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**Assessment of Gloves for Use with Cleaning
Fluids Used in the Printing Industry**

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EXECUTIVE SUMMARY

Objectives

To identify the best performing chemical protective glove, by type, against the permeation of a range of cleaning fluids used in screen, digital, flexographic/gravure and offset (newsprint) lithographic printing.

Main Findings

Findings related to the gloves:

The best performing glove was a nitrile glove (Ansell Solvex) which prevented permeation for eight hours for three of the fifteen cleaning fluids, and 8 to 364 minutes for the remainder.

A thick rubber glove (Marigold Emperor) was the next best performing glove, although it did not resist permeation for 8 hours for any of the fifteen washes. In general, protection of greater than 30 minutes was observed (only two washes permeated quicker, at 14 and 23 minutes).

The KCL Camapren glove in general performed very poorly with permeation occurring within 30 minutes for the majority of washes and in four cases within 10 minutes. Where short permeation times are observed (e.g. 3 minutes), only splash protection is afforded (immediate removal would be required after contamination).

The KCL Dermatrill P and Marigold Tripletec G44R nitrile gloves only underwent a small number of tests, however both types performed well for over 8 hours against specific washes.

Specific findings relating to the washes:

1. Screen printing washes (5 types) with Ansell Solvex (nitrile), KCL Camapren (neoprene on natural rubber) and Marigold Emperor (natural rubber).

- Permeation occurred in 10 to 73 minutes for all three glove types and all five screen washes except for one wash with Ansell Solvex and Marigold emperor gloves which resisted permeation for 201-364 minutes.
- The poorest performing glove was the KCL Camapren with permeation times of 17 minutes or less for all but the one wash. The best performing glove was Ansell Solvex nitrile gloves which prevented permeation of three of the fifteen cleaning fluids tested .

2. Digital printing washes (2) with Ansell Solvex, KCL Camapren, Marigold Emperor, Marigold Tripletec (nitrile coated natural rubber) and KCL Dermatrill P (nitrile).

- For one wash, the Ansell Solvex (160 minutes) and Marigold Emperor (88 minutes) offered some resistance to permeation whilst the KCL Camapren resisted for only 28 minutes. For the other wash, the Ansell Solvex, KCL Camapren and Marigold Tripletec resisted permeation for greater than eight hours. Surprisingly the KCL Dermatrill P nitrile glove resisted permeation for only 155 minutes.

3. Offset (Newsprint) Lithographic printing washes (2) with Ansell Solvex, Marigold Tripletec and KCL Dermatril P.

- Ansell Solvex and KCL Dermatril P, performed well against both of the washes, lasting over eight hours. The performance of the Marigold Tripletec glove was poorer with permeation occurring at 89 and 73 minutes.

4. Flexographic/Gravure printing washes (6) with Ansell Solvex, KCL Camapren and Marigold Emperor.

- The Ansell Solvex and KCL Camapren gloves performed poorly with permeation times of under 39 and 19 minutes respectively for all 6 washes but some permeation times were as low as 3 to 9 minutes. The Marigold Emperor in general performed slightly better with a permeation time of 120 minutes for n-Propyl acetate in methylated spirits. However permeation occurred within 70 minutes for the remaining washes.

Recommendations

- The best performing glove was the Ansell Solvex nitrile glove which prevented permeation for eight hours for three of the fifteen cleaning fluids. When not suitable for eight hour protection, they can be used for splash protection.
- Glove choice is only one aspect of this problem, and pattern of use (e.g. repeat use, task time and physical demands) should also be attended.

1 INTRODUCTION

This project is part of a group of work being carried out by HSE in the printing industry under the Disease Reduction Programme, part of HSE's FIT3 Programme. This work will help HSE to recommend suitable gloves for printing tasks (taking into account the complex mixtures of chemicals used) in its 'COSHH Essentials for Printers' guidance (HSE 2006).

The aim of this work was to find a chemical protective glove for protection against the permeation of cleaning fluids used in screen, digital, flexographic/gravure and offset (newsprint) lithographic printing.

It should be noted that glove resistance to chemical permeation is only one element of the problem. There are also other factors involved such as the nature and duration of the task to be considered as well.

This work was one of two studies, the other being an investigation of the effectiveness of gloves used in UV lithographic printing (Roff, 2005).

2 EXPERIMENTAL

2.1 OVERVIEW

Chemical permeation tests were performed for most combinations of glove and cleaning fluid. The test was terminated when it was thought that the normalised breakthrough time had been reached (that is when the permeation rate was estimated to have exceeded 1 $\mu\text{g}/\text{cm}^2/\text{min}$), or when eight hours had been completed. After termination each glove sample then underwent puncture testing to demonstrate any degradation that may have occurred affecting glove performance. It should be noted that the normalised breakthrough time is a method by which the resistance to permeation of different glove materials can be compared, and is not a time period where there will be no permeation or effects to health.

