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Resistance of Diving Suit Fabrics to Abrasion and Chemical Contamination through Abrasion

FINAL REPORT
Rev. 2

by

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EXECUTIVE SUMMARY

The CF is developing specifications for dry suits suitable for contaminated water. One factor is the effect of wear and tear on molecular permeability and non-molecular penetration of the suits & fabric. In this study, Mustang Survival Corporation studied the effect of abrasion on dry suit material contaminant penetration resistance. Five dry suit fabrics were sampled from five different, new dry suits. Two fabrics were vulcanized rubber laminated to cloth. The three others were polyurethane coated fabrics, two single coated, the other double coated. The fabrics were subjected to abrasion tests done according to ASTM D3886. Based on the results of these tests, further samples were abraded to 0%, 35% and 50% abrasion levels and then exposed to the chemicals JP8 with methyl carbitol, methyl ethyl ketone (MEK) and toluene according to ASTM F903 to determine the resistance to penetration.

Abrasion results showed high between- and within-sample variances. Nevertheless, the polyurethane coated fabrics (NPU) showed a tendency for greater resistance to surface abrasion than the vulcanized rubber (VR) samples. The NPU fabrics were not significantly different from each other. Similarly, the VR fabrics were not significantly different.

The high variability in the results was not unexpected but it does put into question the validity of the comparisons. The ASTM recommends that D3886 not be used for acceptance testing and may only be reliable where there are large differences in performance. The discussion covers some of the factors that need to be addressed to reduce the variability and obtain valid comparisons.

Chemical penetration was tested at 0%, 35% and 50% abrasion, determined as a percentage of the mean number of cycles to hole formation for each fabric. At 35% abrasion, all five suits were resistant to penetration by JP8 with methyl carbitol, methyl ethyl ketone (MEK) and toluene. At 50% abrasion JP8 and MEK were able to penetrate VR1 and NPU2, respectively. However, the variability in abrasion results puts into question the results of these tests as well. Nevertheless, all five unabraded fabrics withstood penetration by the three chemicals. Furthermore, at some level of abrasion, penetration becomes likely.

In conclusion, the ASTM D3886 abrasion method has poor reproducibility for the fabrics of concern. A more reliable abrasion method needs to be identified before the effect of abrasion on penetration or permeation resistance can be quantified.

Abstract

An investigation was conducted to determine the surface abrasion resistance of the base fabric of five dry suits and the resistance of the abraded fabrics to chemical penetration. Chemical penetration was tested at 0, 35 and 50% abrasion, determined as a percentage of the number of cycles to hole formation for each fabric. At 35% abrasion, all five suits were resistant to penetration by JP8 with methyl carbitol, methyl ethyl ketone (MEK) and toluene. At 50% abrasion JP8 and MEK were able to penetrate some suits. Recommendations are made for additional abrasion and leakage testing needed before the effect of abrasion on chemical penetration could be determined.

Sommaire

Les FC élaborent des spécifications visant des combinaisons étanches résistant à l'eau contaminée. Un des facteurs à prendre en considération est l'effet de l'usage intensif sur la perméabilité moléculaire et la pénétration non moléculaire des vêtements et du tissu. Dans la présente étude, Mustang Survival Corporation a examiné l'effet de l'usure sur la résistance du tissu des combinaisons à la pénétration des contaminants. Des échantillons de cinq tissus pour combinaisons étanches ont été prélevés sur cinq différentes nouvelles combinaisons étanches. Deux tissus étaient enduits de caoutchouc vulcanisé. Les trois autres étaient des tissus enduits de polyuréthane dont deux d'un côté seulement et l'autre, des deux côtés. Les tissus ont été soumis à des essais d'abrasion conformément à la méthode D3886 de l'ASTM. Selon les résultats de ces essais, d'autres échantillons ont été abrasés à des niveaux d'usure de 0 %, de 35 % et de 50 %, puis exposés aux produits chimiques JP8 avec méthylcarbitol, méthyléthylcétone (MEK) et toluène conformément à la méthode F903 de l'ASTM afin de déterminer leur résistance à la pénétration.

Les résultats des essais d'abrasion démontrent des variations élevées entre les échantillons et au sein de chaque échantillon. Néammoins, les tissus enduits de polyuréthane (NPU) présentaient une tendance de résistance plus élevée à l'usure de surface que les échantillons de caoutchouc vulcanisé (VR). Les tissus NPU ne différaient pas beaucoup entre eux. Il en était de même pour les tissus VR.

