Diode Array Micro Spectrometry of Colour Ink-Jet Printers

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Ink-jet printed documents, produced on 70 different brands and models of ink-jet printers available on the European market were analyzed by a micro spectrophotometer (reflection mode) using a diode array detector. The research focused on the measure of the reflection spectrum between 380 and 760 nm. Only the magenta and the cyan colours were measured since the yellow, according to a preliminary study, does not have a significant variation and subsequently was not analyzed. For each colour analyzed, three measurements were made and the mean was calculated. The results obtained enabled us to create a database. Such a database can be used to identify a particular model of printer (or group of models) used to print a forged or counterfeit document. The problems encountered due to the paper stock and compatible ink cartridges (non-OEM cartridges) are also discussed.

Introduction

Interest in the forensic analysis of ink-jet printers has increased over recent years with the proliferation and improvement of such office machines. The increasing popularity and quality of colour ink-jet printers clearly demonstrates the need for Forensic Document Examiners (FDEs) to stay abreast of the changing technology in order to keep up with criminal activities involving colour printed documents. Ink-jet printers provide an efficient and effortless means of counterfeit and forgery, especially in the reproduction of currency. The number of cases sent to the forensic laboratory involving ink-jet printers has significantly increased over the last few years. In the absence of a "suspect printing machine," the questioned document examiner is more often than not called to determine the manufacturer of a particular model of ink-jet printer. This paper demonstrates how it is possible to develop such a "class" identification system.

Many technical brochures have been published on the ink-jet printing process, however, few forensic papers have dealt with this topic. Concerning the classification of ink-jet printers, Doherty has written a comprehensive paper (Doherty, 1998).

Colour micro spectrometry (MSP) for the comparison and identification of dyes is widely used in forensic sciences, especially in the forensic examinations of documents (Pfefferli, 1983; Laing, 1983; Totty, 1985; Zeichner, 1988; Aginsky, 1993; Seipp, 1997). This is the first paper dealing with the analysis of the ink of ink-jet printers by diode array micro spectrometry. The theory of micro spectrometry/colour measurements is very well explained by Adolf and Dunlop (Adolf, 1999). The use of a Diode Array Detector (DAD) is a new approach in the MSP of document evidence (Mazzella, 1999). The DAD consists of a multichannel spectroscopy, which allows spectra to be created from simultaneous recording across the entire spectral range being scanned. The measuring time for each analysis is therefore reduced to a few seconds. The objective of the use of this non-destructive technique is to determine if it is possible:

- to create an ink-jet colour printers database
- to use such database to link a questioned ink-jet printed document to a particular ink-jet printer
- to validate the technique

Methods and Materials

The samples used in this study included 9 OEM ink-jet cartridges, 2 compatible ink jet cartridges and 70 documents printed on 70 ink-jet printers (Appendix A).

Each sample was analyzed with a microscope Zeiss Axioskop, equipped with a 50X Axioplan objective and fitted with a DAD (TIDAS, J&M). The visible spectra were collected by transmittance for the pure ink and by reflection for the printed documents using the Lamdascan 1.7 software. The instrumental parameters were: spectral range 380-760 nm; measured area: circular with a 1.6 mm diameter; resolution 5 nm; and the mean of the three measurements for each sample was calculated. Monoxide magnesium was used as background. Only the magenta and the cyan colours were measured since the yellow, according to a preliminary study (Dubail, 1998), does not have a significant variation between different inks. To analyze the ink on the printed documents we focused on the pure dots of cyan and magenta (Figure 1).

Results and Discussion

The preliminary work was conducted on pure ink, extracted from the cartridges. This was carried out in order to verify some differences between brands and within the same brand. The region of interest (ROI) is between 500 and 600 nm for the magenta and between 600 and 700 nm for the cyan. Figure 2 illustrates the difference for the magenta between different brands. It should be noted that the differences are small, 3 to 10 nm, but reproducible.

The differences noted in the same brand of printer are highlighted in Figure 3. The spectra of the magenta from the cartridges HP 51649A and HP C1832A is the same, but the spectra from the cartridge HP 51625A is clearly different from the previous two.