2.2 GLOVE TYPES AND CHEMICAL WASHES

Five glove types (Table 1) were selected by HSE for testing against fifteen cleaning washes (Table 2), identified as representing the different printing techniques being considered.

Table 1. Gloves Tested

Glove Reference	Description	Surface	Price Per Pair*	Thickness (mm)	Weight / Unit Area (g/m^2)
Type 1 Ansell Solvex 37-675	Green nitrile with cotton flock lining.	Glossy with slightly uneven crazed pattern.	£0.68	0.40	387
Type 2 KCL Camapren 720	Black neoprene covering natural rubber with cotton flock lining.	Tacky with ridged zig-zag pattern.	£2.02	0.72	1009
Type 3 Marigold Emperor ME101	Thick, stiff unlined black natural rubber.	Shiny smooth.	£3.39	1.04	731
Type 4 Marigold Tripletec + G44R	Pink nitrile coated natural rubber with flock lining.	Ridged hexagonal pattern.	£1.49	0.61	533
Type 5 KCL Dermatril P 743	Thin single use type pliable blue nitrile.	Smooth but slightly tacky, and with roughened finger tips.	£0.44	0.19	191
*As quoted August 2006					

The thickness measurements were taken using an RS Digital Electronic Micrometer which has a 6 mm diameter foot exerting 6-10 N force on the sample (21-36 kPa). When measuring rubber test pieces, the recommended pressure for such a foot is 22 kPa \pm 5 kPa (BSI 2004). Additionally it should be noted that occasionally the glove palm samples had a raised pattern (i.e. KCL Camapren and Marigold Tripletec brands) that would have contributed to the value recorded.

Table 2. Printing Industry Cleaning Fluids (Washes)

Manufacturer	Chemical Wash*
SCREEN PRINTING	
Manufacturer A	Wash A
	Wash B
Manufacturer B	Wash C
	Wash D
Manufacturer C	Wash E
DIGITAL PRINTING	
Manufacturer A	Wash F
	Wash G
OFFSET (NEWSPRINT) LITHOGRAPHIC PRINTING	
Manufacturer D	Wash H
Manufacturer E	Wash I
FLEXOGRAPHIC / GRAVURE PRINTING	
Flexographic and Gravure Publications	
Direct from Printers A. Solvent wash recovered from washings.	100% Toluene
Gravure Packaging	
Direct from Printers B. Solvent wash recovered from washings.	50% Ethyl Acetate 50% Industrial Methylated Spirits
Flexographic Packaging	
Manufacturer F	75% Industrial Methylated Spirits 25% nPropyl Acetate
	100% Ethyl Acetate
	50% Ethyl Acetate 25% Industrial Methylated Spirits 25% nPropyl Acetate
Direct from Printers B. Solvent wash recovered from washings.	75% Industrial Methylated Spirits 25% Ethyl Acetate
*No chemical analysis was made on the washes, however Table 5 in the Appendix lists the components that were detected permeating through the gloves.	

2.3 SAMPLE PREPARATION

Glove samples (76 mm diameter discs) were taken from glove palms and conditioned for 24 h at a temperature of $23 \pm 2^\circ\text{C}$ and relative humidity of $50 \pm 5\% \text{RH}$, after which the weight and thickness of the samples were measured.

2.4 PERMEATION RESISTANCE TESTING

The chemical permeation tests were performed (in triplicate) following method BS EN 374-3 (BSI 2003a). The equipment used was designed and built at HSL comprising of three proprietary permeation test cells (Figure 1) in conjunction with a Signal 3000HM flame ionisation detector (FID) to detect volatile organic compounds (VOCs) permeating through the glove. A computer program was written to control operation of the system and to monitor and

log the data produced. The FID was calibrated with methane, however sensitivity changes with VOC type, and so the data collected needed to be retrospectively calibrated.



Figure 1. Permeation Resistance Test Cell



Figure 2. Permeation Resistance Test Equipment

The composition of the permeating vapour was determined by collecting samples on sorbent tubes immediately before termination of the test, followed by analysis of the tubes by automated thermal desorption-gas chromatography. The identity of the components was determined by mass-spectrometry, and the relative concentrations using an FID. This data was used to calculate an average relative response factor and molecular weight for the vapour, enabling the vapour permeation rate to be calculated in terms of $\mu\text{g}/\text{cm}^2/\text{min}$.

Most of the fluids are complex mixtures. The resistance of the glove materials will vary for each component of the fluids. For a multi-component mixture, some components are likely to permeate through the glove faster than others, and the action of some aggressive components may allow the permeation of other less mobile compounds. If the composition of the vapour permeating through the glove changes over time, then the relative response of the FID is also likely to change. The type of glove being tested may also affect the relative composition of the permeating vapour.

