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SPECIAL ISSUE PAPER

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Forensic discrimination of photocopy and printer toners. I. The development of an infrared spectral library

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Abstract Microscopical reflection-absorption by infrared spectroscopy (R-A IR) was shown as a viable technique for analyzing the polymer resins contained in dry, black photocopy and printer toners. The sampling technique involves a heat transfer of the toner from a document to the reflective surface of aluminum foil followed by analysis by R-A IR. The technique is simple, fast, and readily available to most forensic laboratories. A searchable spectral library was created that contains 807 toner samples analyzed by R-A IR. Ninety-eight groups were established based on spectral characteristics, and a flowchart was developed to assist with group assignments. A blind study was conducted to compare twenty photocopied documents each paired to a test document to determine if the pair could have been produced from the same copier. The analyst obtained 100% correct results in this study. Tests on thirty samples with the spectral library produced 90% first hits for the correct group. The three remaining samples were correctly determined by visual comparison of spectra for the top three hits. An actual case study was conducted where the investigation was narrowed from 400 possible machines to eight based on a comparative study of the photocopy toners.

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Keywords Questioned documents · Photocopy toner · Infrared microscopical analysis · Reflection-absorption infrared spectroscopy · Spectral library

Introduction

The examination of documents of questioned origin has long been a concern for forensic investigators, especially as technical methods available for the creation and analysis of these documents have evolved [1]. The emergence and widespread use of photocopiers and computer printers during the last two decades has complicated the investigative process [2]. Laser printers have blurred the line between printed and copied documents, necessitating a shift away from the traditional methods used for the analysis of typewritten documents [3]. Given the wide variety and frequent occurrence of criminal acts involving fraud, counterfeiting, transmission of sensitive or confidential materials, anonymous letters, etc., the ability to compare toners with discriminating methods or to identify copy toner types and machines is desirable. The capability to match the chemical fingerprints of questioned toner samples to standards and to apply the methodology for investigative purposes could be a valuable asset.

Totty [4] reviewed analytical techniques that have been used to characterize toners: visual examination, optical microscopy, scanning electron microscopy (SEM), magnetic viewers, infrared spectroscopy (IR), pyrolysis gas chromatography and/or mass spectrometry (Py-GC, Py-GC/MS, Py-MS), and differential scanning calorimetry (DSC). Early work by Kemp and Totty [5] found that 79 toners from various models of photocopier machines could be separated into 10 groups based on their IR spectra. Williams [6] identified numerous resins and the pigment Prussian blue based on characteristic IR absorptions. Zimmerman et al. [7] analyzed 35 toners by IR and determined 18 separate groups.

More recently, toner samples extracted from photocopies with carbon tetrachloride have been analyzed by FT-IR to identify chemical constituents and group toners

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This is publication number 03-02 of the Laboratory Division of the Federal Bureau of Investigation. Names of commercial manufacturers are provided for identification only and inclusion does not imply endorsement by the Federal Bureau of Investigation. This paper was presented in part as a poster at the International Symposium on the Forensic Examination of Trace Evidence in Transition, San Antonio, Texas, 24–28 June 1996.

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by similar spectra [8]. Trzcinska, and Brozek-Mucha [9] removed toners physically and conducted the analysis by IR transmission on a microscope. The possibilities of toner analysis and classification by diffuse reflection infrared Fourier transform spectroscopy (DRIFTS) have been described by other researchers [10, 11, 12, 13, 14, 15] Bartick and Merrill [16] conducted studies using attenuated total reflectance (ATR) with a diamond internal reflection element (IRE) that was built into an FT-IR microscope objective. This method provided a completely nondestructive technique, because the toner remained on the document during the analysis. However, dispersion and incomplete compensation of the diamond IRE complicated analysis of the data. Andrasko [17] demonstrated a reflection-absorption infrared spectroscopy (R-A IR) method by heating and transferring the toner to an SEM sample stub. Moel et al. [18] made comparative studies of R-A IR, DRIFTS, and transmission. The most favorable results were produced by removing the toner by contact with a heated metal disc, slicing the deposit from the disc, and placing the sample onto a KBr disc to conduct transmission spectroscopy. Merrill et al. [19] conducted a comparative study of ATR and R-A IR microscopical-based IR techniques and DRIFTS for the analysis of toner samples. R-A IR microscopy, with toner transferred to aluminum foil on microscope slides, was selected as the method of choice. The considerations were in terms of low cost, rapid speed of analysis, non-destructiveness, and quality of spectra.

