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Increased Ink Space with Existing Thermal Inkjet Silicon and Printhead Modules using Micro Pumping

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Abstract

High solids aqueous ink chemistries are desirable to provide high optical density and durability after application to the media but these inks can have tradeoffs in jettability due to Pigment/Vehicle separation (PiVS) and increased solvent evaporation in idle nozzles and fluidic chambers (decap) which can reduce both jettability and observed image quality (IQ). Low volatility co-solvents are commonly used to reduce decap by slowing the rate of evaporation through uncapped nozzles but these solvents have tradeoffs at the system level because final removal of these agents after deposition on media by drying can be challenging. The increased density (2400 nozzles per inch per color) of the HDNA thermal inkjet (TIJ) silicon die has been used on recently introduced HP industrial packaging printing and signage presses in a 1200 nozzle per inch configuration to enable high solids, high volatility ink chemistries with existing printhead silicon circuit designs and printhead modules by utilizing the unused nozzle positions as in-situ ink pumps to mix and flush stagnant ink from ink chambers. This configuration enables good jettability and IQ with high solids ink chemistries without requiring external ink recirculation systems.

Introduction

Aqueous pigmented ink formulations in Thermal Inkjet (TIJ) printheads must meet a long list of simultaneous demands for both on-page attributes and jettability. Among the most challenging for jettability and IQ are effects that occur when nozzles are uncapped and have seen a delayed interval of non-firing. Depending on the ink chemistry, either of the following processes can affect the nozzle health.

1. The tendency for stagnant ink in the nozzle and firing chamber to separate into its constituents
2. The tendency for solvents to preferentially evaporate through the meniscus/air interface.

These challenges are depicted in Figure 1.

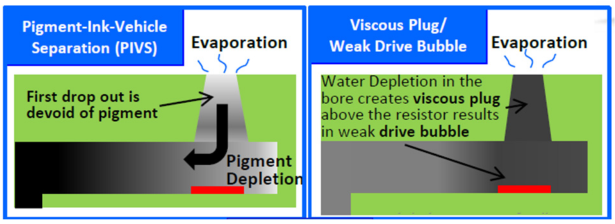

Figure 1 *– Physical processes leading to poor nozzle health after intervals of non-firing*

Typically, these concerns arise when a nozzle is uncapped and ready to fire, but no print data is presented to the nozzle, resulting in an interval of non-firing wherein these effects can occur. This interval between firings while uncapped shall be referred to as the decap time. The maximum decap time that can be endured without a jettability or IQ impact on the first drop fired is an attribute of an ink/printhead system. A system which can sustain good IQ over a longer decap time is desirable because of the inherent unpredictability of print data and infrequent demands on some nozzle positions and ink colors. In some cases, the environment around the printhead in the system is disadvantageous to decap performance. Examples are systems with driers near the printzone or heated substrates in the printzone. In these cases, adequate decap performance is even more challenging.

Various solutions for these issues have been previously proposed. Three common approaches are adding low volatility co-solvents to reduce evaporation at the nozzle[1], spit on page[2]; where nozzles are periodically fired independently from the print data to replace stagnant ink with fresh ink, and external recirculation systems which use external pumps or differential pressure control to flush ink through the firing chamber regardless of print data.

Design Considerations and Theory of Operation

Firing a TIJ resistor in a fluid chamber causes a vapor bubble to form which creates a pressure wave within the firing chamber. Typical firing chambers use three walls around the resistor to constrain the drive bubble and direct much of the pressure towards the open nozzle resulting in drop ejection as shown in Figure 2.

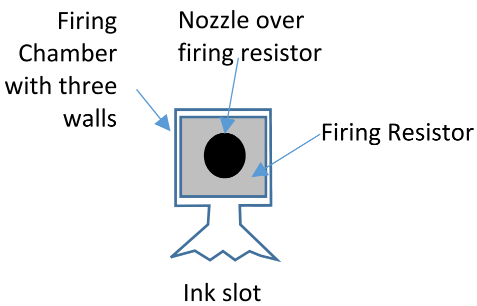

Figure 2*- Typical Thermal Inkjet Firing Chamber*

Some of the resultant force is directed towards the fluidic inlet where the pressure dissipates when it meets the open boundary of the ink plenum. Capillary effects driven by the fluid's surface tension and adhesive forces with the chamber walls cause the fluidic chamber to be refilled for the next firing event.

For the inertial pump several fundamental fluidic chamber attributes are changed. These changes are illustrated in Figure 3.

