Temperature Control in Thermal Inkjet

Pere Cantí, Hewlett Packard, Barcelona, Spain

Abstract

Current demands for higher production and higher throughput put usually print-heads to the limits of their thermal performance. Due to the very nature of the inkjet ejection process heat tends to accumulate on the print-heads parts, raising its temperature and challenging its Print Quality performance and Reliability. The change of the viscosity properties with temperature result in variations in drop weight that alter the colors along the page. Some materials and special glues can break down after many thermal cycles above an specific temperature. For that reason it is of great importance to have a temperature control strategy. Hardware and software strategies are discussed in this paper.

Introduction

It is well known how thermal inkjet print-heads work. In a micro etched chamber that fits a few pico-liters an element resistor is heated for a few microseconds. The heat transfer to the ink causes nucleation of a drive bubble that pushes liquid out of the chamber through a convenient exit nozzle. Drops ejected land in paper creating a color dot. Smart combination spatially and temporally of this color dots can configure from text pages to graphics and photographs up to a quality that compares evenly to that given by silver halide. As we fire, although most of the heat generated by each individual resistor is carried away by the ejected drop, not all of it. Remaining ink keeps some, some gets diffused into the surrounding die materials, the heat keeps accumulating fire after fire and thus die temperature starts increasing, so we see operating temperature go up as printing goes on. Whenever a nozzle or a few of them stop working, for those, all heat stays in the system so temperature rises even faster. At some point, if we did nothing else, temperature would become so high that operation would not be possible because large bubbles in the hot chamber would not collapse and they would clog the ink exit, and at this point , if we still continued firing operation, without any drop ejected, temperature in the die would raise so high that we could eventually burn the print-head.

On the other hand, even in a milder printing condition, where heat pumped in the system is not so that temperature goes up to the point where we block the nozzles with non-collapsing bubbles, (low densities, low speeds) , we still could go over the desired temperature limits. Materials reliability requires that certain glues used in the print-head assembling do not go over a maximum temperature for a number of cycles. Failing to do so would result in material degradation and detachment of some layers.

But **Reliability** and **Safety** are not the only reasons to keep operating temperature under control, actually the print quality itself is at stake when it comes to face excursions of several degrees within a swath or printing above or beyond the desired limits.

These problems are caused by the changes in the ink properties induced by the different temperatures. As it raises, viscosity lowers and so resistance to ejection, and then drop weight increases for the same firing energy. An increased drop weight would be seen on paper as increased optical density and saturation, and if we talk about secondary colors we would see a hue shift that would challenge color accuracy in our prints. For the same reason operating below certain degrees would result in a defective small drop or no drop at all.

The nature of the ejection itself will also change with temperature. Actually factors key for dot placement like drop speed or satellites largely depend on ink temperature.

The key problems are, summarizing, getting the ink out in a consistent manner that delivers accurate and repeatable output while keeping the temperature within operating parameters to ensure reliability and endurance of the system.

Now it is true that this does not come for free, we need to place mechanisms in place to enable this control in the thermal conditions.

As a quick reminder of how a Thermal inkjet works we can look at the figure below, where we can see how a heating a resistor causes a drive bubble to be generated and push ink out of the top Orifice in form of a drop traveling at certain speed. As the drop is ejected a space is left empty in the chamber and new ink is let in, what is known as refill.

Refill speed is an important print-head characteristic, the faster the speed, the highest frequencies that it will be able to operate and thus printing speed. When firing frequency is so high that we enter in the no refill zone, ejected drop volume start falling down since there is not enough ink in the chamber when the new firing starts. As the applied energy is same but the heat carried away by the smaller drop is less, this condition leads quickly to an undesired rise in die temperature above allowed operating conditions.

Nucleation and Bubble Growth

In this picture we can see how as resistor transfers heat to ink, nucleation bubbles grow at separate spots over resistor surface and they aggregate.