La variation élevée des résultats n'était pas inattendue, mais elle remet en question la validité des comparaisons. L'ASTM recommande de ne pas utiliser la méthode D3886 pour les essais d'acceptation et de s'y fier seulement dans les cas où il y a des différences notables de performance. L'examen traite de certains des facteurs qui doivent être abordés afin de diminuer la variabilité et d'obtenir des comparaisons valides.

La pénétration de produits chimiques a été mesurée à des degrés d'usure de 0 %, de 35 % et de 50 %, exprimés en pourcentage d'une quantité moyenne de cycles requis pour entraîner la formation de trous dans chaque tissu. À 35 % d'usure, les cinq combinaisons résistaient à la pénétration des produits chimiques JP8 avec méthylcarbitol, méthyléthylcétone (MEK) et toluène. À 50 % d'usure, les produits JP8 et MEK pénétraient VR1 et NPU2, respectivement. Cependant, la variabilité des résultats des essais d'abrasion remet également en question les résultats de ces essais. Par contre, les cinq tissus non usés ont résisté à la pénétration par trois produits chimiques. De plus, à un certain degré d'usure, la pénétration devient probable.

En conclusion, la méthode d'abrasion D3886 de l'ASTM présente une pauvre reproductibilité pour les tissus en question. Une méthode d'abrasion plus fiable

doit être identifiée avant de pouvoir mesurer les effets de l'usure sur la résistance à la pénétration ou à la perméabilité.

Résumé

Une enquête a été menée afin de déterminer la résistance à l'usure de surface du tissu de base de cinq combinaisons étanches et la résistance des tissus usés à la pénétration de produits chimiques. La pénétration de produits chimiques a été mesurée à des degrés d'usure de 0, de 35 et de 50 %, exprimés en pourcentage de la quantité de cycles entraînant la formation de trous dans chaque tissu. À 35 % d'usure, les cinq combinaisons résistaient à la pénétration par JP8 avec méthylcarbitol, méthyléthylcétone (MEK) et toluène. À 50 % d'usure, JP8 et MEK réussissaient à pénétrer certaines combinaisons étanches. Des recommandations ont été faites portant sur la nécessité de procéder à d'autres essais d'étanchéité et d'abrasion avant de pouvoir déterminer les effets de l'usure sur la pénétration de produits chimiques.

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1.0 INTRODUCTION

The Canadian Forces (CF) are moving to equip all CF divers with dry suits to protect them from common contaminants. This is to supplement the dry suits used by Clearance Divers during operations in heavily contaminated waters. In each case, performance specifications need to be developed to ensure the acquisition process provides the needed equipment. Dry suit performance depends on many factors such as puncture resistance, garment fit, mobility, ease of decontamination, durability, disposability, and cost. One factor at the top of the list is the abililty to resist penetration by chemicals and pathogens. Some manufacturers of dry suits have tested their products and published permeation (ASTM F739) results. However, the tests were performed on new materials. It was of interest to consider the effect of wear and tear, and in particular abrasion, on dry suit fabrics. Consequently, through Technical Investigation and Engineering Services contract W7711-8-7479/01-SRV, the CF's Defence and Civil Institute of Environmental Medicine (DCIEM) contracted Mustang Survival Corp. (Mustang) to investigate the effect of abrasion on the chemical and biological penetration of dry suit fabrics.

Mustang determined the test protocols by reviewing available literature, existing test data, test standards and available resources. Dry suit fabrics were selected by DCIEM and Mustang. Fabric samples were obtained by cutting from new dry suits. Two of the dry suits compared were made of vulcanized rubber, one laminated to a heavy duty woven nylon (VR1) and the other to a 2-way stretch polyester knit (VR2). A third dry suit was a double-coated thermoplastic polyurethane nylon (NPU2) and two others were single-coated (NPU1 and NPU3). The samples were not intended to be representative of the state-of-the-art nor could the sampling procedure be considered for valid comparisons of the fabrics. However, the samples provided the necessary material to provide some insight into abrasion testing techniques and the effects of abrasion on penetration.

This study is divided into three sections: Abrasion Resistance, Selection of Contaminants, and Chemical Penetration.

2.0 ABRASION RESISTANCE

The first stage of the study was to determine a suitable standard abrasion test and establish the abrasion resistance of the 5 different materials. This data could then be used to establish levels of abrasion needed to study abrasion's effect on penetration.

