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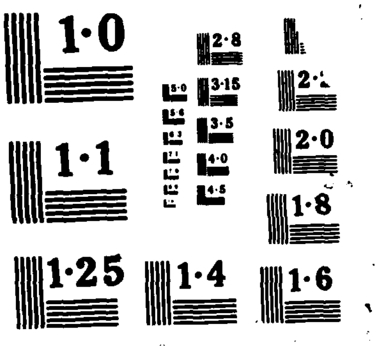
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RECLAMATION OF USED MIL-L-23699 LUBRICANTS FOR REUSE IN MILITARY AIRCRAFT TURBINE ENGINES

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AD-A190 859

NOVEMBER 1987

FINAL REPORT FOR PERIOD AUGUST 1985 - JULY 1987

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This technical report has been reviewed and is approved for publication.

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Following on from a successful investigation; under two previous USAF Contracts; into the feasibility of reclaiming used MIL-L-7808 Turbine Engine Lubricant and the establishment of minimum quality specification and inspection procedures for used MIL-L-7808 available for reclamation, the present contract is undertaken with the objective of determining whether the established Daltons technology is capable of reclaiming used arisings of MIL-L-23699 Turbine Engine Lubricant.

Thirteen 55 gallon drums of this type of used oil were provided by United States Navy for this research.

Three of these were purported to contain arisings from Helicopter transmissions and the remainder to contain arisings from Turbine Engines.

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Summary

Encouraging results have been obtained in two research programmes carried out under USAF contracts by Dalton & Co. (Synthetic Products) Ltd. into the feasibility of reclaiming used MIL-L-7808 turbine engine lubricants to reproduce the quality of virgin lubricant as defined by MIL-L-7808. Concurrently, a minimum quality specification and inspection techniques have been established for acceptance of used MIL-L-7808 lubricants for reprocessing by the Dalton reclamation technology.

The USAF operate some of their aircraft on MIL-L-23699, and it is anticipated that in the near future this lubricant will have additional uses in other USAF aircraft.

The present report covers the results of a further research programme carried out under USAF contract by Dalton with the objective of determining whether the Dalton reclamation technology is capable of reclaiming used arisings of MIL-L-23699 to reproduce the quality of virgin lubricant as defined by that specification.

Thirteen coded 55-gallon drums of used MIL-L-23699 were supplied by the USN for this research. Three of these were purported to contain arisings from helicopter transmissions, and the remainder to contain arisings from turbine engines.

Results obtained upon Laboratory examination of each drum of lubricant are presented and, based upon Dalton experience, a minimum quality specification analogous to the one devised for acceptance of used MIL-L-7808 lubricants, and embodying the same inspection techniques, is presented for acceptance of used MIL-L-23699 lubricants.

The specification originally restricted volatile contaminant content (VCC) to not more than 20 percent on economical grounds but, apart from the helicopter lubricants which contained from 0.3 to 1.1 percent VCC, only one drum of the turbine engine lubricants complied with the requirement, the remainder containing from 20 to over 40 percent VCC, and which in the main consisted of Avcat turbine fuel. The specification was therefore amended, at the expense of increasing operational cost and reducing the yield of reclaimed product, to permit up to 30 percent VCC so that a larger proportion of the turbine engine lubricants could be accepted for the reclamation exercise.

Seven drums of the turbine engine lubricants, and the three drums of helicopter lubricants, met all the requirements of the amended specification. All these lubricants, after laboratory removal of VCC from the test samples, were very high foamers in the context of USAF requirements for virgin lubricant, but were low foamers in the context of Rolls-Royce requirements for foaming propensity.

Residual fuel in the VCC-stripped samples of the turbine engine lubricants was sufficient, in consequence of the high fuel contents of the original samples, to produce reaction manifestations in the Rf range normally employed by Dalton in the TLC assessment of mineral oil content (MOC). Test data are presented showing that another reaction manifestation given by mineral oil in a different Rf range can be utilised for assessment of MOC without interference from turbine engine fuel.

The seven drums of turbine engine lubricant which satisfied the minimum quality specification were blended together to produce one feedstock designated CAT.3/T for reclamation. Likewise, the three drums of helicopter lubricants were blended together to produce CAT.3/H feedstock. Both feedstocks fell into the High Foam/Low Chlorine Category of the minimum quality specification but, whereas CAT.3/T contained 24 percent VCC, CAT.3/H contained only 0.8 percent.

Reclamation of CAT.3/T was first started by means of the Dalton technology employed for the reclamation of used MIL-L-7808 in the two previous research programmes, but fire from a neighbouring plant put the reclamation plant out of action. It then became necessary, because of time contraints and excessive delays incurred while attempting to repair the damaged plant, to go ahead with the reclamation of both feedstocks before the full extent of the damage could be rectified. The operational characteristics of the plant at this stage were somewhat unpredictable; therefore, it was not possible to strictly adhere to the operational details of the established technology.

Feedstocks CAT.3/T and CAT.3/H were reclaimed on this basis up to the beginning of the last process step comprising additive treatment, and then each additive was treated with 0.05 percent BTZ in producing the final reclaimed products CAT.3/T/F and CAT.3/H/F respectively.

Both final products failed to satisfy the foaming tendency and foam stability restrictions imposed by MIL-L-23699, and the KV at 210°F and open flash point of CAT.3/T/F were marginally below specification requirements. We conclude that the shortcomings are due to contamination of the used lubricants during their collection and/or storage.

PREFACE

This report describes the work performed by Dalton and Company (Synthetic Products), Ltd., Belper, Derby, England, under U. S. Air Force Contract F49620-85-C-0138. The report covers work during the period from August 1985 - July 1987.

The effort established the feasibility of reprocessing MIL-L-23699 Aviation Turbine Engine Lubricant and was sponsored by the Naval Air Propulsion Center, Trenton, New Jersey, the Aero Propulsion Laboratory, Air Force Wright Aeronautical Laboratories (AFWAL/POSL), Air Force Systems Command, Wright-Patterson AFB, Ohio, and the European Office of Aerospace Research and Development, Air Force Office of Scientific Research (EOARD/LNT), Air Force Systems Command, London, England. The work was carried out under Project 3048, Task 304806. Work unit 30480649. Project Managers for this effort were Mr. A. D'Orazio, NAPC, Code 33, Lt Col O. W. Mancarella, EOARD/LNT, and Mr H. F. Jones, AFWAL/POSL. Dalton and Company, Ltd., Project Managers were Mr Roger A. Micallef and Mr Alan T. B. P. Squires.

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1. Introduction

An estimated total of 250,000 to 500,000 gallons of used ester base oils which could be collected for reclamation are generated per year by the US Air Force. The capability to reprocess these lubricants for reuse in military aircraft turbine engines would be a significant source of supply in the event of serious shortages. In addition, significant cost savings may be possible if the technique proves successful.

Dalton and Company (Synthetic Products) Limited, hereafter referred to as "Dalton," has been since 1956 reclaiming used ester base oil arising for reuse in Rolls-Royce turbine engines operated by commercial airlines and the Ministry of Defence. The technological know-how has been progressively improved since that date, and has been successfully applied to used arisings of diester and polyol-ester base oils typified in their virgin states by such military specifications as MIL-L-7808, MIL-L-23699 and D.ENG.RD.2497. These lubricants are reclaimed to satisfy the requirements of Rolls-Royce specifications, but it does not necessarily follow that they would comply with the requirements of the corresponding military specifications which differ in detail.

However, during the period 1 May 79 to 31 May 81 promising results were obtained in a research programme carried out by Dalton under USAF contract F49620-79-C-0073 into the applicability of the Dalton technology to used MIL-L-7808 lubricant taken from USAF aircraft based at Lakenheath and Upper Heyford in the UK.

Both diester and polyol-ester oils were featured in the collections of used lubricant which were reclaimed to the quality of virgin lubricant as defined by MIL-L-7808. The reclaimed product amounted to 95 percent of the used oil feedstock, but the latter had been collected in clean vessels under close supervision to reduce the hazard of contamination by other materials employed at the two bases. The programme, therefore, demonstrated the efficacy of the technology in reducing to insignificant levels trace elements and lubricant degradation products, but it did not of course provide information about the proportion of reclaimable lubricant which would be available on average from arising of used lubricant collected under conditions where no special precautions are taken to exclude contamination by materials outside the engine environment.

Experience in the commercial arena has shown that post contamination of used lubricant which may be incurred during its collection and storage influences the efficacy of the reclamation process, and may adversely affect the yield of reclaimed oil. Exceptionally clean collection equipment and implementation of good housekeeping under close supervision has significantly increased the yield of reclaimable material from used airisings, but such precautions may not be practicable in the military arena as a result of world-wide operations at a large number of sites and the large number of personnel involved and their frequent changes in position.

Accordingly, a second research programme was carried out during 1981 to 1984 by Dalton under USAF contract F49620-81-C-0064 with the objective of first, establishing a minimum quality specification for acceptance of used MIL-L-7808 lubricants for reclamation, and second, determining the proportion of reclaimable lubricant in used MIL-L-7808 which was collected from a wide selection of USAF bases where no special precautions had been taken to exclude post contamination of the arisings.

The minimum quality specification was based upon two inspection procedures which were devised, one of which was titled minimum quality preliminary inspection (MQPI), and the other minimum quality final inspection (MQFI). The proportion of potentially reclaimable lubricant as derived from the application of these inspection procedures to a total of 71 samples submitted amounted to 80.3 percent, and the yield of reclaimed product was 80 percent of this feedstock, i.e., 64.2 percent of total samples submitted.

The USAF operate some of their aircraft on MIL-L-23699 lubricant which is also employed by the United States Navy. The Dalton technology has been successful in reclaiming commercial arisings of MIL-L-23699 type lubricant to the requirements of Rolls-Royce specifications, but it was not known whether or not it is capable of reclaiming military arisings to the standard of virgin lubricant quality as defined by MIL-L-23699.