Uncorroborated reports expected the type 1 gloves to resist chemical permeation for a full 8-hour shift. If this was found to be the case for a given cleaning fluid, then further testing of the other glove types was to be restricted to types 4 and 5 (for that fluid). Should the type 1 glove not resist chemical permeation for up to 8 hours then glove types 2 and 3 would be tested. Therefore three types of gloves (i.e. types 1, 2 and 3 or, types 1, 4 and 5) were to be tested against each of fifteen different cleaning washes i.e. 45 combinations.

The testing system was checked prior to operation by testing a reference material and solvent with known permeation characteristics (standard 16 mil neoprene and acetone). Satisfactory results were achieved.

2.5 PUNCTURE RESISTANCE TESTING

Glove puncture resistance testing was performed using a Testometric CX materials testing machine following a method based upon BS EN 388 (BSI 2003b), but having no preliminary standard conditioning period.

Puncture testing was carried out immediately after termination of the permeation test (either when it was estimated that the $1 \mu\text{g}/\text{cm}^2/\text{min}$ permeation rate level had been exceeded or soon after, or when 8 hours of the test had been completed), however experimentally this was very hard to achieve. The exact permeation rate could not be calculated until the composition of the vapour was known; therefore the precise degree of saturation was difficult to control. Similarly samples puncture tested after withstanding eight hours of permeation testing may have had very little fluid present. Nevertheless the tests were able to indicate any change (reduction) in performance.

For comparison, six samples of each glove type were also puncture tested without having undergone the chemical permeation test. These samples were preconditioned for temperature and humidity. Although EN 388 requires the test to be performed on only four samples, in this work six samples were tested to try to improve the statistical significance of the results.

3 RESULTS

The individual data from the permeation and puncture test results can be found in Tables 3 and 4 respectively in the Appendix. The composition of the vapour permeating through the gloves from the cleaning fluids is given in Table 5 in the Appendix.

The results can also be expressed using the “performance level” classification system described in the respective standards and employed by the glove industry. These are both defined in Table 6.

Table 6. Performance Level Requirements

Permeation Resistance		Puncture Resistance	
Breakthrough Time (min)	Performance Level	Force (N)	Performance Level
>10	1	20	1
>30	2	60	2
>60	3	100	3
>120	4	150	4
>240	5		
>480	6		

Although no performance level of 0 has been defined, it has been used in Table 7 to indicate that the glove failed to meet the lowest requirement of the relevant standard i.e. <10 min for permeation resistance or <20 N for puncture resistance.

Summary results of the tests in terms of the “performance level” are presented in Table 7. In line with the respective standards, the lowest values recorded were used to determine performance levels. As far as this work is concerned, HSE are ideally seeking gloves that offer performance level 6 for permeation resistance. While most of this report discusses findings based on permeation resistance time, it may be preferable to use the “performance level requirement” classification scheme when issuing guidance.

Table 7. Permeation and Puncture Test Results

Chemical Wash	Permeation Resistance / Puncture Resistance Performance Level by Glove Type									
	Ansell Solvex 37-675		KCL Camapren 720		Marigold Emperor ME101		Marigold Tripletec G44R		KCL Dermatrill P 743	
	Type 1		Type 2		Type 3		Type 4		Type 5	
	Nitrile		Neoprene/rubber		Natural rubber		Nitrile/rubber		Nitrile	
	Perm.	Punc.	Perm.	Punc.	Perm.	Punc.	Perm.	Punc.	Perm.	Punc.
Unexposed	n/a	2	n/a	1	n/a	1	n/a	0	n/a	1
Screen Printing										
Wash A	1	0	1	0	2	1	n/a		n/a	
Wash B	2	0	1	0	2	1	n/a		n/a	
Wash C	2	0	1	0	2	1	n/a		n/a	
Wash D	2	0	1	0	2	1	n/a		n/a	
Wash E	5	0	3	0	4	1	n/a		n/a	
Digital Printing										
Wash F	4	0	1	0	3	1	n/a		n/a	
Wash G	6	1	6	0	n/a		6	0	4	0
Offset (Newsprint) Lithographic Printing										
Wash H	6	2	n/a		n/a		3	0	6	0
Wash I	6	2	n/a		n/a		3	0	6	1
Flexographic / Gravure Printing										
100% Toluene	1	0	0	0	1	1	n/a		n/a	
50:50 EA/IMS	1	0	0	0	2	1	n/a		n/a	
75:25 IMS/nPA	1	0	1	0	4	1	n/a		n/a	
100% EA	0	0	0	0	1	1	n/a		n/a	
50:25:25 EA/IMS/nPA	0	0	0	0	2	1	n/a		n/a	
75:25 IMS/EA	2	0	1	0	3	1	n/a		n/a	
Key										
Perm.: the permeation resistance performance level from BS EN 374 (BSI 2003a).										
Punc.: the puncture resistance performance level from BS EN 388 (BSI 2003b).										
A value of '0' indicates that the glove did not meet the lowest requirement of the relevant standard: i.e. <10 min for permeation resistance or <20 N for puncture resistance.										
EA – ethyl acetate, IMS – industrial methylated spirits, nPA – n-propyl acetate, n/a – not applicable (or not tested)										

