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The Recoverability of Fingerprints on Paper Exposed to Elevated Temperatures – Part 1: Comparison of Enhancement Techniques

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Abstract

This research investigates the recoverability of fingerprints which have been exposed to elevated temperatures in order to mimic the environment a piece of paper may be exposed to within an arson scene. Arson is an expensive crime, costing the UK economy, on average, £53.8 million each week [1]. Anything which may give rise to the identity of the fire setter should be analysed and as such, unburnt paper may be a potential source of fingerprints. While it is true that even a moderate fire will

obscure and render partially useless some types of evidence, many items, including fingerprints, may still survive [2-4].

This research has shown that fingerprints are still retrievable from paper which has been subjected to the maximum testing conditions of 200˚C for 320min. In fact, some fingerprints naturally enhance themselves by the heating process. This investigation has also shown that the most effective enhancement technique was found to be 1,8-diazafluoren-9-one (DFO) for exposure temperatures upto 100˚C. Physical developer (PD) is the most effective enhancement technique for exposure temperatures from 100˚C to 200˚C.

For porous surfaces, there are fingerprint development techniques which are effective at enhancing fingerprints exposed upto a temperature of 200˚C, irrespective of the firefighting extinguishing technique, as PD, in addition to developing fingerprints exposed to high temperatures, is one of the few processes which will enhance fingermarks on wetted surfaces.

Introduction

Each week in the UK, there are, on average, 2213 arson attacks, which result in 2 fatalities, 53 injuries, and damages or destroys 20 schools and colleges, 262 homes, 360 businesses and public buildings, and 1402 vehicles [1]. The origin and cause of the fire is much easier to determine than the identity of the arsonist. However one clue to a potential perpetrators identity is their fingerprints, if they have been deposited at the scene. There have been many uses for fingerprints throughout history, resulting in their use for identification in the present day [5, 6], however their survivability and recovery from fire scenes is not well researched. This study was undertaken to establish whether various ages of fingerprints deposited on paper and exposed to various temperatures at various exposure times could survive, and if so, to determine the most effective technique for their enhancement.

Previous work into the recoverability of fingerprints on paper had considered a minimum exposure time of 1 hour [7]. However, many fires are extinguished before this period. For example, London Fire Brigade sets attendance time targets, that the first fire appliance must reach the fire 65% of the time within 5min and 90% within 8min [8]. Other fire services will have similar standards.. As such a more comprehensive study is required to investigate the survivability of fingerprints on paper exposed to elevated temperatures. In addition, fingerprints of primary interest are likely to be 1 hour old or less, rather than the 1 day minimum age used previously, and therefore this shorter time period between deposition and exposure was investigated.

Materials and Methods

The paper used was taken from an unopened packet of white 80g/m^2 A4 recycled paper manufactured by Niceday (Andover, Hampshire, UK) and only handled whilst wearing gloves. A depletion grid was drawn onto the paper surface as shown in figure 1.

