# The Splashing of Ink Drops in CIJ Printing

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## Abstract

A laboratory-scale test environment has been set up for high-speed imaging of ink jet drops. The impact, the splashing and spreading of ink droplets on paper samples, can be observed in this test environment on micro and millisecond time scales with an accuracy of one to two microseconds. The differences in the mechanisms of interaction between the material combinations has been found almost immediately after the impact.

This study focusses on the differences in the splashing phenomena of the drops hitting the paper surface. The time period under observation comprised the first fifteen microseconds after the impact. The differences in the magnitude of splashing between the different paper samples were obvious. Also the quality of the printed dots was assessed. It was found that the differences in the splashing between the material combinations had a significant effect on the final print quality.

## Introduction

This study covers a part of the project "*Dynamic Interactions and Image Quality in Ink Jet Printing"* which is one of the research projects run by VTT Information Technology 1995-1999. The project focusses on the high-speed ink jet printing methods of the future. The aim is to analyse and model the interactions between ink and paper in the Continuous Ink Jet technique (CIJ), and to develop and modify testing methods for ink jet substrates.

It is a well-known fact that both the physical structure (pore structure, surface structure) and the chemical nature (surface energy) of the papers, as well as the viscosity and the surface energy of the inks affect the absorption behaviour and the print quality in ink jet printing. The problem is how to set the limits to the relevant material properties and to determine their joint effect on the paper performance in quantitative terms.

It is assumed that a better knowledge of the basic mechanisms of dynamic interaction would allow a more reliable and appropriate specification of the quality demands for paper grades and would be of practical value in the product development of the paper industry.

This paper focusses on the differences in the splashing phenomena of the drops hitting the paper surface and presents an experimental method for observing the dynamic ink/paper interactions.

## Background

When an ink drop with a relatively high velocity hits a substrate, part of the drop breaks up into smaller droplets which are deposited randomly on the surface. If these splashes are large enough, the result is a visible decrease in the print quality.

In the CIJ techniques, the ink drops have a higher velocity than the drops in the Drop-on-Demand (DOD) techniques today. The greater the kinetic energy of the drop when it hits the paper, the more it spreads and splashes [1].

Little attention has been paid in the literature to the dependence of drop splashing on the properties of the substrate or to the significance of the splashing phenomena to the quality of the ink jet image.

## Experimental part

### Test environment

A new test environment was specified and set up for high-speed imaging of ink jet drops. In this laboratory-scale test environment the impact, the splashing, spreading, penetration and drying of ink drops on the paper samples, can be observed on micro and millisecond time scales. Figure 1 shows a schematic diagram of the experimental arrangement, which consists of various continuous ink jet devices, a rotating cylinder and an imaging system.

In this study, the ink drops were generated by two identical industrial multi-deflection CIJ devices. The inner diameter of the nozzle was 70 μm and the drop production rate 77 kHz. The impact velocity of the drops was 18 m/s.

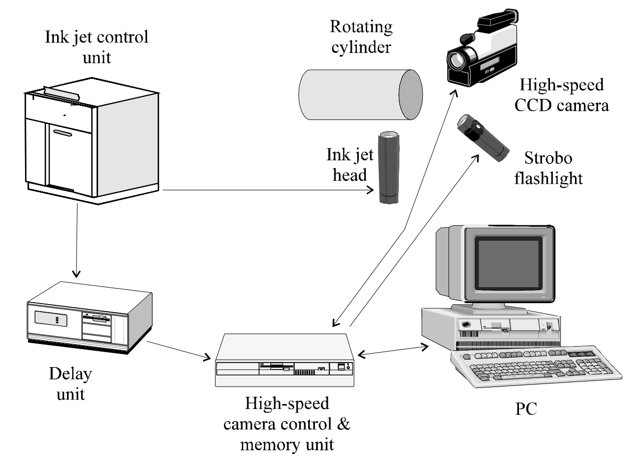


*Figure 1: The experimental arrangement for the high-speed imaging of ink jet drops.*

A motor-driven, balanced drum was set up to move the substrate. The peripherical velocity of the paper-carrying cylinder can be selected in the range of 0 to 10 m/s.

The printing trials were carried out with various material combinations. The substrates and the inks are described later. The period of time under observation comprised the first fifteen microseconds after the drops hit the paper surfaces.

