DEVELOPMENT OF ADVANCED PAPER MACHINE LUBRICANT

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A NEW PAPER MACHINE OIL, WHICH MEETS OR EXCEEDS THE PERFORMANCE OF CURRENT LUBRICANTS, HAS BEEN DEVELOPED. FIELD TRIALS ARE IN PROGRESS.

NEW AND UPGRADED PAPER MACHINES ARE REQUIRING lubricants that are thermally and oxidatively stable and capable of keeping the paper machine parts free of deposits, while simultaneously offering antiwear and extreme pressure (EP) performance characteristics that are normally provided by EP gear oils. A new lubricant was developed and evaluated. It was demonstrated to provide all the desired performance characteristics and to be superior in many respects to conventional paper machine oils and gear oils.

PAPER MACHINE OIL REQUIREMENTS

Paper machine lubricating oils (PMOs) run relatively hot, i.e., hotter than typical hydraulic oil systems, and for economic reasons, paper mills would like to minimize the need for oil changes. The oxidation and thermal stability of a paper machine oil is therefore of utmost importance. With the ever-increasing speeds of existing and new paper machines to enhance production rates, oil-lubricating bearings at the dryer section can exceed 93°C (200°F). This trend is coupled with the paper mills' endeavors to reduce oil loss and thereby make up oil requirements. Stability requirements expected from the paper machine oil are thus continuing to grow *(1)*.

There are even special supercalender applications where the lubricating oil also functions as a heat transfer oil system, and with bulk temperatures exceeding 121°C (250°F), synthetic- based oils are required. This latter application will not be addressed in this article.

Paper machines (PMs) can have several lubrication systems. The wet section (if oil lubricated) and dryer section bearings are relatively lightly loaded and require at most antiwear (AW) protection. The press rolls are typically lubricated by an antiwear lubricant, but some manufacturers of paper machines and roller bearings have imposed extreme pressure (EP) protection requirements to lubricants used in extended nip presses (ENPs), crown control (CC) roll hydraulic systems, and integral gear systems (see **Table I**). These press systems are typically equipped with a separate lubrication system, but dryer roll bearings and dryer gear drives often share a common oil system.

Many mills currently use conventional paper machine oils in press sections where EP protection is required, while other mills use a gear oil in lubricating press sections that require EP. Even though the option exists to use separate oils in the various parts of a paper machine, it is desirable to minimize the number of oil grades, to eliminate excess oil inventory, and to avoid the use of incorrect lubricants.

Paper machine oil would be the obvious lubricant of choice, as it is typically available in bulk quantity at most large mills. Unfortunately, conventional paper machine oils do not provide the EP load-carrying capability needed for CC and ENP systems or loaded gear set applications. On the other hand, conventional EP gear oils do not provide stability that is equivalent to lubricants currently used in paper machines, and these gear oils are not generally suitable to lubricate the dryer sections; these sections are subject to high local temperatures due to their proximity to dryer roll steam joints.

Additionally, paper machine oils, particularly if lubricating the wet and press sections, are typically subjected to substantial water ingress, sometimes in major quantity, for extended time periods. The rust protection and demulsibility properties of a paper machine oil are often stressed beyond that expected for gear oils.

Many mills use fine filtration (6 µm absolute or lower) of circulating system oils to extend bearing life. Today's paper machine oils have to provide good filterability, and the oil formulation components cannot interact with the filtration medium.

In view of all the paper machine lubrication requirements, it is a challenge to formulate an oil that combines the EP performance of a gear oil with the stability of pre-

Commercial Exxon paper machine oil
Competitor 1 paper machine oil A
Competitor 1 paper machine oil B
Competitor 2 paper machine oil
Commercial Exxon EP gear oil
Competitor 1 EP gear oil
Competitor 2 EP gear oil
Competitor 3 EP paper machine oil
New development EP paper machine oil

II. Oils used for comparative testing (ISO 220 viscosity grade)

mium paper machine oil. An advanced new oil, which provides the desired features, was developed and evaluated. Performance testing of the new oil will be discussed in light of paper mill operation requirements, and comparative performance results with commercial paper machine and gear oils will be provided.

COMMERCIAL PAPER MACHINE AND GEAR OILS

Stability and detergency are two lubricant performance characteristics that determine the ability of the paper machine oil to keep the paper machine free of deposits. *Thermal and oxidation stability* relates to the oil's tendency to form, by thermal degradation or oxidation mechanisms, oil-insoluble products that precipitate and deposit on metal surfaces. *Detergency* relates to the oil's ability to solubilize oxidation/degradation products (prevent precipitation) and to gradually remove soft deposits that are in the process of being formed on metal surfaces.

Detergents, which are ash-forming (metallic) additives, are used in essentially all conventional paper machine oils to achieve cleanliness performance. Ashless (non-ash-forming) dispersants are used for the same purpose in premium gear oils, but since they are less polar than detergents, they are less effective in keeping insoluble oil oxidation products from precipitating and forming deposits; they are also not effective in removing already-formed soft

Paper machine section	Beloit	SKF	Valmet
Wet end			
4-Ball wear (D4172) (75°C/1200 rpm/ 40kg/1 h)	None	<1 mm scar diameter	<1 mm scar diameter
Press section			
4-Ball EP (D2783)	-	≥250 kg	≥250 kg
ENP CC rolls with attached gear drive			
Timken OK (D2782)	≥50 lb	-	-
FZG (D5182)	Pass stage 12	-	-
ENP CC rolls w/o attached gear drive	None	-	-
ENP blanket	None	-	-
Dryer section			
4-Ball wear	None	<1 mm scar diameter	<1 mm scar diameter
4-Ball EP	None	≤200 kg*	≤200 kg*

*Unless stability and corrosivity of the oil is demonstrated to be suitable for operation above 80°C (176°F)