The most likely modes of abrasion against the dry suit would be: 1. The dry suit fabric abrading against itself as in the crotch, knees and elbows during walking, working or swimming, 2. The dry suit fabric abrading against webbing straps and diving equipment, 3. Fabric abrasion against hard surfaces in the environment itself, including sediment and natural or unnatural structures, 4. During the handling of equipment required to perform the diver's assigned task. These abrasion modes tend to be different in the abradant type, the pressure applied during abrasion, the degrees of freedom of the material during exposure and the frequency of exposure. A surface abrasion tester (Model CS-059, Standard Scientific) was selected for this study that corresponds to ASTM D3886, the standard test for abrasion resistance of textiles using the inflated diaphragm method. This test appeared to provide a good estimate of resistance for the applicable abrasion modes. In the test, the fabric sample is fixed in place over a circular diaphragm inflated to approximately 27.6 kPa (4 psi), creating an even tension on the fabric. The sample can be abraded either uni- or multidirectionally against an abradant with specified surface characteristics. The weight of the abradant on the fabric surface can be adjusted up to 2.3 kg (5 lbs).

2.1 Objective

To determine and compare the surface abrasion resistance of the base fabric of 5 dry suits: NPU1, NPU2, NPU3, VR1 and VR2.

2.2 Method

Five samples (111 mm diameter) were cut from random areas of the base fabric of each suit, including the arms, torso and legs and abraded multi-directionally. Following several trials at various speeds, diaphragm pressures and applied surface weights, it was determined that a speed setting of 4 (125 cycles/min, checked with a stop watch), a diaphragm pressure of 27.6 kPa (4 psi), and a surface weight of 0.91 kg (2 lbs) provides a circular abrasion area of 4.2 to 4.9 cm^2 depending on the stretch of the fabric.

Choosing the abradant was also a challenge. Fabric to fabric abrasion was attempted however, it proved to be impractical for the stretch fabrics (VR1, VR2, NPU3) as it was not possible to place the fabric piece used as the abradant under enough tension to prevent it from being pulled forward and back within the clamps. After approximately 1 hour of fabric to fabric abrasion (7202 cycles), the non-stretch NPU1 fabric showed no visible surface damage. Given these results, data for fabric-to-fabric abrasion resistance would be difficult and time consuming to obtain.

ASTM D3886 recommends No. 0 emery polishing paper, a grade of paper not listed in any reference or known by the 3M Company, a major supplier, or by local autobody finishing shops. Mustang chose to use a coarser 100 grit garnet sandpaper and somewhat controlled for variable coarseness by changing the sandpaper between replicates.

The samples were abraded to hole formation failure as per ASTM D3886, para 11.1.1.

Thickness of each replicate was measured four times (ASTM D751) in different locations and the mean and standard deviation recorded.

2.3 Results

Table 2.3.1 summarizes the results of abrading 5 replicates of each fabric to hole formation. Because the largest group variance is more than twice the smallest variance, the data does not meet the assumption of a normal distribution thus the Kruskal-Wallis nonparametric ANOVA was chosen to analyze the data, followed by Dunn's multiple comparisons test to determine where the differences are significant. NPU2 was found to be significantly more abrasion resistant than VR1 ($P < 0.05$) and VR2 ($P < 0.001$). NPU3 was significantly more abrasion resistant than VR2 ($P < 0.05$). There was no significant difference between NPU1, NPU2 and NPU3 and no significant difference between VR1 and VR2.

TABLE 2.3.1 – Number of cycles to hole formation.

Sample	Number of cycles to failure ± SD	Fabric Description
VR1	2271 ± 499	Vulcanized rubber laminated to nylon knit.
VR2	1538 ± 228	Vulcanized rubber laminated to 2-way stretch polyester knit.
NPU1	2617 ± 581	Single coated thermoplastic PU coated nylon packcloth.
NPU2	8787 ± 1985	Double coated thermoplastic PU nylon.
NPU3	5458 ± 1992	Single coated thermoplastic PU coated nylon knit.

VR1 was the thickest fabric (Table 2.3.2). NPU1 and NPU2 suits were approximately the same thickness and were the thinnest of the fabrics tested. The vulcanized rubber suits (VR1 and VR2) had the greatest measured thickness range compared to the coated fabric suits. If variability is determined as the percentage the range is of the fabric thickness, then NPU2 has the greatest variability at 13.6 ± 4.5 %.

TABLE 2.3.2 – Fabric thickness measured as per ASTM D751

	VR1	VR2	NPU1	NPU2	NPU3
Thickness (mm)	1.63 ± 0.04	1.22 ± 0.04	0.46 ± 0.01	0.44 ± 0.02	1.10 ± 0.02
Thickness range (mm)	0.14	0.13	0.04	0.06	0.07
Variability (%)	8.6	10.7	8.7	13.6	6.4

2.4 Discussion

The large between and within sample variability causes problems in comparing fabrics and in establishing abrasion levels for penetration testing. The lack of homogeneity of variance requires the use of non-parametric statistical comparisons. This reduces the power of the comparison, that is the likelihood of identifying differences when differences do indeed exist. Increasing the number of replicates of each sample would increase the power; however, the number of tests were limited by the amount of fabric available.

