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Improved Sludge Dispersion And Retention of Vital Properties By New Generation Ashless Antiwear Hydraulic Oil

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ABSTRACT

The hydraulic fluids form one of the most important components of highly sophisticated hydraulic equipment designs. The hydraulic fluids are required to transmit power, provide a viscous seal, maintain pressure, be a heat transfer medium, and to lubricate critical pumps and efficiently operate numerically controlled valves etc. In order to provide satisfactory and smooth lubrication of high-tech hydraulic equipments, hydraulic oils should possess excellent thermal / oxidation stability with sludge dispersing tendency and retention of original physico-chemical properties such as demulsibility, air release value, filterability and tribological performance even after extended use in actual operating hydraulic machines.

In order to assess the sludge dispersing tendency and retention of original physico-chemical and tribological properties, a new generation antiwear (AW) hydraulic fluid based on ashless additive system has been evaluated and compared for demulsibility, air release value (ARV), Denison filterability and wear scar dia (WSD) properties as per standard test procedures, with conventional antiwear hydraulic oil, after collecting aged oil samples in ASTM D-943 oxidation test for 1000 hrs, in the authors' laboratory. The new ashless AW hydraulic oil after 1000hrs of aging in the oxidation test was found to possess improved sludge dispersing tendency and better retention of original properties with respect to demulsibility, air release value, Denison filterability and wear scar dia in comparison to conventional AW hydraulic oil based on the use of Zn containing additives.

KEY WORDS: Antiwear Hydraulic oil, Demulsibility, Air Release Value, Denison Filterability, PDSC

INTRODUCTION

There is increasing international trend to use ashless technology in the industrial world. The move towards ashless technology has created many new challenges for the lubricant formulators. In addition to identifying new non-metal containing chemistry that could provide the similar or better level of performance compared to the old technology. It is also essential that the chosen ashless additive system should be compatible with calcium and zinc containing fluids. This is a concern for the users/customers who realizes that both ash and ash-less fluids would get mixed within the hydraulic system during conversion from one fluid to the other.

In the recent past, it has been seen that the use of non-conventional base oils is becoming common in the industrial sector market. The OEMs and users expect problem free operation of hydraulic machines working under severe operations (Table – 1).

REQUIREMENTS OF MODERN ANTIWEAR HYDRAULIC OILS

The hydraulic fluids have to work under severe operating requirements. The important requirements of antiwear hydraulic fluids are proper viscosity, non-compressibility, superior thermal/oxidation stability, superior demulsibility, resistance to air entrainment, hydrolytic stability, anti-rust, low foaming tendencies, good metal compatibility, superior filterability, and adequate antiwear performance. The chosen additive system should not have any adverse effects on the performance including demulsibility, air release value, filterability, hydrolytic stability, thermal / oxidation stability and pump test according to the international specification requirements of AW hydraulic oils (Table 2).

Amongst the hydraulic oil specifications, the most dominant are the following;

- Denison HF-O
- Cincinnati Milacron P-68, P-69 & P-70
- DIN 51524 Part II
- US Steel 127 & US steel 136
- Vickers I-128-S & M-2950-S

SIGNIFICANCE OF RETENTION OF VITAL PROPERTIES OF ANTIWEAR HYDRAULIC OILS

The important properties of antiwear hydraulic oil are demulsibility, air release value, hydrolytic stability, filterability, thermal / oxidation stability and tribological properties including wear in pump tests. It is evident that the retention of original physico-chemical properties such as demulsibility, air release value, filterability and tribological properties becomes more important for smooth operation of hydraulic machines during extended use in the field.

During actual operation in field, moisture may enter in the hydraulic system through contamination or condensation; therefore fluid must quickly separate out the water. The presence of water can result in rusting and corrosion of metal components, formation of fluid emulsion, and poor lubrication. The particulate contamination can have adverse effects on the system. The metal containing hydraulic fluid could result in poor filtration in presence of moisture. It is well known that in the presence of moisture, zinc dialkyl dithiophosphate and metal sulphonates may degrade and may block the micronic filter pores and could lead for inefficient operation of hydraulic system. The antiwear hydraulic fluids based on ashless additive system could provide problem free operation avoiding the blockage of micronic filter pores due to lower degradation of chosen additive system for hydraulic oils.

EXPERIMENTAL

In the present study, candidate oil 1 (ISO VG 32) was prepared with commercially available Zn containing additive system and candidate oil 2 (ISO VG 32) with ashless additives in new quality base oil.