In this work a computer searchable spectral library of dry black toners analyzed by R-A IR microscopy was prepared, and a flowchart was constructed based on the presence or absence of spectral absorbances. Groups of similar toner types were determined from the flowcharts and the main composition of the resin was determined. The use of the spectral library was tested by both known and unknown samples for comparing questioned and known documents to determine whether or not they were produced with the same toner type. Additionally, R-A IR microscopy was used for a case investigation involving toners.

Experimental methods

Instrumental conditions

Spectra were collected using one of two separate systems, a Thermo Nicolet (Madison, WI) 20SXC infrared spectrometer equipped with an IR-Plan microscope or a Thermo Nicolet 760 Magna infrared spectrometer equipped with a Nicolet Nic-Plan microscope. Both microscopes utilized medium band Mercury Cadmium Telluride (MCT) detectors. All analyses were conducted at 4-cm^{-1} resolution. Between 128 and 256 scans were acquired as needed for each spectrum over the range of 4,000 to 650 cm^{-1}. Baseline adjustment was performed using the Thermo Nicolet OMNIC software to flatten the baseline on each spectrum. The OMNIC correlation algorithm was used for searching the copy toner libraries that were created in this work.

Identifying dry toners

Our studies apply to analysis of black dry toner only. Because the sampling and analysis techniques are different, the toner must be identified microscopically as either standard dry toner or liquid toner. Standard dry toner adheres as an opaque solid to the surface of the paper, whereas liquid toner penetrates into the paper to the extent that cellulose fibers are visibly saturated with liquid toner.

Sample preparation

Samples were prepared using a heat transfer process to move dry toner from documents to aluminum foil affixed to standard microscope slides as described in a previous publication [19]. A variable temperature soldering iron, set at 288 °C, was used to transfer the toner to the aluminum foil. The heat was applied to the back of the document containing the toner to be sampled, so most of the heat dissipated before reaching the toner. The temperature at the point of transfer, measured with a thermocouple, was 85 °C. This temperature is significantly lower than the operating temperature of most office equipment (which ranges from near 135 °C to 165 °C). Although other materials provide a suitable reflective surface for the R-A IR technique, aluminum foil is readily available, inexpensive, and permits the sample to be stored for further studies. The sample preparation is simple, fast, and essentially nondestructive. The document is still legible after transferring the toner sample, and only minimal destruction is visible microscopically. Care should be taken when sampling two-sided documents to avoid direct contact between the soldering iron and toner on the back of the document being sampled.

Sampling concerns and spectral quality

When transferring the toner sample to the aluminum foil, it is necessary to apply heat with light pressure while gently sliding the document over the aluminum foil. This technique produces a smear of toner with a variety of thicknesses at different sites on the smear. If the heat and pressure are applied straight down and the document is lifted straight up, in a blotting fashion, the toner transfer is often too thick to analyze by R-A IR. Attempts to analyze a sample that is too thick may result in insufficient penetration and increased scattering of the IR energy due to high levels of carbon black. Sampling in a blotting fashion also increases the presence of cellulose fibers embedded in the transferred toner. Figure 1A shows a toner spectrum from a sample that is contaminated with cellulose fibers. Cellulose fibers are usually easy to identify under a microscope; cellulose exhibits the characteristic spectrum shown