On the other hand, the variability is not unexpected. The ASTM states in D 3886 that: "All the test methods and instruments so far developed for measuring abrasion resistance may show a high degree of variability in results obtained by different operators and in different laboratories," and that "This test method is accordingly not recommended for acceptance testing in contractual agreements..." Given this recommendation, it would seem futile to continue investigation for abrasion testing. In a more positive vain, the tests can be used as a starting point to develop an abrasion standard specific to dry suit materials. Consquently, it is valuable to examine the test and results to see how it could be improved.

Limitations to the abrasion test method itself can explain the variance among replicates of a single fabric type. The abradant grain size may be variable in coarseness which could partially explain inconsistent results; however, with a sufficient number of replicates, any errors associated with variable coarseness should be randomly distributed among the samples. This further supports the need for more replicates.

The frequency of changing the abradant is also a factor. ASTM suggests changing "at some regular frequency, such as after every 100 to 300 cycles." Mustang chose to change the abradant after every replicate. Additionally, throughout the test, the machine was stopped periodically to lift the abrasion head from the fabric surface and remove debris with a paint brush. Occasionally, larger bits of fabric pilled on the sample surface reducing abradant contact with the abrasion area. Fabric debris between the sample and a hard abradant would likely increase the number of cycles to hole formation. Consequently, frequency of abradant changes and clearing of abraded material are factors that need to be investigated to attempt to reduce variability of test results.

Preliminary experiments with adjusting air pressure beneath the sample demonstrated that the higher the pressure, the fewer the number of cycles to hole formation. For example, we found that hole formation occurs in approximately 2 to 5 times the number of cycles at 4 psi (depending on the fabric) compared to 10 psi so it is important when comparing fabric test data that the diaphragm pressure is the same for all sets of data. For the data collected in table 2.3.1, the diaphragm pressure was closely monitored and maintained at 4 psi so it is unlikely this was a factor contributing to the variable abrasion resistance of the test samples.

The possibilty that variability was partially associated with fabric thickness was considered. The thickness of each fabric is variable which could partially explain the large variances in the number of cycles to hole formation among replicates of the same fabric. However, VR1 was the thickest fabric yet had fewer cycles to hole formation than NPU2 the thinnest fabric, so it appears that abrasion resistance does not have a strong correlation to thickness at least when comparing different fabrics. Part of the reason maybe that for the coated fabrics, it is unknown how much of the thickness is due to the fabric and how much to the coating. Streaks could be seen throughout a NPU2 fabric sample, suggesting the coating thickness might be variable. Also, in one area, where the fabric had been folded, the coating appeared damaged. This observation highlights the importance of including bending, roll and fold testing, suggesting that flex abrasion testing (eg. ASTM D3885) may be an additional measure of abrasion resistanceto consider.

The results of surface abrasion testing according to ASTM D3886 do not appear to be reproducible for the fabrics used in this experiment. It would be useful to test a non-stretch, non-coated/non-laminated fabric to see whether repeatable, less variable results can be obtained. This would confirm whether the fabric properties or the test method itself has the greatest contribution to producing unreliable test results.

3.0 CONTAMINANT SELECTION

A review of the literature revealed many potential chemical and biological hazards that the Canadian Forces diver may be exposed to during a diving operation (Amson, 1991, Barsky, 1999, Carter, 1999). The sources of underwater contaminants include leaking and sunken vessels, damaged pipelines, aviation crash sites, and industrial outfall pipes. Likely contaminants would be aviation and diesel fuels, solvents, contraband substances such as heroin and cocaine, and chemicals used in industrial processing. Exposure to pathogens is likely to occur at sites where there has been a marine or aviation mishap where loss of life has occurred. Harmful coliform bacteria will be found near sewage outfall pipes or where current has transported raw sewage or sewage contaminated sediments. Exposure to harmful cyanobacteria or zooplankton can be seasonal and depends somewhat upon the amount of water movement in the area.

Penetration testing of specific biological contaminants such as E. coli, into protective clothing is usually not done in commercial labs for health safety reasons. A surrogate microbe suspended in a body fluid simulant is used to measure the effectiveness of materials in protecting the wearer against contact with blood-borne pathogens (ASTM F1671). Mustang's original proposal was to expose fabric samples to decontaminant chemicals followed by a water leak test on the assumption that if water couldn't get through neither could a biological organism. However, this method does not test whether the organism itself could prevent water penetration by entering pores created by abrasion, or whether water penetration could occur with organisms filtered out or trapped in the fabric.