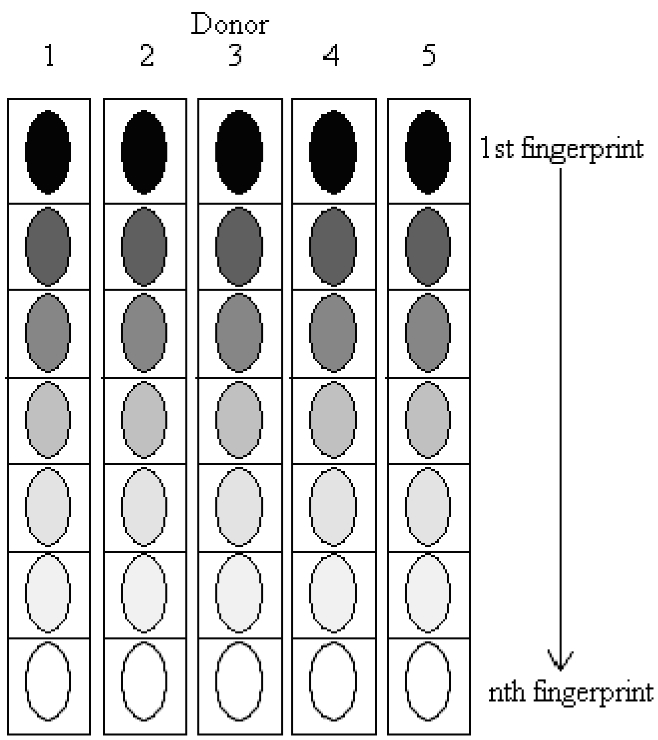

Figure 1: Example of a depletion grid

Fingerprint depletions samples were donated by five donors from a mix of male and female donors over a wide age range to represent a cross section of people. Only donors who hadn’t washed their hands in the past half an hour were allowed to deposit and before donation, they rubbed their hands together to evenly distribute the sweat across all digits used for deposition.

These fingerprints were subjected to different environmental exposure times to age the prints before being subjected to different temperatures for different periods of time, and enhanced by different methods. A summary of the experiments is given in table 1.

Table 1: Summary of exposure to heat experiments

Substrate	Environmental Ageing Time	Temperature (˚C)	Exposure Time (min)	Treatment
Paper	1 hour, 1 day, 1 week, 1 month	50	10, 20, 40, 80, 160, 320	1. Ninhydrin 2. DFO 3. PD
		100		
		150		
		200		

Paper was only heated to 200˚C as its autoignition temperature is in the range of 233˚C (although this depends on the type of pulp used, chemical content, paper thickness, and a variety of other characteristics).

Three enhancement techniques for porous surfaces were employed, ninhydrin, 1,8-diazafluoren-9-one (DFO), and physical developer (PD). These solutions were all made up in accordance with the Home Office's Manual of Fingerprint Development Techniques (MoFDT) with chemical suppliers for each chemical listed as an appendix within the manual [9].

Results and Discussion

The chemical techniques used to enhance the fingerprints on the paper were ninhydrin, DFO, and PD. However, when the paper was subjected to the conditions described in table 1, it was discovered that when the paper was placed in the oven at 150˚C and 200˚C, even for the minimum exposure time of 10 minutes and at the longest environmental exposure time of 1 month, some of the deposited fingerprints became naturally enhanced by the action of the heat alone. This has been previously been noted by Almog and Marmur [10], Hamm [11] and Olsen [12]. This is shown in figure 2, which also shows the colour change exhibited by the paper at 200˚C (all photographs in this paper are taken at 40min exposure time), with prints only becoming visible at 150˚C and 200˚C.

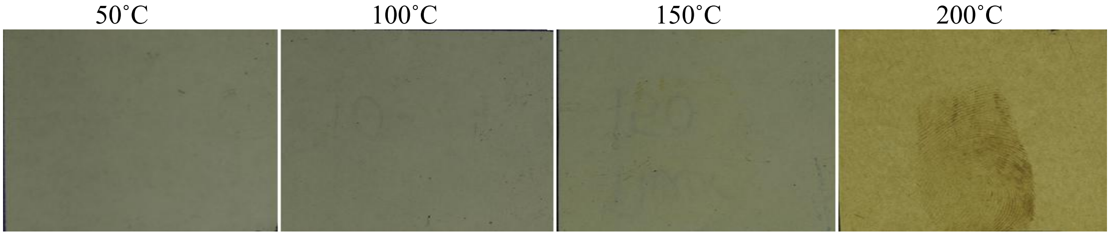

Figure 2: Naturally enhanced fingerprints under normal lighting conditions

As a consequence of observations made in operational work and subsequent laboratory experiments [13], it was suggested that the paper be examined under fluorescent lighting conditions used for examining DFO enhanced prints. Fluorescence was therefore also included as an enhancement technique.