The fresh samples of both the candidate oils were evaluated for the properties as per international standards of antiwear hydraulic oils. These included demulsibility, air release value, hydrolytic stability, filterability and wear scar dia tests as per standard procedures i.e. ASTM D 1401, ASTM D 3427, ASTM D 2619, Denison filterability TP 02100 & ASTM D 4172 respectively.

In order to further simulate the field conditions in the laboratory and to observe the aged oil behavior of candidate oils with respect to sludge dispersing tendency and retention of original properties, standard ASTM D 943 oxidation test for 1000 hours was run on both the candidate oils. Aged oils and water content collected after completion of 1000 hours of D 943 test, was separated-out and was analyzed for metal contents (copper & iron) by ICAP technique. Both the aged candidate oils (1 & 2) collected after 1000 hours of D 943 test, were filtered through 5-micron Millipore membrane and sludge / deposits obtained on the membrane was determined. The filtered aged oils were evaluated for demulsibility, air release value, Denison filterability and wear scar dia (table – 3) to assess the retention of vital properties of AW hydraulic oils. Further to understand the behavior of candidate oils with respect to thermal / oxidation stability characteristics, onset induction time (OIT) of aged oil and fresh oil was done by PDSC technique as per ASTM D 6186 test method.

The details of performance test procedures are provided below;

Demulsibility Test
The ASTM D-1401 test method [2] measures the demulsibility characteristics of industrial oils. Demulsibility is ability of oil to separate out from water. This test measures the how rapidly and completely an oil/water emulsion separate after mixing equal volumes of the oil and water for 5 minutes interval as per test conditions.

Air Release Value (ARV) Test
This test method measures the time for entrained air content to fall to the relatively low value of 0.2 % volume under a standardized test conditions and hence permits the comparison of the ability of oils to separate entrained air under a specified test conditions where separation time is measured and is reported time in minutes as ARV at the specified test temperature [3].

Hydrolytic Stability Test
This test is designed to measure the hydrolytic stability of hydraulic oils. The hydrolytically unstable oils form acidic and insoluble components that can cause system malfunctions due to rust, corrosion and valve sticking. This test is being done as per ASTM D 2619 [4] and accordingly 75 grams of test sample, 25 grams of distilled water, and pre-weighed copper strip are sealed in a beverage bottle. The bottle is rotated end to end at 5 rpm for 48 hours in an oven maintained at 93 ^{0}C. Then the liquid layer is separated, and acidity of water layer & weight loss of copper strip are determined.

DENISON Filtration Test
The Denison filtration test measures the ability of oil to pass through a 1.2 u filter membrane with / without water under the specified test conditions as per Denison TP 012100 [5]. Place a 1.2 u membrane filter on the glass frit of the filtering apparatus, pour a 100 ml of test sample into the filter funnel and apply & maintain 65 cm of mercury to the filtering apparatus. Measure the time required to filter 75 ml of test sample. Discontinue the test if it exceeds more than 600 seconds. Transfer 100 ml of test sample in glass bottle and add 2ml of distilled water and shake the mixture vigorously for 5 minutes. Transfer the sample to the filter funnel holding a fresh membrane and measure the time required to filter 75 ml of the fluid as with the fresh oils.

ASTM D 943 Oxidation Stability Test
This test is being done to evaluate the oxidation stability of industrial oils such as turbine, hydraulic & circulating oils in the presence of water, and copper & iron metal

catalysts at an elevated temperature [6]. The oil test sample is contacted with oxygen in the presence of water and an iron-copper catalysts at 95^{0}C. The international standard of antiwear hydraulic fluid (DIN 51524 Part 2) specifies D 943 oxidation test for 1000 hrs, to report the build-up of total acid number.

Four Ball Wear Test
The ASTM D 4172 test procedure is used for evaluation of the antiwear properties of industrial oils. The oil is tested in a four ball system, where a rotating ball slides over three stationary balls [7]. Three ½ inch diameter steel balls are clamped together and covered with the test oil. The oil is heated @ 75C and then a forth ball (top ball) is pressed downward with the force of 15 Kg into the cavity formed by the three clamped, stationary balls. This arrangement forms three-point contact. The top ball is then rotated at 1200 rpm for 60 minutes. The average scar diameter (mm) of the three stationary balls and load used in the test are reported.

Pressure Differential Scanning Calorimetry (PDSC)
Pressure differential scanning calorimetry (PDSC) is a technique to study the onset induction time (OIT) versus normalized heat flow at the specified temperature for the test oil as per ASTM D 6186 standard procedure. The test oil is heated in pans as per standard procedure, computer plots the normalized heat flow (Watt per gram) against time (in minutes). The time at which the lowest point of dip comes is considered as the onset induction time (OIT) of the test oil at the specified onset oxidation temperature [8].

