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CONVERSION OF HYDRAULIC BRAKE SYSTEMS FROM POLYGLYCOL
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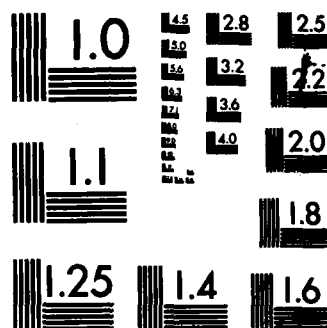
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TECHNICAL NOTE

MRL-TN-491

CONVERSION OF HYDRAULIC BRAKE SYSTEMS
FROM POLYGLYCOL TO SILICONE BRAKE FLUID:
RESIDUAL POLYGLYCOL REMAINING AFTER CONVERSION

P.J. Sanders and J. Barry*

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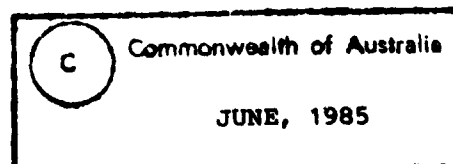
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Selected Australian Army vehicles were converted from polyglycol to silicone brake fluid using experimental "flush-fill" techniques. Performance trials and analysis of samples taken after conversion indicate that techniques associated with the conversion do not remove all polyglycol from the vehicles tested. Accordingly, the technical advantages possible from the use of silicone fluids are not achieved.

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Conversion of hydraulic brake systems from polyglycol to silicone
brake fluid: residual polyglycol remaining after conversion

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CONVERSION OF HYDRAULIC BRAKE SYSTEMS
FROM POLYGLYCOL TO SILICONE BRAKE FLUID:
RESIDUAL POLYGLYCOL REMAINING AFTER CONVERSION

1. INTRODUCTION

In 1981 a new brake fluid type was adopted by the United States of America for use in its fleet of land vehicles. This fluid, a silicone liquid formulation, offered advantages in use by reason of its water repelling properties and low freezing point. In an attempt to reduce corrosion damage, improve system performance and maintain interoperability with U.S. forces, the Australian army recently began trials to investigate the feasibility of following the American lead in converting army vehicles to silicone brake fluid.

2. BACKGROUND

Hydraulic fluids are employed in automotive braking systems to transfer the force exerted on a pedal, possibly augmented by some type of servo assistance, to the components of the braking system which will actually perform the retarding function. While performing this duty, modern brake fluids are required to minimise internal friction; operate properly within components which have become extremely hot during heavy use or cold following low environmental temperatures; protect the braking system against internal corrosion and wear and be compatible with brake system materials.

The formulations of automotive brake fluids were originally dictated by the requirement that they must be compatible with natural rubber which was the only material available at the time for use in flexible seals and hoses. Although the compositions of brake fluids and seals have evolved in response to increasingly severe market demands on performance, their compositions have always been primarily dictated by the requirement that they must remain mutually compatible. In practical terms, this has meant that when prescribed rubber seals are immersed in a candidate fluid, dimensional changes, rubber degradation and simulated operational performance must comply with limits nominated in the range of internationally aligned specifications deemed to be acceptable by brake system designers and manufacturers.

Historically, fluids which have demonstrated acceptable performance with the prescribed rubber formulations have generally shown a strong tendency to take up water into solution from the air and from impingement of water or steam onto exposed components. Although brake system manufacturers have recognised this water take-up problem and have tried all manner of sealing techniques in an attempt to prevent its occurrence, water take-up eventually occurs if the fluid does not consist of materials which are themselves water repelling. As modern brake fluid formulations are primarily based on polyglycols which are strongly hydrophilic, water take-up is inevitable and may only be effectively controlled by careful and regular maintenance scheduling.

Under field operational conditions the presence of water-contaminated fluid in contact with the metallic components of braking systems leads to corrosion of those components with corresponding maintenance costs. Accordingly, a degree of corrosion has come to be accepted in automotive braking systems.

Additionally, the presence of water in brake fluid lowers its boiling point which results in a greater rate of evaporation within components of braking systems which have become excessively heated during heavy and/or prolonged braking. This formation of vapour may result in "vapour locking" and may cause catastrophic failure of the braking system at fluid temperatures well below the "reflux" boiling point usually quoted as characteristic of polyglycol/water mixtures. Under severe "vapour lock" conditions a volume of vapour greater than the swept volume of the master cylinder forms and displaces incompressible fluid. Subsequent brake application merely compresses the "vapour space", resulting in severely reduced effective line pressure and thus braking efficiency. "Pumping" of the brake pedal will not usually correct this condition since line pressure resulting from the compressed vapour pocket forces fluid back into the master cylinder reservoir on the relaxation stroke of the brake pedal pumping action.

