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WHITE PAPER

From: **Austin Kozman, Ph.D., P.E.**
Date: **September 9, 2009**
Subject: **Proofer Oil Testing Version 2.0**

There are many oils currently on the market that are designed for performance at the moderate temperature, high relative humidity, slightly acidic, and other aspects of the atmosphere in a conveyorized proofer. Some lubricant vendors even offer additive packages specifically tailored for the extreme pressure applications of our conveyorized proofer chain and its ball bearings. Generally, each specific lubricant vendor claims superior performance and has test data to support their claim. The goal of the current testing project is to independently determine which oils will work the best in our conveyorized proofers.

Selected Lubricants and Testing:

We selected the oils for the initial testing based on what our customers are currently using (with various degrees of success) as well as other lubricants that appeared suited for the application based on the vendors' sales literature. For the conveyorized proofer application, the most critical performance characteristics of the lubricant are:

- Evaporation/volatilization – allows longer intervals between re-lubrication
- Thermal oxidative stability – desire minimal residue, deposits, or sludge
- Anti-wear performance / load capacity – obtain longer life from the bearings and pins
- Water Separation – demulsibility
- Corrosion / rust prevention

Ideally the oil would be H1 rated by the FDA (per regulation 21 CFR 178.3570 for lubricants with incidental contact with food: these products may be used as a lubricant, release agent, or anti-rust film on equipment and machine parts where the lubricated part is exposed to edible products), but some customers accept an H2 rated oil (lubricants with no contact: these products may be used as a lubricant, release agent, or anti-rust film on equipment where there is no possibility of the lubricant or lubricated part contacting edible products) because their oven uses an H2 oil and they hope to achieve better performance. Table 1 below shows the list of the 15 oils tested, their base chemistry, and food grade rating.

Table 1. List of Tested Oils

Oil	Chemistry	Rating
JAX Proofer Chain Oil	Mineral	H1
Kluber Structovis FHD		H2
Fuchs Geralyn Chain Oil		H1
Anderol RAX 050059		H2
PetroCanada Purity FG 46		H1
Lubrication Engineers 1603		H2
Fuchs Powergear 100+		H2
Petrochem PR-500	Ester	H2
Petrochem PR-1000		H2
Keystone Nevastane SL220	PAO	H1
Petrochem PR-150		H1
Petrochem PR-220		H1
Kem-A-Trix XHT-750		H1
Nye 368A		H1
Krytox FG-50	PFPE	H1

A wide majority of our customers are using mineral oil based lubricants with proprietary anti-corrosion, anti-wear, and extreme pressure additives. Some customers are utilizing a synthetic polyaphaolefin (PAO, a synthesized petroleum oil). Some customers are utilizing synthetic ester based lubricants. The cost of these oils generally increases from mineral to PAO to ester. Prior to this testing, the Stewart Systems Approved Lubricant List included the following lubricants: JAX Proofer Chain Oil (mineral) and Petrochem PR-500 (ester). Note that the Nye oil tested was the base oil for their 368A grease and can be purchased under Experimental Oil LB30325.

Another type of lubricant that has been experimented with recently in bakeries as an oven lubricant is Perfluoropolyether (PFPE). PFPE based oils appear to offer several advantages over synthetic ester oils for the oven application, but for the proofer their main advantage is their insolubility in water (no water washout, which in previous oil samples taken from customers' proofers is the largest contaminant in ppm, and can break-down the oil). The largest drawback to the PFPE oils is their significantly higher costs.

Evaporation / Volatilization Performance:

