Some Properties of Canadian Steam Turbine Oils©

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Six Canadian steam turbine oils, ISO VG32, were evaluated in a number of laboratory bench tests at National Research Council Canada. These were: 1.0 oxidation stability tests, such as TOST (ASTM D943), RBOT (ASTM D2272), CIGRE (IP 280), and sludge (ASTM D4310); 2.0 air separation tests, such as foaming (ASTM D 892) and air release (ASTM D3427); and 3.0 water separation tests, such as demulsibility (ASTM D1401) and steam emulsion number (ASTM D1935).

These data helped to identify the best properties of Canadian steam turbine oils and to rationalize differences among various specifications including ASTM specification D4304, ISO draft specification DIS 8068, and various user specifications.

INTRODUCTION

Three specifications for steam turbine oils have either recently emerged or are in the final stages of development. They include those issued by ASTM (*1*), Ontario Hydro (*2*), and a third which is a draft of a standard (*3*) which is being circulated by the International Organization for Standardization (ISO) to member nations for comment and approval.

These specifications show some distinct differences in requirements, principally in the oxidation stability and air and water release tests and their limits (Table 1). Also, in order to satisfy both European and North American requirements, the ISO document had to have a number of compromises in that the oxidation stability can be assessed by the European CIGRE test or by the ASTM D 943 test. This latter test is also often called the turbine oxidation stability test, or TOST for short. Water demulsibility can be assessed by either examination of the breakup of emulsions made mechanically (i.e. D 1401) or by steam blowing (i.e., D 1935) and, in addition, air release limits are given. This latter requirement, reportedly, has been found to be important in European designs but has been of little interest in North America. A number of Canadian laboratories have now obtained the necessary air release test equipment and results are becoming increasingly available.

The ASTM document which is presumably aimed at North American users offers no CIGRE, steam emulsion alternatives, or air release requirements. There are, however, TOST, mechanical demulsibility, and rotating bomb oxidation test (RBOT) limits.

The specification from Ontario Hydro, a large Canadian utility, was recently revised to introduce a limit on the sludge in a modified D 943 test. This was reportedly necessary because of sludging problems (not one of the formulations tested at NRCC) observed in the field. Neither ASTM D 4304 nor ISO DIS 8068 has such a sludge limit for the D 943 test. Measurement of sludge after 1000 hours in a D 943-type test now carries the designation D 4310. It is believed that lubrication engineers tend to agree that there should be a sludge limit but disagree on the limiting sludge level and the test technique. A good TOST lifetime without consideration of sludge measurement in the test does not guarantee the absence of sludging in field equipment. This had been recognized in a Canadian General Standards Board (CGSB) specification (*4*) and in the related US military specification (*5*), as they both have a sludge limit by a modified D 943 test.

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TESTING PROGRAM

In response to a request from K. J. Brown one of the coauthors, and the Canadian representative on an International Electrotechnical Commission (IEC) working group preparing steam turbine oil documents, the Fuels and Lubricants Laboratory of the National Research Council of Canada (NRCC) agreed to perform oxidation stability tests (CIGRE, TOST, RBOT) and air and water separation tests (foaming, air release, steam and mechanical emulsion) on six ISO VG32 steam turbine oils from Canadian suppliers. The aim was to determine how the results compare with the limits of the specifications and, where possible, to compare these with the actual performance of the oils in some large steam turbines. The oxidation results included both the familiar D 943 and the newer D 4310 sludge tests.