Temperature Dependencies

<u>Ink Properties</u> both fluidics (viscosity) and reliability (degradation of ink properties)

<u>Print-head Materials</u> reliability

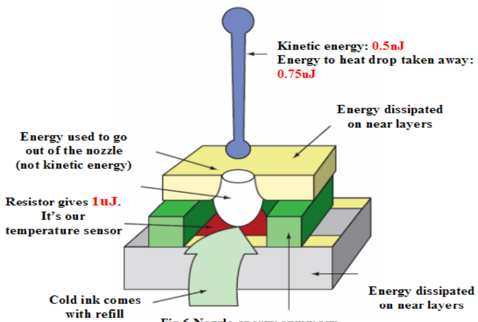
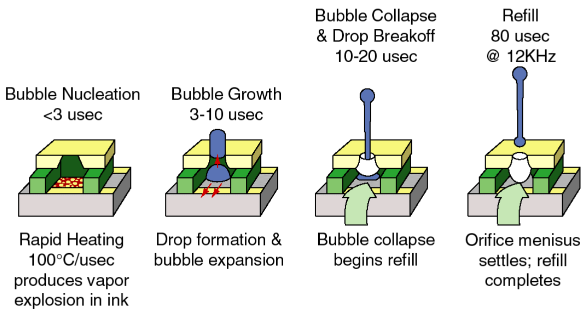
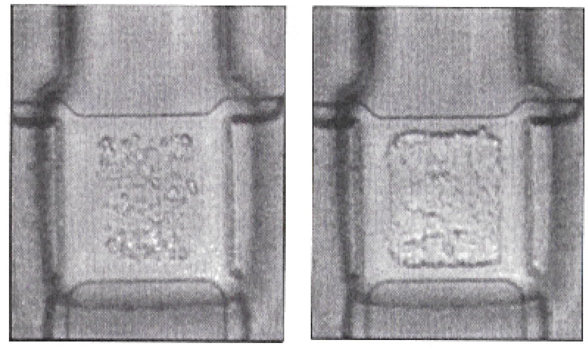
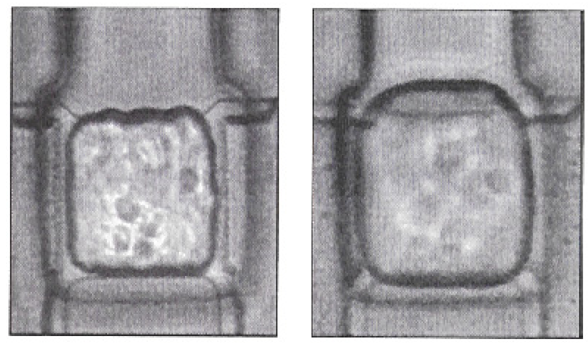
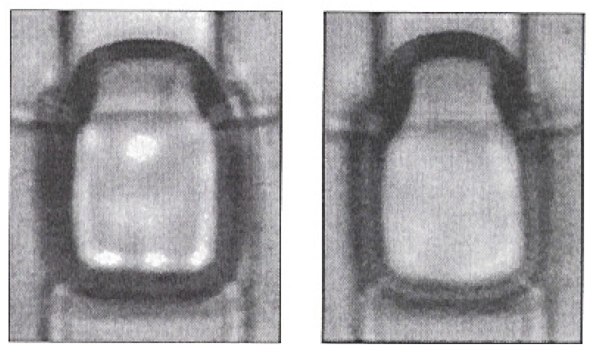


Fig.6 Nozzle energy summary




Bubbles coalesce


Bubbles expand


Maximum bubble expansion

Drop Weight Changes-Optical Density-Color Changes

Typical change of drop volume in inkjet inks with temperature are usually around values of 1 to 1.5% per degree C. In a medium duty cycle in a normal or fast mode temperature can raise about 10 - 15 degrees from start to end of the swath which can translate in up to around 20% of change in drop volume.

Ultimate Goal for Thermal Control in the Print-head

Deliver constant energy to the print-head, control drop ejection and ink conditions, control operating limits for material reliability.

Functions Required in the Print-Head to Enable Thermal Control

Temperature sensing	Heating Mechanisms
Cooling mechanisms	Energy Calibration System

Temperature Sensing

In a system where we want to remain within some operational limits (typical limits for a thermal inkjet pen range from 35C to 70C, but for a given printing mode the range can be narrower depending on the targeted quality or throughput, e.g. a quality mode will only allow 55C-65C range as opposed to a max throughput where 45C-70C range could be allowed), it is necessary to have means to sense with accuracy what is the die temperature. Having an on die sensor is, thus a requirement. What we are interested in measuring is the overall die temperature so it is an advantage if our sensor does an average and does not just sense at a concrete point. This would be tricky, specially at the beginning of a plot, because some nozzles could be printing more than others and there would be a temperature distribution in the die that could lead to inappropriate actions from the thermal control. If we use a sensor or group of sensors that is able to average the temperature on the whole die, then we react to a value much closer to the average die temperature.