The operating conditions (almost continuous) of the proofer warrant re-lubrication at regular intervals. Note that at our standard proofing temperatures, 100-120ºF, even the synthetic oils will still evaporate some. The time between re-lubrication intervals is directly proportional to the evaporation and volatility of the lubricant. The re-lubrication interval is dependent on the proofer (length, speed, temperature, etc.) and it is desirable to stay out of the boundary lubrication phase (i.e. when motor amperage begins to increase due to the increased frictional resistance in the ball bearings). Some customers have reported lubrication intervals as long as 30 days with Petrochem's PR-500. Note that for "proper" lubrication, only the inner portion of the races and the ball surfaces need to be coated. This does not require a large amount of lubricant as the interior of the bearing is small and filling the cavity with more than approximately 40% of oil will cause churning losses and will be detrimental. Over lubrication also produces increased oil build up and deposits in the track (also refereed to as "sludge" in the track) that can increase motor amperage (load) and cause significant oil dripping that can contaminate product if there is a track leak and must be periodically removed with the rubber track scrapper. The evaporation and volatilization characteristics of chain lubricants are critical to maintaining a liquid lubricating film at the elevated temperatures. Minimizing evaporation and volatilization provides improved metal adhesion, longer lubrication intervals, reduced lubricant consumption, and less objectionable odors. The better the adhesion or "wetting" performance of the lubricant, the better the migration of the lubricant to the pivot points of the chain to ensure that proper lubrication occurs in the hard to reach locations of the bearings and chain. A lubricant with a low level of evaporation or volatility has an increased "dwell time"; therefore, the time available for the lubricant to migrate to critical friction points of the chain increases. If the chain and bearing components are not properly wetted (either boundary lubrication or none), then their life will be significantly reduced.

There is no ASTM test for lubricant evaporation/volatilization so we utilized our own test method. Equal volumes of the lubricants were placed in 5.0 in. (127.0 mm) x 2.0 in (50.8 mm) rectangular aluminum pans with a height of 1.0 in. (25.4 mm). The samples were stored at 120ºF (48.9ºC) for a period of time (168 hours or 1 week) and were weighed periodically to record the amount of evaporation based on their mass loss. The cups were also studied to see the amount of residue that volatized on them (see Thermal Oxidative Stability Performance below). If enough oil was available, the evaporation test was repeated three times (and the results averaged). Table 2 shows the results of the evaporation testing as a function of percentage mass loss. The uncertainty and repeatability in the evaporation test is approximately 0.8%. Note that the only oils that experienced any mass loss were JAX Proofer Chain Oil, Fuchs Geralyn Chain Oil, and Petro Canada Purity FG 46.

Table 2. Evaporation/Volatilization Performance

Oil	8 Hours	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours
JAX Proofer Chain Oil	0.00%	2.70%	2.70%	2.70%	2.70%	2.70%	2.70%	2.70%
Kluber Structovis FHD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Fuchs Geralyn Chain Oil	7.69%	11.54%	15.38%	15.38%	15.38%	15.38%	15.38%	15.38%
Anderol RAX 050059	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
PetroCanada Purity FG 46	0.00%	0.00%	2.70%	2.70%	2.70%	2.70%	2.70%	2.70%
Lubrication Engineers 1603	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Fuchs Powergear 100+	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Petrochem PR-500	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Petrochem PR-1000	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Keystone Nevastane SL220	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Petrochem PR-150	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Petrochem PR-220	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Kem-A-Trix XHT-750	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Nye 368A	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Krytox FG-50	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Thermal Oxidative Stability Performance:

The thermal and oxidative stability of a lubricant is critical to the protection and performance of the chain in our conveyorized oven application. However, the moderate temperatures of the proofer application minimized any deposits or residue. Every time the pans were weighed for mass loss (for the evaporation/volatility testing described above), we also visually inspected the pans for the amount of residue left behind (visual inspection was based on the total area and thickness of residue coverage on the interior of the pan after the oil was drained, analyzed using photography software to calculate). Note that aluminum from the pans (aluminum oxide as well) can catalyze oxidation reactions for ester fluids, but using the same type of pan for all the tests should minimize the bias from the pans. Table 3 shows the oxidation results. None of the oils displayed any residue or build-up throughout the testing. The only noticeable issue was with Lubrication Engineers 1603 that had a green tint at the perimeter of the pan after 8 hours (surface oxidation) on one of the trials.