Since ISO DIS 8068 was being circulated to member na-

Table 1—Selected Specification Limits for Steam Turbine Oils	ASTM D 4304 Type 1	ISO DIS 8068 Type A	Ontario Hydro M-332M-85	CGSB 3-CP-357M
	VG 32	VG 32	VG 32	*
OXIDATION STABILITY TESTS				
CIGRE TESTS (IP 280, DP 7624)				
Total Acidity, max	—	1.8	—	—
Total sludge, % mass, max	—	0.4	—	—
RBOT TESTS (D 2272)				
ΔP 175 kPa, minutes, min	200	—	—	—
TOST TEST (D 943, DIS 4263)				
Time to TAN 2.0, hours, min	2000	2000	—	—
TAN after 1000 hours, max	—	—	0.3	2.0§
Sludge after 1000 hours, mg, max†	—	—	15‡	100§
Acidity of Water Phase, mg KOH/g, max	—	—	—	1.0
AIR AND WATER SEPARATION TESTS				
FOAMING (D 892, DP 6247)				
Tendency/stability, mL, max				
Sequence I, 24°C	400/0	450/0	—	250/0
Sequence II, 93.5°C	—	100/0	—	100/0
Sequence III, 24°C after 93.5°C	—	450/0	—	250/0
AIR RELEASE (D 3427, IP 313, DIN 51381, DP 9120)				
At 50°C, minutes, max	—	5	—	—
STEAM EMULSION NO. (D 1935, DIN 51589)				
Seconds, max	—	300	300	—
MECHANICAL EMULSION (D 1401, ISO 6614)				
Time to 3 mL emulsion at 54°C minutes, max	30	30	—	30‖

*VG grade between ISO VG 68 and 100, i.e., 73–82 mm^2/s (cSt) at 40°C.
†Ontario Hydro test based on modified ASTM D 4310 using a glass microfibre filter instead of the specified membrane filter.
‡Approximate. Specified limit is 0.05 g/L.
§Figure given for information only. A higher viscosity oil such as this permitted more sludge and a shorter TOST oxidation lifetime than ISO VG 32.
‖Time to 1 mL emulsion.

tions during this period, it was thought that the data generated would be very beneficial to help develop a Canadian position—especially with respect to the CIGRE and air release tests for which little test data were available on Canadian oils. It was also hoped that the matter of how long the TOST had to be run and the matter of sludge limits could be resolved.

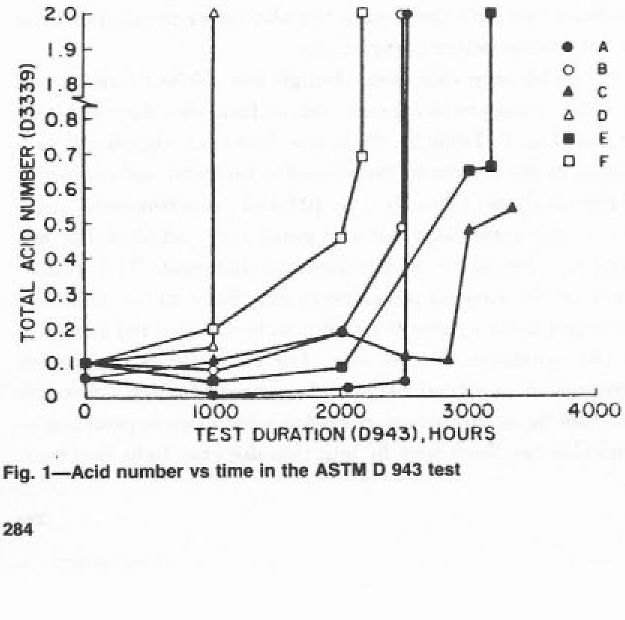

Fig. 1—Acid number vs time in the ASTM D 943 test

TEST RESULTS

All tests at NRCC were performed in duplicate on the oils identified as A to F. The results are shown for the D 943 test (Fig. 1, Table 2) and the D 4310 sludge test (Table 3). The averages shown for the other data are based on duplicate determinations which were within the ASTM testing repeatability limits. Comparative oxidation stability data are given in Table 4 and air and water separation data in Table 5. NRCC has developed confidence in its test data for all tests noted in this report through participation in ASTM, Canadian General Standards Board (CGSB), and through informal laboratory cooperative testing programs.