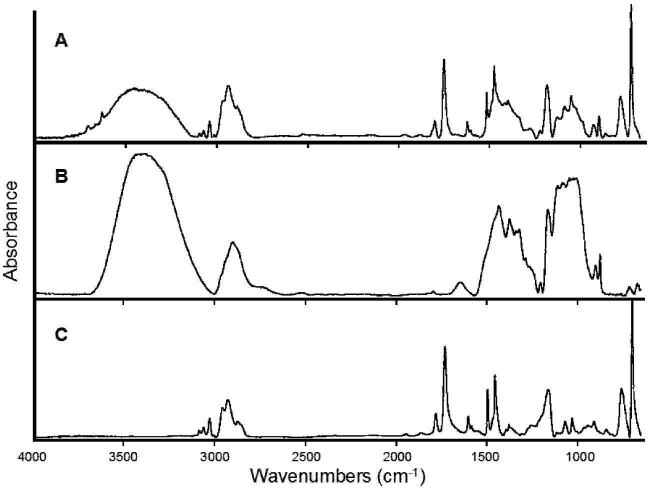

Fig. 1A–C R-A IR spectra of **A** toner from a document showing interference from cellulose; **B** reference spectrum of cellulose; and, **C** spectrum of toner taken from the same document as before without cellulose interference

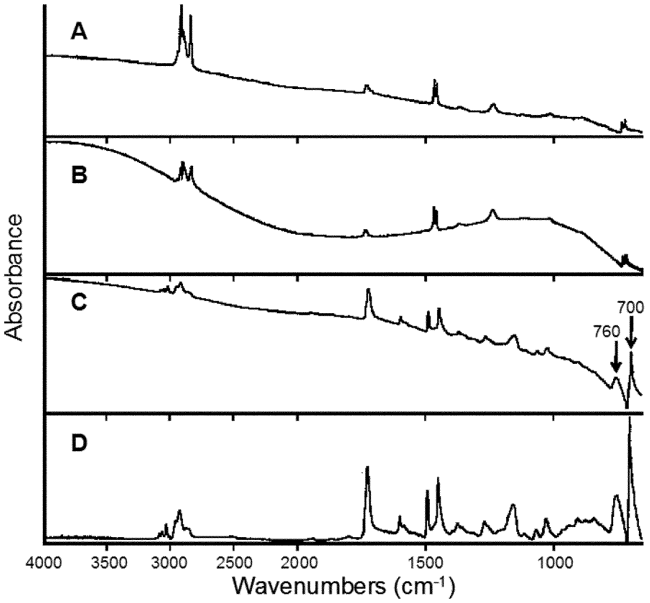

Fig. 2A–D Spectra showing variations in baselines: **A** carbon black absorption and particle scattering; **B** interference fringes; **C** anomalous dispersion; and, **D** spectrum from **C** after baseline adjustment

in Fig. 1B. Large O–H stretching vibrations appear from 3,600–3,000 cm^{-1} and the broad envelope from about 1,500–1,200 cm^{-1} includes the C–H bending. The C–O stretching vibrations are included in the envelope from 1,200–900 cm^{-1}. Figure 1C shows an uncontaminated spectrum of the same toner. In the more resinous toners, use of the blotting technique for transferring the sample may result in a microscopical appearance of sticky, syrupy filaments rising upwards from the reflective surface. Such samples have large variations in sample thickness, which makes site selection for the analysis difficult.

Site selection on a sample smear is an important factor in obtaining a good spectrum. The ideal sample site is thin enough to see through, but with enough resin to acquire adequate absorbances. To obtain the best spectrum, the microscope should be apertured to as clear an area as possible that is evenly smeared but not perfectly smooth. A reasonably good spectrum (e.g., Fig. 2A) should require minimal baseline adjustment. Figure 2B shows a spectrum with a severely sloping baseline that results from absorption of the IR radiation at the higher wavenumbers by the carbon black particles. A sharp downward inflection is often observed on the leading edge of absorption bands as shown in the C–H stretching region of Fig. 2C. This inflection is a result of anomalous dispersion caused by a rapid change of refractive index in the region of an absorption band. Curved baselines and interference fringes are an indication of a very smooth film; improved spectra are obtained by taking data from a rougher sample area.