The present report covers a research programme carried out by Dalton with the objective of establishing the efficacy of the Dalton reclamation technology in restoring to virgin lubricant quality, as defined by MIL-L-23699, used arisings of MIL-L-23699 lubricants from American military aircraft.

2. Used Lubricant Samples

A consignment of material, purported to comprise collections of used MIL-L-23699 lubricants for carrying out the research, arrived in 13 coded 55-gallon drums at the Dalton Refinery on 85 July 29. The shipping weight recorded on each drum was 470 lbs.

Three of the lubricants, coded NAPC-A, B and C, were purported to represent arisings from helicopter transmissions, the remainder coded NAPC-D through N comprising arisings from turbine engines. We understood that these arisings had been collected from a number of different USA military aircraft bases without taking special precautions to exclude contamination by materials outside the engine environment.

3. Sampling for Inspection

A one litre sample for preliminary and final inspection was withdrawn from each drum of used lubricant immediately after the content thereof had been thoroughly agitated by means of dry nitrogen gas.

4. Preliminary Inspection

The samples were first inspected in accordance with the minimum quality preliminary inspection (MQPI) schemes given in (1)*, and reproduced here in Figures 1,2,3 and 4.

The appearances and odours of the samples are recorded in Table 1. Five of the samples fell into Group I, and the remaining eight fell into Group III of the MQPI Groups in Figure 1; the appearances of the samples were adjudged by placing aliquots in 250 ml measuring cylinders and viewing them diametrically by transmitted and reflected daylight.

4.1. MQPI Group I Samples

The five samples in this group were examined in accordance with the scheme for MQPI Group I in Figure 2. All these samples, after removal of volatile contaminants, and filtration where necessary, exhibited normal appearance and odour, thereby indicating that their abnormal appearances originally would be eliminated during reprocessing by the Dalton reclamation technology.

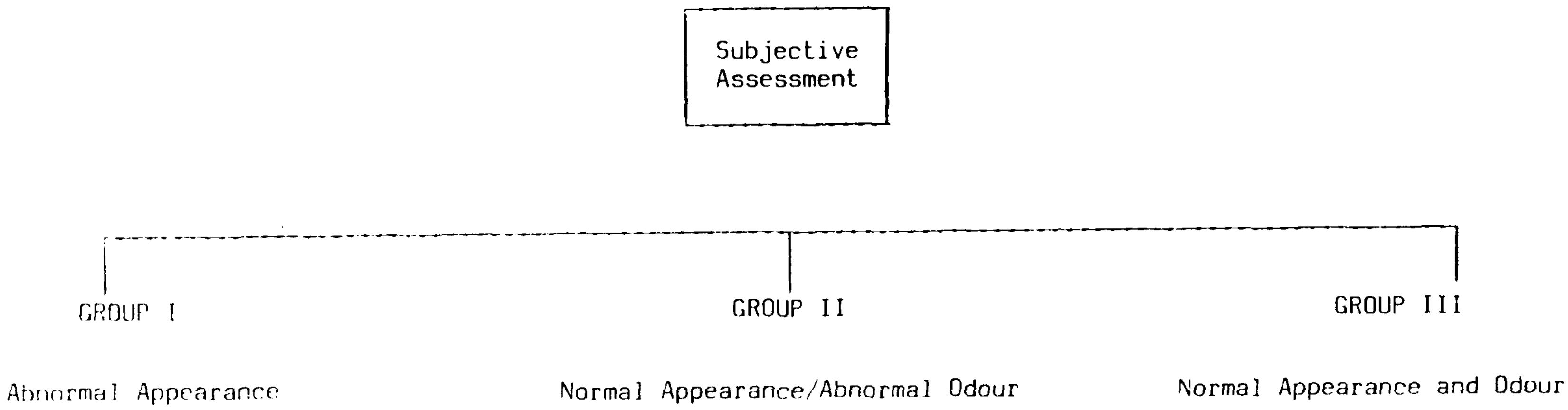
4.2. MQPI Group III Samples

Referring to the scheme for MQPI Group III in Figure 4, volatile hydrocarbon content (VHC) was determined by GLC in accordance with STM.No. 2 which has been given in (2). All eight samples in this group, with the single exception of NAPC-C, were found to contain more than 1 percent VHC, and it was therefore necessary in accordance with Figure 4 to determine and eliminate the volatile contaminant content (VCC) of each sample, other then NAPC-C. No need existed for doing this in the case of NAPC-C since this sample was found to contain less than 1 percent VHC but, by way of confirming the validity of the VHC result, the VCC of this sample was in fact determined.

4.3. VCC Results

VCC was determined and at the same time substantially removed from the samples by means of STM. No. 1 which has been given in (3).

* Numbers in parenthesis denote references at end of report.



NOTE: Kerosene odour and/or appearance of free-water <u>not</u> regarded as abnormal in application of the above scheme.

Figure 1 - Minimum Quality Preliminary Inspection (MQPI) Groups

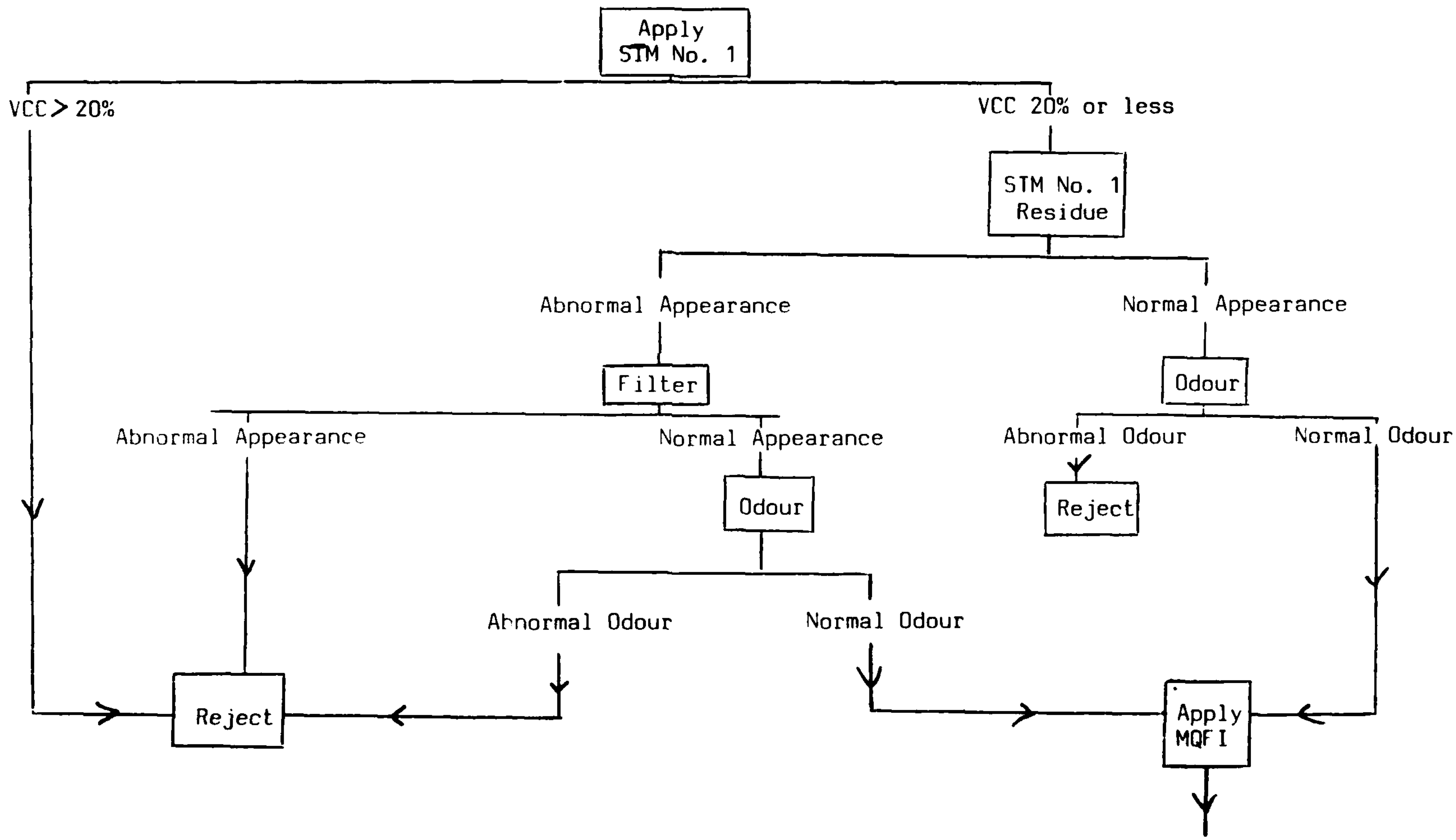


Figure 2 Scheme for Examination of MQPI Group I Samples (Abnormal Appearance)