DISCUSSION

ASTM Turbine Oxidation Stability Tests

These tests or variations of them are generally regarded as being the most important for steam turbine oils because the tests attempt to duplicate the oxygen, water, metals, and heat found in service. As with many procedures, the generation of results is accelerated by increasing the severity of the test conditions. D 943 results have been found to correlate fairly well with the performance of oils in service; however, the test procedure stipulates testing, or at least

Table 2—ASTM D 943 Test Times at Various TANs

	Oil A	Oil B	Oil C	Oil D	Oil E	Oil F
TAN 0.25						
Replicate 1	2519	1722	2911	1002	2117	1460
Replicate 2	3018	2128	3095	1175	2231	1369
TAN 0.30						
Replicate 1	2521	2198	2933	1004	2159	1617
Replicate 2	3019	2418	3114	1178	2298	1542
TAN 0.50						
Replicate 1	2530	2511	3137	1010	2892	2045
Replicate 2	3022	2681	>3100	1191	2660	2123
TAN 1.0						
Replicate 1	2550	2520	>3300	1026	3375	2191
Replicate 2	3029	2700	>3100	1224	3205	2359
TAN 2.0						
Replicate 1	2591	2537	>3300	1058	3408	2215
Replicate 2	3044	2738	>3100	1289	3242	2390

reporting, to a cutoff point of a total acid number (TAN) of 2.0. The number of test hours required to reach this value is the "oxidation lifetime."

The TAN 2.0 cutoff point has long been regarded by many users as being too high and the test as being too long to run. Based on the data (Fig. 1) obtained on the six oils, it is clearly possible to lower the cutoff point to TAN 1.0 without significantly altering the "oxidation lifetime" because the rapid breaks occur at or below 0.7. One wonders, however, whether any particular advantage would be realized from this because the break does give a rapid increase in TAN anyway. The test hours to various TANs is shown in Table 2 and, even if the cutoff point was lowered to TAN 0.5, all the oils that passed at 2.0 would still pass. However, since this point occurs before oxidation lifetime stabilization with some oils (C, E, and F), it may not be acceptable to everyone as it would reduce the oxidation lifetime of these oils for no justifiable reason. Correlation between rapidly changing acidity in the laboratory test with that occurring in the field is not easily obtained owing to the length of time it takes to generate field data. As well, oil formulations will likely change during that period and not all field conditions are identical.

The two oils known to show good performance in the field (Oils B and earlier formulations of E) meet the 2000-hour TOST oxidation lifetimes with even a TAN 0.5 cutoff point, and, in fact, could meet TAN 0.3 at both 1000 and 2000 hours, but the lower limit could lead to failures and disagreements due to test reproducibility at this point.

Ontario Hydro has had good success in over 58 units and 24 000 MWe of installed steam turbine capacity for many years (i.e., some with oil lives in excess of 20 years) with the new oils having to meet a TAN 0.3 limit at 1000 hours when tested using D 943 equipment. This is now coupled with a sludge limit. This two-pronged limit reduces the duration of the TOST test while attaching a sludging requirement. It should be noted that much of this operating experience is based on the B and E oils as these had been the only ones consistently qualified. It should be noted too, that the only oil to do very badly in the TOST, Oil D, had given quite good results when previous samples were tested so it is suspected that a formulation mistake may have been made.

A comment also seems to be in order about the unusual performance in the TOST test of Oil C which exhibited an unusual rise and fall in the TAN during the course of oxidation (Fig. 1). Also, a rather poor sludge repeatability was coupled with a poor TAN repeatability for this oil after 1000 hours. It is suggested that the sludge and TAN results noted in Table 3 and the generally oscillating TAN values are related. One can reason that TAN values (excluding the initial TAN) indicate the presence of largely soluble oxidation products. As these TAN values increase, so does the level of such soluble oxidation products. Once a critical TAN value is reached, these then precipitate as sludge. After precipitation, the TAN value drops and the cycle repeats. Further testing on Oil C is needed to establish a firm theory. Concern about such sludge formation, the acidity of the sludge, and the metal catalyst corrosion were behind some of the doubts regarding D 943 as it was written because it may not be discriminating enough. The newer test D 4310 uses the same test equipment, tests for only 1000 hours, and allows for other parameters to be determined. Many of these are reported in Table 3 as attempts were made to measure not only the sludge but also other properties so as to determine better correlations.