Baseline adjustment

Once the best possible spectrum has been obtained, adjustments are still sometimes required to flatten the baseline. Some spectra require only minimal adjustment, such as the spectrum shown in Fig. 2A, while others require a more involved procedure, such as the spectrum shown in Fig. 2B. Consistency in baseline adjustment is necessary for valid spectral comparisons. However, the spectroscopist should be conservative when adjusting a spectrum baseline to avoid distortion of spectral shapes. Interferences from interference fringes and dispersion, shown in Fig. 2B and C, often contribute a variety of deformations to the baseline which must be adjusted to provide the flattest baseline possible. Under normal circumstances, the region from 1,500 to 1,000 cm^{-1} is generally left alone during a simple baseline adjustment. The wide variety of baseline deformations that occur in toner spectra often present distortions in this region and makes baseline adjustment difficult. To maintain consistency within spectra in the library, the entire spectrum, including points within the region of 1,500 to 1,000 cm^{-1}, was adjusted to create the flattest possible baseline. Initially, a point in the beginning of the fingerprint range and a point near 650 cm^{-1} were chosen to get the entire region at the same absorbance level in the beginning and end. Valleys were then selected to bring the bottoms of the peaks to the same baseline. With some practice, the analyst can produce spectra processed in a similar fashion for analysis by search algorithms. However, original spectra should always be retained in case it is necessary to repeat the baseline adjustment process, as well as to ensure forensic integrity.

Results and discussion

Reproducibility

Good spectral reproducibility, based on peak presence, has been demonstrated by analysis of sample smears obtained at different locations on the same document and from different documents generated by the same office machine using the same toner cartridge. Variations in peak height ratios have been observed which suggests differences in concentration of some toner components. A minor variation has been seen at 872.0 cm^{-1} in some toners. Figure 3 shows two spectra taken from different toner smears removed from the same document generated on a Xerox 5328 CS photocopier. One spectrum shows a small absorption at 872.0 cm^{-1} associated with a small absorption at 1,694.5 cm^{-1}, which is often hidden by the carbonyl band in many toners. These small variations indicate the presence of a nonhomogeneous minor component that has not been identified. For accurate comparison of toner spectra, it is necessary to analyze replicate sample smears when inhomogeneities are observed. Analysis of at least three replicate smears should be sufficient to account for the

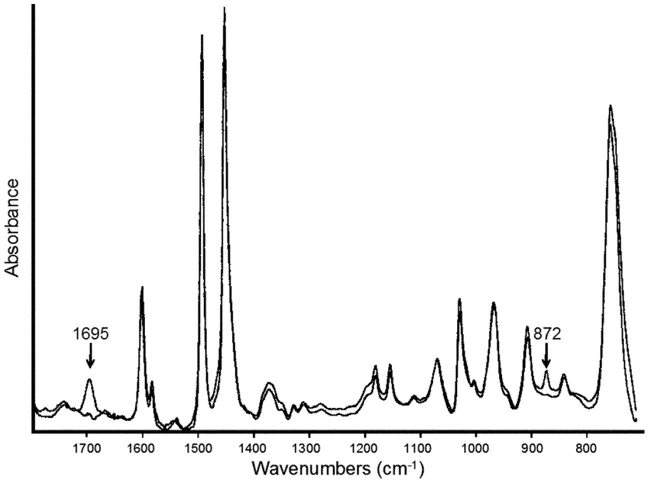

Fig. 3 Spectra taken from two different toner sample smears taken from the same document generated on a Xerox 5328 CS photocopier. Spectral variations at 1,694 and 872 cm^{-1} indicate the presence of a nonhomogeneous minor component

presence of any nonhomogeneous components encountered in a comparison.

IR spectral library and component identification

All documents involved in this study were generated on office equipment utilizing original equipment manufacturers (OEM) toner cartridges. The documents were obtained from a variety of trade shows to be used as samples for the FBI Photocopy Library. To date, 807 toner samples, taken from documents filed in the FBI Photocopy Library, have been analyzed by R-A IR at 4-cm^{-1} resolution and a searchable spectral library has been created. These samples represent the 72 brands of office equipment shown in Table 1. A total of 98 different groups were assigned based on visual inspection of spectral characteristics with respect to the presence or absence of peaks. Minor variations in peak height ratios, representing differences in component concentrations, were not used to differentiate among groups. A flowchart shown in the supplement,