I. Paper machine oil AW/EP requirements by various OEMs

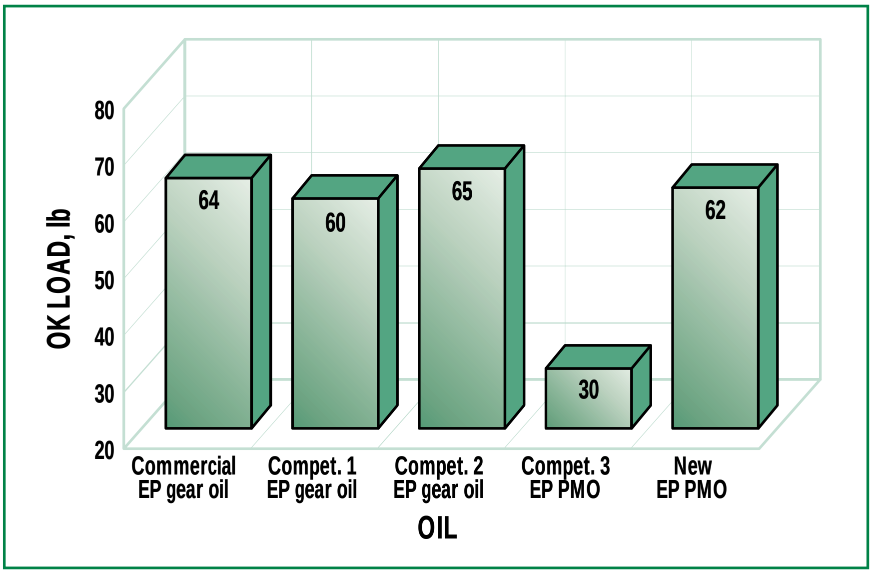
Oil	Timken OK load D2782, lb	4-Ball EP D2783 Weld load, kg	4-Ball EP D2783 Load wear index, kg	FZG D5182 pass stage
Commercial EP gear oil	64[a]	250	49	-
Competitor 1 EP gear oil	60	-	-	-
Competitor 2 EP gear oil	65	-	-	-
Competitor 3 EP PMO	30[b]	200[c]	42[c]	-
New development EP PMO	62[c]	250[c]	48[c]	12

[a]Average of 19 tests. Standard deviation was 5.6 lb. Repeatability was 14.6 lb or 23% of average. (Repeatability of 14.6 lb indicates that two random tests of the same oil, by the same operator, on the same test machine are expected not to differ by more than 14.6 lb, 95% of the time.)

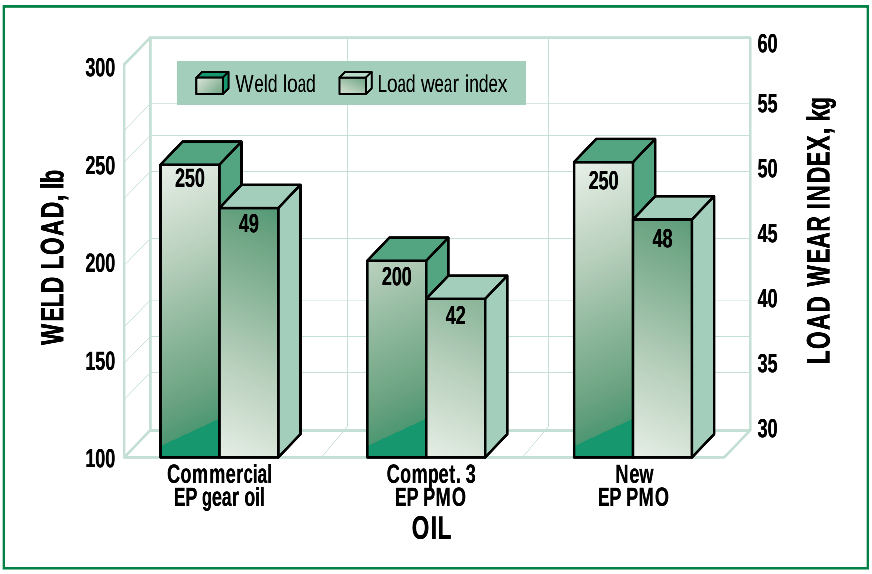
[b]Average of four tests

[c]Average of two tests

III. Extreme pressure performance of EP oils



1. Extreme pressure performance of EP oils–Timken test



2. Extreme pressure performance of EP oils–4-Ball EP test

deposits on metal surfaces. Ashless dispersants are primarily used in engine lubricants as supplementary additives to detergents to keep in solution fuel-derived oxidation products (soot) and oil oxidation products catalyzed by free radicals coming from fuel combustion. Soot and free radicals from the engine combustion chamber contaminate the lubricant due to combustion gas blow-by around the pistons and rings.

Gear systems typically run cooler than paper machine dryer systems. In cases of systems or gear boxes that do run hot, since oil capacity is typically small, conducting periodic oil changes is the normal operating procedure. For this reason, gear oils have not been traditionally formulated to achieve high levels of thermal and oxidation stability or detergency (cleanliness), and they feature ashless dispersants.

Using ashless dispersant additives instead of detergents in paper machine oils can result in degradation of paper machine element cleanliness performance (deposit formation) due to the severe typical operating conditions.

To achieve the best of both worlds, i.e., the stability and detergency of a paper machine oil and the antiwear/extreme pressure protection of a gear oil, our new oil was formulated as a detergent–EP lubricant rather than as a dispersant–EP lubricant (the traditional approach used in gear oils).

OILS USED FOR COMPARATIVE TESTING

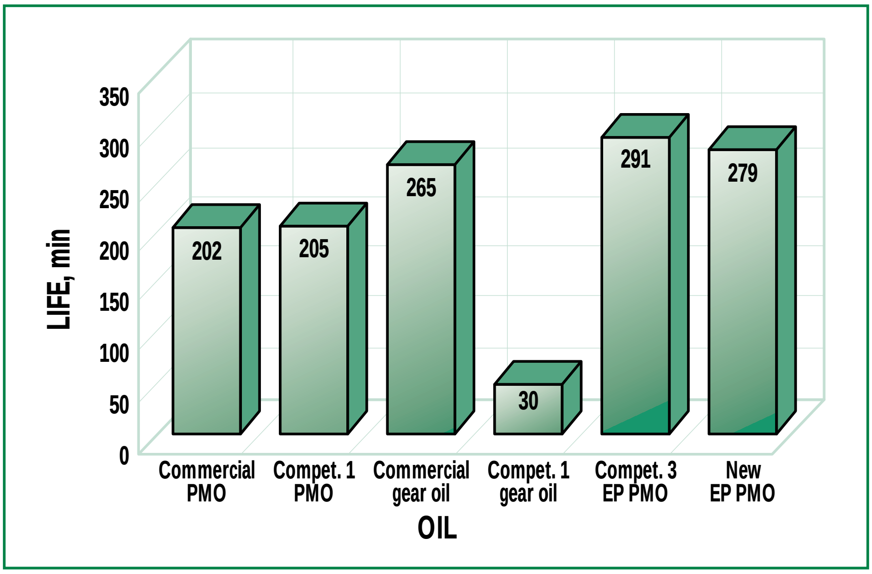
Table II lists the oils used for side-by-side testing with the new EP paper machine oil. Included are commercial paper machine and gear oils.