4 DISCUSSION

4.1 PERMEATION RESISTANCE

When determining normalised breakthrough times, if the composition of the permeating vapour changed during the course of a test, it would introduce some uncertainty into the calculated permeation rate. The breakthrough times determined for mixtures therefore may not be as accurate as those for single components. Obviously the effect will depend on the gradient of the permeation rate versus time graph. Some examples of the permeation graphs are presented in Figures 3 to 5. Figure 3 shows a slow increase in permeation rate whereas Figure 4 shows rapid breakdown in resistance to permeation. Figure 5 is an example of a test that ran to completion without the permeation rate reaching the $1 \mu\text{g}/\text{cm}^2/\text{min}$ permeation rate required to calculate a normalised breakthrough time.

Screen Printing

None of the glove types tested prevented permeation for over eight hours. All the normalised breakthrough times were under one hour except for Wash E, which did not permeate KCL Camapren gloves for over 71 minutes, Marigold Emperor gloves for 201 minutes and Ansell Solvex gloves for over 319 minutes. This wash differed somewhat from the other fluids in composition, containing no light aromatic solvent naphtha or cyclohexanone. Overall the Ansell Solvex and Marigold Emperor gloves achieved the same performance level as each other for three wash types, and were the best of the glove types tested for one case each. The KCL Camapren gloves were third in all tests.

Digital Printing

One wash (Wash F) permeated all three gloves tested, Ansell Solvex giving the best protection with a normalised breakthrough time of 160 minutes. The other fluid tested (Wash G) only managed to permeate one glove type (KCL Dermatrill P), after 155 minutes. Although both washes contained 2-butoxy ethyl acetate, only one permeated the Ansell Solvex glove, presumably due to matrix effects.

Offset (Newsprint) Lithographic Printing

Ansell Solvex and KCL Dermatrill P gloves both performed well against the two washes tested for over eight hours. Marigold Tripletec gloves failed after just over one hour. Although the Marigold Tripletec gloves are thicker overall, the nitrile coating was less effective than the thinner pure nitrile Dermatrill P gloves. The permeant detected for both washes contained relatively mild chemicals (mostly aliphatic hydrocarbons).

Flexographic / Gravure Printing

None of the gloves tested gave more than short-term protection against the Flexographic / Gravure print washes with breakthrough times typically being less than half an hour. Higher proportions of ethyl acetate had a detrimental effect on resistance to permeation, although the other components also permeated the gloves quite well. The natural rubber Marigold Emperor gloves gave better resistance to permeation for five of the six washes, the exception being recycled toluene.