Fluorescence

By viewing all the paper samples under fluorescent lighting conditions, it was found that fingerprints subjected to temperatures of 150˚C naturally fluoresced on exposure to the green light waveband of Quaser 2000 (473-548nm) when viewed using a 549nm viewing filter. No fluorescence of the fingerprints was observed at 50˚C, 100˚C, and 200˚C and this is indicated in the figure below. This phenomenon has been investigated in more detail by the current authors and will be reported in a subsequent paper.

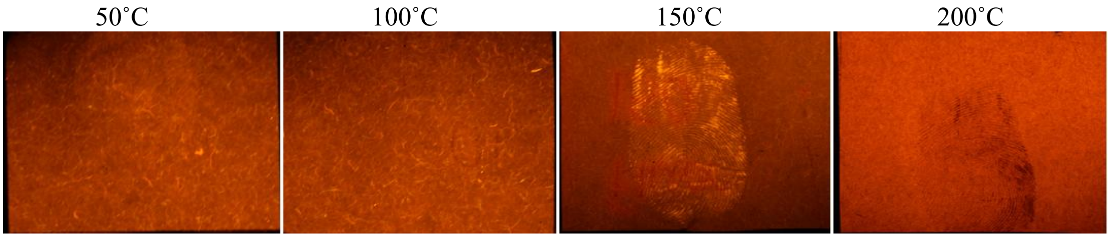

Figure 3: Photograph of fingerprints under light of 473-548nm with a viewing filter of 549nm

Each fingerprint had to be assessed and as such the assessment method employed estimated the proportion of the developed fingerprint's clear ridge detail, with a score assigned to each fingerprint of 0 to 4. This was a much quicker and simpler method for a non-expert to use rather than counting minutiae. Fingerprints were all graded as follows:

Table 2: Fingerprint scoring system

Score	Level of Detail
0	No evidence of print
1	0 -1/3 ridge detail
2	1/3 – 2/3 ridge detail
3	2/3 – 1 ridge detail
4	Ridge detail over every point of contact visible

The fingerprint scores obtained were inputted into Minitab v.15 software package for statistical analysis. A balanced ANOVA (analysis of variance) test was conducted, which investigates the factors which were varied during the experiment (type of deposit, age, temperature, and time) in order to determine their effect on the response variable (fingerprint score). The ANOVA calculation is not as simple as one mathematical equation. The sum of squares (SS in the table) must be calculated first and this measures the variability in the data. The mean squares (MS in the table) are also calculated. This is the estimate of the variance in the data left over after the differences in the mean have been accounted for, and this is calculated by dividing the sum of squares by the degrees of freedom (DF in the table). Degrees of freedom are one less than the number of levels in each factor. The F value in the table is the comparison of the mean squares for each effect to the mean square error value. This value is used to determine which of the effects in the model are statistically significant, by generating the P-value. This P-value is compared to the α-value of 0.05, with $P < 0.05$ indicating the variable has a significant effect on the response, or $P > 0.05$ indicating no significant effect on the response [14]. The following output is the ANOVA table generated by Minitab.

Table 3: ANOVA table for fluorescence in terms of score

Analysis of Variance for Score

Source	DF	SS	MS	F	P
Age	3	0.05785	0.01928	1.63	0.187
Temp	3	8.64185	2.88062	244.08	0.000
Time	5	0.63856	0.12771	10.82	0.000
Age*Temp	9	0.50079	0.05564	4.71	0.000
Age*Time	15	0.16297	0.01086	0.92	0.545
Temp*Time	15	0.70232	0.04682	3.97	0.000
Age*Temp*Time	45	0.54749	0.01217	1.03	0.442
Error	90	1.06218	0.01180		
Total	287	17.25820			

The P-values indicate that *temperature* and *time* have a significant effect on the fingerprint score obtained, but not the age of the fingerprint. Age is only causing a significant effect when interacting with the change in temperature.