The chemical industry in the United States addressed the automotive brake fluid problem during the late 1970's. Silicone brake fluids (SBF) were developed which, after initial lubricity problems subsequently overcome by the incorporation of suitable additives [8], appeared to be of satisfactory compatibility with the elastomeric materials currently in use [8]; had water exclusion properties superior even to mineral oils [2] and the additional benefit of a low freezing point.

In 1981 the U.S. Army made the decision [5] that all additions to its vehicle fleet would contain SBF and that all existing fleet vehicles would be converted from one of the three polyglycol-type fluids to SBF [5] during July '81 to June '82. The advantages expected from this change were the replacement of three fluid types with one type [3] and reduction in fleet maintenance costs through elimination of corrosion due to take-up of water by the existing polyglycol brake fluid [3]. An additional benefit expected [2] was the elimination of the risk of brake failure due to vapour lock of water-contaminated brake systems.

Maintenance Engineering Agency, Melbourne, (MEA) were recently tasked with investigating methods and effects of converting selected "B" vehicles of the Australian Army vehicle fleet from Polyglycol brake fluid JSD-OX(Aust.)8 to Silicone brake fluid JSD-OX-6. When MEA began to investigate ways and means of performing this task, a number of methods of conversion became apparent.

1. The simplest and least expensive method considered was a "flush-fill" technique whereby the brake system is purged of polyglycol by simply pressure-bleeding with OX-6 until no further OX(Aust.)8 is expelled [4,6,7,8]. However braking systems are designed with bleed nipples located on the upper surfaces of components to facilitate the removal of material (air) less dense than the brake fluid. Since the OX-6 to be retained in the system is less dense than and immiscible with the OX(Aust.)8 being expelled, the removal of all pockets of polyglycol fluid by this method was seen as unlikely.
2. A variation of the flush-fill method is to firstly expel the used polyglycol fluid through opened air bleeder nipples by forcing compressed air through the system [4,6,7]. Although this method appeared to offer greater effectiveness, a problem of health risk is caused by vapour carried into the atmosphere with the purging air.
3. A further variation involves initial flushing of the brake system with a solvent miscible with polyglycol [4,6,7], producing a solution immiscible with and less dense than OX-6. This method has been used in the U.S. but no details are to hand as to its effectiveness. Moreover it was thought probable that, with the solvents under consideration for Australian use, residual solvent could create even greater vapour lock problems and have deleterious effects on rubber components.
4. Finally, as an alternative to the above flush-fill techniques it was proposed to effect fluid replacement by dismantling and cleaning the entire braking system, renewing parts where necessary, then reassembling and refilling the system with OX-6. Such measures would very likely be effective in removing all trace of polyglycol but were judged too expensive for adoption by the Australian Army.

As part of this conversion task, MEA requested Materials Research Laboratories, Melbourne, (MRL) to investigate the effect on various brake system rubber components of immersion in used OX(Aust.)8, OX-6 and mixtures of these two fluids.

3. EXPERIMENTAL

3.1 Sampling

3.1.1 Initial Sampling from Vehicle Army 37-971

Samples of brake fluid were first taken by MRL staff from the master cylinder and wheel cylinders of Falcon station wagon ARMY 37-971 which had earlier been converted to OX-6 by a flush-fill technique (refer Table 4). A syringe sampling technique which did not require disassembly of the brake components was used (refer section 3.3.1).

Further samples were taken by MEA staff:

- two from a 20 litre Polyglycol Brake Fluid (OX(Aust.)8) supply drum,
- one from a drum containing collected "Used" OX(Aust.)8 bled from vehicles undergoing major and minor servicing.

All of the samples taken from 37-971 showed partition into two layers which infra-red spectroscopic analysis showed were an upper layer of OX-6 and a lower layer of OX(Aust.)8. Karl Fischer analysis of the lower OX(Aust.)8 layers yielded water contents and corresponding boiling points as shown in Table 1.