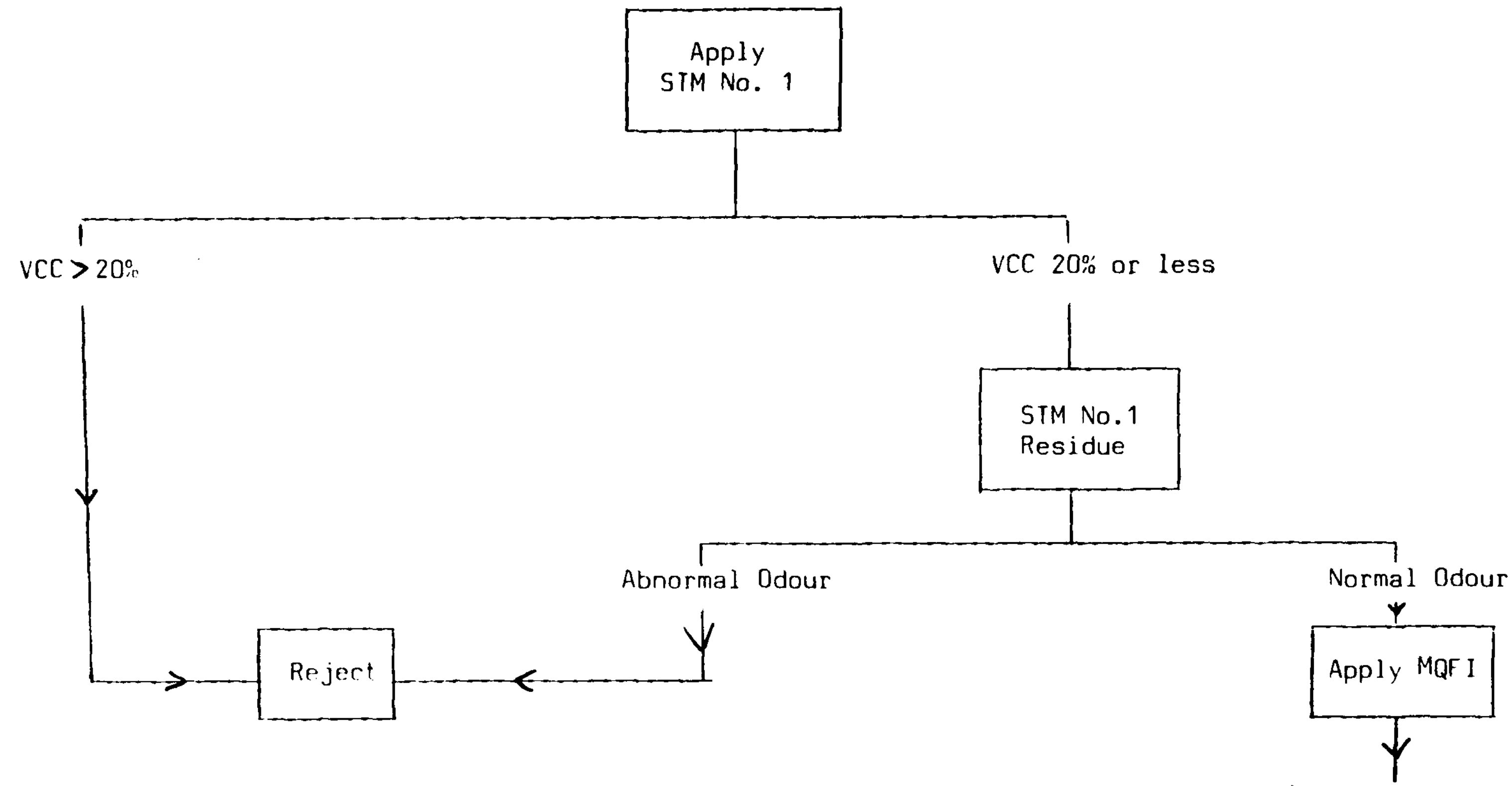


Figure 3 - Scheme for Examination of MQPI Group II Samples (Normal Appearance/Abnormal Odour)

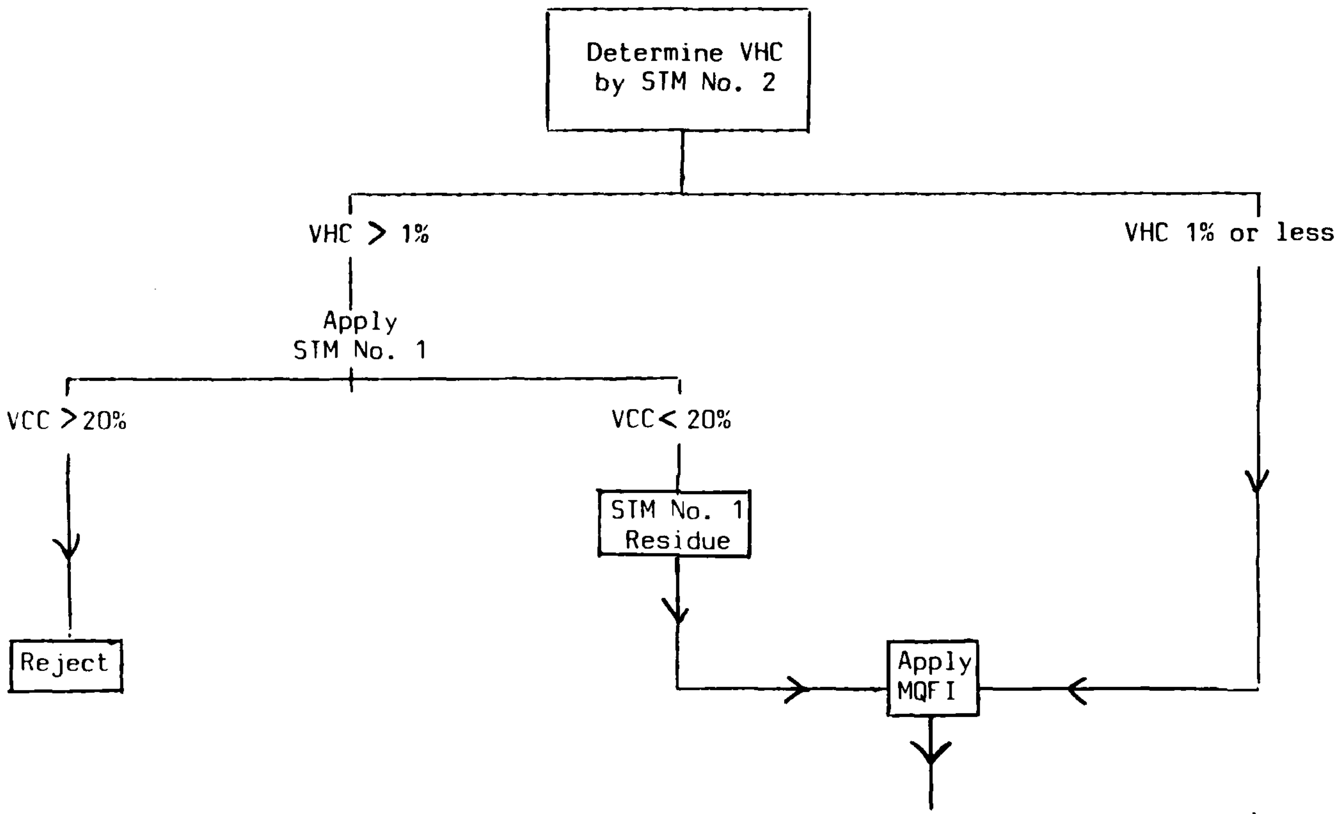


Figure 4 - Scheme for Examination of MQPI Group III Samples (Normal Appearance and Odour)

Table 1

Appearances and Odours of Used Lubricant Samples

Sample	Appearance	Odour	MQPI Group Number Classification (Fig.1)
NAPC-A	Red-Brown/Clear	Faint Kerosene	III
NAPC-B	Red-Brown/Clear	Faint Kerosene	III
NAPC-C	Red-Brown/Clear	Normal	III
NAPC-D	Red-Brown/Opalescent/Wet	Kerosene	I
NAPC-E	Dark-Amber/Cloudy	Kerosene	I
NAPC-F	Red-Brown/Cloudy	Kerosene	I
NAPC-G	Red-Brown/Opalescent	Kerosene	I
NAPC-H	Red-Amber/Clear/Wet	Strong Kerosene	III
NAPC-I	Red-Amber/Cloudy	Kerosene	I
NAPC-J	Red-Brown/Clear	Kerosene	III
NAPC-K	Red-Brown/Clear	Kerosene	III
NAPC-L	Red-Brown/Clear/Wet	Kerosene	III
NAPC-M	Amber/Clear	Strong Kerosene	III

The volatile contaminant contents of the 13 samples of used lubricants are presented in Table 2 which shows that nine samples failed to comply with the MQPI requirement of not more than 20 percent VCC, thereby leaving only four samples for final inspection. Thus, even assuming the latter were found upon final inspection to be acceptable for reclamation, only four drums of the used lubricants could have been released for the reclamation exercise.

The limit of 20 percent maximum VCC in the MQPI was imposed purely on economical grounds. Volatile contaminant contents exceeding this limit can be removed by the Dalton reclamation technology, but at the expense of increased operational cost and reduced yield of reclaimed product. However, in order to utilise as many drums of the collected material as possible in carrying out the reclamation exercise for assessment of the quality of reclaimed product, the decision was taken to uplift the VCC limit from 20 to 30 percent maximum. The MQPI modified in this respect only will be hereafter referred to as MQPI/2.

Based upon this modification, NAPC-H and NAPC-M are shown in Table 2 as the only samples which were rejected on account of excessive VCC.

NAPC-H behaved erratically during the determination of VCC, and was suspected to consist mainly of something other than turbine engine lubricant.

5. Specific Gravity; VCC Distillates and NAPC-H

The work so far described completed preliminary inspection of the samples in accordance with the procedure and requirements specified by MQPI/2, but by way of furnishing additional data which were felt would be of interest, the following work was also carried out:

(a) Determination of the specific gravities of the samples before, and after, removal of VCC in accordance with STM. No. 1.

(b) Determination of the specific gravities of the VCC distillates obtained from the used samples, excepting those from NAPC-A, B and C which were too small to invite further attention.

(c) Comparison of the chromatograms obtained upon GLC examination of the VCC distillates, excepting those from NAPC-A, B and C, with chromatograms obtained for Avgas, Avtur and Avcat turbine fuels by the same GLC methodology.

5.1. Results and Discussion

The results are presented in Table 3 in which the VCC results in Table 2 have been brought forward for ready comparison with the specific gravity results.