It is recommended that biological penetration testing be subcontracted to the Texas Research Institute (TRI) who have both the expertise and equipment to provide an informative analysis of the protection offered by each of our test fabrics against biocontamination. They can process 10 tests within a week at a cost of $400 USD per test ($375 USD per test for 20 or more tests).

The following chemicals to which a diver may be exposed were selected for investigation based on past test fabric performance during chemical permeation testing and possible occurrence in the environment (Barsky, 1999):

<u>JP8 with methyl carbitol</u>

JP8 is known to cause skin cancer and kidney damage in animals. It can enter the body via inhalation, ingestion and through the skin (Material Safety Data Sheet, 1999). It will cause deterioration of most diving equipment with extended exposure (Barsky, 1999).

Canadian commercial and military aircraft use either JP4 or JP8 fuels whereas JP5 is specifically produced for naval shipboard aircraft and is only used in the southern United States (Carter, 1999 and Reid, 2000 personal communications). JP5 has a higher flashpoint than JP8 and contains an icing inhibitor, diethylene glycol monomethyl ether (DiEGME), also known as methyl carbitol. This same icing inhibitor is injected into JP8 during the aircraft fueling process. According to J. Reid of Royal Pacific Petroleum (2000), the icing inhibitor itself “melts plastic”.

Toluene

Toluene is a common solvent used in many manufacturing processes. It is known to attack bone marrow and can enter the body via inhalation and through the skin (Material Safety Data Sheet, 1999). Because it floats, it can occur as a film of pure product that rapidly attacks rubber parts in diving equipment (Barsky, 1999).

Methyl Ethyl Ketone (MEK)

MEK, another common solvent, is only slightly to moderately soluble in water and can create a slick of pure product on the surface of the dive site (Barsky, 1999). MEK may cause central nervous system depression, and can enter the body via inhalation, ingestion and through the skin (Material Safety Data Sheet, 1999).

Sodium Hydroxide (NaOH)

Sodium hydroxide, or caustic soda, is used to manufacture, soap, rayon and cellophane (Barsky, 1999). It generates heat when mixed with water and is very corrosive to bare skin.

Bleach (Sodium hypochlorite)

Exposure to bleach is likely during the decontamination process if pathogen exposure is suspected.

Visual observations were made of the reaction of the test fabrics to each of the chemicals listed above. Both sides of the fabric were immersed based on the reasoning that if pinholes caused by abrasion allowed penetration of a chemical then the inner surface of the fabric would also be exposed to the chemical, possibly resulting in further degradation and chemical penetration.

3.1 Objective

To determine whether JP8 + inhibitor, Toluene, MEK, NaOH, or bleach cause chemical degradation of the dry suit test fabrics after a 12h exposure.

3.2 Method

The JP8 solution was prepared by adding 1 ml of methyl carbitol to 500ml of fuel (0.2 vol%) and this solution tested at 100%. Industrial grade toluene and MEK were each tested at 100%. A 10% sodium hydroxide solution was prepared by dissolving 106.5 g NaOH in artificial seawater (density 1.02 g/ml). Laundry bleach was also tested at 100%.

Strips of fabric were cut from each suit and weighed three times on an analytical balance, to the nearest 0.001 g. Each strip was placed in a test tube to which the chemical was added until the strip was completely immersed. There were two replicates of each fabric sample, in each chemical. The samples were left in the solutions for a minimum of 12 hours. Visual observations were recorded prior to removal of the samples from the chemicals. The samples were left overnight to dry and then weighed.

3.3 Results:

Table 3.3.1 shows the average percent change in weight (n=2) following at least 12h exposure to chemical. Any change in weight less than or equal to 0.5% is likely to be within measurement error. Where no value is reported, the sample had degraded to the point where it was impractical to weigh it.

TABLE 3.3.1 – Percent change in weight.

	JP8+Inhib (100%)	Toluene (100%)	MEK (100%)	NaOH (10%)	Bleach (100%)
VR1	17.9	-5.5	-4.4	2.9	4.4
VR2	11.8	-6.2	-5.1	-0.1	2.2
NPU1	0.0	-0.4	-	0.4	1.7
NPU2	-0.5	-1.8	-12.2	0.5	1.0
NPU3	4.3	-1.4	-	1.4	7.0

The visual observations made prior to removing each sample strip from the test chemical are summarized in Table 3.3.2.

TABLE 3.3.2 – Visual observations after at least 12 h chemical exposure.