The encouraging results obtained from the pure ink demonstrated that it was worthwhile continuing the research and all of the 70 printed documents were analyzed. The reproducibility (Figure 4) was tested using 3 identical cartridges (Canon BC-21) on three different Canon ink-jet printers

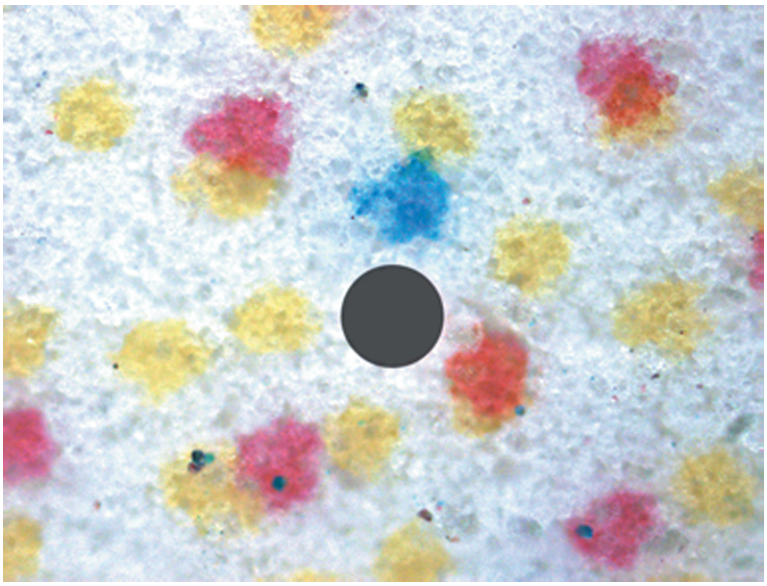

Figure 1. The circular measured area (black circle) used for this method.

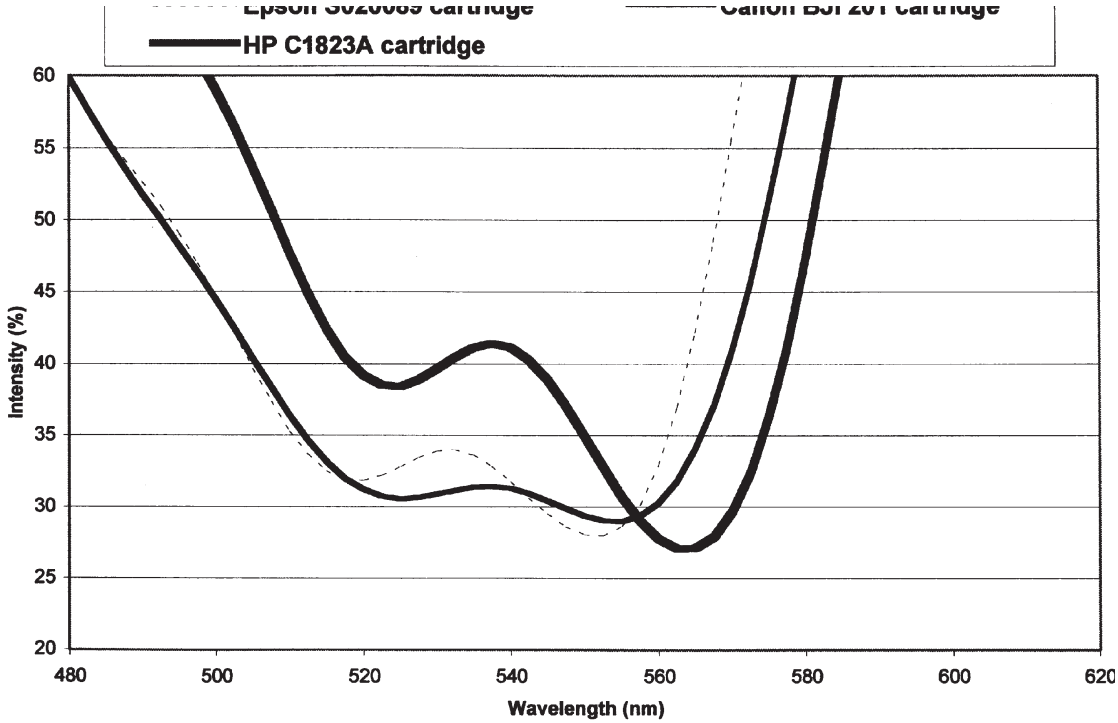

Figure 2. Inks from different cartridges (magenta)