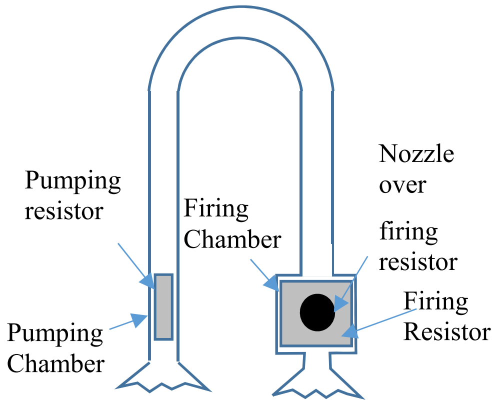

***Figure 3** – Firing chamber with inertial pump added*

1. A second resistor (the pumping resistor) is fluidically connected to the firing chamber.
2. There is no nozzle above the pumping resistor - firing the pumping resistor does not result in an ejected ink drop. The absence of a nozzle directs the resultant pressure wave laterally along the fluidic channels.
3. The inertial pump resistor is located such that the fluidic resistance towards one plenum opening is lower than the fluidic resistance to the other plenum. As a result, the dissipation of the pressure wave occurs first in the shorter fluidic leg. This asymmetry results in a net flow of ink towards the leg with higher fluidic resistance[3]. The details of operation principles of the inertial pump are described elsewhere. [3,4]

Because the firing chamber sits between the pumping resistor and its outlet, fresh ink from the ink slot can be pumped through the firing chamber by actuating the pumping resistor. The fresh ink mitigates decap effects from either separation of the ink components or preferential evaporation of the ink solvents in the firing chamber.

Test Results

Decap Tests on Various Inks

To test decap effects, a simple printing diagnostic is used. After pre-firing the nozzles, a firing delay is introduced. A subset of the nozzles is fired to restore their health then lines are printed with both the freshly fired reference nozzles and adjacent nozzles under test which have not been operated since the initial firing. The time delay for the nozzles under test is defined as the decap time. The test is repeated at increasing decap intervals and the results are graded by software. A representative print sample showing decap induced nozzle health issues is shown in Figure 4.

By evaluating each line's position and quality, a statistical measure of the decap performance across many nozzles is possible. Thresholds for acceptable quality can be determined by human judgement, but the relative grading of line position and quality can be done by sophisticated computer algorithms.

A variety of experimental inks were tested for short term decap performance with and without actuation of the pumping firing resistor. To achieve acceptable line quality with the first ink ejection from a nozzle for many of these inks, decap intervals had to be maintained at less than 1 second. Some test inks could not even be jetted because decap intervals were essentially zero. Short decap intervals make inks difficult to deploy with acceptable image quality across the myriad of firing conditions expected across various applications and images.

When inertial pumping was used to force fresh ink into the firing chamber, the decap intervals for all inks were significantly improved as shown in Figure 5

As solids levels in the ink increase, decap performance tends to worsen. In general, applications requiring the most durability are the most challenging for decap performance. Signage and packaging inks were the best candidates for improved jetting performance with this technology. Latex inks are more challenging than the above test indicates because they are typically deployed with heat near the printzone which enhances viscous plug formation.

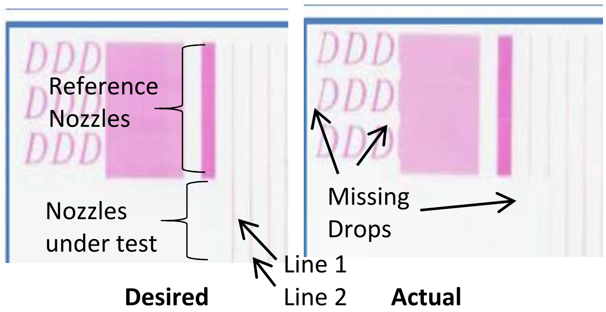

***Figure 4** – Decap Printing Diagnostic –*
Left – no evidence of decap, Right – decap induced nozzle health defects

Ink Type	Decap time No Pumping (poor 1st line)	Decap time With Pumping (good 1st line)
Signage	Low	> 10X
Packaging	Very Low	> 10X
Photo	Moderate to very low	> 10X
Experimental	Moderate	> 8X
White	Moderate	> 8X
PIJ Packaging	Does not fire	> 40X
Publishing	Moderate	> 5X