The new EP paper machine oil samples used in the testing program were blended on a pilot scale in the blending facilities of the research laboratory and on a commercial scale at a northeastern lubricant blending plant. The commercial oil samples were acquired "blind" from the plants, i.e., they were from a random batch and not preselected in any way. The competitive oil samples were acquired in sealed containers (55-gal drums or 5-gal pails) filled by the petroleum company or its contractor, not by a distributor or secondary packager.

Unless indicated otherwise, all testing was carried out at the research laboratory.

Extreme pressure and antiwear performance

A major challenge was to achieve extreme pressure (EP) performance in the presence of detergents that are polar chemicals and compete for access to the ferrous metal surface with antiwear and EP additives. Addition of typical paper machine oil detergent additives to conventional gear oils will often result in the loss of antiwear and EP performance as well as the deterioration in properties such as demulsibility and filterability. Careful additive selection and balancing were required in developing the new EP paper machine oil.



3. Oxidation stability of PM and gear oil–Rotary bomb oxidation test

Oil	Average ball scar diameter,* mm
Commercial paper machine oil	0.26
Commercial EP gear oil	0.28
Competitor 3 EP paper machine oil	0.27
New development EP paper machine oil	0.27
USS 224 spec. max.	0.35

*Average of two tests

IV. Antiwear performance comparison 4-Ball wear test under USS S-205 conditions [20 kg, 54.4°C (130°F), 1800 rpm, 1 h]

Oil	Rotary bomb oxidation test life ASTM D2272, min
Commercial paper machine oil	202
Competitor 1 paper machine oil A	205
Competitor 1 paper machine oil B	144
Competitor 2 paper machine oil	155
Commercial EP gear oil	265
Competitor 1 EP gear oil	50
Competitor 2 EP gear oil	38
Competitor 3 EP paper machine oil	291
New development EP paper machine oil	279[b]

[a]Results shown are averages for duplicate results.
[b]Average for pilot plant and blend plant batches of new EP paper machine oil, each tested in duplicate.

V. Rotary bomb oxidation stability of paper machine and gear oilsa

Table III and **Figs. 1 and 2** show comparative results on oils tested for EP performance. The Timken, the 4-Ball EP, and the 4-Ball wear tests were carried out at the USX Consultants and Engineers Inc. laboratory in Pittsburgh, PA. The FZG test was conducted at Southwest Research Institute in San Antonio, TX.

The Timken test (ASTM D2782) measures EP performance in a Timken tester where a cylindrical steel test cup rotates against a steel block. The load is varied in stages: (a) 1.36-kg (3-lb) stages below 13.62 kg (30 lb) and (b) 2.27-kg (5-lb) stages above 13.62 kg (30 lb). The OK load is the maximum load at which the rotating cup will not rupture the lubricant film on the steel block. The fail load is one stage higher, where scoring on the steel block or seizure occurs.

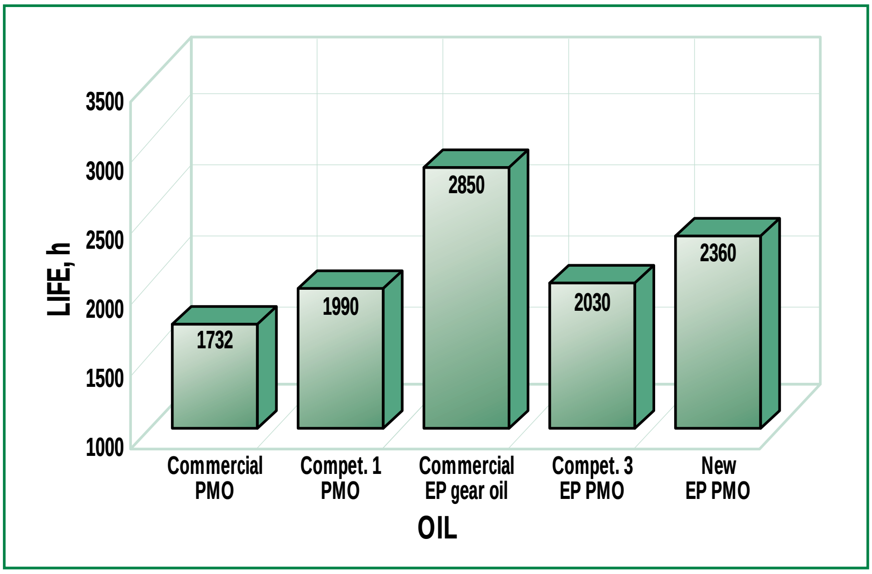
The commercial EP gear oil was used as a reference oil for the Timken test program and was thus the reason for 19 repeat tests. The reference oil was run once in every eighth test or when a new set of test parts were started. Table III shows a test repeatability of 23% in this program, slightly better than the 30% quoted in ASTM D2782.

The commercial and competitive gear oils achieved 27.2–29.5kg (60–65lb) Timken OK load; this is expected from oils claiming compliance with American Gear Manufacturers Association (AGMA) specifications 9005-D94. The new EP paper machine oil gave an average Timken OK load of 28.2 kg (62 lb) in duplicate testing. The competitive EP paper machine oil sample gave an average of 13.62 kg (30 lb) Timken OK load in quadruplicate testing.

In the 4-Ball tester (ASTM D2783), a loaded steel ball is rotated against three steel balls held stationary in the form of a cradle. The test lubricant covers the lower three balls. Testing is carried out at several loads to determine the welding load and the load–wear index (LWI), which is calculated from loads below the weld point, and relates to the ability of the lubricant to minimize wear at the applied loads. The higher the LWI, the higher the wear protection.

The commercial gear oil and the new EP paper machine oil both gave 4-Ball EP weld loads of 250 kg, with LWIs of 49 and 48 kg, respectively. The competitive gear oils were not tested but are expected to give similar results, since they claim compliance with US Steel USS 224 requirements. The competitive EP paper machine oil gave a 200-kg weld load and a 42-kg LWI.

The Forschungstelle fur Zahnrader und Getriebebau (FZG, Research Site for Gears and Transmissions) method measures the scuffing load capacity of oils (ASTM D5182). The gear test machine is run at successively higher load stages until the failure criterion (cumulative



4. Oxidation stability of PM and gear oils–Turbine oil oxidation test

Oil	Turbine oil oxidation test life ASTM D943, hours
Commercial paper machine oil	1732
Competitor 1 paper machine oil A	1990
Commercial EP gear oil	2850
Competitor 3 EP paper machine oil	2030
New development EP paper machine oil	2360

*Results shown are averages for duplicate results.