Figure 3. Ansell Solvex Gloves Versus Wash F

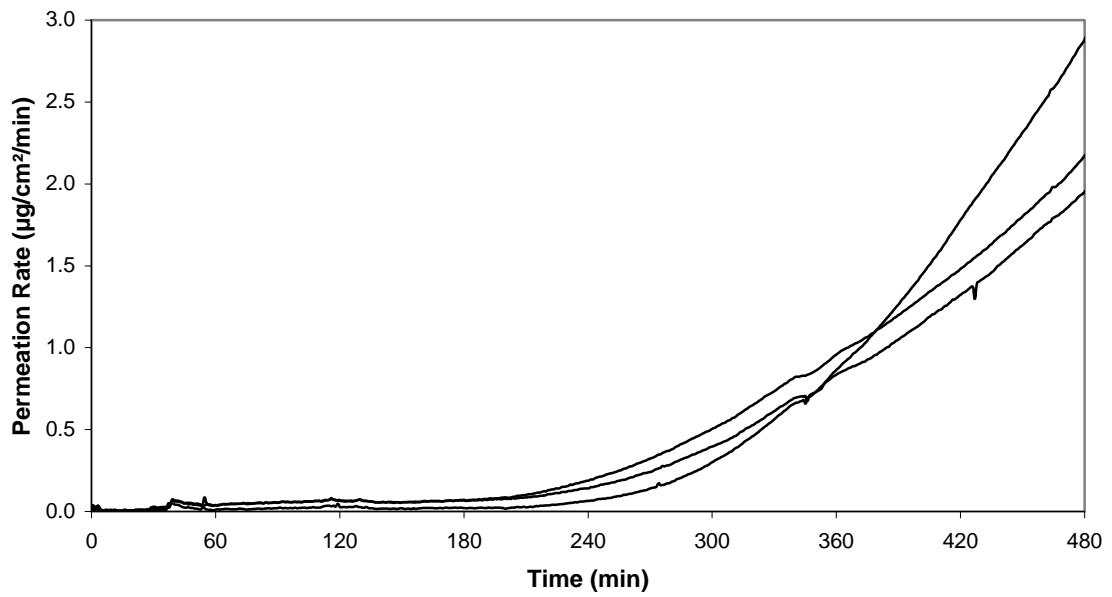


Figure 4. Marigold Emperor Gloves Versus Recycled Toluene

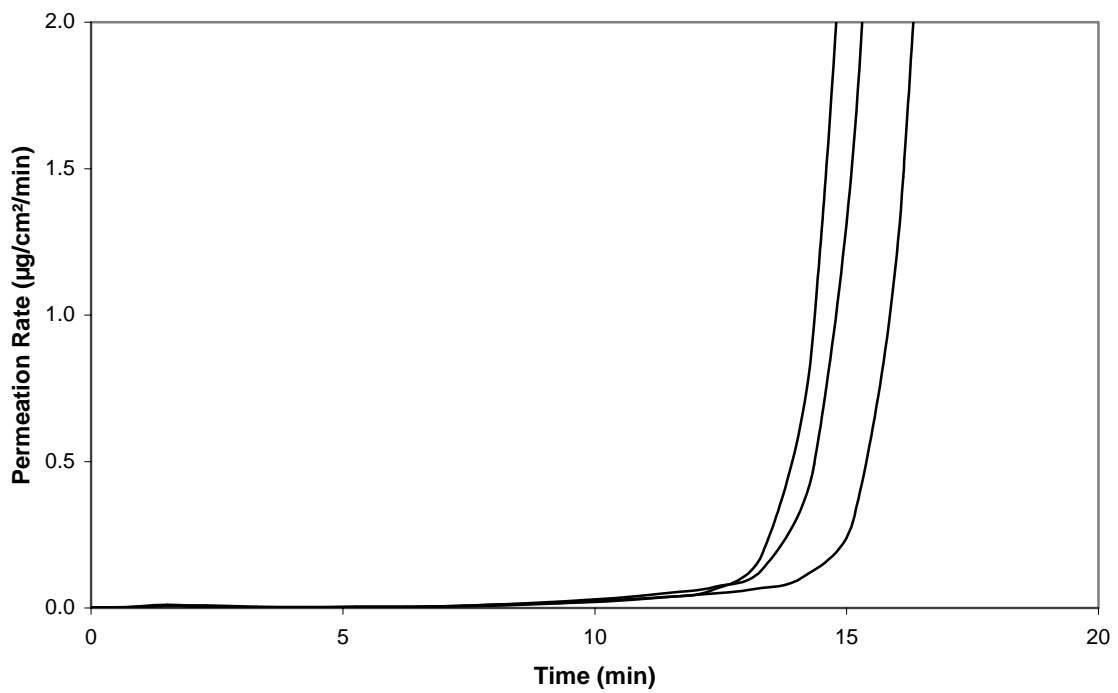
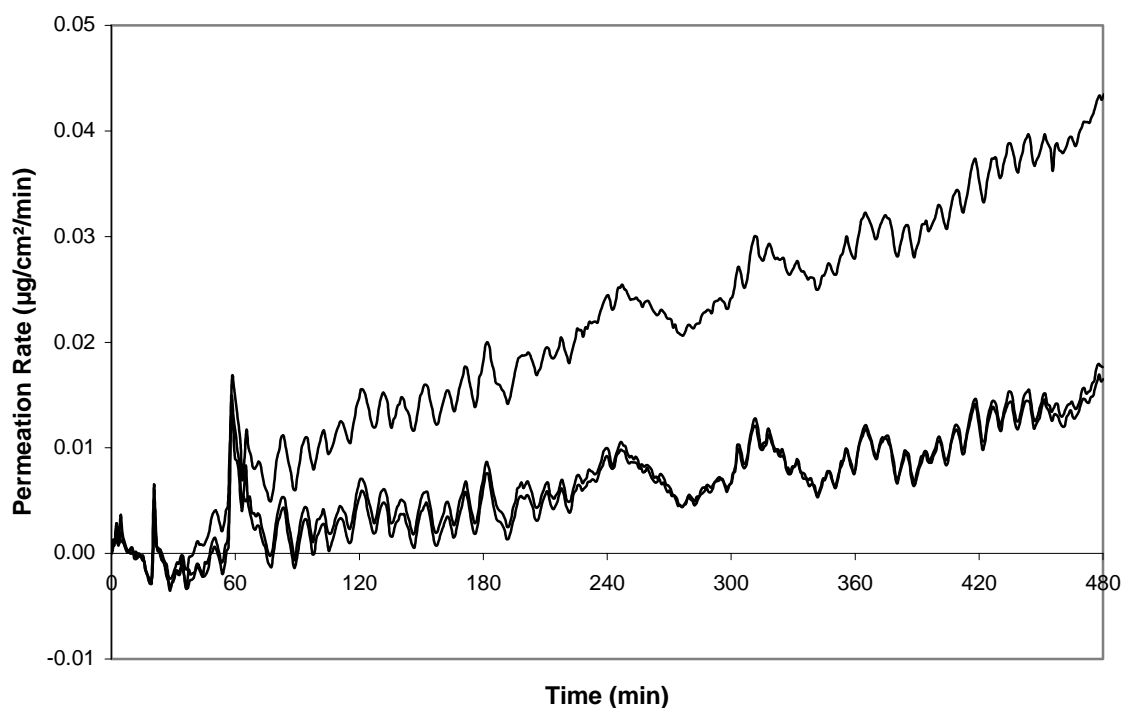