Table 3. Thermal Oxidative Stability Performance (Residue Deposition)

Oil	8 Hours	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours	168 Hours
JAX Proofer Chain Oil	None	None	None	None	None	None	None	None
Kluber Structovis FHD	None	None	None	None	None	None	None	None
Fuchs Geralyn Chain Oil	None	None	None	None	None	None	None	None
Anderol RAX 050059	None	None	None	None	None	None	None	None
PetroCanada Purity FG 46	None	None	None	None	None	None	None	None
Lubrication Engineers 1603	None	None	None	None	None	None	None	None
Fuchs Powergear 100+	None	None	None	None	None	None	None	None
Petrochem PR-500	None	None	None	None	None	None	None	None
Petrochem PR-1000	None	None	None	None	None	None	None	None
Keystone Nevastane SL220	None	None	None	None	None	None	None	None
Petrochem PR-150	None	None	None	None	None	None	None	None
Petrochem PR-220	None	None	None	None	None	None	None	None
Kem-A-Trix XHT-750	None	None	None	None	None	None	None	None
Nye 368A	None	None	None	None	None	None	None	None
Krytox FG-50	None	None	None	None	None	None	None	None

Anti-Wear and Extreme Pressure Performance:

Our chain has two types of motion and therefore two separate wear mechanisms. The first wear mechanism is the rotation of the link pins in the clevis castings. This motion is similar to a plain bearing. The ASTM D-4172 Four Ball Wear Test produces a measure of the lubricant's anti-wear capabilities in this type of loading. For this test, three 0.50 in. (12.7 mm) diameter steel balls are locked in a chamber containing the test fluid, which is then forced against a fourth ball that is rotating at the desired test speed and load. After 60 minutes of exposure the wear scar on each of the three stationary balls is measured by a specialized stereoscope and then averaged together. The test was conducted at 600 rpm, 88.2 lb (40 kg), and 167°F (75°C). The more resistant the lubricant is to wear, the smaller the wear scar diameter will be. The uncertainty and repeatability of the 4-ball wear test is approximately 0.13 mm.

The second wear mechanism is for the ball bearings, which have a very high contact stress level or "extreme pressure" type loading. Rather than conducting an ASTM test for bearing wear we used our internal bearing test fixture for the oils. For this test, four of our standard vertical chain bearings were dipped in the lubricant and then installed in a fixture that applied loads similar to the application loads (50 lb., 22.7 kg) at an elevated speed (727 rpm). These tests were conducted at room temperature and the time until failure was measured (bearing failure defined as seizure, 0.075 in. wear, or any cracking or fatigue damage on the bearing races or balls) for each bearing. The final average wear life of the four bearings is shown in Table 4 on the following page. The uncertainty and repeatability of the bearing wear test is approximately 22.5 hours.

Table 4. Anti-Wear Performance

Oil	Average Bearing Life (Hours)	4-Ball Wear Scar (mm)
Nye 368A	723.9	0.43
Kluber Structovis FHD	712.4	0.43
Lubrication Engineers 1603	694.5	0.28
Kem-A-Trix XHT-750	660.9	0.43
Anderol RAX 050059	565.1	0.30
Keystone Nevastane SL220	505.4	0.29
Fuchs Powergear 100+	416.5	0.33
Petrochem PR-220	412.5	0.36
JAX Proofer Chain Oil	349.3	0.36
Petrochem PR-500	340.8	0.33
PetroCanada Purity FG 46	315.0	0.46
Petrochem PR-150	309.0	0.33
Krytox FG-50	304.3	0.53
Fuchs Geralyn Chain Oil	205.8	0.42
Petrochem PR-1000	138.3	0.30

Water Separation:

The high relative humidity of the proofer environment can cause water to condense in the track and/or on the bearing/chain surfaces. Therefore, the oil can mix with this water and we desire oil that does not separate or "wash-out" when this water is added (i.e. 100% emulsion). To test the oil performance we used a modified ASTM D1401. A 40 mL sample of the oil is added to 40 mL solution containing 2% whole milk, 5% ethanol, 40% vinegar, 1% flour, and 52% distilled water. The solution is then heated to a steady state temperature of 100°F (38°C) and mixed at 1500 rpm for 5 minutes. The test is run for 30 minutes (or can be run for 60 minutes for oils with a viscosity more than 90 cSt, can also increase test temperature to 180°F or 82°C) or until there is less than 3 mL of emulsion remaining. Table 5 below shows the water separation test results. We then left the samples in the heated chamber for 336 hours (no agitation). As you can see from table 5, even the oils that failed the initial demulsibility test (Krytox FG-50, Petrochem PR-1000, Petrochem PR-150, and Anderol RAX 050061), would settle out fairly quickly. We desire the oil to separate from the solution (emulsion resistant) so it can adequately lubricate the bearing and chain surfaces (and ideally keep free water and other containments off these surfaces). To further test the lubricants' abilities to reduce wear after exposure to a simulated proofer environment, we took the above separated oils and performed another 4-ball wear test similar to the one performed above in Table 4.