3.1.2 Further Sampling from Vehicle Army 37-971

Subsequent to the above, MEA conducted a trial using four of the vehicles involved in experimental conversion to OX-6. This involved repeated cycles of acceleration to high speed followed by heavy braking and the use of temperature-recording decals attached to wheel braking assemblies. Details of the temperatures recorded during that trial are shown in Table 2.

In the case of 37-971, total loss of braking effect and loss of pedal resistance was noted approximately 15 minutes after the vehicle had been returned to the garage. Next day the brakes had returned to normal with no sign of fluid loss or leakage from the system. All brake assemblies were stripped from this vehicle with the liquid contents intact and taken to MRL for disassembly and inspection. All were found to contain residues of OX(Aust.)8 despite the syringe sampling operation which had resulted in the samples to which Table 1 refers. Details of fluid recovered from the stripped assemblies are collated in Table 3.

3.2 Stripdown of Braking Systems in Trial Vehicles

MEA staff then performed a total stripdown of the braking systems in all the vehicles involved in experimental conversion to OX-6. Details of the methods used to convert each of the vehicles, the date of conversion and the distance covered by each of the converted vehicles are shown in Table 4. Fluids from the disassembled braking components were recovered and forwarded to MRL for examination. The results of those examinations are collated in Table 5.

3.3 Procedures

3.3.1 Syringe Sampling Technique used for Army 37-971

A one-metre length of 1mm diameter plastic tubing was tightly fitted over a hypodermic needle on a 50cc Luer-lock syringe. The brake line attached to the bottom of the rear wheel cylinder was removed and the tubing inserted to draw as much fluid as possible out of the cylinder. In the case of front wheel disc calipers, the bleed nipple was removed and the tubing inserted to draw out as nearly all the fluid as possible. Collected fluid was then transferred to a labelled sample container.

3.3.2 Volume Measurements

Sample containers were vigorously shaken until the contents formed a homogenous suspension. The suspended mixture of fluids was then transferred to a graduated, tapered-bottom centrifuge tube and centrifuged for 40 minutes. The tubes and centrifuge conditions were as specified for the American Society for Testing and Materials (ASTM) method number D893-80 for Insolubles in Used Lubricating Oils. After centrifuging, the total fluid volume and the volume of the lower layer were recorded. In addition the lower layer was analysed for water by the Karl Fischer titration method.

3.4 Tabulated Results

T A B L E 1

ANALYSES OF POLYGLYCOL BRAKE FLUID

RESIDUES FROM ARMY VEHICLE 37-971

SAMPLE SOURCE	VOLUME OX(Aust.)8 LAYER	WATER CONTENT	BOILING POINT Note(1)
Ford Falcon XE Wagon ARMY 37-971			
Master Cylinder Front Reservoir	19 ml	5.6%	125C
Master Cylinder Rear Reservoir	7.5 ml	6.5%	123C
Left Rear Wheel Cylinder	1 ml(2)	3.3%	143C
Right Rear Wheel Cylinder	10 ml	1.7%	173C
Left Front Wheel Caliper	5 ml	6.6%	123C
Right Front Wheel Caliper	5 ml	6.3%	123C
20 litre OX(Aust.)8 supply drum	-	0.9%	205C
Bulk Used OX(Aust.)8 Waste drum	-	2.5%	156C

Note (1). Boiling points were obtained from the water contents by interpolation of results published in Ref.3 which assumed a water-free boiling point of 292C.

Note (2). A large proportion of the fluid from the Left Rear Wheel Cylinder was lost during sampling so the volume shown is likely to be only a fraction of the polyglycol residue which remained in that cylinder.

T A B L E 2

TEMPERATURES RECORDED DURING MEA BRAKING

TRIALS AT BROADMEADOWS

RECORDING POINT	TEMPERATURE REACHED
Mercedes Unimog U1700L ARMY 38-017	
L/H Front Leading Caliper	>160C
L/H Front Trailing Caliper	110C
R/H Front Leading Caliper	110C
R/H Rear Disc	>160C
R/H Rear Caliper	88C
L/H Rear Caliper	93C
Land Rover Series 3 ARMY 29-639	
L/H Front Wheel Cylinder	70C
L/H Front Brake Drum	>160C
R/H Rear Wheel Cylinder	70C
Toyota Land Cruiser ARMY 35-973	
L/H Front Caliper	130C
L/H Front Disc	>160C
R/H Rear Wheel Cylinder	110C
R/H Rear Brake Drum	>160C
Ford Falcon XE Wagon ARMY 37-971	
L/H Front Caliper	130C
L/H Front Disc	>160C
R/H Front Disc	>160C
R/H Rear Wheel Cylinder	77C