**Imaging arrangement**

The imaging system consists of a high-speed CCD camera, a stroboscopic flashlight and a personal computer.

The high-speed digital CCD camera system (HiSIS 2001) allows to store a large number of digitized images in the system memory (RAM), to view them on the monitor of the PC and to save them on the hard disk for subsequent image analysis. In addition, the system supports external triggering and has an output for controlling the stroboscopic flashlight. Since the dynamic interaction is faster than the maximum rate of the image recording (450 frames/sec) of the CCD camera, the various stages of the spreading droplet can be observed by adjusting the synchronization pulse delay.

**Test materials**

The substrates consisted of seven commercial ink jet papers. The samples from one to four were coated papers designed for ink jet, sample five was a polymeric laminate, and samples six and seven were plain office papers.

Two different compositions of black ink were used in the printing tests; one was MEK (methyl-ethyl-ketone)- and the other was water-based. The viscosity of the inks was 3.3 cP. Some properties of the test materials are presented in Tables 1 and 2.

*Table 1: Test materials.*

| | Type | Pigments in the coating layer |
|---|---|---|
| Paper 1 | IJ-Coated Paper | Kaolin |
| Paper 2 | IJ-Coated Paper | $CaCO_3$ |
| Paper 3 | IJ-Coated Paper | $CaCO_3$, Talc, Kaolin |
| Paper 4 | IJ-Coated Paper | Kaolin |
| Paper 5 | Polymeric Laminate | $BaSO_4$, Kaolin |
| Paper 6 | Plain Copy Paper | |
| Paper 7 | Plain Copy Paper | |
| Ink 1 | Water-Based Ink | |
| Ink 2 | MEK-Based Ink | |

*Table 2: The surface energy components and roughness of the paper surface.*

| | Surface energy Disp. (mN/m) | Polar | Roughness, PPS (µm) | Bendtsen (ml/min) |
|---|---|---|---|---|
| Paper 1 | 52 | 0 | 5.2 | 169 |
| Paper 2 | 31 | 21 | 3.6 | 103 |
| Paper 3 | 32 | 25 | 2.0 | 9 |
| Paper 4 | 34 | 25 | 4.1 | 68 |
| Paper 5 | 26 | 32 | 1.6 | 26 |
| Paper 6 | 40 | 2 | 4.2 | 92 |
| Paper 7 | 46 | 1 | 6.5 | 304 |
| Ink 1 | 22 | 3 | | |
| Ink 2 | 16 | 2 | | |

## Results and discussion

After hitting the paper, the ink drop formed a spherical segment with a flat bottom. During the following microseconds the height of the segment decreased and the width increased.

Five microseconds after the impact, minor differences were observed between the different material combinations in the shapes of the drops. After seven microseconds the differences were more obvious. Some images of the ink drops on Papers 1 and 3 during the first fifteen microseconds after the impact are included as examples in Figure 1. In these images, the possible splashes can be seen on the left-hand side of the drops, because the substrate was running at 10 m/s from the left to the right. When the substrate was kept immobile or ran at a low velocity, the splashes occurred with the same likelihood anywhere around the drops.