RESULTS & DISCUSSION

The general physico-chemical properties of the selected candidate oils are provided in the table – 4. Both the candidate oils (1 & 2) are meeting the international standard specification including Denison HF O requirements.

The copper metal dissolution in the aged oil sample (candidate 1) was significantly higher i.e. 370 ppm to candidate 2 with nil value. The copper content in the water layer of both the candidates was nil. The iron content in the oil and water layer was nil in both (Figure 1). The deposits / sludge collected on the Millipore membrane after filtration of aged candidate oil 1 was 37% higher compared to candidate 2 (Figure 2).

Aged candidate oil 2 sample showed improved performance with respect to demulsibility and air release value properties over aged candidate oil 1 (Figure 3). The filterability index (FI) of aged candidate 1 & aged candidate 2 is 1.36 and 1.21 respectively. Aged candidate 2 possesses 11.1 % improvement in filterability index (FI) over aged candidate 1 (Figure 4). The tribological performance was found comparable for aged candidates (1 & 2) as seen in wear scar dia as per ASTM D 4172.

The onset induction time data for fresh and aged candidate oils indicates that candidate 2 possesses 55.7% higher remaining useful life over candidate 1, as seen in PDSC (Figure 5).

It can be concluded from the present study that candidate oil 2 prepared with new generation ashless additive system possesses better retention of vital properties with respect to demulsibility, air release value and Denison filterability, in comparison to candidate oil 1, as seen after evaluating aged candidate oil samples in D 943 oxidation test. It is evident from the present study that higher amount of copper dissolution in the aged oil (candidate 1) acts as a catalyst and is responsible for enhancing the aging process in D 943 oxidation test and hence leading to generation of higher amount of sludge / deposits and this may be plausible cause for deleterious performance of candidate 1.

Problem free operation during actual field service is expected with the use of new antiwear hydraulic fluid (candidate oil 2) prepared with new generation ashless additive system in new quality base oils.

CONCLUSIONS

- Both the candidate oils (1 & 2) are meeting international specification requirements of AW Hydraulic oils
- Candidate 2 provided better sludge dispersion in comparison to Candidate 1
- Candidate 2 showed comparatively better retention of original properties such as demulsibility, air release value & filterability, over Candidate 1, as seen after evaluation of aged candidate oils in ASTM D 943 oxidation test
- Aged candidate 2 possesses 55.7 % higher remaining useful life over aged candidate 1 as seen in PDSC as per ASTM D 6186 method
- Problem free operation during actual field service is expected with the use of new generation antiwear hydraulic oil (candidate 2)

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7. Standard Test Method For Wear Preventive Characteristics of Lubricating Fluids (Four Ball Method) ASTM D 4172, Annual Book of ASTM Standards
8. Standard Test Method For Oxidation Induction Time of Lubricating Oils By Pressure Differential Scanning Calorimetry (PDSC) as per ASTM D 6186, Annual Book of ASTM Standards

Table – 1 : Performance Requirements of AntiWear Hydraulic Oils

Market Needs		Required Lubricant Performance
Original Equipment Manufacturers (OEMs)	• Smaller / Compact Machine Size • High-tech Efficient Equipment / System • Longer Life & Problem Free Operation	• Excellent thermal / oxidation stability with adequate AW property • No sludge / deposit forming tendency and free from abnormal functioning • Excellent performance of oil during extended use
Customers / Users	• Smooth Operation • Higher performance of machine as well as Oil • Less Maintenance	• Good demulsibility, antirust and other basic features • Excellent compatibility of lubricant with metals / metallurgy of machine • Outstanding filterability • Longer drain interval of oil

Table – 2 : Vital Properties of Antiwear Hydraulic Oils

No.	Properties	Method	Cincinnati Milacron (P 68)	Denison HF-O	DIN 51524 Part II
1.	**Demulsibility** @ 54C, time in minutes, 40-37-3, Max	D 1401	30	30	30
2.	**Air Release Value,** @ 50C , time in minutes, Max		5	--	5
3.	**Filterability**	TP-02100			--
i.	Filterability without water, seconds, Max		--	600	--
ii.	Filterability with 2% water		--	Don't exceed twice the time with 2% water	--
4.	**Ageing Properties** (Max increase in neutralization no after 1000 hrs), mg KOH / gm	D 943	--	--	2.0