Table 5. Water Separation; Initial and After 336 Hours: Amount of Oil (mL) / Amount of Solution (mL) / Amount of Emulsion (mL) Time to Reach Full Solution Separation (min.); and 4-Ball Wear (mm) Data

Lubrication Engineers 1603	40 / 38 / 2 (10)	40 / 39 / 1	0.37
Petrochem PR-500	37 / 40 / 3 (10)	40 / 39 / 1	0.38
PetroCanada Purity FG 46	40 / 39 / 1 (5)	40 / 39 / 1	0.47
Nye 368A	40 / 37 / 3 (50)	40 / 37 / 3	0.54
Petrochem PR-220	40 / 38 / 2 (10)	40 / 39 / 1	0.56
Krytox FG-50	26 / 0 / 54	39 / 38 / 3	0.56
Petrochem PR-1000	10 / 35 / 35	39 / 38 / 3	0.66
Kem-A-Trix XHT-750	40 / 38 / 2 (20)	40 / 39 / 1	0.79
Keystone Nevastane SL220	39 / 38 / 3 (20)	39 / 40 / 1	0.35
Anderol RAX 050059	39 / 37 / 4 (60)	39 / 40 / 1	0.40
Fuchs Powergear 100+	40 / 37 / 3 (20)	40 / 39 / 1	0.44
Anderol RAX 050060	40 / 37 / 3 (5)	40 / 39 / 1	0.46
JAX Proofer Chain Oil	39 / 40 / 1 (15)	39 / 40 / 1	0.52
Petrochem PR-150	27 / 39 / 14	39 / 38 / 3	0.56
Kluber Structovis FHD	40 / 37 / 3 (30)	40 / 38 / 2	0.57
Fuchs Geralyn Chain Oil	39 / 39 / 2 (30)	40 / 39 / 1	0.59
Anderol RAX 050061	18 / 39 / 23	38 / 39 / 3	0.61

Corrosion / Rust Prevention:

In the proofer environment a lubricant can be exposed to water washout (depending on the sanitation method), high humidity as mentioned previously, as well as some mildly acidic and caustic substances (depending on the product) such as ethanol vapor, lactic and acetic acid vapor, calcium, salt, etc. Therefore, it is important that the lubricant contain some corrosion inhibiting additives. We used several tests to analyze the corrosion resistance of the oils. We used a modified ASTM D1743 (which is designed for bearing greases). The test bearings are oiled and immersed in a modified test solution containing: whole milk (2% by volume), ethanol (5%), vinegar (40%), and water (53%) for 48 hours at 125°F (52°C). At the end of the test the bearings are cleaned and examined visually for amount of corrosion (photography software used to analyze images and measure area and severity of corrosion). Figures 1 to 3 show the end results for a few of the different oils.