Excluding for the moment NAPC-H, the GLC results indicated Avcat turbine fuel to be the main component of the volatile contaminant in

Table 2

Volatile Contaminant Contents of

Used Lubricant Samples

Sample	VCC % w/w	Remarks*
NAPC-A	1.1	Released for final inspection
NAPC-B	1.1	Released for final inspection
NAPC-C	0.3	Released for final inspection
NAPC-D	22	Released for final inspection
NAPC-E	26	Released for final inspection
NAPC-F	25	Released for final inspection
NAPC-G	29	Released for final inspection
NAPC-H	49	Rejected
NAPC-I	20	Released for final inspection
NAPC-J	25	Released for final inspection
NAPC-K	22	Released for final inspection
NAPC-L	26	Released for final inspection
NAPC-M	42	Rejected

* Only four samples pass the original MQP1 in which VCC tolerance = 20% max.

Eleven samples pass MQPI/2 which differs only from original MQPI in respect of greater VCC tolerance of 30 percent maximum.

Table 3

Specific Gravities and VCC Distillates

Sample	Specific Gravity 60°F/60°F		VCC % w/w	VCC Distillate from Sample	
	Before Removal of VCC	After Removal of VCC		Specific Gravity 60°F/60°F	Inference from GLC
NAPC-A	0.995	0.996	1.1	-	-
NAPC-B	0.994	0.996	1.1	-	-
NAPC-C	0.996	0.996	0.3	-	-
NAPC-D	0.951	0.995	22	0.81	Avcat
NAPC-E	0.935	0.984	26	0.80	Avcat + Minor proportion avtur
NAPC-F	0.942	0.997	25	0.80	Avcat + small proportion volatile solvent
NAPC-G	0.935	0.993	29	0.81	Avcat
NAPC-H	0.895	0.991	49	0.88	Abnormal chromatogram
NAPC-I	0.955	0.995	20	0.81	Avcat
NAPC-J	0.943	0.994	25	0.81	Avcat
NAPC-K	0.947	0.991	22	0.81	Avcat
NAPC-L	0.939	0.994	26	0.80	Avcat
NAPC-M	0.914	0.996	42	0.80	Avcat

most of the remaining samples, this being consistent with the specific gravities of the VCC distillates.

The specific gravities of the samples before removal of VCC are seen to decrease with increasing VCC which also is consistent with Avcat contamination; deviations from a precise correlation could be due to differences between the specific gravities of the virgin lubricants from which the used arisings had emanated and/or possible presence of non-volatile contaminants such as mineral oil for example.

The specific gravities of the samples after removal of VCC lie within the range 0.965 to 1.010 experienced by Dalton for commercial 5 cSt polyol-ester lubricants. Lubricants qualified against MIL-L-23699 may perhaps exhibit less difference between their range of specific gravities, but the specific gravity of NAPC-E in particular, is somewhat lower than the results obtained for the other samples after removal of VCC.

5.1.1. Sample NAPC-H

The evolution of vapour from this sample during the determination of VCC was accompanied by violent ebullition and "bumping," and we suspected that this may have resulted in some carryover with the VCC distillate of unvapourized material.

GLC examination of the VCC distillate inclusive of unvapourized material which may have been carried over indicated about 5% turbine fuel in some other material exhibiting entirely different GLC characteristics.

A sample of NAPC-H in the "as received" condition, i.e. without removal of VCC, was therefore examined by GLC, and the chromatogram was compared with that obtained under the same conditions for a sample of NAPC-F in the "as received" condition.

The chromatogram for NAPC-F exhibited good separation of the Avcat contaminant peaks from those eluted later by the lubricant base - stock as illustrated in Figure 5. In contrast, NAPC-H produced a chromatogram typical of mineral oil giving most of the peaks in the zone separating the polyol-ester peaks from those produced by turbine fuel as illustrated in Figure 6 which also shows that only a minor proportion of polyol-ester was evident.

The following results were obtained from additional tests carried out on NAPC-H in the "as received" condition:

Saponification value ..... 56 mg KOH/g
KV @ 100°F 18.8
KV @ 200°F 3.99

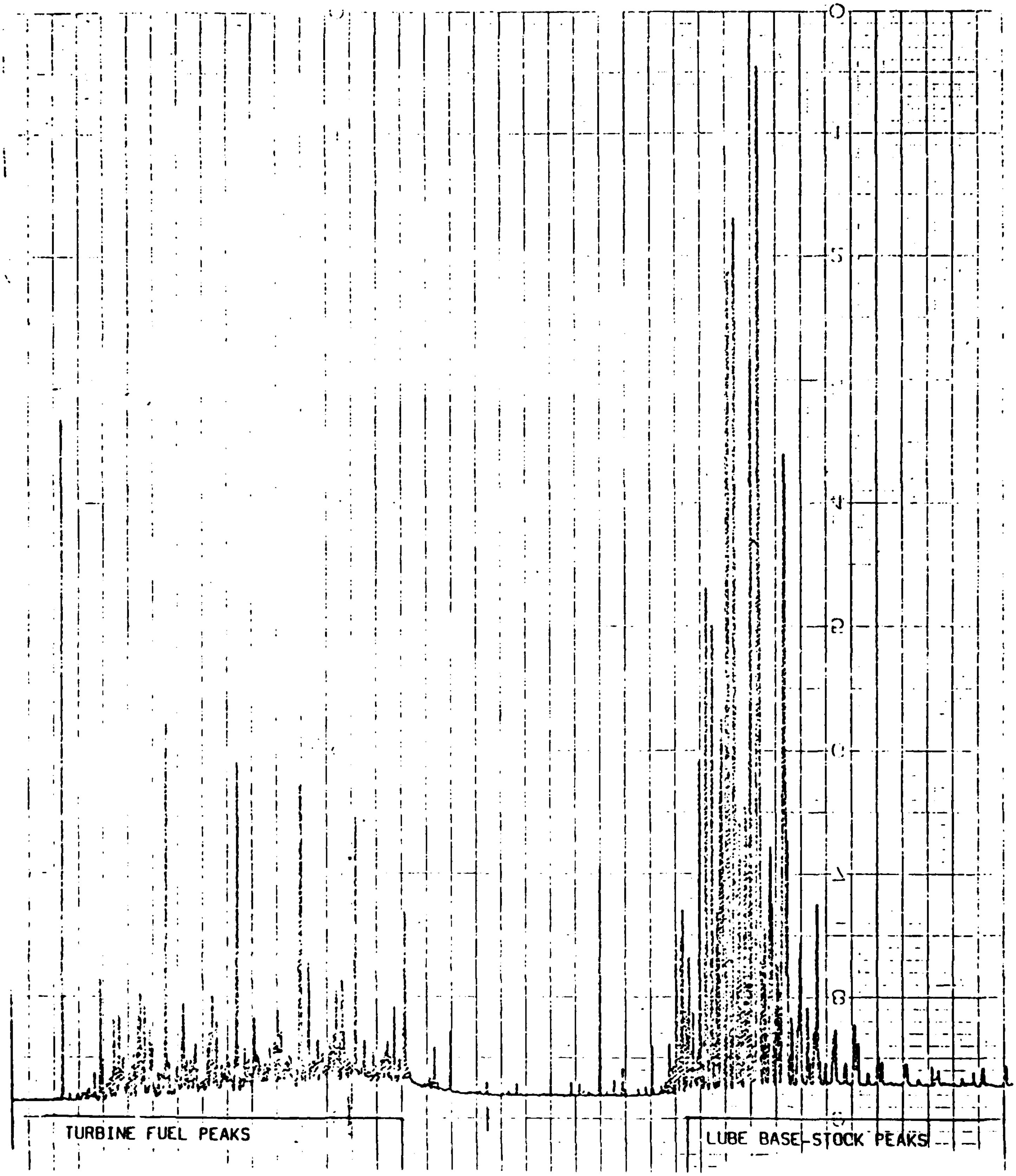


Figure 5...GLC Chromatogram for sample NAPC-F in the "as received" condition.