Table 1 Listing of the brands of office equipment represented in the spectral library and the number of models analyzed from each brand

Brand	Number of models analyzed	Brand	Number of models analyzed
3M	27	Image Vision	1
AB Dick	40	Imagen	1
Address-O-Graph	3	Imperial	1
Adler Royal	31	Kentek	2
Advanced Matrix	1	KIP	3
Agfa-Geveart	7	Konica	13
Alps	2	Konica/Royal	24
Apple	2	Kyocera	8
Atari	1	Mannesmann Tally	4
Blaser	1	Microtek	1
Brother	9	Minolta	49
C Itoh	8	Mita	65
Canon	87	NCR	1
Clark	1	NEC	5
Colorocs	1	Newgen	7
Compaq	1	Nissho Electronics	1
Copystar	13	Okidata	5
CPT	1	Output Technology	1
Datagraphix	2	Panasonic	7
Dataproducts	8	Pentax	1
Develop	5	Printronix	1
Diablo/Xerox	2	Printware	1
Digital	1	QMS	12
Eastman Kodak	18	Qume	4
Electronic Form	1	Ricoh	67
Epson	7	Savin	2
Eskofot	2	Seikosha	1
Facit	2	Sharp	63
Fortis	1	Star Micronics	2
Fujitsu	9	Talaris	1
Genicom	6	Texas Instruments	7
Gestetner	39	Toshiba	5
Harris/3M	12	Troy	1
Hewlett-Packard	12	Varityper	1
Hyundai	2	Vistron	1
IBM	14	Xerox	59

Table 2 Listing of the toner groups showing the number of files contained within each group

Group	Number of files	Group	Number of files
1	3	42A	10
2	3	43	3
3	1	44	2
4	7	44A	6
5	2	45	2
6	17	45A	6
6A	9	45B	1
7	1	46	3
8	9	46A	1
9	1	46B	34
10	2	47	99
11	2	48	1
12	9	49	22
13	2	49A	2
14	1	49B	2
15	1	49C	2
16	4	50	1
17	51	51	4
18	2	52	1
19	1	53	2
20	5	54	1
20A	1	55	1
20B	1	56	4
20D	2	57	1
21	8	58	1
22	2	59	19
22A	2	60	1
23	2	61	4
24	1	62	2
25	3	63	1
26	1	64	16
27	2	65	1
28	1	66	22
29	1	67	1
30	10	68	11
31	3	69	8
32	1	70	17
33	4	71	1
34	2	72	6
35	2	73	1
36	2	74	1
37	48	74A	1
38	1	75	1
39	56	76	1
39A	2	77	8
39B	4	77A	3
40	5	78	1
41	7	79	1
42	144	80	6

requiring five separate charts, was developed to assist with group assignments. Generally, each branch of the chart represents the presence or absence of peaks at specific locations or in specific regions of the spectrum. Finer discrimination is obtained at some points in the flowchart by looking at shape variations in specific absorption regions. The flowchart is useful for identifying a previously classified toner group but may be quite misleading if the toner in question belongs to a group that has not yet been classified. By the identification of the group assignment of a toner in question, it is possible to determine which machines utilize similar toner based on IR spectra. Identification of a toner group can also provide information on the prevalence of that particular toner type based on the contents of the spectral library and sales figures for toners or machines.

Group sizes vary significantly; many groups contain only one sample; one group contains 144 samples. Table 2 tabulates the number of toner samples contained in each group. Within the large groups, small variations can be observed in peak shapes and intensities.

