Printhead Maintenance – Low Pressure Assist Improvement on Effectiveness

Rodney B. Hill
Xerox Corporation
Wilsonville, Oregon

Abstract

Printheads of all types have historically had a difficult time keeping contamination from entering their apertures during the printhead maintanence cycle. This is due to a negative pressure at the aperture that must be maintained for jetting performance. The current study examined this problem analytically and experimentally. It has demonstrated that maintaining a low pressure during the entire printhead maintenance cycle almost completely eliminates this problem. Results are applicable to most ink-based printing technologies, and will improve print quality and reliability.

Introduction

Contamination in jet orifices is a significant print quality and reliability issue for inkjet printers. This contamination comes in the form of external particles (typically paper fiber) or ink from an adjacent jet. Both of these sources are exacerbated by printhead maintenance, where some type of purge / wipe sequence is typically used.

Contamination problems during the printhead maintenance cycle arise from the slightly negative pressure at the jet orifice. Both bubble jet and piezo-driven solid ink printers utilize this negative pressure to force the meniscus to a consistent shape, which improves jetting robustness. This negative pressure has a detrimental effect during the printhead maintenance cycle. In particular, immediately after a purge, ink and particles that are left on the faceplate are readily drawn into the jets creating print quality and reliability problems. This occurs because the orifices are now "flooded", greatly reducing surface tension forces.

These effects can be greatly reduced with the application of a low pressure to the system; just enough to bring the orifice to atmospheric pressure. For this condition, the flow of contaminants into the jet orifice is examined analytically, and compared to experimental results from a solid ink printhead. From this, it is possible to determine a range of acceptable pressures for a given printhead configuration.

Meniscus Characteristics and Control

Repeatable meniscus characteristics are always important for jetting performance of an ink jet printhead. Applying the appropriate pressure force to the nozzle can achieve these goals.

A range of meniscus shapes and positions are shown in Figure 1 for a simple cylindrical aperture.

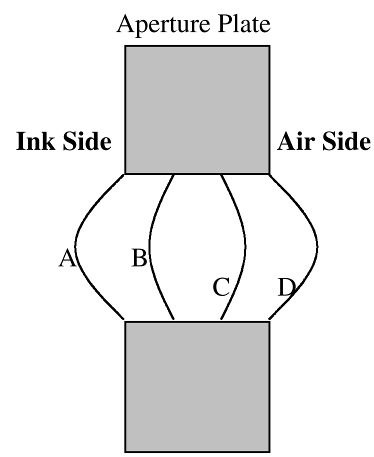

Figure 1. Aperture cross section showing possible meniscus shapes and locations

If no pressure is applied, the possibility exists to have a meniscus shaped like that depicted by curves B or C, located anywhere within the bore of the aperture. This case is problematic because both the curvature and location are highly sensitive to small changes in pressure. If a small positive pressure is applied to the ink side of the aperture plate, a meniscus as depicted by curve D results. While this scenario is relatively insensitive to pressure changes, it is highly sensitive to external contamination or intentional perturbations such as a wiper blade (to be discussed). If a slight vacuum is applied to the ink side of the aperture plate, a meniscus as depicted by curve A results. As with the positive pressure, this condition is insensitive to small changes in pressure. This condition is also insensitive to external contamination, and is not affected by wiper blade motion. In summary, a slight negative pressure leads the most stable meniscus condition for jetting.

The two most common methods of supplying a precise negative pressure to the jet apertures include a simple free surface height difference and capillary action of a porous media (Figures 2).

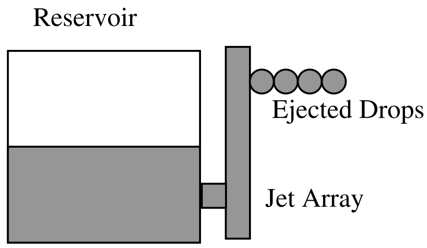

Figure 2a. Pressure force via height difference

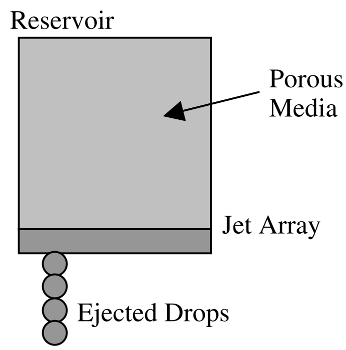

Figure 2b. Pressure force via surface tension

Xerox Corporation's Phaser solid ink printers provide an example of a simple free surface height difference which yields a pressure at the orifice of:

$$\Delta P = -\rho g \Delta h \tag{1}$$

where ρ is the ink density, g is gravity, and Δh is the difference in height between the reservoir free surface and the aperture (Figure 2a).

Epson (and many other manufactures) bubble jet printers provide an example of utilizing capillary action to supply the pressure at the apertures. In this case, the pore size of the media determines the negative pressure at the aperture and is given by:

$$\Delta P = -\frac{4\gamma \cos\theta}{D_p} + \rho g \Delta h \tag{2}$$

where γ is the surface tension of the ink, θ is its contact angle with the aperture, and D_p is the pore size of the media.

No technical reasons exist to limit either of the preceding examples to their current (or alternate) form of pressure generation. Either, in fact, could readily use the methodology of the other. Firing direction, however, generally makes one more appealing than the other.