	JP8+inhib (100%)	Toluene (100%)	MEK (100%)	NaOH* (10%)	Bleach (100%)
VR1	Tightly curled with scrim outside, rubber inside. Partially uncurled after drying.	Tightly curled with scrim outside, rubber inside. Completely uncurled after drying.	Slight curl with scrim inside, rubber outside.	White sediment on surface	The black rubber and scrim layers appeared faded in patches.
VR2	Tightly curled with scrim outside, rubber inside. Partially uncurled after drying.	Tightly curled with scrim outside, rubber inside. Completely uncurled after drying.	Curled with scrim inside, rubber outside. Rubber degraded.	No visible change.	No visible change.
NPU1	Curled with P.U. coating outside, nylon inside. Straightened after drying.	Tightly curled with P.U. coating outside. Partially uncurled after drying.	PU coating degraded and separated from nylon fabric layer.	No visible change	Edges of strip curled up slightly, towards nylon layer.
NPU2	No visible change.	No visible change.	Coating appears to be roughened.	Solution had turned very pale yellow.	No visible change.
NPU3	Slight curl with scrim inside, coating outside.	Tightly curled into tube with scrim inside, coating outside. Straightened after drying but bowed with coating on concave surface.	P.U. coating degraded and separated from scrim (nylon knit).	No visible change until dry. Sample bowed with coating on convex surface.	Edges of strip curled up slightly, towards scrim.

*Note that solid NaOH had settled from the solution indicating that the actual concentration to which each strip was exposed was likely less than 10%.

3.4 Discussion

VR1 and VR2 showed the greatest increase in sample weight in JP8 + inhibitor (17.9 and 11.8 %, respectively) and the greatest loss in weight in toluene (5.5 and 6.2 %, respectively) after overnight drying. Both samples, under both conditions became tightly curled with the scrim on the outside and rubber on the inside during exposure indicating that either the scrim was expanding or the rubber was shrinking, or expansion and shrinkage were occurring at different rates. The gain in weight during exposure to the fuel indicates that the samples absorbed some of the chemical or byproducts were formed in reaction with the fabric samples that were not eliminated during the drying process. The loss in weight during exposure to toluene suggests that the solvent caused degradation, likely of the rubber layer.

Though all the samples showed a loss in weight with exposure to MEK, the most detrimental effects were to those fabrics with a polyurethane coating (NPU1, NPU2, and NPU3) where the coating had visibly degraded. In MEK, the rubber layer of VR2 was also visibly degraded. VR1 had the least weight loss and no visible degradation, though the samples had a tendency to curl during exposure.

Exposure to NaOH caused a slight to no change in weight with the largest change measured for the VR1 sample (2.9% gain). This was the only sample where white sediment was visible on the rubber surface. The sediment could not be easily removed upon drying.

The NPU3 samples showed the greatest weight change (7.0% gain) following exposure to bleach. The edges along the length of the sample strips had curled inward toward the scrim on the NPU3 sample and toward the nylon layer of the NPU1 sample, such that the polyurethane layer of both fabrics was on the concave surface. Exposure of fabrics to high concentrations of bleach would only be likely during the decontamination process following suspected exposure to a pathogen.

Specific information regarding the chemicals used during the decontamination procedure of the CF diver following exposure to a potential biohazard is difficult to obtain. However, according to Carter (1999), the most corrosive decontaminant used is a bleach solution (up to 100%) applied in a short duration flush followed by a water rinse. Amson (1991) describes a procedure where the diver is washed down with a high pressure spray to remove adhering contaminants or residues, followed by a second washdown with a surfactant such as trisodium phosphate or other solvent appropriate to the contaminant. Following this step, divers exposed to pathogens are sprayed down with a clinical disinfectant such as Betadine surgical scrub solution. Phoel and Wells (1991) report results of a 1982 NOAA study where it was determined that suits with rough exteriors, such as nylon or neoprene, were almost impossible to disinfect after use in polluted water.

4.0 CHEMICAL PENETRATION

ASTM F903 was selected for resistance of materials used in protective clothing to penetration by liquids. This method does not quantify the amount of chemical penetration whereas ASTM F739 is a more sensitive analysis, which quantifies the amount of chemical permeation and penetration via UV/IR spectroscopy or gas chromatography. Mustang chose to construct a leak tester conforming to ASTM F903 which does not require the sensitive analysis equipment but would provide comparative information of whether leakage occurs at similar abrasion levels for each fabric sample. This is measured as a visual pass or fail. However, it should be noted that some materials that pass the fabric penetration test, may not pass a permeation test which tests for fluid passing through the fabric at a molecular level.