While a large number of groups were classified, only seven general types of resins were identified. Based on our findings, styrene-*co*-acrylate resins make up approximately 75% percent of toners. It is the differences, sometimes minor, in types of acrylates, comonomer concentrations and additives that produce spectra differentiating the groups. Figure 4 shows spectra of eight typical styrene-*co*-acrylate resins with variations between them. Figure 5 presents spectra of seven general types of resins. The first three are based on polystyrene. Figure 5A shows the spectrum of polystyrene with the characteristic C–H stretching bands above 3,000 cm^{-1} and out-of-plane deformation substitution bands near 700 and 760 cm^{-1}. Figure 5B shows a styrene-*co*-acrylate spectrum identified by the addition of the ester carbonyl near 1,730 cm^{-1} and the C–O–C stretch near 1,130 cm^{-1}. The CN band from Prussian blue near 2,220 cm^{-1} depicts this as a distinct group as shown in Fig. 5C. An epoxy spectrum is shown in Fig. 5D. The acrylate addition to the epoxy is seen in Fig. 5E by the addition of the carbonyl peak near 1,730 cm^{-1} plus other new features between 1,300 and 900 cm^{-1}. A polyethylene (PE) spectrum is shown in Fig. 1F, and Fig. 5G shows the addition of a broad band peaking near 1,100 cm^{-1}, possibly from SiO_2. The addition of characteristic ester bands near 1,730 and 1,100 cm^{-1} were also observed in certain PE spectra.

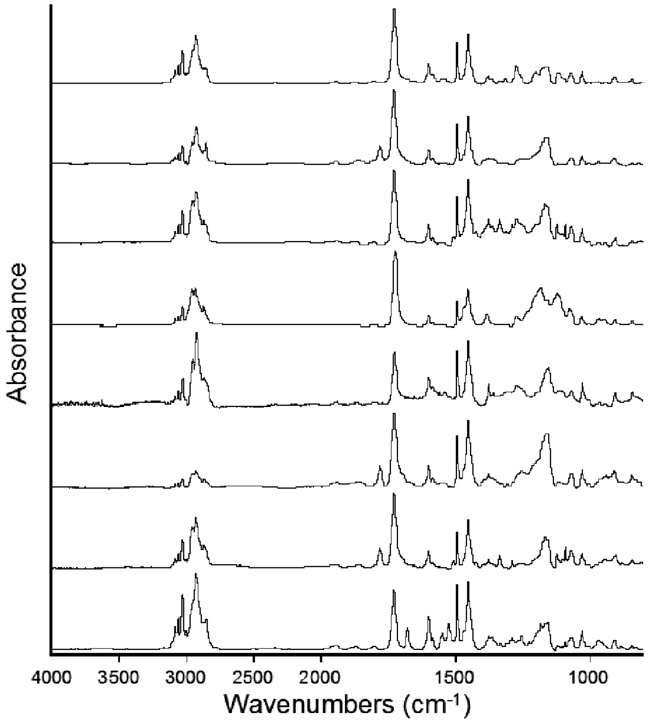

Fig. 4 Toner spectra from documents generated with various styrene-*co*-acrylate resins as the major component

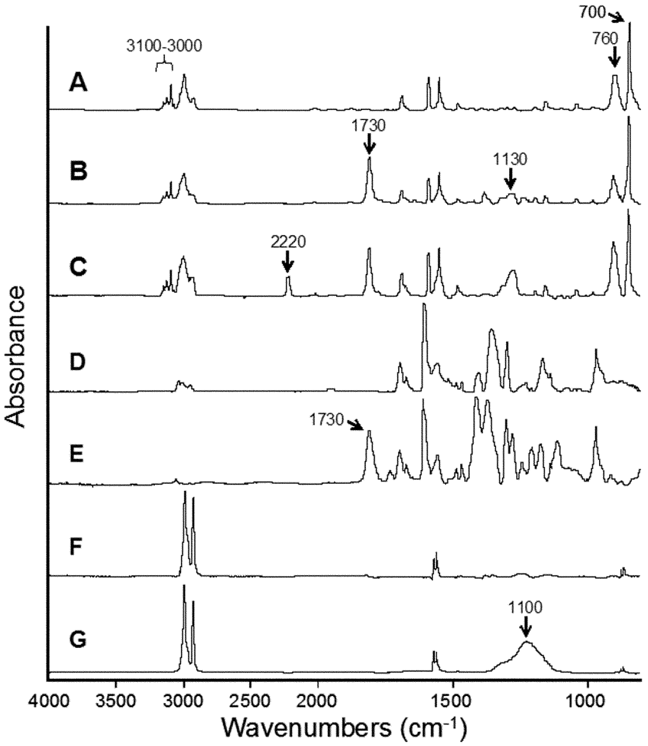

Fig. 5A–G Spectra of major resin types found in photocopy toners: **A** polystyrene; **B** polystyrene-*co*-acrylate; **C** polystyrene-*co*-acrylate with Prussian blue; **D** epoxy; **E** epoxy plus acrylate; **F** polyethylene; and, **G** polyethylene with an additive, possibly SiO_2