This phenomenon may be the result of two things: the decomposition of the fingerprint under heating, the physical change which the paper is exhibiting at 150˚C, or a mixture of both. This requires further work to be undertaken.

Ninhydrin

Ninhydrin is a colorimetric fingerprint development process, and by subjecting the paper to varying degrees of heat, the paper is also changing colour (as previously seen in figure 1). This causes a limitation when using ninhydrin as an enhancement technique. At higher temperatures, and longer exposure times, the paper becomes a dark brown colour. As ninhydrin changes colour from clear to purple when reacting with amino acids present in fingerprints, this causes a contrast problem. The lack of contrast at 200˚C could be two fold – either the ninhydrin is reacting but the colour change does not have any contrast against the dark background of the paper, or there is no reaction with ninhydrin on these naturally enhanced fingerprints to provide a colour change. DeHaan states that ‘the proteins in latent residue can be denatured by high temperatures so that they no longer react, but if the paper has not been charred by the fire it may be worth testing’ [2]. This work has shown that if the paper is significantly charred and has changed colour to a dark brown, enhancement with ninhydrin is unnecessary as the contrast between the ridges and the charred paper is not significant enough to give a viable print. This is shown in figure 4.

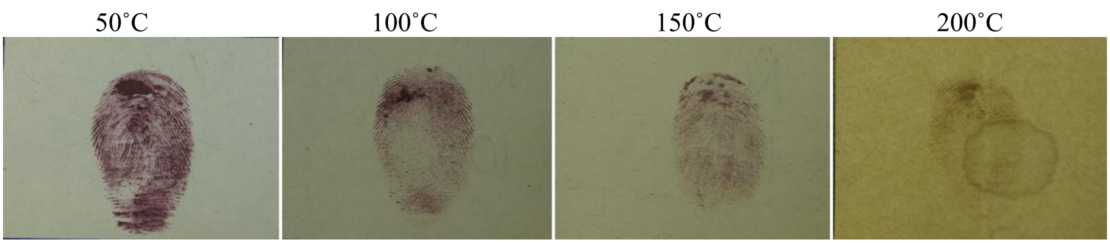

Figure 4: Photograph of fingerprints enhanced by ninhydrin

The ANOVA analysis for the scores obtained by ninhydrin enhancement is shown in table 4.

Table 4: ANOVA table for ninhydrin in terms of score

Analysis of Variance for Score

Source	DF	SS	MS	F	P
Age	3	3.3402	1.1134	13.83	0.000
Temp	3	70.6955	23.5652	292.65	0.000
Time	5	3.0511	0.6102	7.58	0.000
Age*Temp	9	8.9032	0.9892	12.29	0.000
Age*Time	15	3.4844	0.2323	2.88	0.001
Temp*Time	15	7.0201	0.4680	5.81	0.000
Age*Temp*Time	45	5.0466	0.1121	1.39	0.092
Error	90	7.2470	0.0805		
Total	287	189.6750			

Using the significance rule outlined previously, the ANOVA analysis shows that all three variables, and their subsequent interactions (except for the three way interaction), all have a significant effect to the resulting fingerprint score.

DFO

DFO enhanced fingerprints are only visible when viewed under specific lighting conditions (green light between 473-548nm and using a 549nm viewing filter). It was found that as the paper changed colour, the contrast between the fluorescent fingerprint and the background changed. Examples of the changes in this contrast are shown below in figure 5.