It has been explored to take actions at nozzle level, this is, measure the temperature in the nozzle chamber using either the firing resistor's own thermal coefficient of resistance (TCR) or putting a separate thermistor, but the high temperature excursions that the firing resistor sees locally (several hundred degrees), coupled with its low TCR or the difficulty for placing a separate sensing element in the chamber make this a complicated and costly option.

$$R = R_0 e^{[TCR*(T-T_0)]}$$

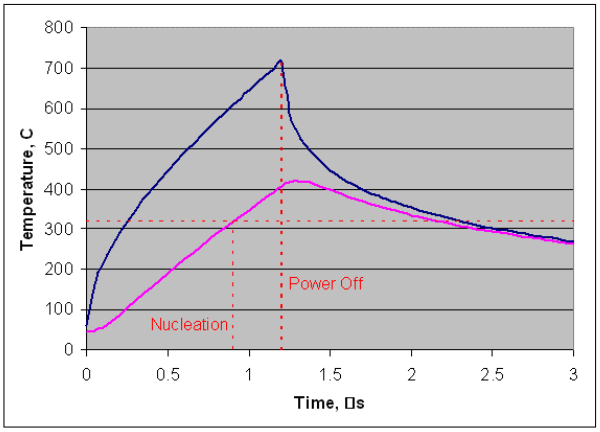


Figure showing temperature raise at resistor (blue line) vs. temperature in one of the passivation layers that protect the resistor from being in direct contact with ink

Well apart from the discussion about what sensor and where it is also important to determine whether we are interested in using analog or digital sensing. The advantages of digital are speed and easy integration in the pen digital control electronics, but we to get an average of the overall die temperature a long analog resistor is the best option. A solution is to use an ADC to encode the measurement in a register so the pen electronics can read it and use it in the thermal control loop.

Such an scheme is sensitive to noise, specially when the pen fires, for this reason, we will need to perform several readings and their average for each individual measurement.

In the end we can achieve accuracies in the order of ± 2%.

Heating Mechanisms

Warming

Apart from the obvious firing process, a preconditioning is required for 2 reasons, raising the ink temperature to a level that provides the best ejection conditions and to limit the temperature excursion during the swath, otherwise, specially in Large Format printers, when printing busy uniform area fills, where we would see how color changes as dw increases following the temperature raise from the cold edge where we started until the end edge of the page.

Currently this can be achieved by either applying short pulses to the firing resistor so we transfer heat but not enough to eject a drop, or by having an auxiliary circuit of FETs that heats the surroundings of the firing chamber. The first method, using short pulses on the firing resistor previous to the final one has disadvantages because it interferes with the firing process limiting the maximum frequency that we can fire at. Do not confuse this scheme with the dual pulse one were we fire in 2 stages with a pre pulse and a final pulse. In the warming scheme there is an specific warming process that does not allow the pen to start firing until die is in the operating range. For this reason, using the second option mentioned above where we have a separate circuit of FETs to do the warming is far more convenient. Actually this circuit controls the number of FETs that are activated simultaneously as a function of the gap between ambient temperature and target temperature also known as SetPoint:

WarmMode = (SetPoint – Temp) / Gain

With such electronics, the die can be brought into operating range in less than a second in any adverse environment.

Cooling Mechanisms

There is no a lot of options for cooling mechanisms per se, but there are resources to control the energy and thus the heat we deliver to the die as a function of die current and projected temperature and also waits to allow the die to reenter operating range.

***Mechanisms in Die**:* a variety of devices has been tried. Following some trends in the IC industry some heat dissipation Fins can be attached to the print-head. There are a number of inconvenients, the size being the most obvious.

***Waits**:* They are effective but do require time that could interfere in throughput goals, for this reason this is a very limited resource that can be applied only for fractions of a second in the swath edge.

Energy/Heat Reduction as a Function of Die Temperature

This is the most effective strategy to keep die operating within operating limits. The theory underneath is to reduce the amount of energy supplied to the print-head that will be used to raise ink temperature since ink is already hot to some point. Knowing what is this point allows us to adjust the firing pulse accordingly to supply only the required heat to produce the drive bubble and not have excess diffused into the die.

Effectively if we look into the energy we put in for the ejection of a single drop we can calculate:

$$\frac{dE}{dt} = \frac{V^2}{R} \Rightarrow E = \int_{t=0}^{t=PW} \frac{V^2}{R(T(t))} dt = \int_{t=0}^{t=PW} \frac{V^2}{R_0 e^{[TCR*(T(t)-T_0)]}} dt$$

From this energy a fraction gets diffused into the die: when energy to nucleate the drive bubble is completed, the excess remains in the die raising its materials temperature.