*VI. Turbine oil oxidation stability of paper machine and gear oils**

scuffing/scoring/adhesive wear in 16 gear teeth) is reached. The highest load stage of the test machine is 12. The new EP paper machine oil passed the maximum 12 stage of the FZG test. The commercial gear oil was not tested but readily passes the 12 stage (AGMA 9005-D94 requires a 12-pass stage). Similarly, competitive gear oils are expected to pass 12 stages as well and were not tested.

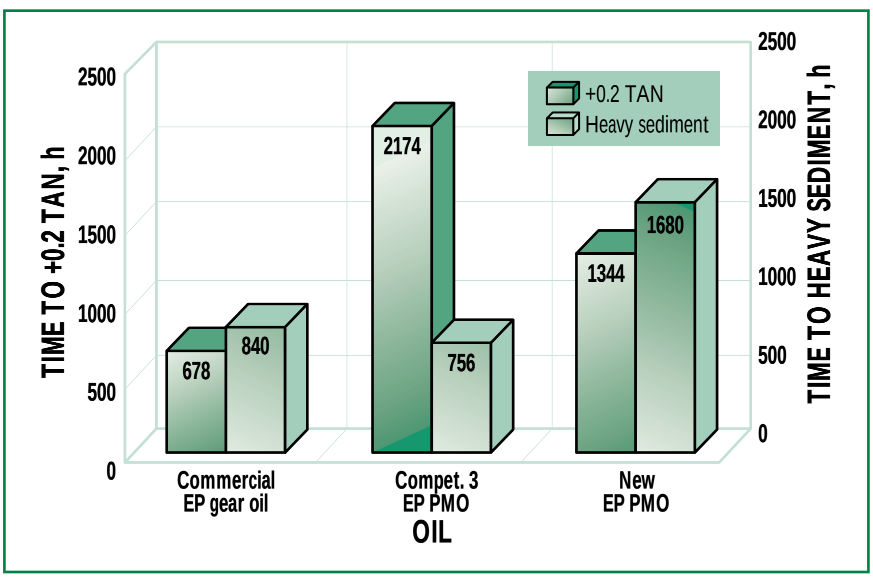
In addition to the wear evaluation included in the 4-Ball EP test (ASTM D2783), the new EP oil was tested for antiwear performance according to the 4-Ball wear test specified by US Steel USS 224 gear oil specifications. The 4-Ball wear test is carried out under the same geometry as the 4-Ball EP test but under lower steel-to-steel contact loads. The wear scars of the three stationary balls are measured at the end of a 1-hour test at 54.4°C (130°F), 20-kg load, and 1800 rpm. Comparative results, shown in **Table IV,** indicate that the antiwear performance of the commercial paper machine oil was retained by the new EP paper machine oil, which gives equivalent performance to gear oils and competitive EP paper machine oil in this test.

The overall EP performance of the advanced EP paper machine oil was comparable to that of conven-

Oil	STAEGER OXIDATION TEST LIFE* AM-S 110.32 Hours to +0.2 acid no.	Hours to moderate sediment	Hours to heavy sediment
Commercial EP gear oil	678	672	840
Competitor 3 EP paper machine oil	2174	756	840
New development EP paper machine oil	1344	1176	1680

*Results shown are averages for duplicate results.

VII. Staeger oxidation stability of EP gear oils



5. Oxidation stability of EP oils. Staeger oxidation test.

tional gear oils designed solely for industrial applications. The product meets EP oil requirements specified by AGMA and the USS 224 gear oil specifications.

Oxidation and thermal stability

The new advanced EP paper machine oil was evaluated for oxidation and thermal stability by a variety of industry and in-house oxidation tests. It is important to conduct a series of tests as it is difficult to precisely mimic the oxidative and thermal stressing of paper machine oils in a single laboratory test. Robust performance across a spectrum of such tests has generally been the best indicator of good field performance.

In the Rotary Bomb Oxidation Test (ASTM D2272), oils are tested in the presence of a copper catalyst and water at high temperature [150°C (302°F)] and high pressure [approximately 1380 kPa (200 psi) oxygen atmosphere]. Oil oxidation life in this test can last several hundred minutes (see **Table V** and **Fig. 3**). This test is not intended to compare different oil formulations, because base stocks and additive types may respond very differently under these accelerated test conditions, and these results may not correlate with oxidation stability under normal equipment operating conditions. However, very low oxidation life would be an indication of an essential absence of potent oxidation inhibitors, as can be observed for some of the competitive EP gear oils.

Oil	USS S-200 OXIDATION TEST (MODIFIEDASTM D2893) Viscosity increase at 98.9°C (210°F), %	Tube condition
Commercial EP gear oil	2.3	Clean
Competitor 1 EP gear oil	4.7	Deposits
Competitor 2 EP gear oil	0.6	Deposits
Competitor 3 EP paper machine oil	1.4	Deposits
New development EP paper machine oil	3.5	Clean

VIII. USS S-200 oxidation stability of EP gear oils

Oil	COPPER Rating by D130	Weight change, mg
Commercial paper machine oil	3b	+0.5
Competitor 1 paper machine oil B	4b	+5.7
Competitor 2 paper machine oil	4b	+5.3
Commercial EP gear oil	4b	–146.3
Competitor 1 EP gear oil	4b	–186.8
Competitor 2 EP gear oil	4b	–91.7
Competitor 3 EP paper machine oil	3a	+1.1
New development EP paper machine oil	3b/4a	+5.0

IX. Copper corrosion by ASTM D130 [20 hours at 162.8°C (325°F)]

The Turbine Oil Oxidation Test (ASTM D943) is often used as a benchmark for the long-term stability performance of industrial circulating oils. In this test, oils are tested in the presence of iron and copper catalysts, in water, and with bubbling oxygen at 95°C (203°F). These conditions are close to bearing temperatures in a paper machine, although rather on the hot side of what is typical for a sump temperature. Oxidation life for the oil in this test is several thousand hours (see **Table VI** and **Fig. 4**). The new EP paper machine oil has retained the high oxidation life that is typical of conventional paper machine oils tested under these conditions.

The end of oxidation life in ASTM D943 is determined by the degrading condition of the oil [in this case, a total acid number (TAN) increase to 2.0 mg KOH/g oil], with no attention to oxidation products that precipitate out of solution. Conventional EP oils tested, although showing high oxidation lives, do not match the paper machine oils in the low levels of deposits formed on the catalyst coil or oxidation tube.

In the Staeger Oxidation Life Test, another long-term oxidation test, the test parameters include oil degradation in terms of (a) acid number increase and (b) oil sediment, the product of oxidation that precipitates out of solution.