***Figure 5** – Decap intervals with and without inertial pumping*

Decap Tests on R2000 Latex Ink

The latex ink for the R2000 printer had unique requirements. Like previous HP latex inks, the ink needed good flexibility and durability on flexible substrates, but unlike previous latex inks, it also was formulated for printing on rigid substrates. This presented a significant technical challenge, because rigid substrates require lower drying temperatures than flexible substrates, implying easier evaporation of the carrier fluid. Easier evaporation on the substrate translated to higher evaporation rates in the nozzle and an increased risk of viscous plug formation. The new ink was tested in existing architectures resembling Figure 1 and new inertial pump architectures similar to that shown in Figure 2. The inertial pump architectures were tested with and without pump actuation and decap performance after eight seconds was compared. The metric used was the darkness of the first five lines printed after the decap interval (see Figure 4) where a score of 100 represents a nominal line darkness. The data collected is shown in Figure 6.

Although performance is improving which each subsequent ejection, the conventional fluidic architecture is unable to print a nominal line even after five drop ejections. The inertial design's performance is also poor after five ejections if the pumps are not used. When the pumps are used, the inertial design can achieve good or perfect first drop performance on the first drop fired. More pumping gives a slightly better result.

Side Effects of Inertial Pumping

Most of the heat generated by thermal inkjet resistors during feature of the inertial pump is its ability to push fresh ink through the firing chamber without ejecting ink, reducing waste and unwanted drops on the media, but this has the side effect of retaining all the heat generated by the resistor within the printhead die. This puts a practical limit on the number of continuous firings the inertial pumps can be used for.

The temperature effect of pumping all nozzles simultaneously on a worst-case test plot is shown in Figure 7.

With judicious use of pumping, undue thermal effects can be avoided while still pumping sufficient ink through the firing chamber to attain good decap performance.

Implementation on the R2000 and C500

Printhead Design and Leverage from other Applications

HP's R2000[5] hybrid signage/display printer and C500[6] Pagewide packaging press use the same base printhead module and silicon design as HP's T2xx/3xx/4xxHD Pagewide webpress employing HDNA technology. [7] In the webpress systems, 2400 nozzles per inch (NPI) per color were configured in a 4.25" two color printhead module with two sets of resistors and nozzle sizes. Each nozzle size had a density of 1200 NPI.[8]

For the R2000 and C500, one set of resistors was used for drop ejection at 1200 NPI and the other resistor set was used as the inertial pumping resistor. The HDNA and inertial pumping fluidic architectures are compared in Fig.8.

The 4.25" printhead module used on the R2000 has external dimensions and interfaces identical to that used in the Latex 3000 series and Pagewide webpress.

By updating the same base silicon and printhead modules across multiple markets with new technical innovations, HP can focus development resources on market differentiating features such as new inks and printhead fluidics. In this case the same printhead platform has been re-used and optimized for different key product attributes; IQ improvement on webpress, and ink space for latex and packaging. Targeted innovations such as these enable new application spaces with low capital expense and manufacturing costs while the proven designs and support structure enable high equipment utilization by HP's customers.

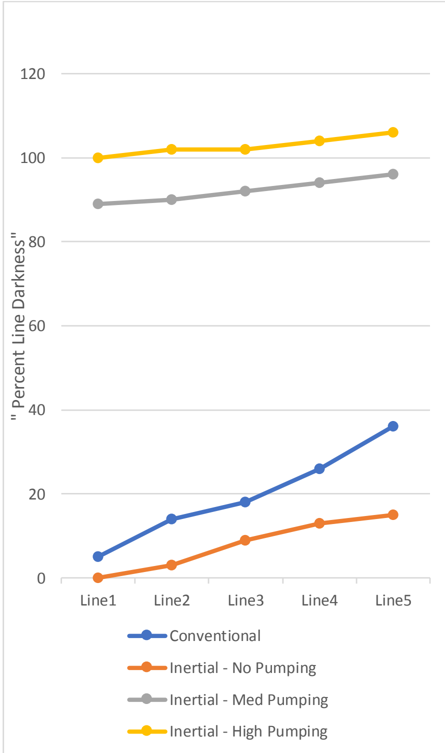

Figure 6 *– Comparison of Traditional and Inertial Pump designs and the impact of pumping on latex inks formulated for rigid substrates*