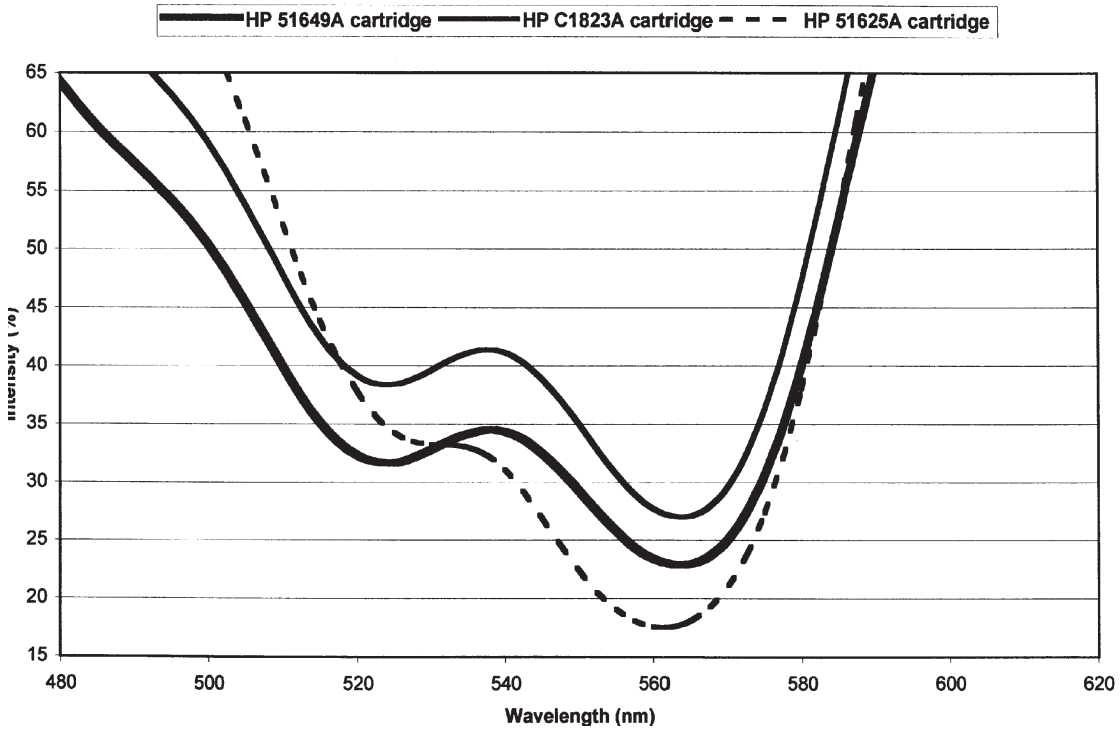

Figure 3. Inks from the HP cartridges (magenta)