Oil	Tin babbit[a] weight change, mg	Lead babbit[b] weight change, mg
Commercial paper machine oil	+0.5	+0.7
Competitor 1 paper machine oil B	+3.7	+1.2
Competitor 2 paper machine oil	+2.2	+1.2
Commercial EP gear oil	+28.4	+1.3
Competitor 1 EP gear oil	+29.3	+0.7
Competitor 2 EP gear oil	+37.2	+4.0
Competitor 3 EP paper machine oil	+15.6	+1.4
New development EP paper machine oil	+2.6	+2.1

[a]SAE B12: 3.5% copper, 7.5% antimony, 89% tin
[b]ASTM B23-7: 0.25% copper, 0.5% arsenic, 15% antimony, 74.25% lead

X. White metal corrosion [ASTM D130 test equipment 20 hours at 162.8°C (325°F)]

Oil	COPPER		STEEL		
	Rating*	Weight change, mg	Rating*	Weight change, mg	Sludge, mg/ 100 mL
Commercial PM oil	2	+0.8	1	+0.1	4.6
Competitor 1 PM oil A	9	-49.2	1	+0.4	25.4
Competitor 1 PM oil B	9	–55.5	1	+0.5	26.4
Competitor 2 PM oil	10	+1.4	1	0	–0.5
Commercial EP gear oil	10	–16.6	1	+0.5	27.9
Competitor 1 EP gear oil	10	+39.9	1	+0.4	33.3
Competitor 2 EP gear oil	10	+16.9	9	+3.3	40.1
Competitor 3 EP PM oil	6	+1.5	2	+1.5	8.6
New EP PM oil	10	+1.9	1	+1.2	–1.2

*Cincinnati Milacron demerit rating scales. Larger values indicate poorer ratings.

XI. Cincinnati Milacron copper corrosion/oil stability test [168 hours at 135°C (275°F)]

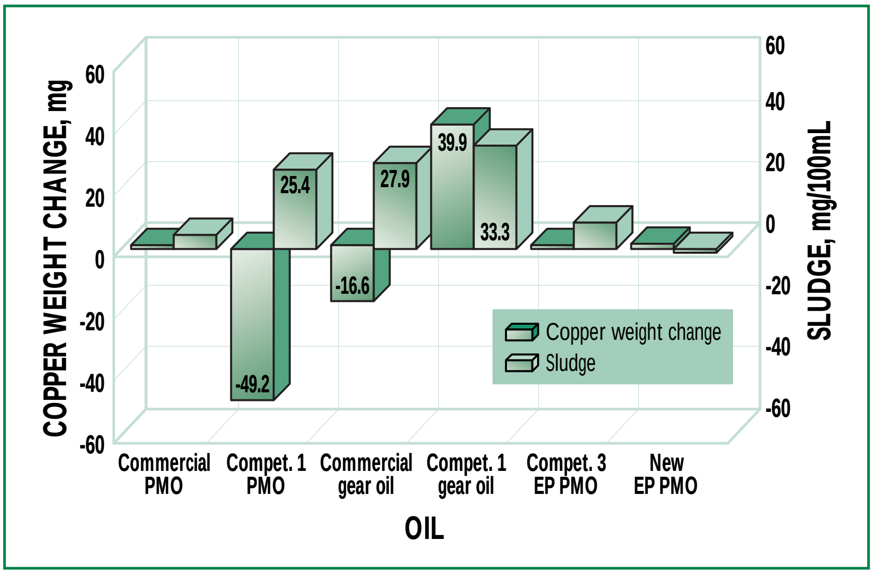
This method was originally developed by Dr. Hans Staeger of the Swiss Brown Boveri Co. as a means of predicting the quality of steam turbine oils after aging. The test is run in a beaker, where the oil is catalyzed by a copper strip at 110°C (230°F). Three end points (lives) are obtained in this test: hours to reach +0.2 acid number increase, hours to reach "moderate" sediment at the bottom of the beaker, and hours to reach "heavy" sediment at the bottom of the beaker. Sediment ratings are carried out by trained raters. Even "heavy sediment," although a small amount in a layman's eyes, can be sufficient in quantity to deposit as harmful sludge in lubricated machinery.

Note in **Table VII** and **Fig. 5** that the new EP paper machine oil is superior to the commercial EP gear oil in acid number control as well as sediment (insoluble oxidation product) control.

The competitive EP paper machine oil evaluated had a very long life to +0.2 acid number increase; however, this was coupled with premature sediment formation. In this example, the oxidation products are precipitating out of the oil rather than remaining in solution and contributing to an increase in acidity. A well-balanced paper machine oil needs to maintain acid buildup and deposit formation. In a paper machine, oil-insoluble oxidation products may deposit in oil return lines and bearing housings, where they may oxidize/degrade further at the higher temperatures of some bearing housings and form hard deposits.

The US Steel 200 Oxidation Test (Modified ASTM D2893) is a standard test run for EP gear oils that are used by the steel industry. This test has also been included in the recent AGMA 9005-D94 specifications. The test is run in a glass tube; it takes 13 days at 121.1°C (250°F) with bubbled air. Thermal stressing in this test is more severe than in previous test methods, but unlike the D943 and Staeger tests, there is no metallic oxidation catalyst in this test. The performance requirement is a maximum of 6% viscosity increase (which relates to the extent of oil oxidation), measured at 98.9°C (210°F) or 100°C (212°F). In addition to this specification, premium gear oils ideally produce an oxidation tube free of deposits, as shown in **Table VIII.** The USS 200 oxidation tests were carried out at the USX Consultants and Engineers Inc. laboratory.

The oxidation stability performance of the advanced EP paper machine oil exceeds the AGMA 9005-D94 and US Steel 224 gear oil performance standards, and its performance is comparable to commercial paper machine and gear oils.



6. Thermal/corrosion stability–Cincinnati Milacron test (1 week at 135°C)

Copper and white metal corrosion

EP additives tend to be very aggressive toward copper and some white metals at high temperature. The new EP paper machine oil was designed to be very passive to copper and babbit metals. This was confirmed with testing run under the standard ASTM D130 protocol, at high temperature and test duration conditions [20 hours at 162.8°C (325°F)], both with copper and two grades of babbit. These tests were conducted using one metal at a time to eliminate electrodeposition from one specimen to the other.

The industry gear oil specifications for copper corrosion is 1b (ASTM D 130 scale) maximum after 34 hours at 100°C (212°F). This is not a severe requirement, because gear systems do not use nonferrous metals if they are to operate at high temperatures. The test that was conducted for 20 hours at 162.8°C (325°F) (reported in **Table IX**) is a much more demanding copper corrosion test than the industry gear oil test. With an EP-additive–containing oil, it is considerably more difficult to achieve results of 3b or 4a (ASTM D130 scale) under these high temperature/duration conditions than it is to achieve 1b after 3 hours at 100°C.