T A B L E 3

ANALYSES OF BRAKE FLUID RECOVERED FROM
ARMY VEHICLE 37-971 AFTER BRAKE FAILURE ON TRIAL

SAMPLE	SOURCE	TOTAL FLUID VOLUME RECOVERED	(OX(Aust.)8) LAYER ANALYSIS		
			VOLUME RECOVERED	WATER CONTENT	BOILING POINT (1)
Ford Falcon XE Wagon ARMY 37-971					
Master cylinder front reservoir	>100 ml	1.7 ml	7.6%	122C	
Master cylinder front port	4.2 ml	0.4 ml	4.1%	132C	
Master cylinder rear reservoir	>100 ml	Nil	-	-	
Master cylinder rear port	18 ml	Nil	-	-	
Front left hydraulic pipe	4.9 ml	Nil	-	-	
Front left disc brake caliper	35 ml	1.0 ml	7.4%	122C	
Front right hydraulic pipe	5.0 ml	Nil	-	-	
Front right disc brake caliper	40 ml	0.6 ml	7.4%	122C	
Hydraulic pipe to rear axle	30 ml	1.3 ml	3.8%	136C	
Left rear wheel cylinder	1.9 ml	0.4 ml	3.2%	145C	
Right rear wheel cylinder	2.9 ml	1.1 ml	3.5%	140C	

T A B L E 4

CONVERSION DETAILS

VEHICLE TYPE	ARN	DATE CONVERTED	KM TRAVELLED	METHOD OF CONVERSION
Ford F250	31-888	17 OCT 83	8413	All OK(Aust.)8 drained from the system. Master cylinder removed, stripped and cleaned. System blown through with compressed air and pressure bled.
Ford Falcon XE Utility	37-705	17 OCT 83	11813	All caliper and wheel cylinder rubbers replaced. All hoses replaced and the system pressure bled with OK-6.
Ford Falcon XE Wagon	37-971	7 OCT 83	18306	Master cylinder reservoir removed and cleaned of OK(Aust.)8, OK-6 introduced using pressure bleeding equipment until all OK(Aust.)8 was expelled.
Mercedes Unimog U1700L	38-017	29 NOV 83	7916	System drained of OK(Aust.)8, pressure bled with OK-6 until no further OK(Aust.)8 expelled.
Land Rover Series 3	29-639	9 DEC 83	4530	Procedure as for 31-888 except L/H rear wheel cylinder also overhauled.
Truck, International F1	174-579	12 DEC 83	4895	Procedure as for 31-888.
Truck, Wrecker, MB16	179-604	9 FEB 84	7992	All components changed, system flushed with methylated spirits then filled with OK-6.
Truck Wrecker Twin Boom	179-623	9 FEB 84	10723	Procedure as for 179-604
Toyota Land Cruiser	35-973	11 APR 84	5493	System drained of all OK(Aust.)8. Front calipers removed and inverted for drainage. System pressure bled until no further OK(Aust.)8 expelled.

T A B L E 5

ANALYSES OF BRAKE FLUIDS RECOVERED

FROM TRIAL VEHICLES

SAMPLE SOURCE	TOTAL FLUID		(OX(Aust.)8) LAYER ANALYSIS			
	VOLUME	RECOVERED	VOLUME	RECOVERED	WATER CONTENT	BOILING POINT (1)
Ford Falcon XE Utility ARMY 37-705						
Master Cylinder Front Reservoir	50	ml	Nil		-	-
Master cylinder rear reservoir	50	ml	Nil		-	-
Front left disc brake caliper	24	ml	Nil		-	-
Front right disc brake caliper	27	ml	Nil		-	-
Left rear wheel cylinder	5	ml	Nil		-	-
Right rear wheel cylinder	4	ml	Nil		-	-
Case W10 Fork Lift						
Left Rear Wheel Cylinder	325	ml	5	ml	7.6%	122C
Land Rover Series 3 ARMY 29-639						
Brake Master Cylinder	49	ml	<0.05	ml	-	-
Left Rear Wheel Cylinder	6	ml	<0.05	ml	-	-
Right Rear Wheel Cylinder	11	ml	0.1	ml	3.2%	145C
Left Front Wheel Cylinder	3	ml	0.1	ml	4.3%	131C
Right Front Wheel Cylinder	2.4	ml	0.05	ml	0.2%	273C
Clutch Master Cylinder	2.6	ml	0.5	ml	6.3%	123C
Clutch Slave Cylinder	6	ml	0.55	ml	4.1%	132C
International F1 Truck MDM MC2 ARMY 174-579						
Left Brake Master Reservoir	224	ml	0.3ml	water	100 %	100C
Left Brake Master Cylinder	67	ml	2.6ml	water	100 %	100C
Right Brake Master Reservoir	143	ml	1.0ml	water	100 %	100C
Right Brake Master Cylinder	45	ml	<0.05	ml	-	-
Left Front Wheel Cylinder	9.5	ml	Nil		-	-
Right Front Wheel Cylinder	55	ml	Nil		-	-
Left Intermediate Wheel Cyl.	17	ml	Nil		-	-
Right Intermediate Wheel Cyl.	12	ml	Nil		-	-
Left Rear Wheel Cylinder	72	ml	<0.05	ml	-	-
Right Rear Wheel Cylinder	92	ml	0.13	ml	6.6%	123C