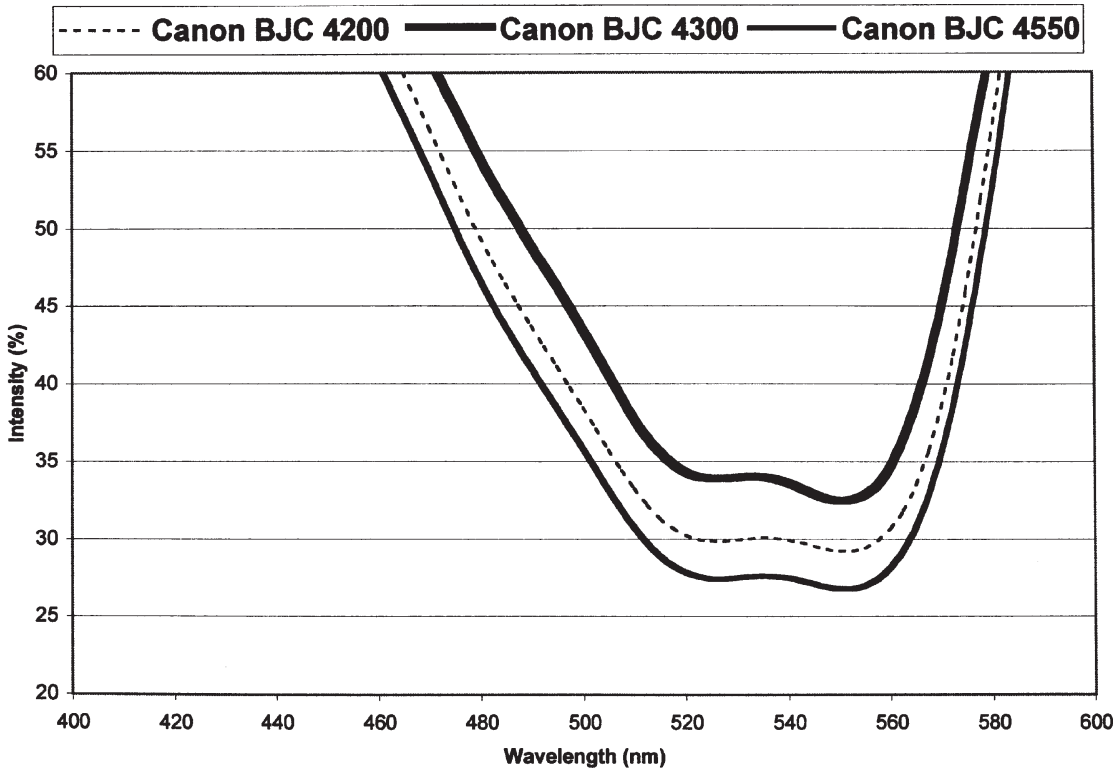

Figure 4. Reproducibility (magenta)

(Canon BJC 4200, 4300 and 4550) using the same paper support.

A database for the cyan and the magenta was created, according to the maxima of absorption. All the samples were classified into:

- 6 groups for the cyan
- 8 groups for the magenta
- 12 groups for the combination of the cyan and magenta (Table 1)

It is interesting to note that all cyan ink for the HP models showed only one peak at about 630 nm, which allows them to be quickly identified (on the basis of our collection).

In order to evaluate the database, searches were conducted using several algorithms. This was done by transferring all the spectra from the Lamdascan software 1.7 to the Winfirst 2.1 software. A preliminary study conducted in our laboratory showed that the squared difference and the absolute difference algorithms allowed the best discrimination (Dubail, 1998). A blind test conducted on 10 samples (10 "anonymous" printed documents) taken from our collection, had a correct identification rate of 100% of the brand and model of ink-jet printer. However, this blind test is biased because of the following two limitations:

1. The 10 samples were already introduced in the database.

2. The 10 samples were printed on the same paper.

To overcome the second limitation, tests were conducted on samples printed on different substrates, since a well-known problem in the printing industry is that the paper characteristics affect the quality of ink–jet printing (Cleary, 1998). The tests included the analysis of the ink from the Epson Stylus 600 and HP 890 printers printed on 4 different paper stocks. The 4 documents printed with the HP 890 did not show a signifi-

