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Date: February 23, 2004

To: Users of Bosch/Rexroth Axial Piston Pumps and Motors

From: The Dow Chemical Company, UCON™ Fluids & Lubricants

Subject: Use of UCON™ TRIDENT™ AW Hydraulic Fluids with Rexroth Pumps

The Dow Chemical Company's UCON™ TRIDENT™ AW Hydraulic Fluids (Viscosity Grades 32, 46, and 68) meet the Rexroth pump fluid requirements according to performance standards published on Mannesmann Rexroth Data Sheet RA 90 223 for Axial Piston Units for use with HF Fluids. The Axial Piston pumps listed in RA 90 223 do not require a reduction of the permissible drive pressure ratings or the pump drive speed when these UCON fluids are used as the power fluids in a hydraulic circuit.

Further, it was found that the UCON™ TRIDENT™ AW Hydraulic Fluids (32, 46, 68) meet the requirements for environmentally acceptable HEPG fluids as listed in the Mannesmann Rexroth Data Sheet RA 90 221 for Environmentally Acceptable Hydraulic Fluids for Axial Piston Units. The UCON™ TRIDENT™ AW fluids are easily soluble in water and are biodegradable.

For technical questions or to request additional information concerning UCON™ TRIDENT™ AW Hydraulic Fluids, contact the Dow Chemical Company's Customer Information Group at:

The Dow Chemical Company
Customer Information Group
P.O. Box 1206
Midland, Michigan U.S.A. 48674
Toll Free (U.S. and Canada): 1-800-447-4369
Tel: 1-989-832-1560
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Regards,

The Dow Chemical Company
UCON™ Fluids & Lubricants Technical Services Group

UCON™ TRIDENT™ - Rexroth Pump Test Report

DISCUSSION

On January 15, 2002 a high-pressure (5000 psi) piston pump test of UCON™ TRIDENT™ 32 AW Hydraulic Fluid, an anhydrous water soluble polyalkylene glycol (PAG) based hydraulic fluid, was completed at Dow's R&D Facility in Tarrytown, NY. The fluid, classified by ISO as HEPG type synthetic hydraulic fluid, passed all three stages on Rexroth's standard mineral oil axial piston pump (A4VSO125) using Buna-N seals. The test was run under the conditions agreed upon by Hans Melief (Axial Piston Equipment Product Manager) and Charles Fey (Service Department Manager) of Bosch-Rexroth USA in Fountain Inn, SC and Bethlehem, PA, respectively. The test method was composed of three stages totaling 660 hours as follows.

Stage-1: Constant pressure (5000 psi) and full flow (~48 gpm at 1450 rpm) for 250 hours.
Stage-2: Variable pressure at a cycle rate of 2.3 Hz for 1 million cycles (121 hours) at full flow.
Stage-3: Variable flow at a cycle rate of 0.96 Hz for 1 million cycles (289 hours) at 5000 psi.

After each stage, fluid samples were taken for analysis and the pump was brought to Bosch-Rexroth in Bethlehem, PA for inspection. After the final stage (Stage-3), both the pump and motor were delivered to Rexroth for a complete disassembly and visually inspected for wear according to Rexroth's Wear Damage Catalog.

The purpose of this test was to obtain Bosch-Rexroth's approval of this fluid to be used in similar pumps and motors as an alternative to mineral oil, where biodegradability and improved fire-resistance over mineral oil is desired. The experimental condidtions and analytical results of the pump test are reported in the following tables as well as photographs of key pump parts. Also, the physical, chemical, lubrication, toxicological, corrosion and elastomer compatibility properties are summarized in technical data sheet for UCON™ TRIDENT™.

Table 1 – A4VSO125 Axial Piston Pump Book Values

Test Parameter	Book Value[(1)]	Test Setting
Temperature (oC)	(For Specified Viscosity)	40 (32 cSt)
Speed (rpm)	1800 max.	1450
Pressure (psi/bar)	5100/350 Nominal 5800/400 Peak	5000/345

(1) Mannesmann Rexroth, "Pump and Motor Catalog", RA10002/11.93.