Table X shows that conventional EP gear oils are also aggressive to tin, as demonstrated by the major weight of tin babbit.

The new EP paper machine oil is comparable in copper and white metal corrosion performance to the non-EP conventional competitive paper machine oils, although the new oil performs somewhat poorer than the commercial paper machine oil [which is the most inert (least corrosive) oil in the group].

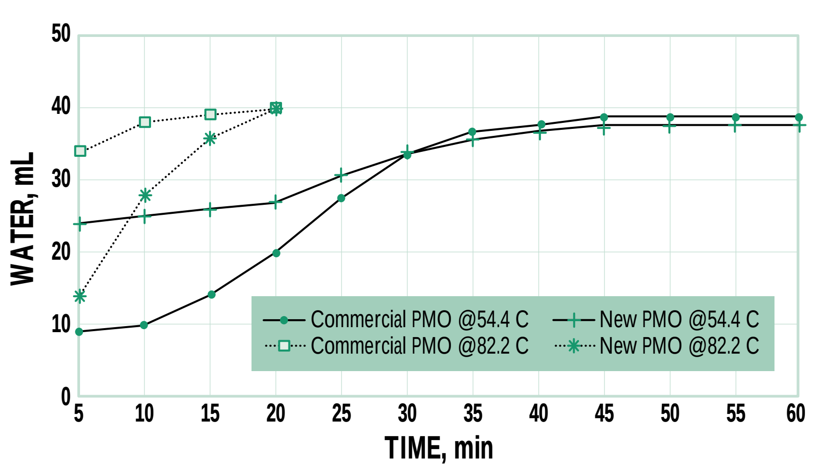
Oil	Panel condition
Commercial paper machine oil	Pass (Clean)
Competitor 1 paper machine oil A	Fail (Brown varnish)
Competitor 1 paper machine oil B	Fail (Dark brown varnish)
Competitor 2 paper machine oil	Fail (Brown varnish)
Commercial EP gear oil	Fail (Black, carbon-like)
Competitor 1 EP gear oil	Fail (Black, carbon-like)
Competitor 2 EP gear oil	Fail (Black, carbon-like)
Competitor 3 EP paper machine oil	Fail (Black, carbon-like)
New development EP paper machine oil	Pass (Light rainbow varnish)

XII. Panel coker detergency (deposit formation) test [24 hours at 276.7°C (530°F)]

Results for other tests of copper corrosion combined with oil stability at high temperature are shown in **Table XI** and **Fig. 6.** The Cincinnati Milacron thermal stability test used for this comparative evaluation [168 hours at 135°C (275°F)] is normally run on antiwear hydraulic oils, while EP gear oils would normally be tested at lower temperatures and duration [24 or 72 hours at 101°C (213.8°F)]. The EP gear oils and paper machine oils from Competitor 1 showed high levels of copper attack and/or high levels of sludge in the oil. The competitive EP paper machine oil and the new EP paper machine oil

Parameter	Commercial PMO	Commercial EP gear oil	New EP PMO
Water separability (D1401)			
At 82.2°C (180°F)			
Oil, mL	37	43	41
Water, mL	40	37	38
Emulsion, mL	3	0	1
Time to 37+ mL H_2O, min	20	15	10
Water separability (D1401)			
At 54.4°C (130°F)			
Time to 30+ mL H_2O, min	30	-	25
Time to 37+ mL H_2O, min	35	-	40
Demulsibility D2711 (EP method)			
At 82.2°C (180°F)			
Water in oil, %	-	1.0	1.5
Free water, mL	-	66.5	80.4
Water from cfg, mL	-	14.0	0.7
Total free water, mL	-	80.5	81.1
Emulsion, mL	-	0	0.03
Dynamic demulsibility 6 hrs at 54.4°C (130°F)			
Top			
Oil, mL	86	-	87
Water, mL	13	-	13
Emulsion, mL	1	-	0
Bottom			
Oil, mL	2	-	0
Water, mL	98	-	100
Emulsion, mL	0	-	0

XIII. Demulsibility performance of paper machine and gear oils



7. ASTM D1401 demulsibility

did well, but of course, these two oils are not matched in EP protection performance. The commercial paper machine oil is again the best performer in the group.

The high copper rod demerit ratings for EP oils in this test reflect the discoloration of copper when exposed to EP additives. Although the rod was discolored by the EP paper machine oil, lack of metal weight loss indicates that no significant metal corrosion has occurred. Oils other than the commercial paper machine oil would not meet the Cincinnati Milacron hydraulic oil copper rod rating specifications; however, these test conditions are much more severe than those typically used to evaluate EP-additive–containing oils.

Detergency

Detergency performance of the oil relates to its ability to keep metal surfaces clean of deposits. The most distinguishing feature of paper machine oils is the provision of good detergency performance.

The panel coker test was used to evaluate detergency. Originally developed by GE as a test to evaluate aviation gas turbine lubricants (MIL-L-7808), the panel coker became Federal Test Method 791b.3462 in 1969. It has been used by many organizations since then in evaluating both engine and industrial lubricants *(2, 3)*.

The test consists of an oil-containing sump on top of which resides a rotating splasher, which splashes oil to the bottom of a heated aluminum panel. The panel is normally several hundred degrees hotter than the sump. Stability of the oil and the cleaning action of the detergent (cleaning while washing off the surface) jointly achieve a "clean panel" at the conclusion of the test.

In dryer roller bearings, oil-wetted surface temperatures can approach or exceed 150°C (302°F), particularly in cases of insulated or slightly misaligned bearings. In a short-duration test, it is necessary to accelerate the deposit-formation tendency of the oil by increased temperatures.

Since EP gear oils are inherently less stable than paper machine oils and do not contain detergents, they are normally tested for 4 hours at 246.1°C (475°F). Premium conventional gear oils provide deposit-free panels under these test conditions.

The commercial paper machine oil was tested under much more demanding conditions [24 hours at 276.7°C (530°F)] and resulted in a clean panel. The higher temperature is intended to accelerate the formation of carbonaceous deposits that may form in bearings operating with very high surface temperatures. Conventional EP oils develop very heavy deposits under these conditions.

The target was to match or approach the performance of the commercial paper machine oil with the new EP paper machine oil, and **Table XII** shows that this goal has been accomplished. Competitive conventional paper machine oils, the competitive EP paper machine oil, and commercial gear oils form heavy deposits at the 24-hour, 276.7°C (530°F) panel temperature conditions.