GROUP	INK JET PRINTER	Magenta	Cyan
1	Apple Style Writer 2500	528,551	625,672
	Canon BJC-70	528,554	624,672
	Canon BJC-4000/4100/4200/4300/4550/4650/5500	527,551	627,675
	Canon Multipass C30	527,551	627,675
	Canon BJC 6000	528,551	630,672
2	Canon BJC-210/240	528,550	609,672
	Epson Stylus Color II	530,552	615,672
3	Canon BJC-600/610/620	527,557	611,670
	Canon BJC-800/820/880	526,557	611,670
	Epson Stylus 1200	525,556	612,672
	Lexmark WinWriter 150C, ExecJet II	530,561	610,672
	Lexmark 4079	530,561	610,672
	Lexmark Colorjet 1000/1020/1100	530,561	610,672
	Lexmark Colorjet 2070	527,558	610,672
	Lexmark Colorjet 5000/5700/7200	527,558	612,672
	Lexmark Optra Color 45	527,558	612,672
	Olivetti JP 792	530,563	612,672
4	Canon BJC 7100	522,551	610,675
	Canon BJC8500	522,551	610,675
	Epson Stylus 300	521,552	615,672
	Epson Stylus 400/600/800/850/1520	521,552	615,672
	Epson Stylus 500	521,552	612,672
	Epson Stylus 700	521,552	613,672
	Epson Stylus 440/640/740	521,552	612,672
	Epson Stylus 750	521,552	612,672
	Epson Stylus 850	521,552	612,670
	Epson Stylus 900	521,552	615,672
5	Epson Stylus Color Pro	544	613,672
6	HP DeskJet 690	526,563	635
	HP DeskJet 720/890	526,563	632
	HP DeskJet 820CXI/850/870CXI	526,563	632
	HP Office Jet Pro 1150	526,563	632
	HP DeskJet 1200/1600	526,560	627
7	HP Paint Jet XL 300	530,550	632
8	HP DeskJet 340/400	533,567	635
9	CitizenPrintiva 600C	538,567	622,630
10	Ilford IlfoJet	525,560	613,665
11	Lanier 3120	530,560	615,662
12	Tektronics Phaser 300X/340/350/360/600	551	622,675

Table 1. Ink jet printers grouping (maxima of absorption,nm)

cant difference, according to their maxima of absorption. Unfortunately this was not the case for the Epson Stylus 600 printer, especially for the magenta (Table 2 and Figure 5).

INK JET BRAND AND MODEL	CARTRIDGE	TYPE OF SUPPORT	MAGENTA ABS (nm)
HP Desk Jet 890	HPC 1823 A	Canon LC 201 Paper	526,564
HP Desk Jet 890	HPC 1823 A	Plain Paper	524,564
HP Desk Jet 890	HPC 1823 A	Epson Premium Paper	526,564
HP Desk Jet 890	HPC 1823 A	Epson Photo Paper	527,564
Transmittance	HPC 1823 A	Glass	526,563
Epson Stylus 600	Epson S020089	Canon LC 201 Paper	525,557
Epson Stylus 600	Epson S020089	Plain Paper	525,557
Epson Stylus 600	Epson S020089	Epson Premium Paper	520,552
Epson Stylus 600	Epson S020089	Epson Photo Paper	520,552
Transmittance	Epson S020089	Glass	519,552
			CYAN
HP Desk Jet 890	HPC 1823 A	Canon LC 201	632
HP Desk Jet 890	HPC 1823 A	Plain Paper	632
HP Desk Jet 890	HPC 1823 A	Epson Premium Paper	632
HPDesk Jet 890	HPC 1823 A	Epson Photo Paper	630
Transmittance	HPC 1823A	Glass	631
Epson Stylus 600	Epson S020089	Canon LC 201 Paper	610,670
Epson Stylus 600	Epson S020089	Plain Paper	612,672
Epson Stylus 600	Epson S020089	Epson Premium Paper	612,670
Epson Stylus 600	Epson S020089	Epson Photo Paper	612,670
Transmittance	Epson S020089	Glass	611,668