The pressure at which to perform the leak test was determined by considering a diver of 193 cm (76 inch) height. Assuming a vertical position in the water, the pressure differential along the length of the diver's suit (165 cm estimate) could be up to 16.5 kPa (2.4 psi). However, this is assuming the diver is not moving in still water, a most unlikely scenario. A test pressure of 34.5 kPa (5 psi) was used to include the pressure differentials that may actually occur during a normal diving operation.

One hundred per cent concentrations of JP8 with inhibitor, MEK and Toluene were tested at three levels of abrasion (plus control) determined from the abrasion test results for each fabric. The levels are a percentage of the mean number of cycles to hole formation for each individual fabric. In determining what our abrasion levels would be, the variability in abrasion resistance within a fabric made it difficult to choose a value greater than 50% of the mean number of cycles to hole formation, without the risk of creating a visible hole. Using relative abrasion levels allowed comparison of the different fabrics at similar levels of surface abrasion wear.

4.1 Objective

To determine the effects of surface abrasion on the resistance to penetration of JP8, MEK and toluene of the base fabrics of 5 polluted underwater diving suits.

4.2 Method

The fabrics tested were NPU1, NPU2, NPU3, VR1 and VR2. Thirty-six 111 mm (4.4 inch) diameter circles were cut from random areas of the base fabric, including the arms, legs and front and back torso of each suit. This allowed for 3 replicates of 3 contaminants at 4 abrasion levels including a non-abraded control.

Prior to abrasion, the thickness of each replicate was measured four times (ASTM D751) in different locations and the mean and standard deviation recorded.

The fabric samples from each suit were abraded at each of 0 (control), 20, 35 and 50% of their predetermined mean number of cycles to hole formation. The number of cycles at each abrasion level is presented in Table 4.2.1 for each fabric. The diaphragm pressure was set at 27.6 kPa (4psi), the surface weight to 0.91 kg (2 lbs) and the speed dial setting measured at 119 ± 1 cycles/min. The number of cycles per minute was confirmed daily with a stopwatch.

TABLE 4.2.1 – Number of abrasion cycles as a percentage to hole formation.

Abrasion %	VR1	VR2	NPU1	NPU2	NPU3
0	0	0	0	0	0
20	454	308	523	1757	1092
35	795	538	916	3075	1910
50	1136	769	1309	4394	2729

Each replicate was leak tested for chemical penetration as per ASTM F903-99a. Initially, three replicates of each fabric at 50% abrasion were leak tested with each of JP8 (plus icing inhibitor), MEK and toluene. Because failures were observed in some of the samples, leak testing was repeated at the 35% abrasion level. Failures did not occur at the 35% level so we did not test the 20% abrasion replicates. Leak testing was performed by placing the sample in the sample holder, with the normally-outside surface facedown against the chemical. A pressure/time sequence of 0 psi for 5 min followed by 5 psi for 10 min was used.

The test was terminated when either a droplet of liquid appeared during the test (recorded as a Fail) or if no liquid appeared over the duration of the test (recorded as a Pass). For those fabrics with a knitted scrim on the normally-inside surface (VR1, VR2 and NPU3), baby powder was used to make any leaks more visible as it was suspected the scrim allowed wicking, making it difficult to identify moisture penetration.

The test cell was rinsed between test chemicals. Following leak tests with MEK and toluene, the O-ring and gasket swelled and were replaced with new seals.
The abrasion level at which leakage occurred was compared for each chemical, for each of the 5 dry suit fabrics.

4.3 Results

At the 50% abrasion level, VR1 failed the leak test in JP8 (plus icing inhibitor) and NPU2 failed in MEK (Table 4.3.1). In both cases, only one of the three replicates leaked.

TABLE 4.3.1 – Leak test results. P = pass, F = fail.

%Abrasion	VR1	VR2	NPU1	NPU2	NPU3
JP8					
0	P	P	P	P	P
35	P	P[1]	P	P	P[1]
50	**F**	P	P	P	P
MEK					
0	P	P	P	P	P
35	P	P	P	P	P
50	P	P	P	**F**	P
Toluene					
0	P	P	P	P	P
35	P	P	P	P	P
50	P	P	P	P	P

[1]Test result for recut sample. Original replicate failed when it leaked outside of abrasion area where fabric was visibly damaged prior to abrasion.

4.4 Discussion

At 35% abrasion, all five suits were resistant to chemical leakage. At 50% abrasion JP8 and MEK were able to penetrate VR1 and NPU2, respectively. Given the poor performance of NPU3 in MEK (Table 3.3.2), it is surprising that this fabric passed the leak test.