Demulsibility

While conventional gear oils are formulated to give good water-shedding (demulsibility) performance, the environmental challenges faced by the lubricant in the paper machine place a very high importance on this aspect of the new EP paper machine oil's performance. The new EP paper machine oil was formulated to match the water-shedding performance requirements of both conventional paper machine and gear oils. Two ASTM tests and an in-house test were used to evaluate the performance of the oil and to ensure robustness of performance.

ASTM D1401 is carried out in a 100-mL graduated cylinder. In this test, 40 mL of oil and 40 mL of distilled water are stirred together while the graduated cylinder is in a controlled- temperature bath. The milliliters of oil, water, and emulsion are then recorded every 5 min. For the ISO 220 viscosity grade, the normal test temperatures are 82.2°C (180°F) or 82°C (179.6°F).

Although the industry standard temperature for paper machine and gear oil demulsibility is 82°C or 82.2°C, the ASTM D1401 test was also run at a lower

Oil	WATER SEPARABILITY AT 82.2°C (180°F) ASTM D1401			
	Oil, mL	Water, mL	Emulsion, mL	Time to 37+ mL H_2O, min
Commercial paper machine oil	37	40	3	20
Competitor 1 paper machine oil A	40	39	1	15
Competitor 1 paper machine oil B	40	40	0	5
Competitor 2 paper machine oil	40	40	0	10
Commercial EP gear oil	43	37	0	15
Competitor 1 EP gear oil	40	40	0	20
Competitor 2 EP gear oil	40	40	0	20
Competitor 3 EP paper machine oil	41	39	0	15
New development EP paper machine oil	41	38	1	10

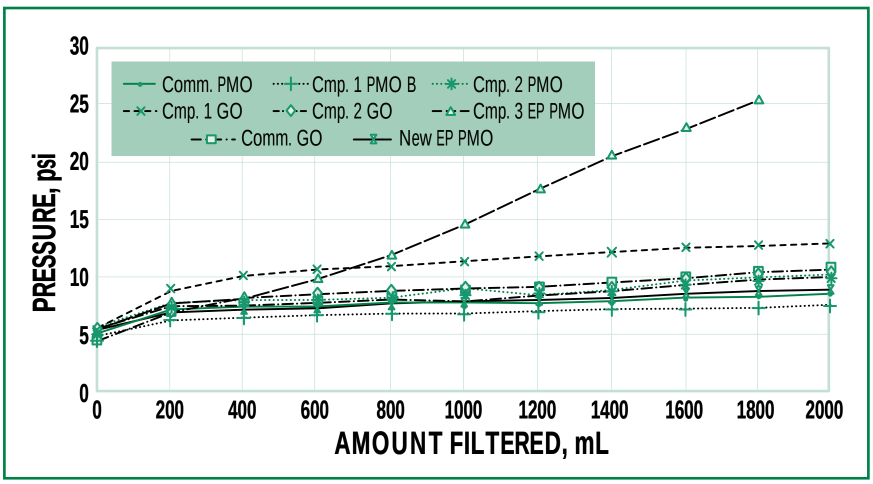
XIV. Demulsibility performance of paper machine and gear oils

Oil	PALL, DRY FILTERABILITY		
	Initial psi	Final psi	mL filtered
Commercial paper machine oil	5.0	9.4	2000
Competitor 1 paper machine oil A	5.4	10.0	2000
Competitor 1 paper machine oil B	4.4	7.6	2000
Competitor 2 paper machine oil	4.4	10.0	2000
Commercial EP gear oil	4.4	10.8	2000
Competitor 1 EP gear oil	5.0	13.0	2000
Competitor 2 EP gear oil	5.4	10.2	2000
Competitor 3 EP paper machine oil	5.0	25.0	1800
New development EP paper machine oil	5.2	9.0	2000

XV. Dry Pall filterability performance of paper machine and gear oils

Oil	PALL, WET FILTERABILITY		
	Initial psi	Final psi	mL filtered
Commercial paper machine oil	8.6	14.0	2000
Competitor 1 paper machine oil A	7.6	12.6	2000
Competitor 1 paper machine oil B	7.8	13.6	2000
Competitor 2 paper machine oil	6.8	14.6	2000
Commercial EP gear oil	8.0	15.8	2000
Competitor 1 EP gear oil	8.4	15.8	2000
Competitor 2 EP gear oil	5.8	14.4	2000
Competitor 3 EP paper machine oil	5.8	11.2	2000
New development EP paper machine oil	6.4	13.0	2000

XVI. Wet Pall filterability performance of paper machine and gear oils



8. Dry Pall filterability

temperature, 54.4°C (130°F); this is closer to the operating temperature of many paper machine oil systems. The lower temperature makes the test more severe, as the specific gravity difference between oil and water decreases with temperature. The test conditions are very severe, in terms of both energy of agitation and water-to-oil ratio, compared to conditions experienced in a paper machine oil sump. Therefore, the performance target is the separation of the major portions of the water phase (30 mL or more) in 30–45 min instead of the more complete separation required for the higher-temperature test.

EP gear oils are tested by ASTM D2711 (EP oil modification) per AGMA 9005-D94 and USS 224. In this test, 360 mL of oil and 90 mL of distilled water are stirred together at 82.2°C (180°F) in a special graduated separatory funnel. After a 5-hour settling period, the percentage of water in oil and the volumes of water and emulsion separating from the oil are measured. The AGMA/USS 224 requirement of recovering at least 80 mL of the initial 90 mL water as free water, which separates out or is removed by centrifuging the oil phase, was met by the new EP paper machine oil. The new EP paper machine oil shed the 80 mL of water required by industry gear oil specifications during the settling period without requiring additional water extraction by centrifuging, as shown in **Table XIII.**

Finally, demulsibility characteristics were evaluated in a Dynamic Demulsibility Test, which measures the ability of water and oil to separate under actual circulating conditions. This test was designed in the 1950s to simulate water contamination and residence times in kraft paper machine circulation systems *(4)*. For many years, the test was also run at the US Steel laboratories for the evaluation of circulating oils in a steel mill. It has also been used to evaluate demulsibility of steam turbine oils. The test can be carried out at any temperature; 54.4°C (130°F) was selected as a severe condition (but representative of paper machine situations) for purposes of the development program.

Table XIII shows that the new EP paper machine oil provides performance that is similar to the conventional paper machine and EP gear oils, which have many years of successful field experience in paper mill applications. **Figure 7** compares the water-shedding rate of the commercial oil and the new EP paper machine oil at 54.4°C (130°F) and at 82.2°C (180°F).