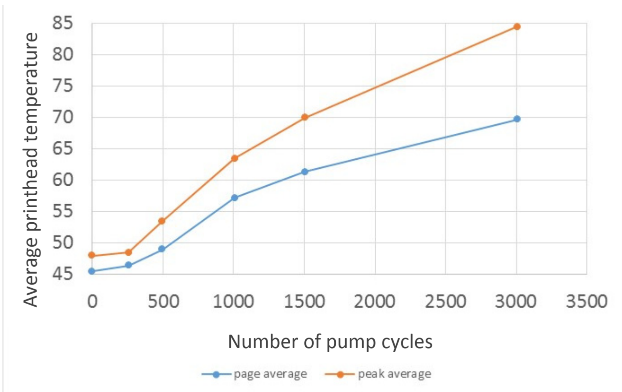

Figure 7 *– Die temperature with all pump resistors operating on worst case test plot*

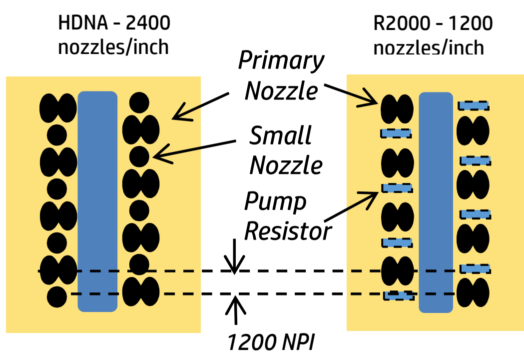

Figure 8 *– Comparison of HP's HDNA and R2000 Fluidic designs for a single color*

R2000 Attributes

The HP Latex R2000 is the first water-based hybrid solution for rigid and flexible sign and display printing in one device. The new printer delivers vibrant colors using HP Latex inks and breakthrough HP Latex White Ink, which delivers the glossiest white on transparent and colored media.

***Figure 9** – HP's R2000 – Flexible/Rigid Water Based 98" printer with white ink*

The R2000's advanced engineering drives high productivity with automatic maintenance, smart vacuum, and continuous loading, allowing users to meet production peaks with high-speed quality on a large variety of substrates for both indoor and outdoor applications while preserving media gloss and feel.

The water-based ink, hybrid application is brand-new to the industry and will help HP's PSP customers do even more with their creative printing needs in signage, graphics, decoration, and more.

C500 Attributes

The HP PageWide C500's water-based inks and HP Bonding Agent enable printing on both primary and secondary food packaging without an additional barrier, meeting stringent global food safety regulations, including Nestle guidance and Swiss Ordinance.

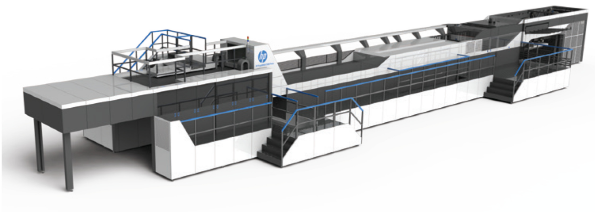

***Figure 10** – HP's C500 – 1.3M Direct to Corrugate Press*

The C500 offers a cost-effective digital alternative to offset lamination or flexo printing. It supports a wide media range, from F-flute to BC-flute, and uncoated or coated media with offset-quality for packaging and displays with high-impact graphics. The press prints 1.3 meter wide boards at 246 linear ft/min using HP's patented Virtual Belt technology for accurate and efficient media handling in demanding corrugated production environments.

HP's PageWide C500 Thermal Inkjet technology uses almost one million nozzles and incorporates 6X redundancy for consistent quality which greatly reduces the risks of nozzle-out white streaks that may result with piezo inkjet printheads.

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Author Biography

Jim Przybyla has 39 years of Silicon and MEMS experience in the design, device and processing realms. At Hewlett Packard he initially worked on 8 generations of internal NMOS and CMOS development as a design, process, device and integration engineer. He began supporting inkjet development in 1998 and led the HP SPT silicon and piezo printhead development efforts. In his current role he develops printhead technology for next generation printheads. He holds 28 US patents.

Alexander Govyadinov has over 35 years of experience in various sensing platform development in academic and R&D industrial environments. Alex works for for HP Inc. in Advance Technology and Product Development Organization developing novel sensing and microfluidic solutions for inkjet applications. He is co-author of more than 100 publications and over 80 US Patents.

Nick McGuinness has worked for HP R&D for more than 7 years in silicon microfluidics. His work includes industrial and graphics printing as well as microfluidics and sensing in adjacent technologies. He is co-author of more than 15 patents.