Penetration occurred in only one replicate each of VR1 and NPU2, suggesting that there was a characteristic of those replicates that allowed penetration to occur. VR1 has a variability in thickness of 8.6 ± 2.5% and NPU2 a variability of 13.6 ± 4.5% (Table 2.3.2) suggesting that the abrasion area of the replicates that leaked may have been at the thinner end of the thickness range for the given fabric.

Due to the variability in number of abrasion cycles to hole formation, as discussed in section 2.4, it is uncertain what the actual relative abrasion levels were for our study. With testing only three replicates of each fabric, one cannot safely conclude that the other test fabrics are resistant to chemical leakage under our test conditions.

Detection of a leak depends on its visibility. Highly volatile substances, such as MEK and Toluene are difficult to detect using the ASTM F903-99a leak test method on fabrics with a knitted scrim. It is possible the chemical could pass through the abraded coating or neoprene surface, disperse into the scrim normally lying against the skin, and evaporate before visual detection. Permeation testing according to ASTM F739 would provide more definitive results.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Due to the large variances in the number of cycles to hole formation for each fabric, it is difficult to make a conclusion regarding which fabric has the greater abrasion resistance. It is important that a reliable test method be used. Five replicates, as specified in ASTM D3886 may not be a sufficient number to allow for random variability when testing coated or laminated fabrics of variable thickness. It is recommended that if the surface abrasion method is used to test these fabrics, more replicates should be included. The observation of coating damage along a fold of NPU2 sample fabric highlights the importance of performing flex abrasion testing on all the suit fabrics.

At 50% surface abrasion, NPU2 failed the penetration test with MEK and VR1 failed with JP8. Due to the large variability in the number of cycles to hole formation for each fabric, and the small number of replicates tested, it is not wise to conclude that the other fabrics do not leak at 50% abrasion without further testing. Though NPU2 leaked at 50% abrasion, it would take much longer for the fabric to reach this level of wear than VR1 or VR2 which had significantly lower abrasion resistances.

It is recommended that chemical permeation testing be conducted to identify chemical leakage that may not be visible with the penetration test method, particularly for volatile substances. The chemicals used by Mustang are relatively common but not necessarily of greatest threat to the Canadian Forces underwater diver. Diesel fuels such as Liquids B, C or F have been tested on VR1 and VR2. It would be useful to compare NPU1, NPU2 and NPU3, as well.

To determine which of the 5 dry suits in this study would be most suitable for polluted underwater diving, there are many other parameters to consider. A suit that has good abrasion resistance may have poor puncture resistance. Garment zippers and seams should be tested for chemical penetration. Other issues to be considered when selecting a suit would be garment fit, mobility, ease of decontamination, disposability, and cost.

6.0 REFERENCES

Amson, J.E. (1991) Protection of divers in waters that are contaminated with chemicals or pathogens. Undersea Biomed. Res., 18: 213 – 219

Barsky, S.M. (1999) Diving in High-Risk Environments. 3rd Edition. Hammerhead Press, Santa Barbara, CA. pp. 197

Carter, R. (1999) Personal Communication. Fighters and Trainers Evaluation Cell, 12-2, AETE (Aerospace Engineering Test Establishment), Coldlake, Alberta.

Phoel, W.C. and J.M. Wells (1991) Evolution of the National Oceanic and Atmospheric Administration's capabilities for polluted water diving. Undersea Biomed. Res., 18: 247 – 252

Reid, J.W. (2000) Personal Communication. Royal Pacific Petroleum, Ltd., Richmond, B.C.

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14 ABSTRACT

(U) An investigation was conducted to determine the surface abrasion resistance of the base fabric of five dry suits and the resistance of the abraded fabrics to chemical penetration. Chemical penetration was tested at 0, 35 and 50% abrasion, determined as a percentage of the number of cycles to hole formation for each fabric. At 35% abrasion, all five suits were resistant to penetration by JP8 with methyl carbitol, methyl ethyl ketone (MEK) and toluene. At 50% abrasion JP8 and MEK were able to penetrate some suits. Recommendations are made for additional abrasion and leakage testing needed before the effect of abrasion on chemical penetration could be determined.

15 KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) surface abrasion resistance;base fabric;dry suit;abraded fabrics;chemical penetration;abrasion cycle;JP8;MEK;Gates ProAm 1050;Whites HazMat,Mustang Survival Corp.,Whites SAR Dive;biological penetration,Viking Pro 1000;contaminants; Fabric debris;biological organism;Barsky;methyl carbitol; Toluene,NaOH;bleach;ASTM F903-99a.;fabric thickness;leakage;vulcanized rubber suit;coated fabric suit