50˚C 100˚C 150˚C 200˚C

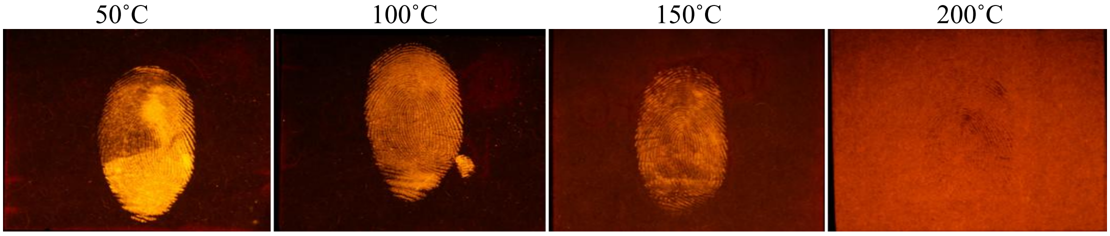

Figure 5: Photograph of fingerprints enhanced by DFO

As figure 5 shows, the prints start to fluoresce, then the background begins to fluoresce, then the prints are no longer fluorescing. This may be due to no reaction taking place, or that the reaction product has degraded under the heat exposure. This may explain the poorer scores observed at 150˚C and 200˚C.

The resulting fingerprints scores where submitted for ANOVA analysis and these results are shown in table 5.

Table 5: ANOVA table for DFO in terms of score

Analysis of Variance for Score

Source	DF	SS	MS	F	P
Age	3	0.8961	0.2987	2.87	0.041
Temp	3	272.6040	90.8680	874.25	0.000
Time	5	1.5232	0.3046	2.93	0.017
Age*Temp	9	20.6931	2.2992	22.12	0.000
Age*Time	15	3.1608	0.2107	2.03	0.021
Temp*Time	15	17.5267	1.1684	11.24	0.000
Age*Temp*Time	45	7.1453	0.1588	1.53	0.045
Error	90	9.3545	0.1039		
Total	287	416.4370			

Similar to the ninhydrin results, all factors and their interactions have a significant effect on the fingerprint scores obtained.

The fingerprint scores obtained indicate that DFO is a more effective development process than ninhydrin (in accordance with all previous HOSDB studies) and is a fairly successful process at all environmental and heat exposure times. This is in agreement with Bleay et al [4] and Bradshaw et al [7] but when the paper is subjected to 200˚C, as with ninhydrin, the enhancement technique performs poorly. This is may be due to the substrate and also the degradation that the fingerprint is experiencing at this high temperature.

PD

PD is the one of the few fingerprint techniques which is known to enhance fingermarks that have been deposited on paper which has subsequently been wetted. Obviously in terms of the practicalities of this research, in order for firefighters to control a fire, they will generally use water as a means to suppress it. Therefore, if a wet document is recovered from a fire scene, it is important that to know whether the prior exposure of the document to heat lessens the chances of PD developing marks. An example of PD enhanced fingerprints is shown below in figure 6.

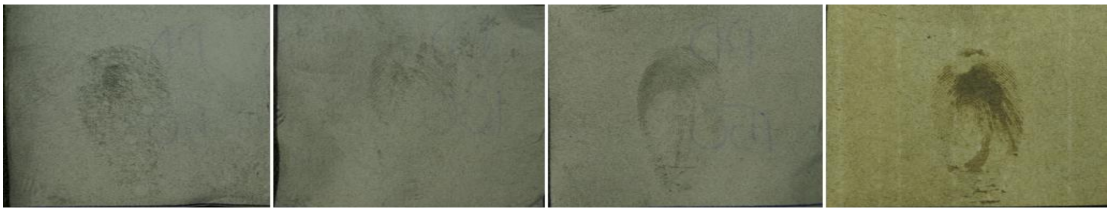

Figure 6: Photograph of fingerprints enhanced by PD

The scores obtained by grading the fingerprints enhanced by PD were analysed by ANOVA.

Table 6: ANOVA table for PD in terms of score

Analysis of Variance for Score

Source	DF	SS	MS	F	P
Age	3	8.5189	2.8396	24.07	0.000
Temp	3	7.7137	2.5712	21.80	0.000
Time	5	6.7436	1.3487	11.43	0.000
Age*Temp	9	23.9355	2.6595	22.54	0.000
Age*Time	15	20.1582	1.3439	11.39	0.000
Temp*Time	15	8.8293	0.5886	4.99	0.000
Age*Temp*Time	45	18.9047	0.4201	3.56	0.000
Error	90	10.6172	0.1180		
Total	287	158.8736			

Again, as with ninhydrin and DFO, the ANOVA results show that the three factors and their interactions are all having a significant effect on the resulting number, and quality, of fingerprints enhanced by PD.