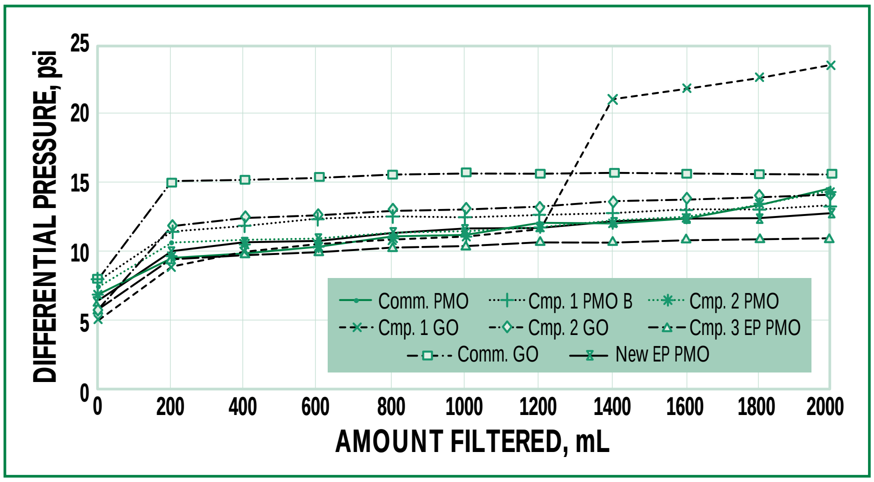
Table XIV compares commercial and competitive oils in the conventional ASTM D1401 specification test temperature condition of 82.2°C (180°F). All oils are essentially equivalent; the majority of oils shed 37+ mL or more in 10–20 min.

Filterability

The North American paper industry uses the Pall filtration test to evaluate filtration performance. This is primarily a test of incompatibility between paper machine oil, water, and nylon filter medium ($\beta_3 = 200$), although an oil with a high particle count would also fail this test.

The Pall test involves filtering 2000 mL of oil through the filter medium at 62.8°C (145°F) without exceeding a differential pressure of 172.2 kPa (25 psi) across the filter.

The oil is run as is (dry test). The oil is also conditioned with 1% water, aged at 70°C (158°F) overnight, and subsequently soaked for 1 day before the filtration test (wet test). **Tables XV and XVI** and **Figs. 8 and 9** show comparative test results.



9. Wet Pall filterability

Conventional EP gear oils would be expected to more easily pass the Pall filterability test due to the lack of polar detergent additive components that may interact with the filtration medium, and this was observed in the test results. Detergent-containing paper machine oils require more careful formulation.

The new EP paper machine oil and the balance of the tested oils, with one exception, met both Pall test requirements.

Rust

The conventional rust test method, ASTM D665, involves evaluating a steel rod immersed in oil at 60°C (140°F) for 30 min and then stirred in a beaker with 300 mL oil and 30 mL water for 24 hours at 60°C (140°F). The water can be distilled water (Procedure A) or synthetic sea water (Procedure B). At the end of the test, any rust spot is considered a failure. **Table XVII** shows that all tested paper machine oils and gear oils pass ASTM D665B.

Commercial and new development paper machine oils were also evaluated for rust in the Humidity Cabinet Test (ASTM D1748). This measures the rust protection capability of the oil film at 48.9°C (120°F) and high humidity conditions. Sandblasted steel panels are dipped into oil, allowed to drain, and suspended in the humidity cabinet. Table XVII shows that the new EP paper machine oil matches the performance of the conventional paper machine oil and is superior to the competitive EP paper machine oil. These tests were run at Petro-Lubricants Test Labs in Wharton, NJ.

Compliance with AGMA 9005-D94

Table XVIII shows that the new EP paper machine oil meets both AGMA and USS 224 gear oil requirements and is suitable for use in gearbox applications in the paper mill. The ability of this oil to meet both gear oil and paper machine oil requirements makes it an excellent choice where a single oil is needed for gear and bearing lubrication.

Oil	ASTM D665B Synthetic sea water	ASTM D1748 Humidity cabinet life*, hours
Commercial paper machine oil	Pass	3000+
Competitor 1 paper machine oil A	Pass	3000+
Competitor 1 paper machine oil B	Pass	-
Competitor 2 paper machine oil	Pass	-
Commercial EP gear oil	Pass	3000+
Competitor 1 EP gear oil	Pass	-
Competitor 2 EP gear oil	Pass	-
Competitor 3 EP paper machine oil	Pass	85
New development EP paper machine oil	Pass	3000+

*Sandblasted panel run in triplicate. Both sides are rated. Life shown is average of six ratings.

XVII. Rust performance of paper machine and gear oils

CONCLUSIONS

The new EP paper machine oil has demonstrated superior performance in laboratory testing. It has matched the stability performance characteristics of the conventional paper machine and gear oils, and it is superior in stability to the EP oils evaluated. At the same time, the new EP paper machine oil is providing the antiwear and extreme pressure protection performance of commercial EP gear oils. Excellent field performance of this new lubricant has been demonstrated in more than a dozen paper machines, in both gear drive and bearing lubrication systems. TJ

Parameter	New EP paper machine oil	Commercial EP gear oil (typical)	AGMA specs.	USS specs.
Oxidation stability (ASTM D2893) (312 hours at 121°C)				
Viscosity increase at 100°C, %	3.5	2.3	6.0 max.	6.0 max.
Timken (ASTM D2782)				
OK load, lb	60–65	60–70	60 min.	60 min.
4-Ball EP (ASTM D2783)				
Load wear index, kg	48	49	-	45 min.
Weld point, kg	250	250	-	250 min.
FZG (A/8.3/90) (ASTM D5182)				
Pass load stage	12	12	12 min.	11 min.
4-Ball wear (USS S-205)				
Avg. scar diameter, mm	0.28	0.27	-	0.35 max.
Rust (ASTM D665)				
D665B, synthetic sea water	Pass	Pass	Pass	Pass
Foam (ASTM D892)				
All three sequences, max.	<30/0	Trace/0	75/10	75/10
Copper corrosion (ASTM D130)				
3 hours at 100°C	lb	1	1b max.	1b max.
Demulsibility (ASTM D2711) (EP procedure)				
Water in oil, %	1.5	0.8	2 max.	2 max.
Total free water, mL	81.1	85	80 min.	80 min.
Emulsion, mL	0.03	Nil	1 max.	1 max.

XVIII. Compliance with AGMA 9005-D94 and USS 224 gear oil performance requirements

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