Figure 5. KCL Dermatril P Gloves Versus Wash H

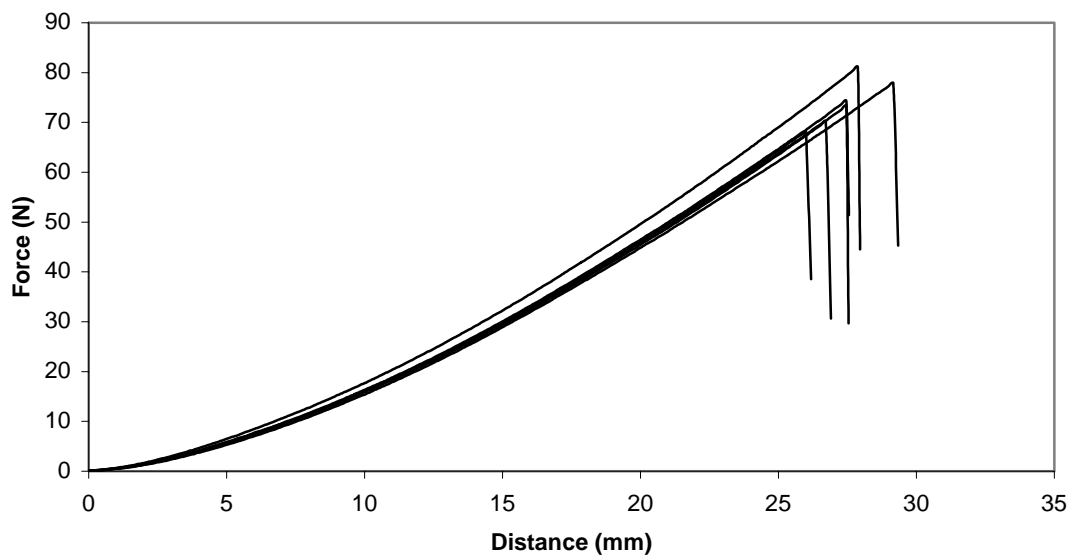


4.2 PUNCTURE RESISTANCE

Tests of the unused gloves gave results that were comparable to the manufacturers stated performance levels. An example of the behaviour of the gloves under stress and the spread of results can be seen in Figure 6. Ansell Solvex gloves had the highest puncture resistance, attaining performance level 2 as stated by the manufacturer. Marigold Emperor gloves gave the second highest puncture resistance, just failing to attain level 2 (the manufacturers give a performance value of level 1). They were also quite stretchy, with three samples exceeding 50 mm displacement. Marigold Tripletec narrowly failed to achieve its stated performance level (level 1), whereas the untested KCL Dermatril P narrowly achieved level 1.

Although Ansell Solvex nitrile gloves had the highest puncture resistance before chemical exposure, afterwards they usually gave results lower than the Marigold Emperor natural rubber gloves. Many of the lowest test results (~5 N) were for KCL Camapren neoprene gloves after exposure to screen-printing washes. After chemical exposure, both the Ansell Solvex and the KCL Camapren gloves failed to meet the performance level 1 requirements, however although the Marigold Emperor glove generally gave lower results, they were still greater than 20 N. Only three fluids were tested against Marigold Tripletec gloves, however on each occasion the puncture resistance fell below 20 N.

Figure 6. Ansell Solvex Glove Puncture Test Results



4.3 ALTERNATIVE GLOVE TYPES

It has been shown that, apart from for offset (newsprint) lithographic printing, none of the glove types tested performed well against permeation for all the washes for over eight hours. Gloves for flexographic and gravure print washes were particularly poor, with some washes breaking through after only ten minutes. This work investigated only natural rubber, neoprene and nitrile rubber gloves. From data supplied by manufacturers and suppliers, butyl rubber, Viton® and advanced laminate materials appear to be able to offer greater protection, although at a higher cost price. Butyl rubber is reported to be good for esters and ketones but poor for aromatic hydrocarbons, and so may perform well for flexographic and gravure printing washes. Viton® on the other hand is said to be good for chlorinated and aromatic solvents but not for some esters and ketones, and is therefore a possible candidate for screenprinting washes. The effect of 1,2-ethanediol diacetate or the presence of small quantities of cyclohexanone on the washes tested here is as yet unknown. Laminate gloves (e.g. polyolefin/polyamide or polyethylene/polyethylene vinyl alcohol) appear to provide the best protection available for any of the washes, but manufacturers recommend double gloving with a tighter glove to improve feel and grip.