Application of the spectral library

Identification of a toner group may be useful as an investigative lead in some situations, although precautions are necessary. As mentioned above, analysis of replicate samples may be required to explain the occasional presence of extra absorptions consistent with nonhomogeneous components. When comparing sample spectra to the spectral library, it is important to understand that the library is limited to toners produced by office equipment manufacturers specifically for use in their equipment. Competitive manufacturers of toner for refilled cartridges are not included in the present spectral library.

Once an unknown toner sample spectrum has been obtained, the recommended technique for searching the toner library consists of an initial search from 4,000 to 800 cm^{-1}. The strongly absorbing styrene bands that appear below 800 cm^{-1} on many of the toner spectra are often accompanied by severe anomalous dispersion inflections. The region below 800 cm^{-1} is not recommended for searching, since the dispersion effects are inconsistent and the region does not contribute any additional information. After the search from 4,000 to 800 cm^{-1}, the top ten spectral hits should be closely compared. If one or more of the hits compare well with the unknown toner spectrum, the hits should be cross-referenced with the library data to determine the group assignment. Further comparisons can then be made with other toners from that group. If none of the top ten hits compare well with the unknown spectrum, a second-level search should be considered.

The use of a two-level search process initially covers the spectral range from 4,000 to 800 cm^{-1} and then focuses in on specific anomalies if necessary. To conduct the second-level search, the analyst should attempt to identify an area of significant variation between the unknown and the best hits from the initial search. A second library search should then be run on the unknown spectrum using just the limited region where the variation was seen. Once again, the top ten hits should be closely compared. Improved matches of spectra will be produced in the second search if the unknown searched toner type exists in the library. If one or more of the hits compare well with the unknown spectrum, the analyst should identify the toner group to which those hits are assigned and compare the unknown spectrum with other members of the group. If none of the top ten hits from the second search compare well with the unknown spectrum, the sample is representative of a toner type that is not included in the library.

Refilled toner cartridges

Several office equipment manufacturers have stated that their toner is engineered specifically for operation in their equipment at designated pressures and temperatures and other toners will not function with the same quality. A study was conducted to verify the accuracy of this statement and to analyze the chemistry of the toners from competitive toner manufacturers. Toner cartridges from two different competitive manufacturers were used to generate documents on the same Hewlett Packard IIID laser printer. One cartridge was labeled General Ribbon Corporation, and the other was labeled Supply Brokers Cartridge #92295A. The test documents were compared to a document generated at a trade show on the same printer type with an OEM toner cartridge. All three documents displayed good print quality with minor variations in toner appearance visible microscopically. Analysis of the toners by R-A IR showed three different chemical compositions. Although competitive manufacturers of toner and refilled cartridges have not been studied extensively, this brief study has shown that cartridges containing chemically different toners may be found in use by the same machine. Therefore, in these circumstances, an investigation would require a more scrutinizing approach with multiple analyses of the involved documents.

Assessment of spectral comparison and use of the library

The assessment of the accuracy of microscopical R-A IR analysis of copy toners was conducted by four methods: document comparison, tests of the library searching, an actual case, and multivariate discriminant statistical analysis. The discrimination of R-A IR spectra of copy toners by multivariate statistics is described in a separate paper [20].

Document photocopy toner comparison

For cases that require copy toner analysis, examiners must compare questioned and known documents to determine if they could have come from the same copy machine. Therefore, the initial step of the assessment included test pairs of copied documents prepared for comparison. For these test pairs, it was necessary to determine if the spectra of two questioned documents compared closely enough to conclude that they could have originated from the same copy machine. Staff from the FBI Laboratory Questioned Documents Unit submitted twenty pairs of test documents for evaluation. Some of the documents in the pairs came from the same machine, while others came from machines of different make or model. By comparing the infrared spectra with assistance of the flowcharts in the supplement, 100% correct results were determined for the pairs, and correct copy machine groups were identified.