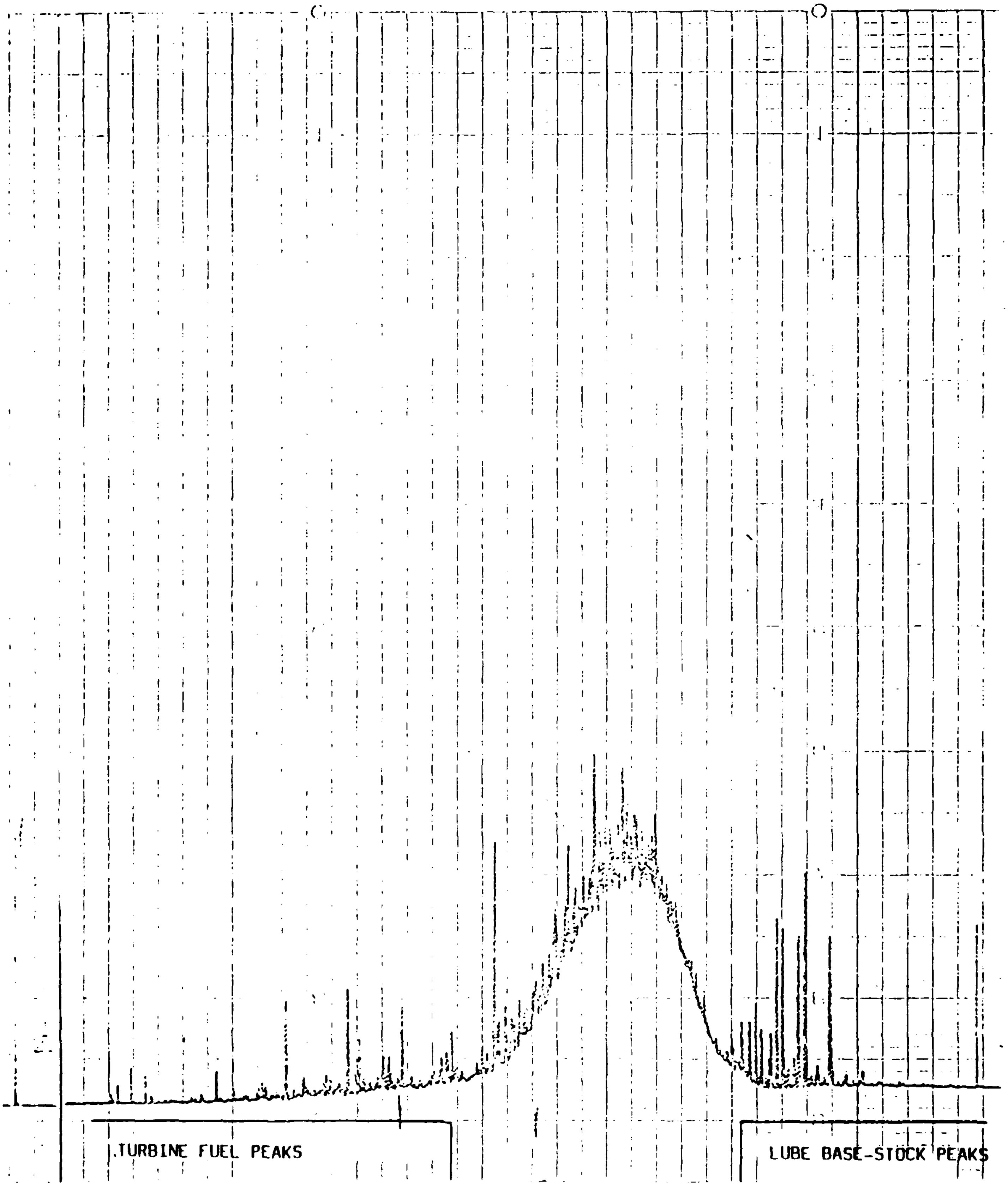


Figure 6...GLC Chromatogram for sample NAPC-H in the "as received" condition.

From these results, we conclude that the bulk of NAPC-H does not consist of MIL-L-23699 but a light fuel oil or light mineral-oil lubricant.

6. Final Inspection

The used lubricant samples, apart from the two rejected by MQPI/2, were subjected, after removal of VCC in accordance with STM. No. 1, to the minimum quality final inspection (MQFI) scheme (4) originally devised for used MIL-L-7808 lubricants, but modified herein in respect of the limits for viscosity and saponification value. These modified limits are based upon Dalton's experience of 5 cSt polyol-ester commercial turbine engine lubricants, and the MQFI modified in this way only will be hereafter referred to as MQFI/2 which is presented in Figure 7.

The foaming categories in MQFI/2 are thus the same as those in MQFI which were based upon foaming tests carried out in accordance with Fed. Std. Method 3213 as specified in MIL-L-7808, and which is considered by Dalton to be more severe than ASTM.D892 as specified in MIL-L-23699. Foaming tests in accordance with both these specifications were scheduled to be carried out on the categories of blended samples after application of the reclamation technology and additive treatment.

The results obtained upon inspection of the samples in accordance with the MQFI/2 are presented in Table 4. Included, though not required by the MQFI/2, are the results of viscosity measurements at 210°F which we thought would be of additional interest in view of the somewhat low results obtained at 100°F. The following comments are relevant:

6.1. Viscosity

The KV at 100°F of NAPC-E fails to comply with the MQFI/2 requirement of not less than 25 cSt., and the KV at 210°F is abnormally low.

The viscosities of the remaining samples comply with the MQF /2 requirement but, apart from NAPC-A, B and C, are significantly lower than would be expected for used MIL-L-23699 lubricants.

These lower viscosities, apart from that of NAPC-E, may be attributed to the high turbine fuel contents of the original samples in consequence of which the VCC - stripped samples contained more residual fuel than would have been the case at lower levels of fuel contamination. For example, STM. No. 1 has been found (5) to strip off about 97 percent of Avtur contamination, and residual fuel from say, 26 percent Avtur contamination would therefore amount to 0.8 percent. This, in the experience of Dalton, would be sufficient to lower the KV of the VCC-stripped sample at 210 and 100°F by about 0.2 and 2.0 centistoke units respectively.

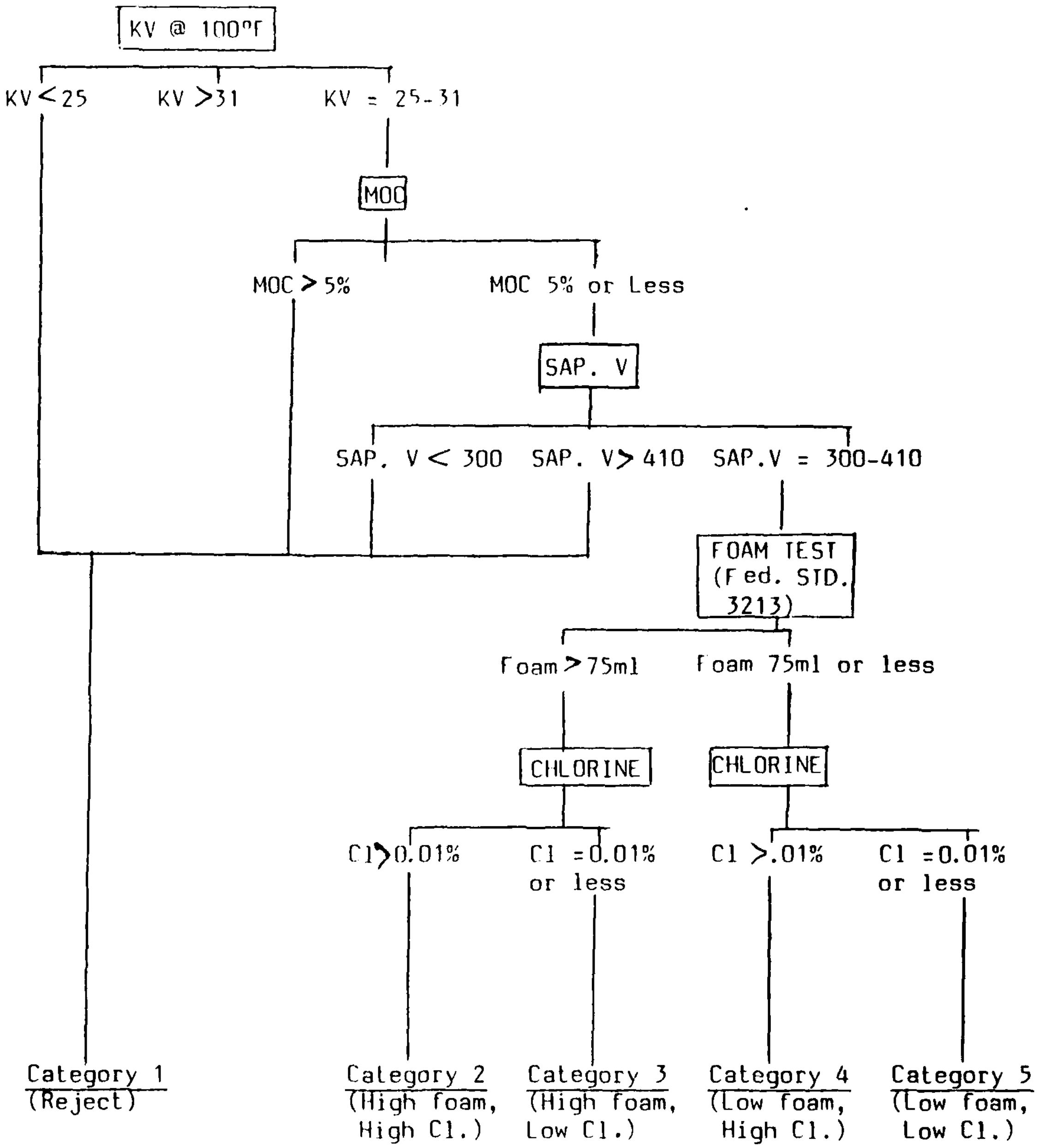


Figure 7 - Minimum Quality Final Inspection (MQFI/2) Scheme

Table 4

MQFI/2 Results for Samples Released by MQPI/2

Sample	KV @		MOC %	Sap V	Foam*		Cl %	Categroy Characterisation
	100°F	210°F			Vol, ml	Collapse, Secs		
NAPC-A	28.[illegible]	5.22	nf	370	500 in 20 secs	80 from 500 mls	<0.01	3 (High foam, low chlorine)
NAPC-B	27.8	5.17	nf	364	500 in 19 secs	73 from 500 mls	<0.01	3 (High foam, low chlorine)
NAPC-C	28.0	5.18	nf	369	490	80	<0.01	3 (High foam, low chlorine)
NAPC-D	26.9	5.05	< 5	373	100	44	<0.01	3 (High foam, low chlorine)
NAPC-E	24.7	4.74	Approx 7.5	342	430	94	<0.01	1 (Reject)
NAPC-F	26.8	5.04	< 5	377	190	70	<0.01	3 (High foam, low chlorine)
NAPC-G	26.1	4.97	<5	377	500 in 430 secs	90 from 500 mls	<0.01	3 (High foam, low chlorine)
NAPC-I	26.4	4.97	< 5	377	470	61	<0.01	3 (High foam, low chlorine)
NAPC-J	26.2	4.94	< 5	374	440	98	<0.01	3 (High foam, low chlorine)
NAPC-K	25.7	4.90	< 5	364	500 in 125 secs	79 from 500 mls	<0.01	3 (High foam, low chlorine)
NAPC-L	26.0	4.91	< 5	373	420	78	<0.01	3 (High foam, low chlorine)

* Fed.St. Method 3213

nf = not found

With regard to the rejected sample NAPC-E, this contained 26 percent VCC, but the residual fuel content viz., 0.8 percent of the VCC-stripped sample falls far short of that which would lower the KV to the observed values, and the low KV of this sample must therefore be due to the presence of some other contaminant.

6.2. Mineral Oil Content

Compliance of the samples with the MQFI/2 limit for mineral oil content of 5 percent maximum was assessed by TLC which was carried out in accordance with STM No. 3 which has been given in (6). This method employs a saturated solution of dimethyl sulphoxide in cyclohexane as eluent, and a solution of antimony pentachloride in carbon tetrachloride as reagent for the chromatogram.