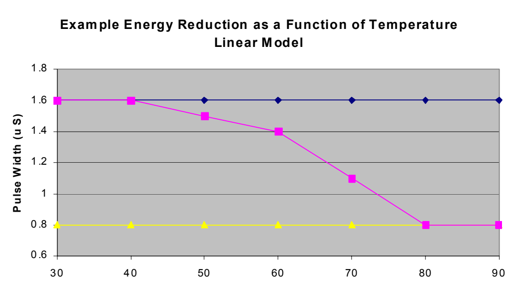
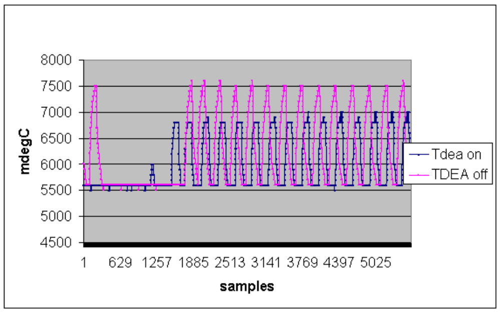


Figure shows an example of a simple implementation of a linear model for this purpose where the pink line shows how firing pulse is reduced for an specific print-head as a function of die temperature.

By calculating and modeling how the delivered energy should change as a function of the starting temperature conditions at beginning of fire we can reduce the duration of the firing pulse or the voltage level and deliver just the energy for the drive bubble to eject the drop.

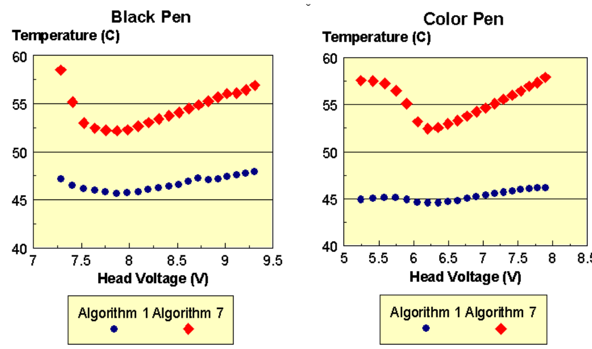
The following figure shows how operating temperature is reduced by applying such an scheme of temperature dependent energy adjustment on a given print-head.



Energy Calibration System

Though not a thermal control strategy in itself, given that the ultimate goal for thermal control is delivery of constant energy to the firing nozzle, we need a method to calibrate the initial parameters (voltage, pulse width), for a particular pen accounting for pen to pen and printer to printer differences. Thermal behavior can help us provide a method for it.

This can be achieved by finding what we could call the thermal signature of the print-head which characteristic will be that die operating temperature under certain conditions, will be minimal when energy delivered for the firing is the appropriate. Below this energy, many nozzles won't fire so the heat applied to them will get diffused in the die raising the temperature. Above this optimum energy level we are giving the die too much energy that can't be used just for the bubble nucleation. So again the excess accumulates in the die rising its temperature. This leaves us with a method where we can play with energy parameters systematically, to find which of them lead us to the minimum temperature setpoint. Parameters for that point represent the right energy values for that pen and operating condition.



Conclusion and Future Directions

Increasing nozzle integration in inkjet print-heads coupled with higher demands for printing speed and quality demand control methods able to harness all the thermal energy that is put into the device. Although this article focuses in thermal inkjet print-heads the issues and solutions have a lot of commonalities with the challenges that MEMS technology faces currently. Accurate sensing, calibration and thermal loop methods are required in order to drive efficiently the power managed by these devices. Integration of control circuits and further development of micro-cooling structures are promising solutions.

Acknowledgements

The author wishes to thank Satya Prakash, Rory Heim and many other colleges in Hewlett Packard since many of the information in this article comes from work done by researchers a the Inkjet Printing Divisions.

Author Biography

Pere Cantí studied Physics in Barcelona Universitat Autonoma de Bellaterra. In He worked for Centre of Applied Technology in Barcelona from 1987 to 1993 and joined HP with a grant in 1994. He was hired by HP in Barcelona in 1997. The last 4 years he joined the printhead development team. He is currently focused on the interaction between the printhead control and writing systems.