Figure 1. New bearing, before modified ASTM D1743 testing

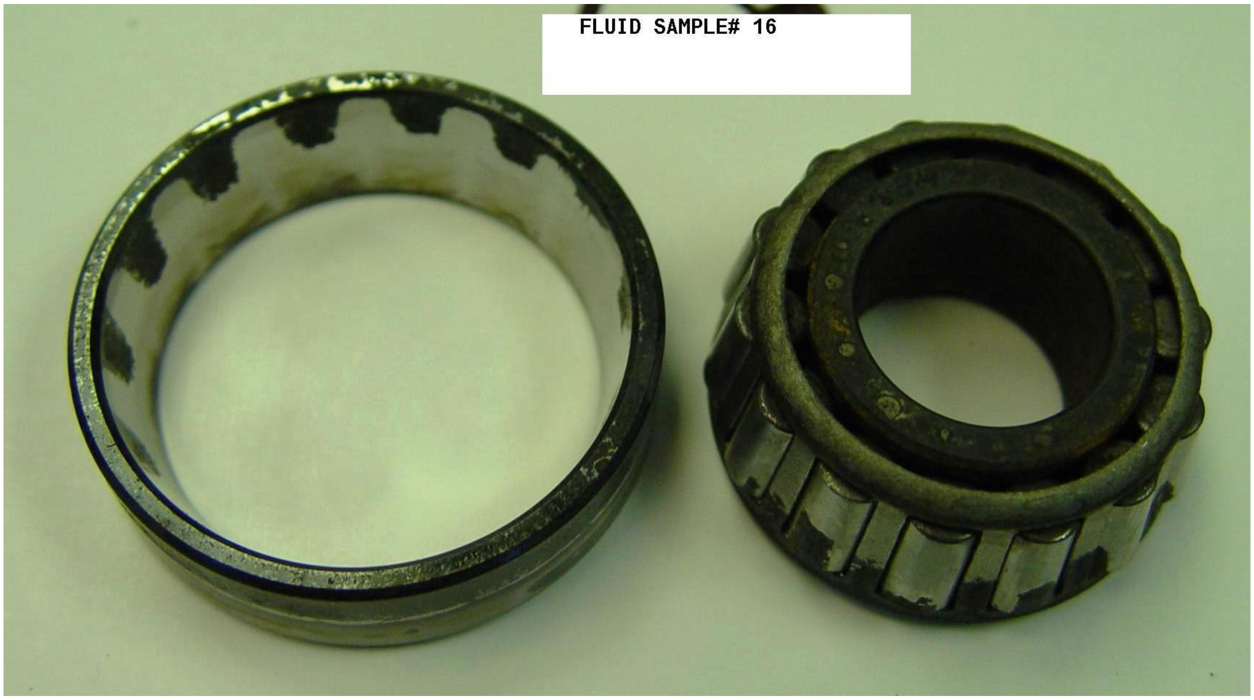

Figure 2. Bearing after test with Lubrication Engineers 1603

Figure 3. Bearing after test with Krytox FG-50

A modified ASTM D-665 test was conducted to provide a measure of a lubricant's resistance to corrosion. The test immerses a steel cylinder (material is 1018 cold finished) in a continuously agitated solution consisting of 300 mL of the lubricant and 30 mL of water (either distilled or salt water) at 140ºF (60ºC) for 24 hours. Note that we modified this test by using 1018 carbon steel washers. The passing criterion is no visible rust when the cylinder is viewed under normal light with no magnification. All the oils tested passed this test.

The third corrosion test was a modified ASTM B-117 humidity cabinet test. In this test three cold rolled 1010 steel panels are cleaned with solvent and then coated with the oils to be evaluated. After coating, the panels are allowed to dry overnight in room temperature. The following morning the panels are placed in a humidity cabinet that is controlled at 100°F and 100% RH. The panels are checked each day for the first onset of corrosion. Figure 4 through 6 show the results of some panels after the completion of the 500-hour test. Jax Proofer Chain Oil, Anderol RAX 050059, PetroCanada Purity FG 46, and Lubrication Engineers 1603 all showed no corrosion after 500 hours; Krytox FG-50 did not show any corrosion until after 216 hours, all the other lubricants showed the first sign of corrosion after 196 hours. Some got progressively worse quickly after the onset of corrosion, while others stayed fairly stable over the remainder of the test.

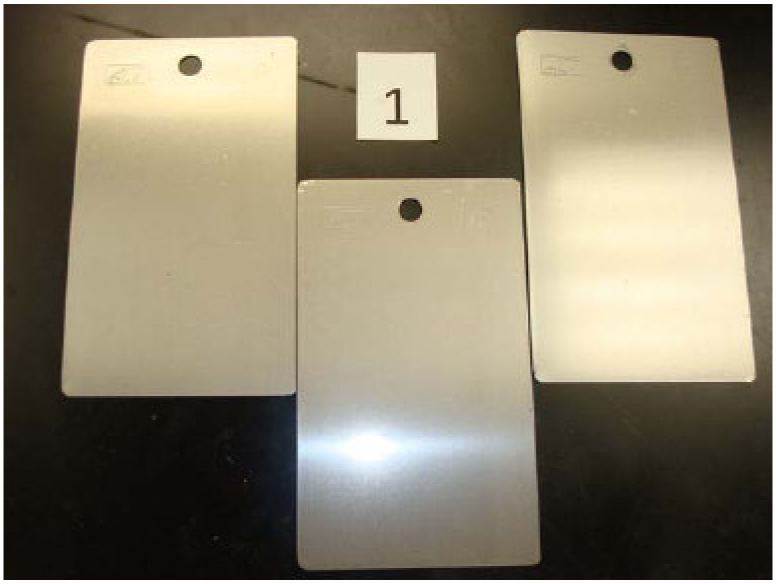

Figure 4. Plates coated with Jax Proofer Chain oil after 500 hour in humidity cabinet