Mineral oil contents exceeding 3 percent are indicated by two reaction manifestations, the one normally employed in adjudging mineral oil content having an Rf value X100 between 40 and 60. However, apart from samples NAPC-A, B and C which produced no reaction at all, the concentrations of residual turbine fuel in the VCC-stripped samples were found to be sufficiently high to produce reaction manifestations in the same Rf range, thereby prohibiting adjudgement of mineral oil content from the intensity of the reaction manifestation in this range.

Chromatograms obtained upon applying the method to (A) standards prepared by adding known amounts of Avtur to NAPC-C, and (B) standards prepared by adding known amounts of mineral oil (DERD.2490) to NAPC-C were therefore studied to ascertain whether a reaction manifestation given by mineral oil in a different Rf range could be utilized. The chromatograms obtained are summarized in Table 5 which shows that a brown reaction spot produced in the RfX100 range 85-95 is sufficiently divorced from the Avtur reaction manifestation for adjudgement of mineral oil content.

This is borne out by the chromatograms obtained for the VCC-stripped samples which are summarised in Table 6. All the samples, excepting NAPC-A, B and C, produced the Avtur reaction manifestations in the RfX100 range 45-70. No reaction was produced by the latter three samples, the residual fuel contents of which were negligible in consequence of the low values obtained for VCC in the original samples. Included in Table 6 are the results obtained upon application of the method to three unused MIL-L-23699 lubricants supplied by AFWAL, and which are seen to have produced no reaction at all.

Chromatograms obtained upon applying the method to standards prepared by adding known amounts of Avcat fuel to NAPC-C produced reaction manifestations identical with those produced by Avtur.

Table 5

TLC Reaction Manifestations and Rf Values Given by Mineral Oil (DERD. 2490) and Avtur Turbine Fuel

Contaminant	RfX100 Range	Reaction Manifestation
Mineral Oil	55 - 75	Narrow elliptic brown stain
	85 - 95	Brown spot
Avtur	45 - 55	Bluish-grey spot
	55 - 70	Diffuse elliptic brown stain

Table 6

TLC Reaction Manifestations Given by VCC-Stripped Used Lubricant Sample and by Unused Lubricant Samples

Sample	Brown Spot in RfX100 Range 85 - 95	Elliptic Brown Stain In RfX100 Range 55 - 70	Bluish-Grey Spot in RfX100 Range 45 - 55
VCC-Stripped Used Samples			
NAPC-A	No	No	No
NAPC-B	No	No	No
NAPC-C	No	No	No
NAPC-D	Yes	Yes	Yes
NAPC-E	Yes	Yes	Yes
NAPC-F	Yes	Yes	Yes
NAPC-G	Yes	Yes	Yes
NAPC-I	Yes	Yes	Yes
NAPC-J	Yes	Yes	Yes
NAPC-K	Yes	Yes	Yes
NAPC-L	Yes	Yes	Yes

Unused Samples

MIL-L-23699B, AM.2 American Oil Supply, May 79	No	No	No
MIL-L- 23699C, AM.1 American Oil Supply, Aug 85	No	No	No
MIL-L-23699C, Hatco Chem. Corp., Aug 80	No	No	No

Table 6 shows that all the samples, except NAPC-A, B and C, contained mineral oil as inferred from the brown spots in the RfX100 range 85-95. The mineral oil contents in Table 4 were adjudged by comparing the intensities of these spots with those produced in the same Rf range by the mineral oil standards.

All the samples, excepting NAPC-E, are seen to comply with the MQFI/2 requirement of not more than 5 percent mineral oil, the MOC of NAPC-E being of the order of 7.5 percent.

6.3. Saponification Value

Saponification values were determined in accordance with joint ASTM.D99-IP.136A except that a sample weight of 1g was taken, and saponified for 3 to 3½ hours using potassium hydroxide prepared by dissolving KOH in reagent grade dehydrated ethanol in place of the 95% ethanol specified; these modifications stem from early Rolls-Royce experience when we found that the polyol-ester turbine engine lubricants are more difficult to saponify completely than those based upon diesters.

The saponification values of all the samples are seen to fall well within the range specified by the MQF1/2, but the result obtained for NAPC-E is significantly lower than those obtained for the other samples. This however would be expected from the relatively high MOC of NAPC-E.

6.4. Foaming Propensity

The foam results in Table 4 were obtained from tests carried out in accordance with Fed. Std. Method 3213 which briefly, specifies an air-flow rate of 1000 mls/min. for 30 minutes duration with the lubricant sample maintained at 80^{o}C.

During the early part of each test, the foam-liquid interface was well defined but, as the foam increased during the later part of the 30 minutes test duration, the foam in the majority of the tests was observed to mingle with air entrained in the turbulent liquid phase, and it then became difficult to discern the true foam-liquid interface.

The foam volumes recorded in Table 4 cannot therefore be regarded as precise, but in spite of this the high foam volumes observed leave no doubt that in the context of MQFI/2 and MIL-L-7808, all the samples are very high foamers indeed. In contrast, very low results were obtained, as presented in Table 7 , when the method was applied to three unused MIL-L-23699 lubricants supplied by AFWAL, and a sample taken from some shelf-life expired MIL-L-23699 purchased by Dalton; the foam-liquid interface was well defined throughout the test duration in each of these tests.

Table 7

Foaming Propensities (Fed. STD. Method 3213)

Of Unused MIL-L-23699 Lubricants

Sample	Foam	
	Vol - ml	Collapse - Secs
MIL-L-23699B, Am.2, American Oil Supply May 79	10	12
MIL-L-23699C, Am.1, American Oil Supply, May 85	10	16
MIL-L-23699C., Hatco Chem. Corp., Aug 80	15	11
Shelf-life expired MIL-L-23699	Trace	--

Presented in Table 8 as a matter of interest are the results obtained when the used lubricant samples were tested in accordance with Fed. Std. Method 3213 but with the single exception that the air-flow rate was lowered from 1000 to 100 mls/min. This represents the test conditions employed by Rolls-Royce in defining their foaming propensity requirement of not more than 500 ml foam volume and not more than 120 secs foam collapse time for 5 cSt turbine engine lubricant.

The foam-liquid interface was well-defined throughout the whole of the test duration in each of these tests, and it is evident in the results that all the used lubricants are low foamers in the context of Rolls-Royce requirements.

6.5. Chlorine

The samples were tested for chlorine by fusion of 1g aliquots with sodium (Lassaigne's Test), and identification as silver chloride after expulsion of any hydrocyanic acid from the acidified extract of the sodium salt. The intensities of the silver chloride opalescence were compared visually with that produced in parallel upon adding silver nitrate solution to an acidified solution of sodium chloride equivalent to 0.01 percent chlorine.

Adjudged in this way, only traces of chlorine well below 0.01 percent were found, this indicating absence of chlorine - containing additives.

6.6. MQFI/2 Category Characterisation

The categories into which the eleven samples fall are presented in Table 9. They fall into the following two of the five categories of the MQFI/2 scheme in Figure 7.

Category 1 (Reject) .... 1 sample
Category 3 (High foam, low chlorine) ..... 10 samples

Expressed in nearest whole numbers on total samples received viz. thirteen, 8 percent of the samples fall into category 1, and 77 percent fall into category 3, the remaining 15 percent comprising the two samples which failed against the MQPI/2.

Thus, at least 23 percent of the samples are unacceptable for reclamation on account of inadequate housekeeping during their collection, and for the same reason, the yield of reclaimed product from the remainder which are acceptable for reclamation will be reduced by their high fuel contents, apart from NAPC-A, B and C, regardless of the efficiency of the reclamation technology.

Table 8

Foaming Propensities of VCC-Stripped Used Lubricant Samples. (Fed. STD. Method 3213, But Air-Flow Rate Lowered From 1000 to 100 mls/Min).

Sample	Foam	
	Vol - ml	Collapse - Secs
NAPC-A	100	16
NAPC-B	130	30
NAPC-C	145	39
NAPC-D	25	12
NAPC-E	160	37
NAPC-F	140	35
NAPC-G	45	26
NAPC-I	150	55
NAPC-J	50	27
NAPC-K	70	28
NAPC-L	35	19

7. Feedstocks for Reclamation

Referring to Table 9, the lubricants in Category 3 would be blended together under normal circumstances to produce one feedstock. However, since the first three of the lubricants listed comprised arisings from helicopter transmissions, and the remainder comprised arisings from turbine engines, we felt it would be of interest if the lubricants from these two sources were divorced from each other and reclaimed separately. Accordingly, two feedstocks designated Cat 3/H and Cat 3/T were prepared from Category 3 by blending together the lubricants as listed in Table 10.

7.1. The seven drums of used lubricants allocated for preparing CAT.3/T feedstock were blended together after cleaning and flushing out the blending plant thoroughly with shelf-life expired MIL-L-23699 purchased by Dalton to ensure removal of residual drag-out from used 7.5 cSt commercial turbine engine lubricant which was the last material that was in the plant. The shelf-life expired MIL-L-23699 contained less than 1 percent VCC, and it's foaming propensity, determined in accordance with Fed. Std. method 3213, was very low viz. foam volume traces, foam collapse time less than one second.

The three drums of used lubricants allocated for preparing CAT.3/H feedstock were blended together in the same plant after having cleaned and flushed out the latter thoroughly with a further quantity of the shelf-life expired MIL-L-23699 to ensure removal of drag-out foam CAT.3/T feedstock.

7.2. Examination of Feedstocks

Results obtained upon examination of the feedstocks are presented in Table 11 in which the highlights are the high VCC of CAT.3/T and, after removal of VCC from the test samples by means of STM. No. 1, the high foaming propensities of both feedstocks. Also, the flash point of CAT.3/T is low, and was due, it is postulated, to residual turbine fuel in the VCC-stripped sample since this would amount to about 0.7 percent (5).