Table 2. The paper influence

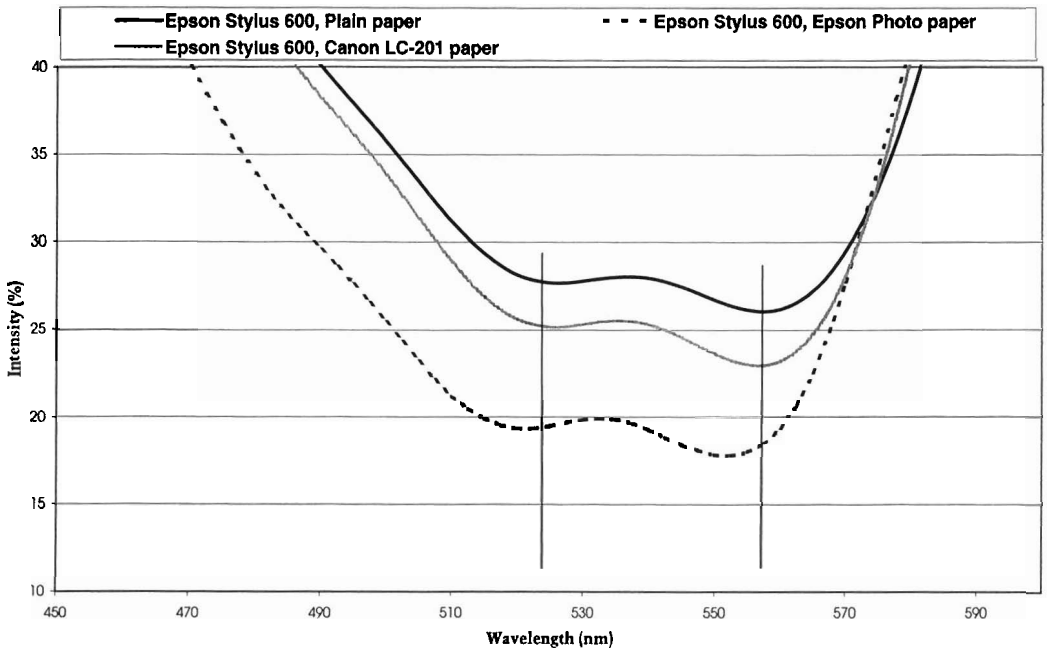

Figure 5. The paper influence (magenta)

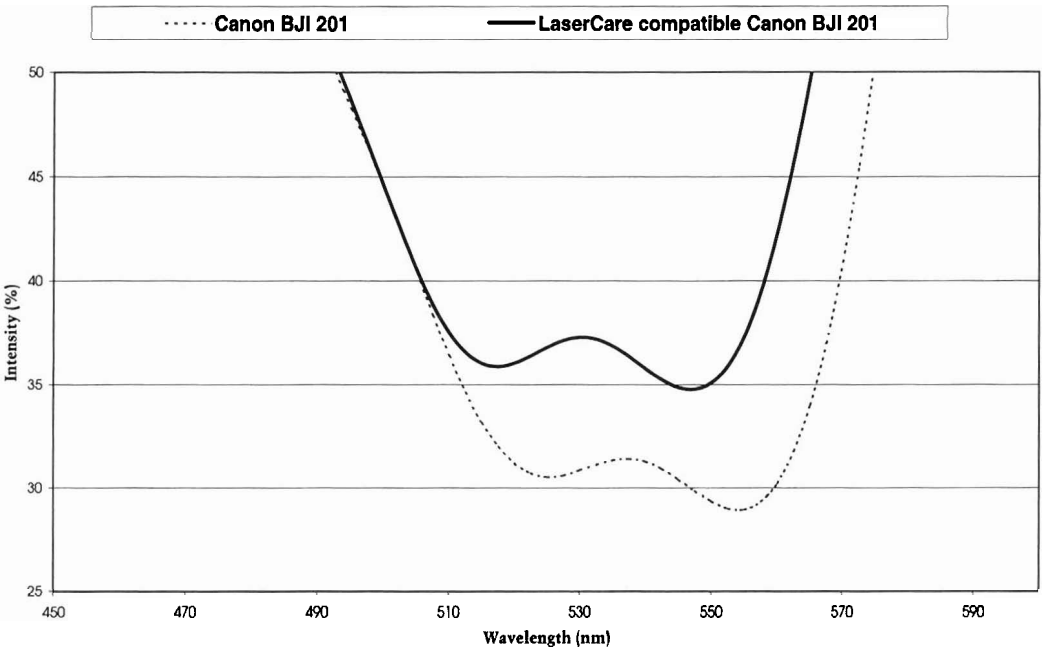

Figure 6. The ink compatibility (magenta)

A secondary problem with the database is the use of compatible ink cartridges. It is well known that on the market there are companies selling cheaper compatible cartridges containing ink different from the ink in the OEM cartridges. The compatible inks tested in our study could be differentiated from the OEM inks (Figure 6), however their visible spectra could be easily confused with other brands, which is potentially a source of error.