It can be seen that even though the TANs of all six oils at 1000 hours are not great and, in fact, all values are 0.25 or less (Fig. 1, Table 2), there are, however, significant variations in the weight of the insoluble material and corrosion of the catalysts (Table 3). The pH and the strong acid number of the water layer of the good and bad sludging oils were not found to be significantly different. The importance of the various parameters may have to be related to the equipment in which an oil is to be used as the selection of the optimum oil can vary. For example, if the system contains no material likely to be attacked, then corrosion may not be as important as sludge which can deposit out in critical areas. Such specific selection does not help, however,

Table 3—ASTM D4310 Data	Oil A	Oil B	Oil C	Oil D	Oil E	Oil F
Weight of Insoluble Materials, mg						
Replicate 1	16.3	5.7	216.5	56.8	13.8	12.5
Replicate 2	17.2	9.7	75.5	69.8	19.5	10.8
Ash Content of Sludge, D 482						
Inorganic ash, % mass						
Replicate 1	1.9	1.0	47.7	13.7	2.6	3.0
Replicate 2	2.8	1.4	20.2	17.1	3.6	2.4
TAN Oil						
Replicate 1	0.04	0.04	0.07	0.14	0.09	0.19
Replicate 2	0.01	0.10	0.25	0.19	0.09	0.17
Sludge Spot Test Rating*						
Replicate 1	SL.TR	NIL	MOD.	SL.TR.	TRACE	SL.TR.
Replicate 2	SL.TR.	NIL	MOD.	SL.TR.	TRACE	SL.TR.
pH of Water Layer						
Replicate 1	6.4	3.7	4.9	4.3	5.4	3.5
Replicate 2	6.0	4.3	5.5	5.5	3.9	3.7
Strong Acid Number of Water Layer						
Replicate 1	NIL	0.04	NIL	NIL	NIL	0.03
Replicate 2	NIL	NIL	NIL	NIL	0.01	0.02
Weight Change of Catalyst Coils, % mass						
Replicate 1	0.00	0.00	−0.12	−0.05	−0.04	−0.06
Replicate 2	0.00	−0.01	−0.04	−0.04	−0.02	−0.02
Corrosion Rating of Catalyst Coils						
Iron Replicate 1	2	2	3A+	2	1	1
Replicate 2	2	2	2	1	1	2
Copper Replicate 1	3A	2	4	3B	2	3A+
Replicate 2	3A	2	4	4	.2	4
Analysis for Iron & Copper by AA						
Elements in oil layer, ppm						
Iron Replicate 1	<1	<1	<1	<1	<1	<1
Replicate 2	2	4	3	1	<1	<1
Copper Replicate 1	<1	<1	9	4	<1	<1
Replicate 2	<1	2	4	4	<1	<1
Elements in Water Layer, ppm						
Iron Replicate 1	<1	<1	<1	<1	<1	<1
Replicate 2	<1	<1	<1	<1	<1	<1
Copper Replicate 1	9	14	40	68	20	80
Replicate 2	6	8	38	65	17	70
Elements in Ashed Sludge, % mass						
Iron Replicate 1	0.1	<.1	17.3	0.1	0.9	3.0
Replicate 2	0.1	<.1	2.4	1.1	<0.1	0.2
Copper Replicate 1	0.9	0.3	6.8	9.6	0.9	11.3
Replicate 2	1.1	0.4	9.7	11.6	2.2	0.8

*SL.TR. = slight trace; MOD = moderate.

when national or international limits are required nor when qualifying oils for general purchases. The D 4310 test does show that these six oils can behave quite differently and that a single parameter such as the TAN of the oil is not likely to be sufficient.