5 CONCLUSIONS

Gloves:

The best performing glove was the Ansell Solvex nitrile glove which prevented permeation for eight hours for three of the fifteen cleaning fluids. However permeation times were less than 10 minutes for some washes. In such cases the gloves maybe used for splash protection (i.e. immediate removal would be required after contamination).

The Marigold Emperor was the next best performing glove, although it did not resist permeation for 8h for any of the twelve washes tested. In general protection of greater than 30 minutes was observed, with only two washes permeating in less than 30 minutes.

The KCL Camapren glove in general performed very poorly with permeation occurring within 30 minutes for the majority of washes and in four cases within 10 minutes. Where short permeation times are observed, only splash protection is afforded.

The KCL Dermatrill P and Marigold Tripletec G44R nitrile gloves only underwent a small number of tests, however both types performed well for over 8 hours against specific washes.

Specific conclusions in relation to the washes:

1. Screen printing washes (5 types) with Ansell Solvex (nitrile), KCL Camapren (neoprene and natural rubber) and Marigold Emperor (natural rubber).

- Permeation occurred in 71 minutes or less for all three glove types and all five screen washes except for Wash E with Ansell Solvex and Marigold emperor gloves, which resisted permeation for 319 and 201 minutes respectively.
- The poorest performing glove was the KCL Camapren with permeation times of 17 minutes or less for all but the Wash E. The best performing glove was Ansell Solvex nitrile gloves which prevented permeation of three of the fifteen cleaning fluids tested.

2. Digital printing washes (2) with Ansell Solvex, KCL Camapren, Marigold Emperor, Marigold Tripletec (nitrile coated natural rubber) and KCL Dermatrill P (nitrile).

- For Wash F, the Ansell Solvex (160 minutes) and Marigold Emperor (88 minutes) offered some resistance to permeation whilst the KCL Camapren resisted for only 28 minutes. For Wash G, the Ansell Solvex, KCL Camapren and Marigold Tripletec resisted permeation for greater than eight hours. Surprisingly the KCL Dermatrill P nitrile glove resisted permeation for only 155 minutes.

3. Offset (Newsprint) Lithographic printing washes (2) with Ansell Solvex, Marigold Tripletec and KCL Dermatrill P.

- Ansell Solvex and KCL Dermatrill P, performed well against both of the washes, lasting over eight hours. The performance of the Marigold Tripletec glove was poorer with permeation occurring at 89 and 73 minutes for Wash H and Wash I respectively.

4. Flexographic/Gravure printing washes (6) with Ansell Solvex, KCL Camapren and Marigold Emperor.

- The Ansell Solvex and KCL Camapren gloves performed poorly with permeation times of under 39 and 19 minutes respectively for all six washes but some permeation times were as low as 3 to 9 minutes. The Marigold Emperor glove in general performed slightly better with a permeation time of 120 minutes for methylated spirits with n-propyl acetate. However permeation occurred within 70 minutes for the remaining washes.

If improved glove protection is required for workers using these chemical washes, it is recommended that further testing is done with butyl rubber, Viton® and laminate gloves.

6 APPENDIX

Table 3. Chemical Permeation Test Results

Chemical Wash	Normalised Breakthrough Time (min) by Glove Type				
	Ansell Solvex 37-675	KCL Camapren 720	Marigold Emperor ME101	Marigold Tripletec G44R	KCL Dermatrill P 743
Screen Printing					
Wash A	29, 30, 32	15, 17, 17	54, 65, 72	n/a	n/a
Wash B	39*, 40*, 42*	11, 11, 14	33, 36, 37	n/a	n/a
Wash C	42, 45, 45	10, 11, 12	40, 41, 46	n/a	n/a
Wash D	38, 39, 45	11, 11, 13	39, 42, 43, 45, 45	n/a	n/a
Wash E	319, 331, 364	71, 72, 73	201, 209, 226	n/a	n/a
Digital Printing					
Wash F	160, 167, 177	28, 30, 30	88, 96, 100, 103, 104	n/a	n/a
Wash G	>480, >480, >480	>480, >480, >480	n/a	>480, >480, >480	155, 169, 174
Offset (Newsprint) Lithographic Printing					
Wash H	>480, >480, >480	n/a	n/a	89, 93, 104	>480, >480, >480
Wash I	>480, >480, >480	n/a	n/a	73, 80, 85, 86, 97	>480, >480, >480
Flexographic / Gravure Printing					
100% Toluene	19, 19, 20	3, 3, 4	14, 15, 16	n/a	n/a
50:50 EA/IMS	13, 13, 14	8, 10, 10	42, 42, 58	n/a	n/a
75:25 IMS/nPA	27, 30, 31	13, 15, 17	120, 121, 123	n/a	n/a
100% EA	8, 9, 10	4, 4, 4	23, 25, 34	n/a	n/a
50:25:25 EA/IMS/nPA	9, 9, 10	5, 7, 7	32, 33, 40	n/a	n/a
75:25 IMS/EA	39, 42, 42	19, 21, 28	70, 73, 77	n/a	n/a
* Temperature Out of Spec (21.5 +/- 0.3°C) EA – ethyl acetate, IMS – industrial methylated spirits, nPA – n-propyl acetate					