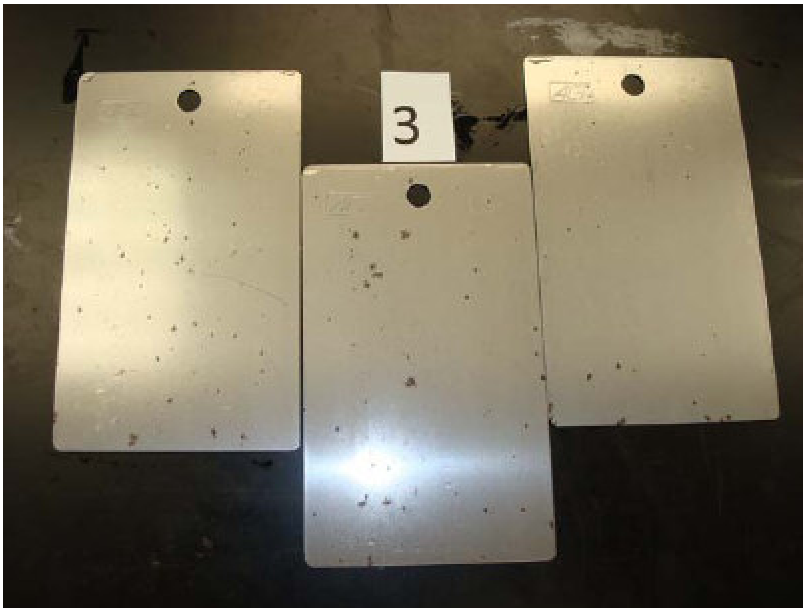

Figure 5. Plates coated with Fuchs Geralyn Chain oil after 500 hour in humidity cabinet