T A B L E 5
(continued)

SAMPLE SOURCE	TOTAL FLUID VOLUME RECOVERED	(OX(Aust.)8) LAYER ANALYSIS		
		VOLUME RECOVERED	WATER CONTENT	BOILING POINT (1)
Clutch Master Cylinder	52 ml	0.2 ml	8.0%	122C
Clutch Slave Cylinder	16 ml	Nil	-	-
Truck Wrecker MB16 ARMY 179-604				
Master Cylinder	~ 30 ml	Nil	-	-
Left Front Wheel Cylinder	~ 30 ml	Nil	-	-
Right Front Wheel Cylinder	~ 30 ml	Nil	-	-
Left Intermediate Wheel Cyl.	~ 30 ml	Nil	-	-
Right Intermediate Wheel Cyl.	~ 30 ml	Nil	-	-
Left Rear Wheel Cylinder	~ 30 ml	Nil	-	-
Right Rear Wheel Cylinder	~ 30 ml	Nil	-	-
International 5 Ton Twin Boom Wrecker ARMY 179-623				
Master Cylinder	~ 30 ml	Nil	-	-
Left Front Wheel Cylinder				-
Right Front Wheel Cylinder	~ 30 ml	Nil	-	-
Left Intermediate Wheel Cyl.	~ 30 ml	Nil	-	-
Right Intermediate Wheel Cyl.	~ 30 ml	Nil		
Left Rear Wheel Cylinder	~ 30 ml	Nil	-	-
Right Rear Wheel Cylinder	~ 30 ml	Nil	-	-
Mercedes Unimog ARMY 38-017				
L/H Front Leading Caliper	55 ml	Nil	-	-
L/H Front Trailing Caliper	60 ml	0.3 ml	6.4%	123C
R/H Front Leading Caliper	60 ml	0.3 ml	10.1%	122C
R/H Front Trailing Caliper	55 ml	0.3 ml	5.0%	128C
Left Rear Caliper	90 ml	0.32 ml	3.4%	142C
Right Rear Caliper	95 ml	0.35 ml	4.8%	129C
Clutch Slave Cylinder and Line	>110 ml	9 ml	7.5%	122C
Clutch Master Cylinder	35 ml	1.8 ml	6.8%	123C
Ford F250 ARMY 31-888				
Brake Master Cyl. Reservoir	187 ml	3.9 ml	4.5%	131C
Left Front Caliper	55 ml	50 ml	2.7%	153C
Right Front Caliper	48 ml	42 ml	3.3%	144C
Composite from Rear Wheel Cyls.	5.5 ml	2.8 ml	5.0%	128C

TABLE 5
(continued)

SAMPLE SOURCE	TOTAL FLUID VOLUME RECOVERED		(OX(Aust.)8) LAYER ANALYSIS			
			VOLUME RECOVERED		WATER CONTENT	BOILING POINT (1)
Clutch Master Cylinder	30	ml	2.5	ml	7.4%	122C
Clutch Slave Cylinder	14	ml	5.5	ml	7.7%	122C
Toyota Land Cruiser ARMY 35-973						
Brake Master Cylinder	32	ml	12	ml	8.1%	122C
Left Front Brake Line Fluid	75	ml	0.8	ml	9.8%	122C
Right Front Brake Line Fluid	55	ml	1.1	ml	8.0%	122C
Left Rear Wheel Cylinder	<0.05	ml	<0.05	ml	-	-
Right Rear Wheel Cylinder	0.2	ml	0.2	ml	6.2%	123C
Clutch Master Cylinder	0.1	ml	0.1	ml	52.5%	112C
Clutch Line and Slave Cylinder	28	ml	Nil		-	-