The objective of these tests was to determine if two questioned documents were copied from the same make and model of copy machine. However in one pair, the test specimens came from different machines of the same make and model. These samples were distinguished as different by their spectra, because they had different toner cartridge types. The toner cartridges, however, came from the same supplier.

Library searching

Spectral library searching can be used to determine the possible group of make and model of copy machines. For the initial testing of library searching, 30 samples were evaluated as unknowns by an analyst. The toner spectra were collected, baseline adjusted as previously described, and searched against the prepared spectral library from 4,000 to 800 cm^{-1}. The search results produced 27 first hits (90%) in the correct toner group. The remaining test spectra were compared with the spectra of the top 10 hits. The proper groups were identified from within the top three hits of the computer searches for the remaining samples.

Considering the many cases of close similarity between spectral curves, very good results were obtained by the computer searches. It is important to keep in mind, however, that correct library searching practice requires the analyst to carefully scrutinize the search results to determine which spectra, if any, match the questioned sample spectrum. Computer searches should be used to assist in narrowing the possibilities of spectral matches. The analyst's judgment is the final assessment in spectral comparison.

A library search was conducted on samples from the 20 test pairs used for comparison. The group that contained the make and model of the copy machine of each sample was correctly identified for all the samples included in the library. One sample that had not been previously analyzed for inclusion in the library did not compare with any library spectra and was reported as such.

Case result

A case where a bomb was mailed to a corporate executive, requiring investigation by the FBI's field personnel, served as an excellent validation of IR visual spectral comparison of copy toners and the use of library searching. The investigators believed that the bomb was mailed by someone from within the company and that the individual used a company copy machine to produce the shipping label. The company had 400 copiers of 61 different models. To narrow the possibilities of individuals, 61 documents, copied from the available copier models in the company, were submitted to the FBI Laboratory to compare with the shipping label from the bomb package. Only one IR spectrum from the known machine documents compared closely to the questioned shipping label spectrum. Of the 400 possible copiers at the facility, there were eight machines of the same model that spectrally matched the questioned document. The library search of the questioned document spectrum produced spectra from Group 49 that includes copy machines produced by 11 different companies. However, close scrutiny of the spectra revealed spectra most closely comparing to six Kodak models. The laboratory personnel were informed that the machine, identified by our initial visual spectral comparison, was a Kodak copier whose model type was also included as one of the six Kodak types determined by library searching. The visual comparison and the library search produced supporting results, which allowed investigators to limit their inquiries to individuals who had ready access to the eight Kodak copy machines at the facility. The information the FBI Laboratory provided resulted in saving significant time during the investigation.

Conclusions

This study has shown that many toners can be differentiated by R-A IR analysis making it a potentially useful method for comparison of questioned and known document copies. Use of the spectral library assists with the identification of the toner group if the toner spectrum is contained within the library. By identifying the group to which a specific toner belongs, it is possible to identify a copy machine's make and model or to obtain a list of machines whose toner has comparable spectral characteristics. To fully understand the significance of matched spectra of compared questioned and known documents, it will be required to conduct additional studies to determine variations between and within copy toner batches. This will require repeat analysis of toners to determine the reproducibility of the toners and measurements. Additionally, copy toner products, listed with copier models they are used with, will require addition to the library as they become available.

Techniques to further discriminate within the large groups will be further studied. In a previous study, Bartick et al. [21] determined that large groups of copy toner R-A IR spectra can be further discriminated by linear discriminant analysis (also known as canonical variates analysis) to assess the statistical validity of the assigned groups. Additionally, this work illustrated the potential for computer-assisted data interpretation to provide decisive forensic identification of questioned samples. In the next paper of this series on forensic toner analysis, the discrimination of copy toner types achieved in the present paper by visual and computer-assisted spectral searching is compared to that achieved by multivariate discriminant analysis for a data set of 430 copy toner spectra [20].

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