CIGRE Test

As shown in Table 4, the total acidity and the total sludge ranking of the oils were the same. This was not the case for the TAN as found in D 943 and the sludge in D 4310. The ranking was similar to that for D 943 and D 2272 in that the best were the same. However, Oil A, one of the worst in CIGRE, performed well in the D 943 test. Also, Oil C, one of the better oils with respect to CIGRE total sludge, was very bad for insoluble material in the D 4310 test. The reasons for this anomalous behavior is not known at this time, nor is it clear which test is a better indicator for performance in the field. However, the performance is believed to be related to the sulfur content of the oils. This was not checked.

Table 4— Comparative Oxidation Stability Data

	Oil A	Oil B	Oil C	Oil D	Oil E	Oil F
CIGRE TEST (IP 280)						
Total acidity	50.6	1.05	0.71	7.00	0.52	5.41
Total sludge, % mass	16.0	0.05	0.05	2.43	0.03	1.63
TOST TESTS (D 943)						
Time to TAN 2.0, hours	2818	2638	>3200	1174	3325	2303
TAN, as rec'd	0.07	0.10	0.07	0.10	0.10	0.10
TAN after 1000 hours	0.03	0.07	0.16	0.17	0.09	0.18
RBOT TEST (D 2272)						
ΔP 175 kPa, minutes	249	248	277	173	339	217
Sludging Tendency (D 4310)						
Insoluble Material, mg	16.8	7.7	146	63.6	16.6	11.6

Table 5—Air and Water Separation Tests Data

	Oil A	Oil B	Oil C	Oil D	Oil E	Oil F
Foaming Characteristics (D 892)						
Tendency, after 5 min, mL						
Sequence I, 24°C	10	25	45	17	225	240
Sequence II, 93.5°C	20	30	30	27	30	33
Sequence III, 24°C	0	0	0	0	265	255
Stability, after 5 min, mL						
All Sequences	0	0	0	0	0	0
Air Release Test (D 3427)						
50°C, min	3.0	3.0	2.1	3.5	2.6	1.3
Steam Emulsion No. (D 1935), S	191	293	197	96	100	88
Mechanical Emulsion (D 1401)						
At 54°C, min to 3mL emulsion	15	25	>30	10	10	10

RBOT Test

Also shown in Table 4 are the RBOT results which paralleled D 943 very closely. In fact, the ranking from best to worst could have been the same depending upon when Oil C would have been broken. Because of the good correlation between TOST oxidation lifetime and RBOT, the latter can and does serve as a quicker test for TOST, particularly for monitoring batch-to-batch consistency and for user checks on individual shipments. Its limitations, though for initial approvals, should be recognized as the RBOT/TOST correlations may not be firm in all cases, and the RBOT test is not intended as a general substitute for the D 943 TOST test.

Foaming Tendency and Air Release

The oils shown in Table 5 exhibited marked differences with respect to foaming in that either they were very good or fair. The Oils E and F that gave fair results are believed to have similar base stocks and it is suspected that they have no antifoam additives. Only Oil D is known to contain low levels of a silicone-type antifoam; however, the air release times were not affected adversely as might be the case when excessive amounts are used. The low air release values may explain why there had not been a demonstrated need for the test in Canada. It is also interesting to note that the oils that ranked better with respect to foaming tendency tended to be a little worse with respect to air release; however, the differences were small. For comparison, the air release value for oils in service reportedly tends to be around 11 minutes; however, these can be a mixture of oils and in the past spiking with silicone type antifoam could have taken place.

