @ \$900 each	130,000
Nine-Year Avoided Cost Total:	\$649,000

### Avoided Cost—Method II

(infrequent changes cause some machinery downtime)

Two complete oil changes, performed during plant turnaround 2×22,000 gal @ \$2.49/gal	\$110,000
Labor and disposal costs, 36 reservoirs, 2 exchange events @ \$900 each	65,000
One turbotrain outage and repair event in 9 years (One event per 45 train-years)	500,000
Nine-Year Avoided Cost Total:	\$675,000

In considering the above calculations, prospective users should substitute their own figures appropriate to the installation. For example, handling and transportation costs could add 400 to 1,000 percent to the cost of oil on an offshore production

platform in the North Sea vs a refinery location in the U.S. where the oil is manufactured.

## CONCLUSION

Both the long term field experience of a modern chemical plant and recent sample studies performed by a major refinery have shown that vacuum oil purifiers designed to provide the essential oil temperature increase, surface area extension and high vacuum exposure can remove process contaminants, free water and dissolved water. These optimally designed purifiers have the ability to restore lube oils to their original properties.

On the subject of cost justification, one knowledgeable source has calculated that for the majority of lubrication systems using more than 200 liters (approximately 50 U.S. gallons) of lubricant, oil analysis generally proves more profitable than a routine time/dump program [12]. Similar findings have been reported by large-scale users of hydraulic oil whose reconditioning efforts have proved successful and profitable [13]. Field experience by a major chemical plant and cost justification studies by both the chemical plant and a major refinery fully support this contention.

There are several reasons why thoughtful engineers should make an effort to put in place lube oil preservation and waste reduction programs; of these the economic and environmental reasons are most important. A conscientiously implemented program of lube oil analysis and reconditioning can rapidly pay for itself through lube oil savings and reductions in machinery failure frequency.

Lube oil analysis techniques are relatively easy to understand and automated laboratory equipment makes the job more precise and efficient than a few decades ago. Employing these techniques in conjunction with a well designed vacuum distillation type lube oil conditioner allows prospective users to justify lube oil reclamation as a considerably better alternative than selling, burning, or otherwise disposing of lube oil in a modern plant environment.

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