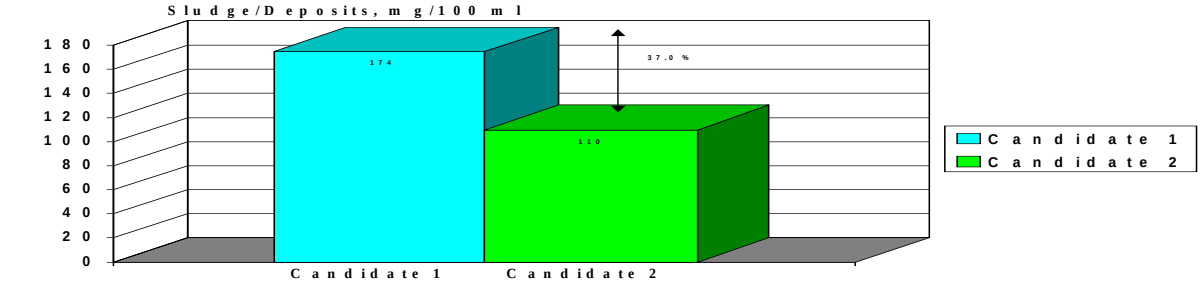
Table – 3 : Test Conditions of ASTM D 943 Oxidation Test & Evaluation Criteria of Aged Candidate Oils

No.	Test Conditions	Test Parameters	Evaluation Criteria
1.	Test Sample, ml	300	- Deposits / Sludge generated after 1000 hrs - Demulsibility, ARV, Filterability Index of aged oils - Metals present in the aged oils & water layer - Tribological performance of aged oils - Onset oxidation time by PDSC
2.	Distilled water, ml	60	
3.	Cu & steel wire (Catalyst)	3 meter of each wire	
4.	Oxygen flow rate	3 $\pm$ 0.1 Liter per hour	
5.	Test Temperature, C	95 $\pm$ 0.2	

Table – 4 : Typical physico-chemical & tribological data of Candidate oils 1 & 2

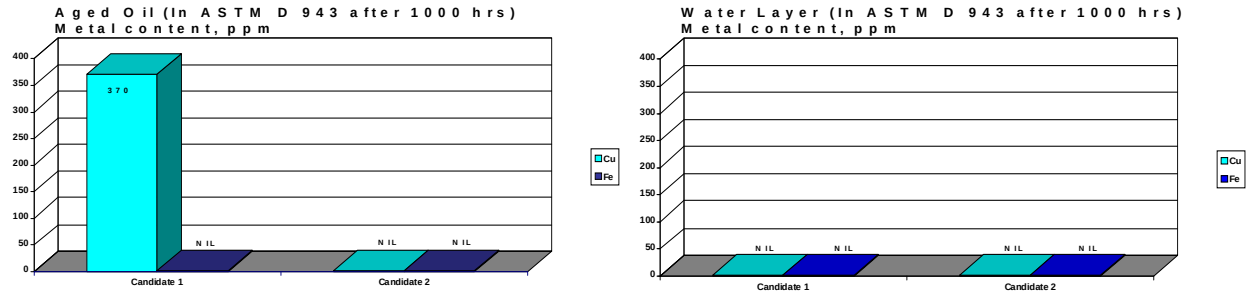
No.	Properties	Method	Candidate oil 1	Candidate oil 2
1.	Appearance	Visual	Clear	Clear
2.	Colour	D 1500	< 1.0	< 1.0
3.	K.Vis @ 40C, cSt	D 445	30.5	30.6
4.	K.Vis @ 100C, cSt	D 445	5.37	5.38
5.	Viscosity Index	D 2270	110	110
6.	TAN, mg KOH/gm	D 974	0.50	0.26
7.	Cu strip corrosion @ 100C for 3 hrs	D 130	1	1
8.	Flash point, COC, C	D 92	232	231
9.	Pour point, C	D 97	(-) 21	(-) 21
10.	Rust test, B	D 665	Pass	Pass
11.	Wear Scar Dia, mm	D 4172	0.35	0.35

Figure 1 : Sludge / Deposits Forming Tendency of Candidate Oils In ASTM D 943 Oxidation Test