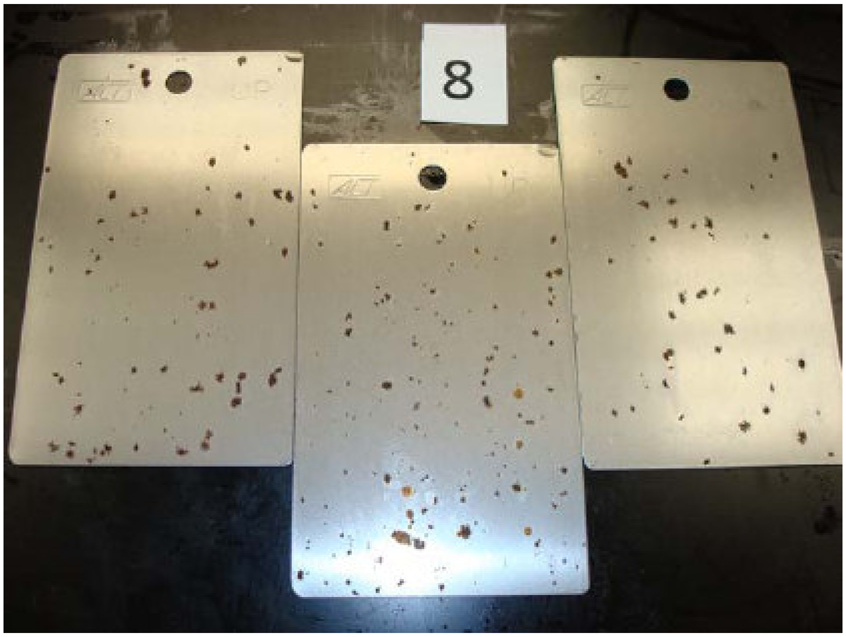

Figure 6. Plates coated with Nye 368A oil after 500 hour in humidity cabinet

Table 6. Corrosion Test Results

	Oil	**D1743 Bearing Corrosion (% Area Rusted)**	**Humidity Cabinet at 100% RH and 100ºF (hr)**
Mineral	JAX Proofer Chain Oil	50%	None
	Kluber Structovis FHD	53%	192 (3%)
	Fuchs Geralyn Chain Oil	55%	192 (7%)
	Anderol RAX 050059	36%	None
	PetroCanada Purity FG 46	63%	None
	Lubrication Engineers 1603	35%	None
	Fuchs Powergear 100+	60%	192 (17%)
Ester	Petrochem PR-500	61%	192 (2%)
	Petrochem PR-1000	57%	192 (2%)
PAO	Keystone Nevastane SL220	40%	192 (6%)
	Petrochem PR-150	57%	192 (6%)
	Petrochem PR-220	71%	192 (3%)
	Kem-A-Trix XHT-750	58%	192 (5%)
	Nye 368A	38%	192 (23%)
PFPE	Krytox FG-50	87%	216 (3%)

Conclusions:

The decision matrix below in Table 7 shows the individual category and total score for each lubricant. We desire a score greater than 64.0 like our two current approved lubricants. We did not add the Petrochem PR-220 because Petrochem already has an approved product (although I am confident that this product would work well, especially if an H1 product is needed). Therefore, the Approved Stewart Proofer Lubricants are as follows:

- Jax Proofer Chain Oil (Stewart part number 29P-00-033)
- Petrochem PR-500 (94P-00-447)

- Kem-A-trix XHT-750 (94P-00-937)
- Fuchs Powergear 100+ (94P-00-938)
- Nye 368A (94P-00-939)
- Anderol RAX 050059 (94P-00-940)
- Kluber Structovis FHD (94P-00-941)
- Lubrication Engineers 1603 (94P-00-942)
- Keystone Nevastane SL220 (94P-00-949)

Table 7. Decision Matrix of Proofer Oils

Company	Oxidation	Evaporation	Bearing Wear	4-Ball Wear	Separation	D1743	D665	B117	4-Ball II	Score
Weight	0.05	0.05	0.3	0.1	0.15	0.05	0.05	0.1	0.15	-
Lubrication Engineers 1603	99.0	100.0	98.9	72.0	93.8	65.0	100.0	100.0	63.0	**88.6**
Kluber Structovis FHD	100.0	100.0	100.0	57.0	97.5	47.0	100.0	94.0	43.0	**83.5**
Anderol RAX 050059	100.0	100.0	73.0	70.0	98.8	64.0	100.0	100.0	60.0	**80.9**
Nye 368A	100.0	100.0	100.0	57.0	96.3	62.0	100.0	54.0	46.0	**80.5**
Kem-A-Trix XHT-750	100.0	100.0	92.2	57.0	98.8	42.0	100.0	90.0	21.0	**77.4**
Keystone Nevastane SL220	100.0	100.0	61.1	71.0	98.8	60.0	100.0	88.0	65.0	**76.8**
Fuchs Powergear 100+	100.0	100.0	43.3	67.0	98.8	40.0	100.0	66.0	56.0	**66.5**
Petrochem PR-220	100.0	100.0	42.5	64.0	98.8	29.0	100.0	94.0	44.0	**66.4**
Petrochem PR-500	100.0	100.0	28.2	67.0	98.8	39.0	100.0	96.0	62.0	**65.8**
JAX Proofer Chain Oil	100.0	85.0	29.9	64.0	98.8	50.0	100.0	100.0	48.0	**64.1**
Petrochem PR-150	100.0	100.0	21.8	67.0	96.3	43.0	100.0	88.0	44.0	**60.2**
Krytox FG-50	100.0	100.0	20.9	47.0	96.3	13.0	100.0	94.0	44.0	**57.0**
Petrochem PR-1000	100.0	100.0	0.0	70.0	96.3	43.0	100.0	96.0	34.0	**53.3**
Fuchs Geralyn Chain Oil	100.0	50.0	1.2	58.0	98.8	45.0	100.0	86.0	41.0	**50.5**
PetroCanada Purity FG 46	100.0	90.0	23.0	54.0	0.0	37.0	100.0	100.0	53.0	**46.6**