7.2.1. Note on Quinizarin

Quinizarin was detected by shaking an aliquot of the VCC-stripped test sample with powdered calcium hydroxide which, in the presence of concentrations of QZ exceeding 0.1ppm assumes a purple-blue colour, the intensity of which increases with QZ concentration.

Upon comparing the intensity of the colour with those produced upon applying the test to standards prepared by dissolving known amounts of QZ in a polyol-ester base stock, the QZ content of the test sample was adjudged to be of the order of 0.05 percent.

This technique was employed in obtaining all the QZ results in the present report.

Table 9

MQF I/2 Category Grouping of Samples

Category 1 (Reject)	Category 3 (High Foam, Low Chlorine)
NAPC-E	NAPC-A
	NAPC-B
	NAPC-C
	NAPC-D
	NAPC-F
	NAPC-G
	NAPC-I
	NAPC-J
	NAPC-K
	NAPC-L

Table 10

Feedstocks for Reclamation

Feedstocks Cat 3/H	Feedstock Cat 3/I
NAPC-A	NAPC-D
NAPC-B	NAPC-F
NAPC-C	NAPC-G
	NAPC-I
	NAPC-J
	NAPC-K
	NAPC-L

Table 11

Examination of Feedstocks for Reclamation

		Cat 3/H	Cat 3/T
VCC % (STM No.1)		0.8	24
After Removal of VCC from Samples by means of STM No. 1			
Transparency		Clear	Clear
Colour		Red-Brown	Red-Brown
Flash point (ASTM D.92) °F		480	460
KV @	210°F	5.18	5.00
	100°F	27.9	26.7
TAN (Note 1)		0.31	0.11
Saponification Value		374	376
Phosphorus - as P% (Note 2)		0.16	0.12
Foaming Propensity (Fed. STD Method 3213)	Max Foam - ml	500 in 20 secs	435
	Foam Collapse - secs	81 from 500 ml	99
Inhibitors %	DODP	0.96	0.86
	PAN	0.74	0.94
	MOPAN	<0.01	0.08
	BTZ + ABA	<0.01	nf.
	QZ	approx 0.05	approx 0.05

Note 1 Sample titrated cold with aqueous standard alkali

Note 2 Determined in accordance with ASTM D1091

nf = not found

7.2.2. Note on HPLC Methodology

The HPLC methodology given in (9) for determination of inhibitors other than QZ in MIL-L-7808 lubricants was employed except for the following two modifications which were found necessary in adapting the methodology to MIL-L-23699.

Mobile Phase

Twenty percent water in acetonitrile substituted by two percent water in acetonitrile to ensure complete solubility of MIL-L-23699 lubricants.

Column

Spherisorb ODS 10 μ substituted by Spherisorb ODS 210 μ to ensure satisfactory separation of inhibitor peaks when using the above substituted mobile phase.

The modified methodology produces from MIL-L-23699 lubricants chromatograms giving good separation of peaks produced by the inhibitors DODP, PAN, MOPAN, DOPT, NADOPT, NBDOPT, PTZ and one or the other of those produced by BTZ and ABA; the last two inhibitors are not differentiated from one another as they have the same retention times under the conditions employed.

DODP and PAN are the only two of the foregoing inhibitors which were found in the feedstocks in significant concentrations. The peak obtained for MOPAN was not all that repeatable quantitatively, and some doubt existed as to whether it really represented MOPAN or some other material such as an oxidation product for example.

This modified methodology was employed in obtaining all the HPLC results in the present report.

8. Reclamation of Feedstocks

The reclamation plant was first cleaned and flushed out thoroughly with shelf-life expired MIL-L-23699 to ensure removal of drag-out from used 7.5 cSt commercial turbine engine lubricant which was the last material reclaimed in the plant. CAT.3/T feedstock was next introduced, and reclamation was commenced by the basic technology employed for the reclamation of used MIL-L-7808 lubricants in two previous research projects (1) and (7).

Unfortunately, by the time Process 1 of that part of the technology for removing VCC (8) was almost completed, the reclamation plant was put out of action as a result of an outbreak of fire from a neighbouring plant which rapidly spread to the synthetic plant and gutted a large part of the premises. Examination of a sample taken from the partly processed feedstock confirmed that it had not suffered great damage, due no doubt to the remoteness of the VCC-stripping plant from the main part of the reclamation facility where most of the damage had occurred.

After a delay of 7 months in restoring the premises to normal working conditions, and desperate attempts to rectify damage to the main plant, the latter was again cleaned and flushed out thoroughly with shelf-life expired MIL-L-23699, and an attempt was made to complete the reclamation of CAT.3/T. However, further delays were incurred in combating a large amount of unscheduled shut-downs. Evidently the fire had caused more extensive and serious damage to the plant than had at first been apparent. We decided that practically the whole plant would have to be reserviced and much of the equipment renewed if to regain trouble-free performance and functional flexibility, but in view of time constraints and the delays already incurred, this would have taken too long to accomplish, and was therefore ruled out.

The decision was then taken to continue the processing in the damaged plant despite the fact that under these conditions it would not be possible, due to erratic behaviour of the plant, to ensure strict compliance of the processing with the established reclamation technology.

CAT.3/T and CAT.3/H feedstocks were reclaimed, on this basis, up to the last process step comprising additive treatment.

8.1. Inspection of Reclaimed Feedstocks before Additive Treatment

Results obtained upon inspection of the reclaimed feedstocks are presented in Table 12, which shows that the viscosity at 210°F and open flash point of CAT.3/T fall below the MIL-L-23699 requirements for these criteria of not less than 5.00 cSt and not less than 475°F respectively. Both CAT.3/T and CAT.3/H fail to comply with the static foam test requirements of the USAF specification MIL-L-7808.

The low viscosity and flash point of CAT.3/T could be due to residual heavy-ends from the original high fuel content (VCC=24 percent), and which the damaged plant may not have removed sufficiently. In contrast, CAT.3/H which originally contained very little fuel (VCC = 0.8 percent) complies with the viscosity and flash point requirements of MIL-L-23699.

It is highly probable that the viscosity and flash point of CAT.3/T could have been brought within specification requirements by modification of operational conditions but confirmation of this was precluded by the damaged state of the plant.

Table 12

Inspection of Reclaimed Feedstocks

Before Additive Treatment

		Cat 3/T	Cat 3/H
Transparency		sparkling clear	sparkling clear
Colour		Red Amber	Red Amber
Flash point (ASTM. D92) °F		460	485
KV @	210°F	4.91	5.03
	100°F	26.0	27.0
TAN (Note 1)		0.06	0.05
Saponification Value (Note 2)		381	375
Phosphorus - as P% (ASTM.D1091)		0.12	0.19
Foaming Propensity (Fed.STD Method 3213)	Max Foam - ml	500 in 15 secs	500 in 18 secs
	Foam Collapse - secs	130 from 500ml	92 from 500ml
Inhibitors %	DODP	0.92	1.01
	PAN	0.74	0.73
	MOPAN	0.02	0.01
	BTZ + ABA	0.01	0.01
	QZ	approx 0.02	approx 0.04

Note 1 Sample titrated cold with aqueous standard alkali.

Note 2 In accordance with joint ASTM D99-1P. 136A except that a sample weight of 1g was taken, and saponified for 3 to 3½ hours using alcoholic potassium hydroxide prepared by dissolving KOH in reagent grade ethanol in place of the 95% ethanol specified.

The high foaming propensities of the two feedstocks after reclamation are disappointing, and presumably indicate the presence in the reclaimed feedstocks of foaming contaminants which cannot be removed by the Dalton technology. This would seem to be the most likely explanation in view of the high foaming propensities of the feedstocks before reclamation. However, copious quantities of detergents and other surface-active materials had been employed in attempts to clean the plant after the fire, and the possibility cannot be dismissed that traces of these, sufficient to contribute significantly to the foaming propensities of the reclaimed feedstocks, may have remained in the plant despite the final flushing with shelf-life expired MIL-L-23699 of low foaming propensity. It may be pertinent to add that all previous experience at Dalton in the application of the reclamation technology to commercial arisings of MIL-L-23699 type lubricant has resulted in some lowering of foaming propensity before additive treatment.

9. Additive Treatment of Reclaimed Feedstocks

Based upon Dalton experience, and the results in Table 12, approximately 0.05% BTZ was introduced into each of the reclaimed feedstocks CAT. 3/T and CAT. 3/H in producing the final products designated CAT. 3/T/F and CAT.3/H/F respectively.

The BTZ employed consisted of "purified benzotriazole" supplied by Ciba-Geigy. No other additives were introduced in view of the high foaming propensities of the reclaimed feedstocks.

10. Evaluation of Additive-treated Reclaimed Feedstocks

Results obtained upon partial laboratory evaluation of the finished products CAT. 3/T/F and CAT. 3/H/F are presented in Tables 13 through 17.

The properties of both products in so far as are revealed by the limited scope of this partial evaluation, are considered by Dalton to be satisfactory apart from the contentious features highlighted below under 10.1.

Oxidative stability in terms of effective-life at 180° and 225°C was determined in accordance with the procedure specified in Rolls-Royce method 1001/Supp. 1 and 2, a summary of which has been given in (10) and further explained on page 70 of the same reference.

Presented in Table 17 are the 192-hour assessment-level temperatures (11) for the two products as calculated for each of the four degradation modes from the determined effective-lives at 180°C and 225°C. These compare favourably with data obtained by Floyd upon applying the Rolls-Royce oxidation test to specification QPL MIL-L-23699 lubricants in 1969 (12), and they fall into Type II of the Rolls-Royce classification of oxidative stability (13).