Table 4. Puncture Test Results

Prior Chemical Exposure	Puncture Resistance (N) by Glove Type				
	Ansell Solvex 37-675	KCL Camapren 720	Marigold Emperor ME101	Marigold Tripletec G44R	KCL Dermatril P 743
Unexposed	68.20, 70.22, 73.27, 74.35, 77.89, 81.14	24.47, 25.61, 25.86, 28.14, 28.42, 30.02	46.82, 48.90, 59.53*, 62.90, 63.45*, 70.45*	18.98, 19.25, 20.29, 22.44, 23.84, 25.87	20.41, 20.96, 23.25, 23.52, 24.33, 24.37
Screen Printing					
Wash A	13.33, 15.33, 19.17	6.04, 7.26, 7.56	38.81, 39.50, 43.19	n/a	n/a
Wash B	9.97, 12.92, 17.37	5.36, 5.48, 6.02	23.34, 24.25, 25.74	n/a	n/a
Wash C	12.13, 12.23, 12.91	5.35, 5.65, 8.17	23.94, 24.83, 26.48	n/a	n/a
Wash D	9.05, 12.82, 14.14	4.81, 5.18, 7.69	27.98, 31.30, 36.26	n/a	n/a
Wash E	17.24, 24.57, 27.46	5.92, 6.80, 7.07	34.96, 35.99, 36.52	n/a	n/a
Digital Printing					
Wash F	17.63, 18.36, 24.18	8.59, 10.13, 10.94	41.40, 41.59, 50.27	n/a	n/a
Wash G	35.78, 54.49, 70.35	12.30, 13.66, 16.29	n/a	11.99, 16.44, 17.71	5.64, 5.67, 7.08
Offset (Newsprint) Lithographic Printing					
Wash H	72.05, 78.02, 87.51	n/a	n/a	10.47, 12.40, 13.03	19.89, 22.41, 22.56
Wash I	71.68, 82.06, 93.69	n/a	n/a	13.04, 14.23, 16.38	20.67, 21.64, 23.99
Flexographic / Gravure Printing					
100% Toluene	19.11, 22.19, 26.53	7.32, 7.78, 9.72	32.90, 33.21, 33.58	n/a	n/a
50:50 EA/IMS	13.28, 14.11, 15.01	13.19, 14.17, 14.83	44.64, 47.07, 59.21	n/a	n/a
75:25 IMS/nPA	13.72, 14.11, 15.18	13.32, 13.53, 14.58	50.90, 54.08, 54.64	n/a	n/a
100% EA	17.66, 18.67, 20.89	13.60, 15.84, 16.41	36.27, 39.89, 43.53	n/a	n/a
50:25:25 EA/IMS/nPA	12.84, 13.32, 14.49	12.75, 12.80, 13.07	46.65, 47.13, 52.59	n/a	n/a
75:25 IMS/EA	16.85, 17.42, 18.07	14.77, 16.88, 18.23	48.36, 54.08, 57.05	n/a	n/a
EA – ethyl acetate, IMS – industrial methylated spirits, nPA – n-propyl acetate, * >50 mm displacement					

Table 5. Chemical Permeation Identification Results

Chemical Wash	Permeating Chemicals
Wash A	'Light aromatic solvent naphtha' (C2-C3 benzenes) Cyclohexanone 1-Methoxy-2-propanol
Wash B	'Light aromatic solvent naphtha' (C2-C4 benzenes) 1-Methoxy-2-propanol Cyclohexanone 4-hydroxy-4-methyl-2-pentanone
Wash C	'Light aromatic solvent naphtha' (C2-C4 benzenes) Cyclohexanone 1-Ethoxy-2-propanol Methoxy propyl acetate
Wash D	'Light aromatic solvent naphtha' (C2-C4 benzenes) 1-Methoxy-2-propanol Cyclohexanone 'White spirit' (C9-C10 alkanes)
Wash E	1,2-Ethane diol diacetate Propylene carbonate 2-(2-Butoxy ethoxy)-ethyl acetate
Wash F	2-Butoxy ethyl acetate
Wash G	Tri(propylene glycol)methyl ether 2-Butoxy ethyl acetate
Wash H	'Hydrotreated light distillates (petroleum)' (mostly C9-15 alkanes)
Wash I	'Hydrotreated light distillates (petroleum)' (mostly C11-14 alkanes)
100% Toluene	Toluene
50:50 EA/IMS	Ethyl acetate Ethanol Methanol
75:25 IMS/nPA	n-Propyl acetate Ethanol Methanol (+Ethyl acetate)
100% EA	Ethyl acetate
50:25:25 EA/IMS/nPA	Ethyl acetate Ethanol Methanol n-Propyl acetate
75:25 IMS/EA	Ethyl acetate Ethanol Methanol

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