Water Separation

The two tests, ASTM D 1401 and D 1935, or the different variations have both had proponents over the years with many utilities preferring the latter steam test, perhaps for historical reasons or because it uses steam and the oil is to be used in steam turbines. The old D 157 steam blowing test reportedly had precision problems and hence it was dropped by ASTM for use on steam turbine oils in favor of the simpler D 1401 test using distilled water and mechanical mixing to form emulsions. D 1935 is available for those still wanting to specify an ASTM test. IP 19 and DIN 51589 are also reportedly similar steam blowing procedures.

Results in Table 5 appear to show some correlation be-

TABLE 6—RESULTS VS SPECIFICATION LIMITS*

	A	B	C	D	E	F
CIGRE (ISO only)	F	P	P	F	P	F
RBOT (ASTM only)	P	P	P	F	P	P
TOST, Time to TAN 2 (ISO/ASTM)	P	P	P	F	P	P
TOST (ONT. HYD. only)						
TAN after 1000 h	P	P	P	P	P	P
Sludge after 1000 h†	M	P	F	F	M F	P
Foam (ISO/ASTM)	P	P	P	P	P	P
Air Release (ISO only)	P	P	P	P	P	P
Steam emulsion (ISO/O.H.)	P	M P	P	P	P	P
Mech. emulsion (ISO/ASTM)	P	M P	F	P	P	P

* F = Fail, P = Pass, M = Marginal
† Comparison is approximate because test method used is not identical to test method specified.

tween the two tests. Oils A, D, E, and F are all about mid-range, with the latter three being a bit better. Oil B is on the high side for both tests and Oil C is very high for the mechanical emulsion and high for the steam emulsion number. It should be noted that the results for Oil B are higher than those determined by others for different samples and could possibly be a result of slight contamination with detergent-type oils. This was not checked in this case but it is not unknown for shipments to be so contaminated. Comparative results for Oil C were not available.

Comparison of Test Results with Specification Limits

A summary of the results versus specification limits is given in Table 6. Five of the oils (A, B, C, E, F) have satisfactory TOST lifetimes by ASTM D 943/DIS 4263 and exceed 2000 hours (Table 2). Accordingly, they meet the ISO and ASTM requirements of "time to TAN 2.0" and the Ontario Hydro requirement of TAN 0.3 after 1000 hours. Oil D, which has a TOST lifetime of just over 1000 hours, obviously fails to meet the ISO and ASTM requirements; however, it does meet the Ontario Hydro requirement. The TAN 0.3 limit at 1000 hours had been thought to be more stringent than 2.0 at 2000 hours. All the oils tended to break fairly rapidly as opposed to reports that some European oils (i.e. German) can rise rapidly initially, followed by a more gradual rise to 2.0. Hence, lower requirements than 2.0 were not acceptable to them.

The sludge aspect is the most interesting in that three of the specifications give limits (Table 1). These are ISO, Ontario Hydro, and CGSB. If the ISO CIGRE limit is taken as correct, then Oils A, D, and F would fail (Table 6). If the same oils could then be presumed to fail the TOST D 4310, then a limit must be set lower than the Oil F results of 10.8 and 12.5 mg of insoluble material (Table 3). However, this would also fail Oil E which has reportedly performed well in service. In addition, Oil C sludges very badly in D 4310 but not in the CIGRE test. The Ontario Hydro limit of 0.05 g/L is based on the normal 300 mL of test oil minus the amount removed for the D 974 TAN determination. If this is 10 mL, then the limit corresponds to about 15 mg. This would fail all the oils except B and F (Tables 3 and 4); however, some batches of E and A may pass. Ontario Hydro testing on oils supplied to them showed that Oil A had exhibited moderate to considerable sludge whereas a light sludge was considered a pass. Oils from the suppliers B, D, and E had performed adequately in their tests but it should be noted that these were not necessarily the same formulations.