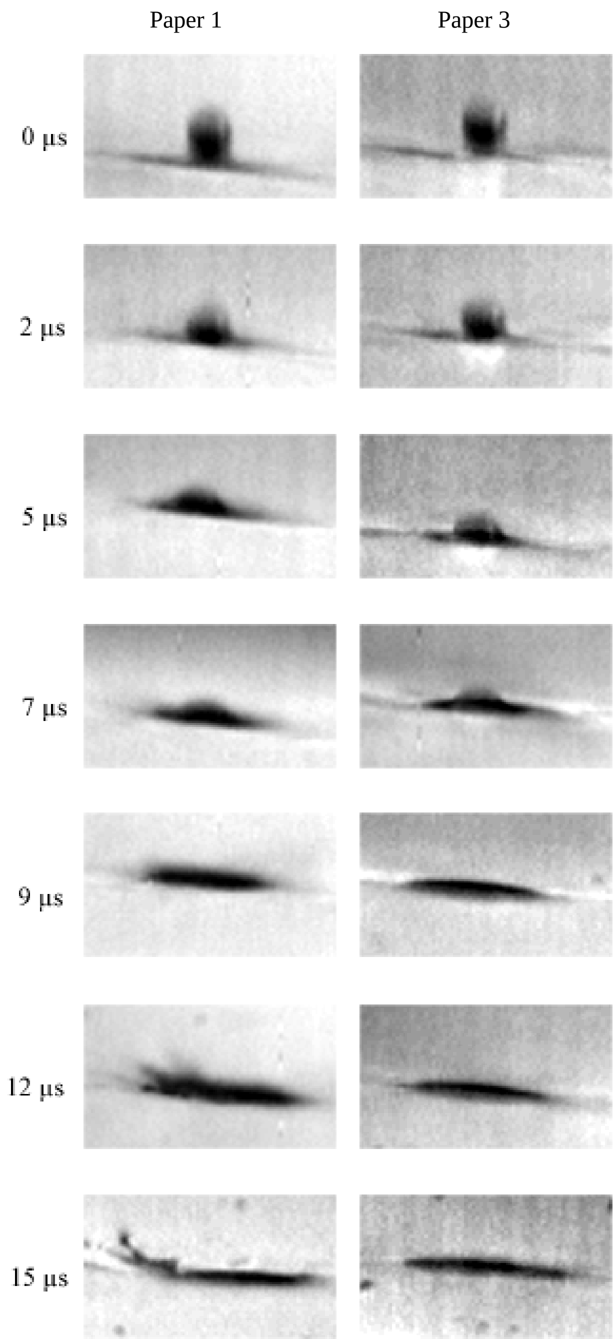


*Figure 2: The behaviour of the ink drops on Papers 1 and 3 during the first fifteen microseconds after the impact. The splashing on Paper 1 began after 12 µs. The splashes can be seen on the left-hand side of the drops, because the substrate was running at 10 m/s from the left to the right.*

**MEK-based ink vs. water-based ink**

The water-based ink splashed more than the MEK-based ink and its splashing began earlier. The MEK-based ink was also found to be less sensitive to the paper properties when the magnitude of the splashing and the slopes of the drop spreading were taken into account. The spreading rates of the water-based and MEK-based ink on the substrates are presented as a function of time in Figures 3 and 4.

The splashing of the water-based ink began 5-12 µs after the impact. With the MEK-based ink it took 9-12 µs before the splashing started. However, the number and the volume of the splashes were greatest only in the last images under observation, in other words 15 µs after the impact.

The dots produced with the water-based ink were larger in size and lighter in their density than those produced with the MEK-based ink. Also circular raggedness and blur were greater with the water-based ink.

The differences in the splashing, absorption and spreading behaviour of the inks are a consequence of the differences in their surface tension properties and in their rate of evaporative drying - the MEK-based ink had a lower surface tension and it dried faster.

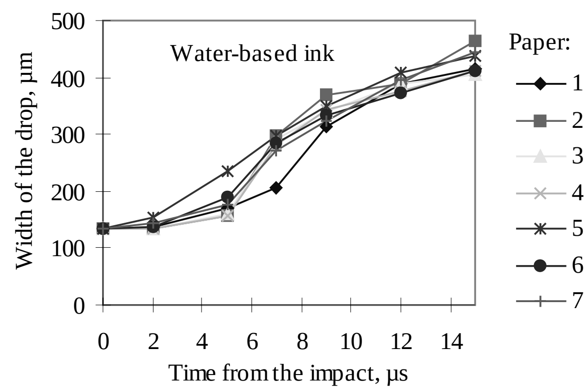


*Figure 3: The spreading of the water-based ink on the paper samples. Five to seven microseconds after the impact differences were observed in the shapes of the drops on the different substrates.*

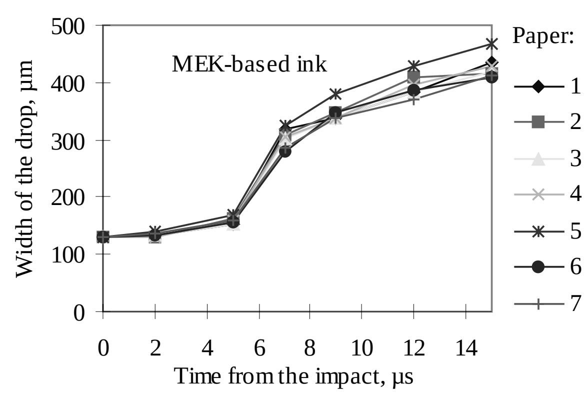


*Figure 4: The spreading of the MEK-based ink on the paper samples. The MEK-based ink was found to be less sensitive to the paper properties than the water-based ink.*

**Coated papers**

The first four paper samples in the study were commercial ink jet coated papers. It was found that both inks splashed most when the printing trials were carried out with Paper 1. Therefore the dots printed on Paper 1 had the highest circular raggedness and blur of all paper samples (Figure 5). The surface area of the dots was smaller than on the other coated paper samples, partly because the splashes wasted some of the original drop volume and partly because the paper surface was hydrophobic and the spreading of the drops was relatively slow.