Test Parameters

Since UCON™ TRIDENT™ was shown, by Southwest Research Institute, to give less wear than mineral oil in the Vickers 35VQ Test, we tested this fluid at a load pressure of 5000 psi (345) bar in a Rextroth A4VSO125 Axial Piston Pump at 1450 rpm. Although this pressure is higher than the 4600 psi pressure specified for a HFD (synthethic, fire-resistant, water-free) type fluid [1], the Vickers 35VQ results suggest that this fluid may have better antiwear properties than conventional hydraulic mineral oils.
The following is a sumary of the test parameters.

Reservoir Temperature:	104^{o}F (40^{o}C)
Fluid Type:	HFD/HETG (Fire-Resistant, Anhydrous PAG, Water Soluble)
Fluid Viscosity Grade:	ISO 46
Test Pump:	A4VSO125 Axial Piston Pump (Standard Mineral Oil Pump; Full complement bearings, ceramic front shaft bushing and 3-hole lens plate).
Pump Speed:	1450 rpm (Derated from 1800 rpm for HFD Type Fluids).
Pump Displacement:	125 cc/rev (Full Stroke).
Pump Flow Rate:	47.9 gpm (181.3 lpm), Theoretical.
Pump Load Pressure:	5000 psi (345 bar).
Hydraulic Power:	140 hp (104 KW), Theoretical.

Test Measurements

The following measurements were recorded in a data logger and plotted after the completion of each test stage. Each measurement, along with the related equipment, is listed below:

Pump Speed (rpm):	Zener Model VSC-2H80 AC Motor Speed Controller with Speed Readout
Flow Rate (gpm):	Hedland Flow Meter (Orifice Pressure Differential)
	Rexroth LVDT Motor Stroke Indicator
Load Pressure (psi):	Rexroth Pressure Transducer Model ST (5000 psi-max)
Pump Inlet Pressure (psia):	Precise Sensors Pressure Transducer (0-25 psia)
Reservoir Temperature:	K-Type Thermocouple

Pump Inspection Protocol

Since these tests were done in partnership with Rexroth, after each test stage the pump was brought to the Rexroth Facility in Bethlehem, PA to be disassembled and inspected. If Bosch-Rexroth ruled the test stage as a pass, then the pump was re-assembled, brought back to Tarrytown, and re-installed on the test stand for the next stage of the test. After completion of the third stage, both the pump and motor were delivered to Bosch-Rexroth for inspection.

The experimental conditions and results are summarized in the following tables.

Experimental Conditions

Table 1 summarizes the hydraulic book values for the piston pump being used. Bosch-Rexroth requires that the pump be derated in speed due to the higher specific gravity of the UCON™ TRIDENT™ 32 fluid (1.03) as compared to mineral oil (~0.85)

Pump Test Problems

Table 4 summarizes the problems that occurred during the pump test.

<u>O-Ring Failures</u>

During the first 117 hours of Stage-3, four Viton o-ring failures occurred. These problems seem to be related to a complex fluid/seal/pressure/flow interaction occurring in the piston motor during Stage-3 of the pump test. The ISO 6072 seal compatibilitiy data on UCON™ TRIDENT™ 32, a water-soluble anhydrous hydraulic fluid, shows that Viton (FPM1) undergpoes a much larger decrease in Shore hardness (-9%) and tensile strength (-26.36%) than does PowerPro™ 46 (-2 and -3.16, respectively), a water insoluble anhydrous hydraulic fluid that was run prior to UCON™ TRIDENT™ 32 with no o-ring problems. However, using Buna N (NBR1) with UCON™ TRIDENT™ 32 appears more favorable due to a much smaller decrease in tensile strength (-17.26%) than with Viton (-26.36%).

<u>Hydraulic Motor Drive shaft Failure</u>

Besides repeated Viton o-ring failures on the motor, the motor suffered a hard failure at 196 hours in to Stage-3 (~677,000 cycles, variable flow). Both the pump and motor were brought to Rexroth for inspection and the motor was reapired before continuance of Stage-3.

Inspection of the failed motore revealed that the cause of the metal debris in the motor case was due to failure of the drive shaft at the rear bearing area (Figure 3A), but the rear bearing was intact and did not fail (Figure 3B). The cause of the shaft failure is unknown.