Table 13

Test Results on Reclaimed Feedstocks
After Additive Treatment

			Cat 3/T/F	Cat 3/H/F
Transparency			Bright & Clear	Bright & Clear
Colour			Red-Amber	Red-Amber
Flash Point (ASTM. D92)°F)			470	485
KV @	210°F		4.91	5.04
	100°F		26.0	27.0
TAN (Note 1)			0.28	0.27
Saponification Value			386	380
Phosphorus - as P% (Note 2)			0.13	0.19
Chlorine %			< 0.01	< 0.01
Hydrolytic Stability (RR,1006, Issue2)	$D^{90}_{1.5}$ - hrs		61	33
	$D^{70}_{1.5}$ - hrs		202	119
	$D^{40}_{1.5}$	hrs	1218	815
		Lunar Months	1.8	1.2
Foaming Propensity (Fed. STD. Method 3213)	Max Foam - ml		500 in 18 secs	385
	Foam Collapse - secs		107 from 500 ml	50
Trace Elements - ppm (Note 3)	Aluminium		1	1
	Iron		1	1
	Chromium		1	1
	Silver		1	1
	Copper		1	1
	Tin		1	3
	Magnesium		1	1
	Nickel		1	1
	Titanium		2	2
	Dirt Silicon		2	1

Note 1 Sample titrated cold with aqueous alkali
Note 2 Determined in accordance with ASTM D1091
Note 3 Spark Emission

Table 13 Continued

		Cat 3/T/F	Cat 3/H/F
Inhibitors %	DODP	0.93	0.98
	PAN	0.74	0.73
	MOPAN	0.01	0.01
	BTZ	0.055	0.053
	QZ	approx 0.03	approx 0.04

Effective Life in Hours at 180°C

		Cat 3/T/F	Cat 3/H/F
Degradation Mode	Volatilisation Loss	725	>1000
	Acidity Increase	>1000	>1000
	Viscosity Increase	930	>1000
	Benzene Insolubles Increase	>1000	700

Effective Life in Hours at 225°C

		Cat 3/T/F	Cat 3/H/F
Degradation Mode	Volatilisation Loss	25	22
	Acidity Increase	15	11
	Viscosity Increase	17	12
	Benzene Insolubles Increase	91	81

Table 13 Continued

Corrosivity 192 hours/150°C

Corrosion (RR 1002) After Pretreatment of Sample by 5 hours/250°C Confined Heating (RR 1004/ Supp.1

Test Specimen	Metal Weight Change -mg/cm²		Appearance of Specimen	
	Cat 3/T/F	Cat 3/H/F	Cat 3/T/F	Cat 3/H/F
Magnesium Alloy	-1.9	-1.0	Eg (m); Dg (m)	Eg (m); Dg (m)
Aluminium Alloy	< 0.1	< 0.1	0	0
Mild Steel	< 0.1	< 0.1	Dg (s)	Dg (s)
Soldered Copper	< 0.1	< 0.1	Dg (s)	Dg (m)
Lead	-49	-56	Eg(s);Dg(s)	Eg(s);Dg(s)
Copper	< 0.1	< 0.1	Dg (s)	Dg (s)
Brass	< 0.1	< 0.1	Dg (s)	Dg (s)

Descriptive Key

0 = No Change E = Etched l = Local (s) = slight
D = Discoloured P = Pitted g = general (m) = moderate
(x) = excessive * = deposition of copper

Table 14

Foaming Test "ASTM. D892-IP146 Alternative" carried out and adjudged under conditions specified by MIL-L-23699

Test Temperature	Cat 3/T/F: Foam Volume in ml at end of: 1 min blowing period	Cat 3/T/F: Foam Volume in ml at end of: 5 mins blowing period	Cat 3/T/F: Foam Collapse Period in secs. after: 1 min blowing period	Cat 3/T/F: Foam Collapse Period in secs. after: 5 mins blowing period
at 75°F (24°C)	105	180	81	110
at 200°F (93.5°C)	70	65	74	68
at 75°F (24°C) after test at 200°F (93.5°C)	105	170	108	128

Table 15

Foaming Test "ASTM. D892-IP146 Alternative"

carried out and adjudged under conditions

specified by MIL-L-23699

Test Temperature	Cat 3/H/F			
	Foam Volume in ml at end of:		Foam Collapse Period in secs. after:	
	1 min blowing period	5 mins blowing period	1 min blowing period	5 mins blowing period
at 75°F (24°C)	40	80	34	45
at 200°F (93.5°C)	40	40	57	49
at 75°F (24°C) after test at 200°F (93.5°C)	95	160	71	85

Table 16

Foaming Propensities of Finished Reclaimed Products

(Fed Std. Method 3213, but Air-Flow Rate Lowered from 1000 to 100mls/min)

	Foam	
	Vol - ml	Collapse - Secs
CAT. 3/T/F	90	90
CAT. 3/H/F	30	60

Table 17

192 - Hour Assessment-Level Temperatures

Degradation Mode	CAT.3/T/F		CAT.3/H/F		MIL-L-23699 QPL Lubes Limits °F*
	°C	°F	°C	°F	
E^{192}	196	385	199	390	378 - 390
A^{192}	200	392	193	379	367 - 397
V^{192}	197	389	199	390	378 - 393
B^{192}	210	410	205	401	400 - 425

* See Table XIII on page 29 of NAPTC-AED-1902 dated August 1969

Returning to Table 13, the losses in weight and appearances of the metal specimens in the corrosion tests are not abnormal, and are in fact a reflection of low corrosivity. The discolourations of the copper and brass specimens in particular took the form of very thin irridescent films exhibiting optical interference colours which are indicative of the effectiveness of the BTZ additive in passivating these materials.

10.1. Contentious Features

These are as follows:

10.1.1. Viscosity and Flash Point

The KV at 210°F and open flash point of CAT. 3/T/F are marginally below the minimum limits of 5.00 cSt and 475°F respectively of MIL-L-23699.

It is almost certain from experience gained in the reclamation of commercial MIL-L-23699 type lubricants that these apparent shortcomings could have been brought within specification limits by modification of processing conditions within the framework of the established technology, experimental verification of which was precluded by the damaged state of the plant.

10.1.2. Foaming Propensity

The foaming propensities of both products, when determined in accordance with Fed. Std. 3213, are seen to fail against MIL-L-7808.

Both products also fail to meet the foaming tendency and foam stability restrictions imposed by MIL-L-23699 as may be seen upon reference to Tables 14 and 15.

It may be of interest to add that both products, when tested in accordance with Fed. Std. method 3213, but with the air-flow rate lowered from 1000 to 100 mls/min, readily satisfies Rolls-Royce requirements of not more than 500 ml foam volume and not more than 120 seconds foam collapse time under these conditions as shown in Table 16.

11. Conclusions

The products obtained upon application of the Dalton reclamation technology to MIL-L-23699 lubricants collected by the USN from aircraft turbine engines and helicopter transmissions did not, in either case, satisfy the foaming tendency and foam stability requirements of MIL-L-23699.

Based upon the high foaming propensities of the used lubricants before reclamation, we concluded that their high foaming propensities after reclamation were due, not to any adverse effect of the technology, but to contamination by foreign materials during their collection and/or storage, and which the technology is incapable of removing.

The used turbine engine lubricants contained excessive quantities of turbine engine fuel, mainly Avcat in concentrations ranging from 20 to 40 percent which, it is concluded, must have gained access to the lubricants during their collection and/or storage. It is concluded that modification of processing conditions, within the framework of the Dalton reclamation technology, is feasible for removing excessive turbine fuel, but that in practise it's application to used lubricant containing more than 20 percent turbine fuel would not be cost effective.

Summing up, it is evident that special segregation and handling procedures would be necessary for the collection and storage of used MIL-L-23699 lubricants destined for reclamation by the Dalton technology.

REFERENCES

(1) AFWAL-TR-85-2017, May 1985, Final Report, Contract Number F.49620-81-C-0064.

(2) Reference (1), Appendix B.

(3) Reference (1), Appendix A.

(4) Reference (1), Fig. 12.

(5) Reference (1), Page 5.

(6) Reference (1), Appendix C.

(7) AFWAL-TR-81-2072, Aug., 1981, Final Report, Contract Number F.49620-79-C-0073.

(8) Reference (7), pages 3 and 31, Figs. 1 and 4.

(9) Reference (1), Appendix F.

(10) Reference (7), Appendix VIII.

(11) Edge, R.G., and Squires, A.T.B.P., Lubricant Evaluation and System Design for Aircraft Gas Turbine Engines, SAE No.690424, 69 April 21-24.

(12) Floyd, P.E., Performance of MIl-L-23699A Oils in the Rolls-Royce Oil Deterioration Apparatus, NAPTC-AED-1902, Aug., 1969, Page 29.

(13) Fig.2, Squires, A.T.B.P., May 1970, Rolls-Royce comments on NAPTC-AED-1902.

List of Abbreviations

Dalton........ Dalton & Company (Synthetic Products) Limited.

MQPI .... Minimum quality preliminary inspection.

MQFI .... Minimum quality final inspection.

VHC .... Volatile hydrocarbon content.

VCC .... Volatile contaminant content.

STM .... Supplement test method.

GLC .... Gas liquid chromatography.

cSt .... Centistoke

KV .... Kinematic Viscosity in cSt units.

TLC .... Thin layer chromatography.

Rf .... Ratio of the distance of the centre of the reaction manifestation in TLC from the starting line to the solvent front.

SAP.V .... Saponification Value.

MOC .... Mineral Oil Content.

HPLC .... High Performance Liquid Chromatography.

QZ .... Quinizarin (1,4-Dihydroxyanthraquinone)

DODP .... 4,4'-Dioctyldiphenylamine

PAN Phenyl-1-Napthylamine

MOPAN N-4-Octylphenyl-1-Napthylamine

DOPT 3,7-Dioctylphenothiazine

NADOPT N-Allyl-3, 7-Dioctylphenothiazine

NBDOPT N-Benzyl-3, 7-Dioctylphenothiazine

PTZ .... Phenothiazine

BTZ .... Benzotriazole

ABA .... Anthranilamide (2-Aminobenzamide)

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