No comments are made on the oils with respect to the CGSB specification because it applies to oils with a viscosity of 73 mm^2/s at 40°C. As such, it is much more viscous than the ISO VG32 oils tested and the end use is also different in that it is for oils to be used in marine steam turbines. Higher sludge and shorter oxidation lifetimes are apparently acceptable.

For almost all the other tests done, the oils meet the requirements of the three applicable standards. However, as noted previously, in a few cases the results approached or exceeded some limits.

FUTURE WORK

Future work is planned to compare these test results with tests done by a number of the oil suppliers and Ontario Hydro, to further investigate the sludging performance, and to do particle counts on the samples. It is hoped that these results will be ready in the near future and that they will be reported in another paper.

CONCLUSIONS

1. The oils tested, with two exceptions, meet the requirements of the various specifications (VG32 grade) considered. The oil that failed one test is suspected of being improperly formulated with regard to oxidation inhibitors and, in the other case, a water separation limit was exceeded.
2. Oils were found to have widely varying behaviors in the oxidation stability tests and TAN testing limits alone are not considered to be sufficient to determine the in-service performance of an oil.
3. There can be seen to be no technical advantage in specifying a lower D 943 TAN limit than 2.0 for a 2000-hour test.
4. A shorter test time for D 943 may be desirable for checks but will not guarantee a 2000-hour oil because

the breakpoint can occur so rapidly with the oils tested.

5. A sludge limit for the D 4310 could not be determined at this time, but sludging must be considered to prevent operational problems.
6. The air release times for the oils tested were all less than 5 minutes.
7. There was evidence of a good correlation between mechanical demulsibility (D 1401) and steam emulsion number (D 1935).
8. There was good agreement between the TOST (D 943) results and the RBOT (D 2272) results.

ACKNOWLEDGMENTS

The authors are grateful to R. B. Whyte, Chairman of the Canadian Advisory Committee, ISO TC 28/SC4 on Classifications and Specifications for Petroleum Products and Lubricants, to oil company and Ontario Hydro experts for their very helpful advice, and to N. Kallio and G. Moroz for performing many of the NRCC tests.

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(2) Ontario Hydro Standard Specification M-332M-85 Oils, Lubricating Steam Turbine, July 1985.

(3) ISO DIS 8068 Specifications for Lubricating Oils for Turbines.

(4) CGSB 3-GP-357M Standard for Lubricating Oil, Steam Turbine, March 1978.

(5) US Military Specification MIL-L-17331G (SH) For Lubrication Oil, Steam Turbine and Gear, and Moderate Service.

APPENDIX

Sludge tests were also performed on the six oils by the Ontario Hydro method. These, however, were not concluded until after the paper was written. The method is similar to ASTM D4310 except for the filter medium. The former specifies a 2.7-μm retention glass microfiber filter while ASTM D4310 specifies 5-μm pore size membrane filter. The following duplicate results were obtained and compared with average D4310 results on the six oils A to F.

Expressed as g/L		*A*	*B*	*C*	*D*	*E*	*F*
Ontario Hydro	1.	0.06	0.02	0.49	0.19	0.03	0.01
	2.	0.05	0.02	0.36	0.17	0.04	0.00
	Avg.	0.055	0.020	0.42	0.18	0.035	0.005
D4310	Avg.	0.056	0.026	0.49	0.21	0.055	0.039

Expressed as mg/300mL							
Ontario Hydro	1.	18.0	6.0	147.0	57.0	9.0	3.0
	2.	15.0	6.0	108.0	51.0	12.0	0.0
	Avg.	16.5	6.0	127.5	54.0	10.5	1.5
D4310	Avg.	16.8	7.7	146.0	63.3	16.6	11.6

As shown, there is a slight bias between results by the two methods; average ASTM D4310 results are higher. This is somewhat unexpected as ASTM D4310 uses a coarser filter. Possibly its structure permits packing and ultimately finer filtration leading to more sludge on the filter and a slower filtration rate.