The fingerprint results indicate that PD is a much more erratic technique and doesn't seem to follow any set pattern. The major advantage associated with enhancement by PD is that as this work has been undertaken to mimic the exposure a document may experience during an actual fire, the technique used in suppressing the fire will also be a major factor in deciding which development technique to use. The results indicate that PD can still effectively develop prints on articles exposed to high temperatures in addition to being wetted, and therefore fingerprint laboratories have access to techniques applicable to a broad range of arson scenarios. DeHaan [2, 15] and Bradshaw et al [7] agree that PD should be used in a wetted paper scenario.

3.5 Enhancement Technique Comparison

The scores obtained by grading the fingerprints enhanced by all four techniques were inputted into Minitab for further ANOVA analysis. The following output illustrated in table 7, is the data generated by the statistical package.

Table 7: ANOVA table for fingerprints in terms of score

Analysis of Variance for SCORE

Source	DF	SS	MS	F	P
TECHNIQUE	3	91.6807	30.5602	475.91	0.000
TEMP	3	31.5179	10.5060	163.61	0.000
TIME	5	2.2960	0.4592	7.15	0.000
AGE	3	3.4259	1.1420	17.78	0.000
TECHNIQUE*TEMP	9	44.5346	4.9483	77.06	0.000
TECHNIQUE*TIME	15	3.7711	0.2514	3.92	0.000
TECHNIQUE*AGE	9	8.9989	0.9999	15.57	0.000
TEMP*TIME	15	1.7036	0.1136	1.77	0.045
TEMP*AGE	9	0.9604	0.1067	1.66	0.104
TIME*AGE	15	3.0869	0.2058	3.20	0.000
TECHNIQUE*TEMP*TIME	45	6.2488	0.1389	2.16	0.000
TECHNIQUE*TEMP*AGE	27	8.3881	0.3107	4.84	0.000
TECHNIQUE*TIME*AGE	45	8.1392	0.1809	2.82	0.000
TEMP*TIME*AGE	45	3.3581	0.0746	1.16	0.254
Error	135	8.6690	0.0642		
Total	383	226.7791			

The four variables in this comparison all have a significant effect on the resulting fingerprints and most of the interaction effects (apart from *temp x age* and *temp x time x age*) are significant to the response. In order to graphically interpret this data, another feature of the ANOVA testing in Minitab is interaction plots. An interaction plot shows the impact that changing the settings of one factor has on another factor by comparing the mean responses. This is shown in figure 7.