When the printing trials were carried out on Paper 3, hardly any splashing was observed with either one of the inks. The dots had the best quality of all the coated paper samples - circular raggedness and blur were low. The behaviour of the ink drops on Papers 1 and 3 is presented in Figure 2.

Paper 2 and Paper 4 behaved quite identically in the printing tests. Some splashes occurred and therefore circular raggedness and blur were higher than on Paper 3.

**Laminated paper**

No splashing occurred with either one of the inks, when the printing trials were carried out with Paper 5, which was the only polymeric laminate in the study. The shape of the dots was almost a perfect circle and their size was equivalent to the best coated paper (Paper 3).

**Plain office papers**

The last two paper samples - Papers 6 and 7 - were surface-sized copy papers. Somewhat more splashing occurred on Paper 7 than on Paper 6 with both inks. However, the circular raggedness of the two papers was similar, because the feathering of the ink along the paper fibres was greater on Paper 6. The ink was absorbed in an unsymmetrical pattern causing ragged edges. The circular raggedness and blur of the plain office papers were found to be equal to those of the coated Papers 2 and 4.

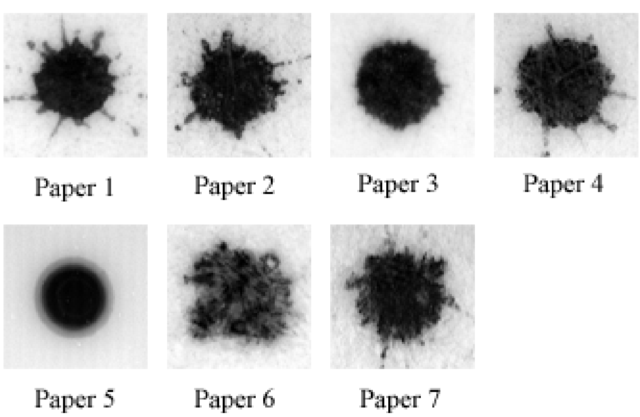


*Figure 5: Examples of the dots printed with the water-based ink on the substrates. When these dots were printed, the velocity of the substrate was only 3.5 m/s and the splashes occurred anywhere around the drops.*

**The effect of the substrate properties**

The tested paper properties included surface energy, pH, Bristow-type absorption, pore size distribution, compressibility and smoothness parameters.

It was found that the rougher and more hydrophobic the surface was, the more likely the inks splashed making the dots ragged. The analyses on the microsecond scale proved to be a good method for studying raggedness caused by the splashes without confusing it with the consequences of feathering.

Circle raggedness is presented in Figure 6 as a function of the Parker Print Surf roughness.

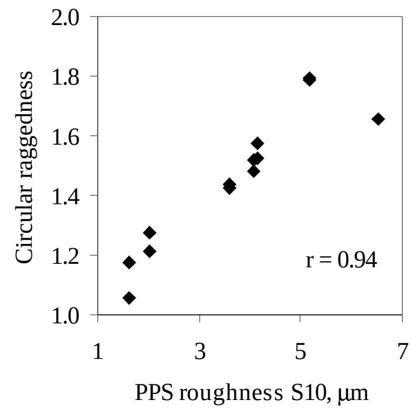


*Figure 6: Circular raggedness as a function of the Parker Print Surf roughness.*

## Conclusions

The above results suggested that the properties of the paper surface have significant effects on the dynamic ink/paper interactions. The differences in the splashing and spreading mechanisms of various material combinations were found on the microsecond time scale almost immediately after the impact.

This paper covers only the first part of a research project, that runs until 1999. Results of a wider interest will be published later when more data has been compiled for a comprehensive statistical analysis.

## References

1. Zable, J.L., Splatter during ink jet printing, IBM. J. Res. Develop., July 1977, pp. 315-320.