Conclusion

Analysis of the ink-jet printers by DAD micro spectrometry is a fast and non-destructive technique but it appears not to be an ideal technique to produce a database of colour ink-jet printer inks. This is due to the two problems encountered during this study. Thus, establishing a colour ink-jet printer database remains a very difficult task. In fact, the analysis of every ink contained in an ink-jet OEM cartridge and compatible cartridge printed on different paper stock available on the market is impracticable. However, an appropriate database could be set up for "intelligence purposes," to establish or to confirm a link between forgeries made on the same paper stock. This technique would also be applicable for comparison purposes of ink on the same document.

Other suitable techniques for the classification of ink-jet printers where the paper does not influence the analytical results, are thin layer chromatography, capillary electrophoresis or high performance liquid chromatography.

Acknowledgements

The author would like to thank Ms. Roslind Winter for her valuable assistance.

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Appendix A. Ink cartridges and ink-jet printed documents analyzed

INK-JET PRINTERS: BRAND AND MODEL	CARTRIDGE
APPLE STYLE WRITER 2500	CANON BC-21
CANON BJC-70	CANON BC-11*
CANON BJC-210/240	CANON BC-05
CANON BJC-600/610/620	CANON BJI-201*
CANON BJC-800/820/880	CANON BJI-643
CANON BJC-4000/4100/4200/4300/4550/4650/5500	CANON BC-21
CANON MULTIPASS C30	CANON BC-21
CANON BJC 6000	CANON BCI-3
CANON BJC 7100	CANON BC-62
CANON BJC 8500	
CITIZEN PRINTIVA 600C	
EPSON STYLUS COLOR PRO	EPSON S020036
EPSON STYLUS COLOR II	EPSON S020049*
EPSON STYLUS 300	EPSON S020138
EPSON STYLUS 400/600/800/850/1520	EPSON S020089*
EPSON STYLUS 500	EPSON S020097
EPSON STYLUS 700	EPSON S020110*
EPSON STYLUS 440/640/740	EPSON S020191*
EPSON STYLUS 750[1]	
EPSON STYLUS 850	EPSON S020193
EPSON STYLUS 900[2]	EPSON T003011
EPSON STYLUS 1200	
HP PAINT JET XL 300	HP 51639
HP DESKJET 340/400	HP 51625A*
HP DESKJET 690	HP 51649A*
HP DESKJET 720/890	HPC1823A*
HP DESKJET 820CXI/850/870CXI	HP 51641A
HP OFFICE JET PRO 1150	HP 51641A
HP DESKJET 1200/1600	HP 51640
ILFORD ILFOJET	
LANIER 3120	
LEXMARK WINWRITER 150C, EXECJET II	LEXMARK 1380619
LEXMARK 4079	LEXMARK 138491/2/3
LEXMARK OPTRA COLOR 45	LEXMARK 12A1985
LEXMARK COLORJET 1000/1020/1100	LEXMARK 13619HC
LEXMARK COLORJET 2070	LEXMARK 1382060
LEXMARK COLORJET 5000/5700/7200	LEXMARK 12A1980
OLIVETTI JP 792	OLIVETTI 84436
TEKTRONICS PHASER 300X/340/350/360/600	TEKTRONICS 016/1308 (SOLID INK)
LASERCARE CARTRIDGE COMPATIBLE CANON BJC-201	COMPATIBLE BJI-201*
LASERCARE CARTRIDGE COMPATIBLE EPSON S020049	COMPATIBLE Epson S020049*

* Cartridges analyzed

1 Size of dots of 45 µm

2 Size of dots of 33 µm