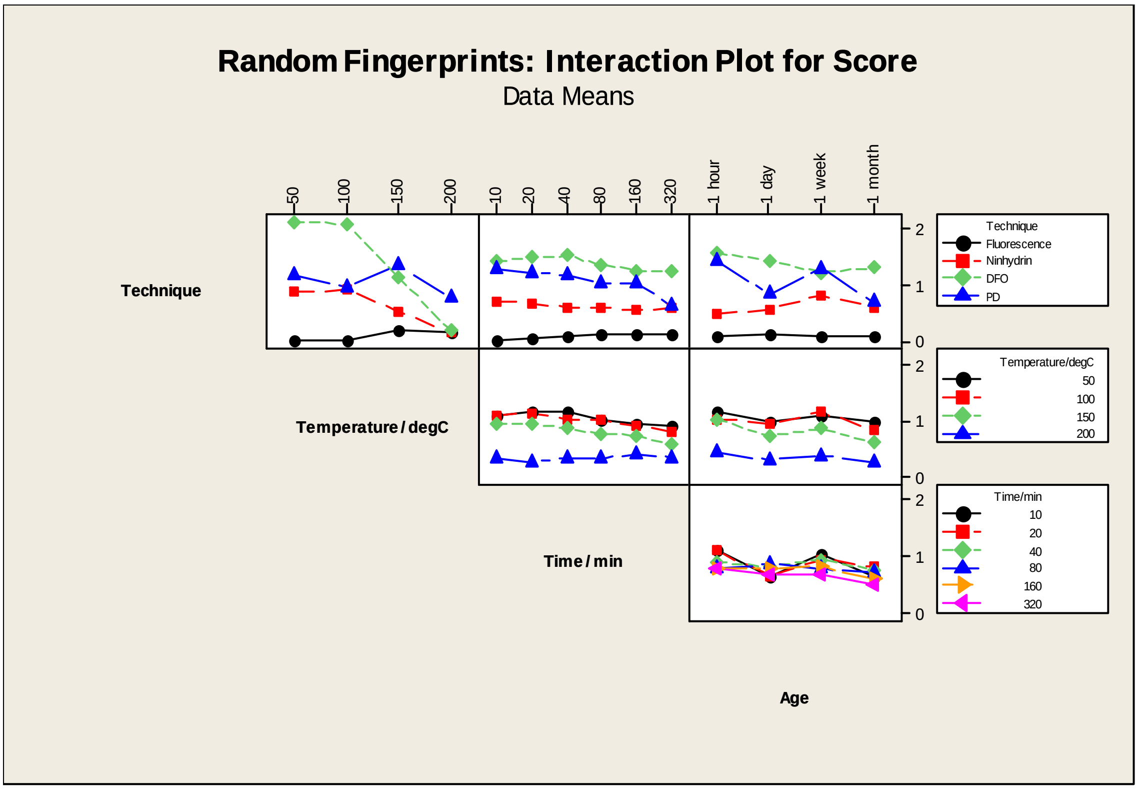

Figure 7: Interaction plot of fingerprints on paper

By looking at the interaction plots, it would appear that on dry paper, DFO is the most effective development process in terms of number and quality of marks compared with the other techniques. This is followed by PD, which can be used on wetted paper. Ninhydrin is not a significant enhancement technique and would only be recommended to be used on dry paper which hasn't undergone much colour change. Fluorescence would always be used before any chemical enhancement after examining the paper for any visible naturally enhanced fingerprints first. The temperature which the paper is exposed to is also a factor with the higher the temperature, the lower recoverability of the marks. The exposure time and the ageing of the fingerprints appear not to affect the results as much as temperature, but there is a slight effect.

Deans [3] and Deans et al [16] have previously carried out some work into the recovery of fingerprints from fire scenes on different surfaces. They achieved results with ninhydrin and PD but had not considered DFO in their research, primarily because ninhydrin is most widely used in UK laboratories for volume crime, although they were aware that the fire suppression method would influence the recoverability of the marks.

Conclusions

In conclusion, all of the fingerprint enhancement techniques did enhance deposited fingerprints to some degree. The technique producing the best results was DFO, followed by PD. Fluorescence was a technique not previously considered but this work has shown it to be effective. It is intended to investigate how this effect occurs in greater detail.

Therefore, when undertaking fingerprint analysis on paper recovered from a fire scene, fluorescence should be the first technique to be considered. It is non destructive and will not affect any further fingerprint enhancement. The next technique would be dependent on whether the paper remained dry or wet during the extinguishing of the fire. If the paper was wet, then only PD would be effective at developing fingerprints. If dry, DFO would be the optimal technique. As DFO targets the eccrine component of the fingerprint deposit and PD targets the sebaceous part, it would be advantageous to further expose the paper to PD after DFO. Ninhydrin has been shown to enhance marks not developed by DFO as part of a sequential process [9], and as such could be used in the sequence of DFO – ninhydrin – PD, but this would be dependent on the paper colour for sufficient contrast (it is also worthwhile to note that these sequential processes have not been studied in this work).

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