4. DISCUSSION

Although the detection of some polyglycol residues in vehicles after conversion to SBF by "flush-fill" techniques (1) and (2) was predictable, the amount of polyglycol remaining in some cases was very large. In one of the worst instances, 50ml still remained in a caliper having a volume of 55ml. Inspection of the data tends to indicate that the effectiveness of "flush-fill" methods of fluid conversion depends more on the geometry of the vehicle braking system than the finer points of the technique itself. This is seen by comparing the data in Table 5 for the Ford F250 which was converted using compressed-air flushing followed by pressure bleeding with those for the Mercedes Unimog which was only pressure bled. Since the data presented in this paper cover such a wide variety of conversion techniques and vehicle types but involve only a small statistical population, a more rigorous analysis of the efficiency of each of the conversion techniques is not justified.

The water content (2.5% - refer Table 1) of the sample taken from the waste drum may be taken to be indicative of the average water content of OX(Aust.)8 in vehicles serviced by MEA Broadmeadows. Since OX(Aust.)8 residues from converted vehicles show water analyses which almost invariably exceed this level of water content, it may be concluded that ingress of water into brake systems will still be experienced following a "flush-fill" conversion from polyglycol to silicone fluid. Since polyglycol residues occur

most often in wheel cylinder and caliper assemblies which are also a common point of entry of water into brake systems, the water taken up must concentrate in the relatively small remaining volumes of polyglycol leading to higher water contents (and thus lower boiling points) in residues than might otherwise be seen in an all-polyglycol system. Because it is these very components which suffer to the greatest degree from excessive heating during heavy and/or prolonged braking, the risk of brake failure due to vapour lock most likely will increase after an OX-6 conversion which leaves polyglycol remnants in the converted system.

As an example, consider the Toyota Land Cruiser data (refer Table 5) to illustrate this point. Fluid in the master cylinder reservoir may be excluded since it is unlikely that fluid in the reservoir would take part in agitation which would mix the contents of the brake system. The total volume of residues recovered was 2.15ml having water contents ranging from 6.2% to 9.8%. If this water were dispersed in the total system volume of 130ml containing polyglycol which had an initial water content of 0.9%, then the system water content would then be only 1.04%. Although it would be unrealistic to suppose that the complete mixing assumed above occurs in a brake system, the tendency must exist for water which enters a polyglycol-filled brake system at any point to be gradually dispersed throughout the system thus reducing the severity of "wet spots".

Quite apart from the vapour locking question, despite fleet trials conducted by Dow Corning [8] who drew the conclusion that "Flush-filling... (of polyglycol-filled brake systems with SBF)... can reduce corrosion ..." the authors of that paper agree that the presence of wet polyglycol residues in a converted brake system will increase the likelihood of corrosion in that system compared to the same system free from such residues. Since the greatest tangible benefit expected on conversion to OX-6 is the elimination of the costs associated with brake system corrosion, a conversion which does not achieve that end is less than satisfactory. Indeed, if the rate of corrosive attack can be associated with the level of water contamination, corrosion rates may tend to increase rather than decrease after a fluid conversion which does not remove all polyglycol.

A further point of consideration concerns the compatibility of OX(Aust.)8/OX-6 mixtures with brake system rubber sealing components. Work done at MRL [9] in this area has shown excessive swelling and severe degradation of one particular type of rubber cup when immersed in such a mixture at 120C. It is, however outside the scope of this paper to explore the polymer compatibility aspects of conversion, interested parties are urged to follow up the appropriate reference.

5. CONCLUSIONS

The available evidence indicates that the loss of effective braking in vehicle ARMY 37-971 on trial was due to the formation of vapour in one or both of the front disc brake calipers due to elevated operating temperatures

and severely depressed boiling point of residual polyglycol fluid in the system converted to OX-6.

Flush-fill techniques of conversion of braking systems from OX(Aust.)8 to OX-6 do not remove enough OX(Aust.)8 to achieve the water-exclusion benefits associated with silicone fluids.

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