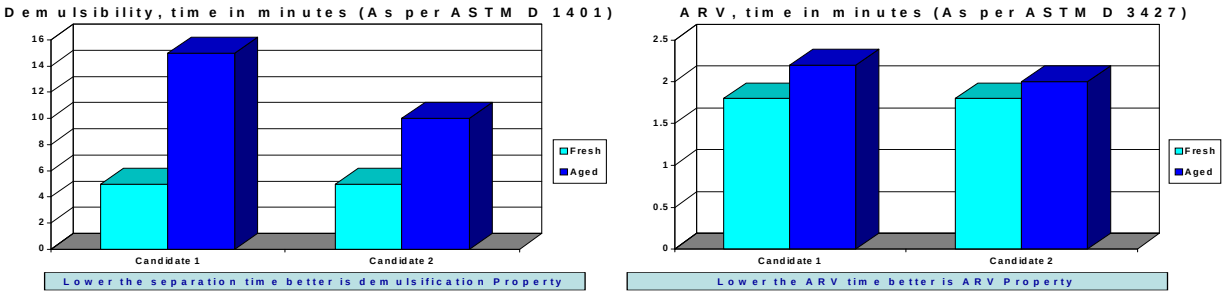
Candidate 2 possess 37 % lower amount of sludge / deposits over Candidate 1

Figure 2 : Metal Dissolution in Aged Oils & Water layer of the Candidates



Aged Candidate 1 contained higher amount of Copper Content In ASTM D 943 Oxidation Test

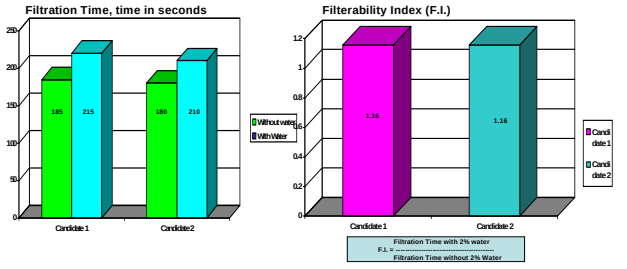
Figure 3 : Evaluation Of Candidate Oils (Fresh Vs. Aged) In Demulsibility & Air Release Value Properties



Aged Candidate oil 2 showed improved performance In Demulsibility & Air Release Value Property

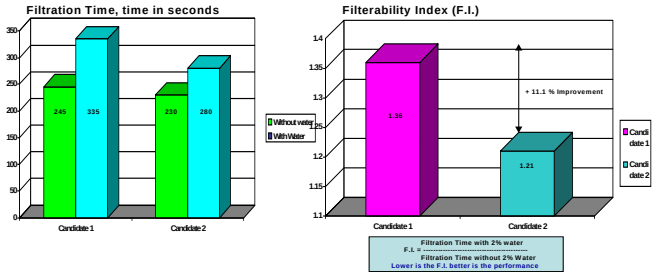
Figure 4 : Evaluation Of Candidate Oils (Fresh & Aged) in Filterability Property (Denison TP 02100)

Evaluation Of Candidate Oils (Fresh) in Filterability Property (Denison TP 02100)



Candidate 1 & Candidate 2 in Fresh Condition Possess Similar Filterability Index

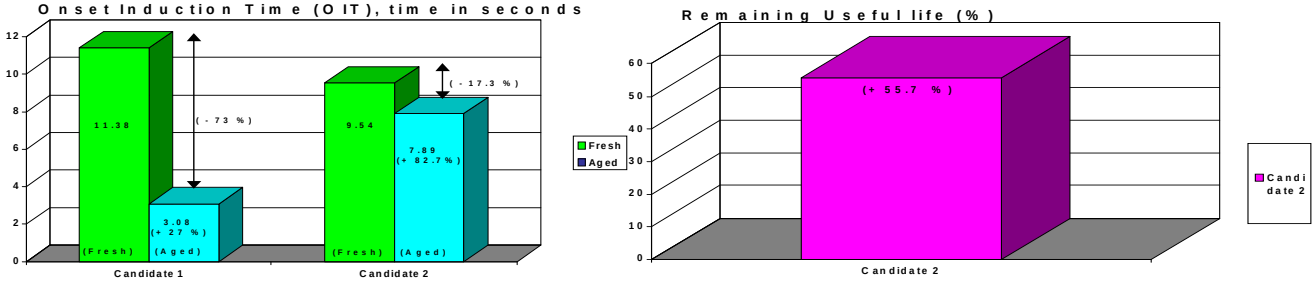
Evaluation Of Aged Candidate Oils in Filterability Property After ASTM D 943 Test



Aged Candidate oil 1 Possess 11.1 % Improved Filterability Index Property

Figure 5 : Evaluation Of Fresh & Aged Candidate Oils in PDSC as per ASTM D 6186 Test

Method : ASTM D 6186, Temperature @ 210C, Thermal Curve : Heat Flow Vs Time
Onset Induction Time (OIT) – Time in minutes



Aged Candidate oil 2 Possess 55.7 % Higher Remaining Useful Life as seen In PDSC over Candidate 1