Table 4 – Problems Encountered During Pump Test

Stage	Description of Problem
1	None
2	None
3	• At 18.5 hours, upper Viton o-ring failed on motor compensator mounting plate, o-ring replaced. • At 38.5 hours, upper Viton o-ring failed on motor compensator mounting plate, o-ring replaced. • At 40.2 hours, Viton o-ring failed on motor control piston lower cap, replaced Viton o-ring with Buna N and installed four new cap bolts. • At 117 hours, lower Viton o-ring now leaking on motor compensator mounting plate, replaced both upper and lower Viton o-rings with Buna N type. • At 196 hours, metal particles in motor case caused contamination switch to trip terminated pump test. Cause of metal debris was severe wear of motor drive shafe at rear bearing (drive shaft failed, not the bearing). Also the front seal was found to be leaking. New rotary group installed. Also, Viton fron bearing seal, control piston and compensator mounting plate o-rings changed to Buna N. • Owing to repeated sticking of the flow sensor a LVDT device was installed on the motor control piston unit to accurately measure the pump flow to the motor. • At 289 hours, test completed normally with no front seal leakage.

The DR spool and valve housing were also damaged (washed out). One of the main pressure ports under the DR sandwich plate showed signs of high-pressure leakage-erosion and there also appeared to be high pressure damage on the main motor housing, where the plate is attached. The sandwich plate was surface milled and all Viton o-rings were replaced, except for Buna N being used for the front seal and the high pressure areas of the sandwich plate and control piston end caps.

Inspection of the pump revealed that the DR spool and housing were also severely scored, but were reused to complete the remaining 93 housts of the Stage-3 test. All other parts of the pump showed very light wear and some metal debris was found in the pump case and retaining ball area, probably originating from the motor failure because the motor case drain was returned, unfiltered to the reservoir.

CONCLUSIONS

Except for the Viton o-ring failures, UCON™ TRIDENT™ 32 appears to be satisfactory for use in Rexroth piston pumps at 5000 psi with a 20% speed reduction, as per Rexroth's specifications for high specific gravity fluids. Since Rexroth's standard mineral oil pumps come with Viton seals and o-rings, then if UCON™ TRIDENT™ 32 is to be used, We recommend that the front seal be changed to Buna N and that Buna N o-rings be used in all high pressure areas (i.e. DR valve sandwich plate ports and control piston end caps).

APPENDIX

A. Copy of UCON™ TRIDENT™ Approval Letter from Bosch-Rexroth

-----Original Message-----
From: Len Koudijs [mailto:len.koudijs@boschrexroth.ca]
Sent: Monday, February 23, 2004 4:17 PM
To: Cooper, Gary (GJ)
Cc: Real Remillard; 'Denis Plourde (plourde.denis@mecfor.com)'; Kevin Eaton
Subject: FW: approval for Trident hydraulic fluid

Good day Mr. Copper,

The R&D group at Bosch Rexroth AG - (AK) axial piston division has confirmed that the technical specification of the specified fluid does fulfill our requirements.

Best regards,
Len Koudijs
>Mobile Market Support
>Bosch Rexroth Canada Corp.
>"The Drive & Control Company"
>490 Prince Charles Drive South, Welland
>Ontario, Canada L3B 5X7
>Phone: (905) 735 0510 Ext. 5223
>Fax: (905) 735 0791
Email: len.koudijs@BoschRexroth.ca

-----Original Message-----
From: Cooper, Gary (GJ) [mailto:GJCooper@dow.com]
Sent: Wednesday, January 28, 2004 1:03 PM
To: Len Koudijs
Subject: approval for Trident hydraulic fluid

Len Koudijs,

Your name has been given to me by Denis Plourde from Mecfor regarding the use of Dow's UCON Trident 46 anhydrous PAG hydraulic fluid in the Multi-Purpose Carrier MTC-20 equipment Mecfor is making for Alcan. UCON Trident is a new product for the Dow Chemical which was launched during the summer of 2003. This product is an anhydrous polyglycol based fire resistant hydraulic fluid. Mecfor will not use this fluid without the approval of Bosch Rexroth. Can you please let me know what will it take to get approval of this fluid for use at Mecfor? I am attaching some product literature about Trident. Please review this material and let me know if there is anything else Dow needs to do to receive approval for Trident at
Mecfor.

<<tridentdow.pdf>>