Maintenance Cycle

Periodic maintenance is essential to maintain printhead performance for all types of ink-based printers. Bubble jets are highly susceptible to external contamination (typically paper fibers) and ink drying (in apertures) issues. Solid ink printers, while less susceptible to these problems, suffer from air coming out of solution as the ink in the printhead freezes during extended periods of nonuse. Both technologies typically remedy these issues by a maintenance cycle which includes ejecting ink from the apertures, followed by removing the residual ink from the face of the jetting array.

The maintenance cycle disturbs the stable meniscus discussed in the previous section. In particular, after ink is ejected from the apertures, residual ink on the face of the jetting array "floods" the apertures, rendering the withholding force of the meniscus useless (Figure 3).

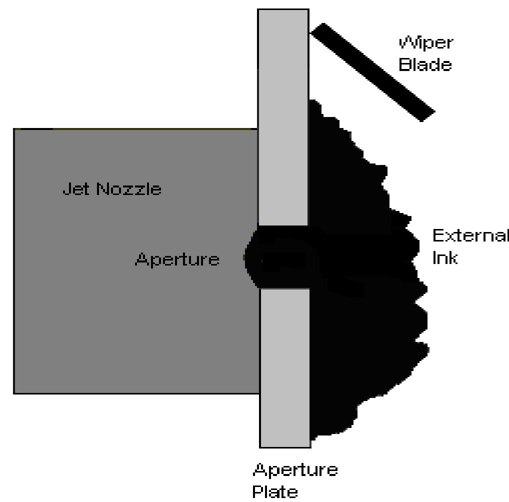

Figure 3. Depiction of ink mixing in a printhead during a maintenance cycle

Ink mixing during the maintenance cycle is a result of ink from a top color running over the apertures of the colors below. The external ink, depicted as black in the sketch of Figure 3, enters the aperture via advection and diffusion. The ink dye is a passive scalar, thus the scalar transport equation is applicable:

$$\frac{\partial S}{\partial t} + V_r \frac{\partial S}{\partial r} + \frac{V_\theta}{r}\frac{\partial S}{\partial \theta} + V_z \frac{\partial S}{\partial z} = D\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial S}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 S}{\partial \theta^2} + \frac{\partial^2 S}{\partial z^2}\right] \tag{3}$$

where S is the passive scalar (ink dye), D is the coefficient of scalar diffusion, and r, θ, z is the cylindrical coordinate system.

For simplicity, only the height difference case of the previous section is considered. The velocity field is driven by a pressure gradient across the aperture, maintained by the (approximately) 3/4" height difference between the apertures and the free surface in the reservoir. The reason for this difference is to bias the meniscus for jetting stability as discussed previously. Under all conditions other than purge, the jetstack faceplate is clean, and the surface tension of the ink at the aperture can easily maintain equilibrium.

During purge, however, the aperture is submerged (Figure 3), making surface tension forces insignificant. In this case, the velocity field, V_i, can be solved apriori, and is the exact solution to the Navier-Stokes equation for circular pipe flow given in Equation 4.

$$V_r = V_\theta = 0\,,\; V_z = \frac{-dp/dx}{4\mu}\left(r_0^2 - r^2\right) \tag{4}$$

Utilizing Equation 4, and assuming that the scalar field is independent of θ, Equation 3 reduces to:

$$\frac{\partial S}{\partial t} = \frac{-dp/dx}{4\mu}\left(r_0^2 - r^2\right)\frac{\partial S}{\partial z} + D\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial S}{\partial r}\right) + \frac{\partial^2 S}{\partial z^2}\right] \tag{5}$$

where the first term on the right hand side is scalar advection (dye being carried by the bulk flow), and the second term is scalar diffusion.

Empirical data (to be discussed in the following section) suggest that the ink mixing is dominated by the pressure gradient driven advection term of Equation 5. If a pressure gradient is applied to counteract this term, the advection term is eliminated. It also results in the first diffusion term being eliminated, as the radial variation of the scalar field is due to radial variation of the velocity field, which is now eliminated. Hence, Equation 5 reduces to Equation 6, for the case of an appropriately applied pressure.

$$\frac{\partial S}{\partial t} = D\frac{\partial^2 S}{\partial z^2} \tag{6}$$

Thus, most ink mixing can be mitigated via applied pressure. A diffusion term, however, will always be present (barring infinitely fast wipe speed). Because of this, printheads typically must jet a small amount of ink prior to making customer prints.

Maintenance Cycle Purge Profile

To validate the analytical analysis of the previous section, extensive testing has been completed on Xerox solid ink printheads. In particular, the maintenance cycle purge profile has been optimized, and is compared with the analysis.

For pressure profile measurement and optimization, a pressure transducer and oscilloscope were incorporated. A typical developmental purge profile is shown in Figure 4. Note that two identical profiles are shown on different scales for clarity. The high pressure purge profile, defined by the rise time, peak pressure, and fall time, are important for clearing existing contamination, but not for ink mixing and other external contamination, thus are not discussed here.

The three important parameters for ink mixing include the delay time and p(low) as they drive advection, as well as the wipe time, as it is important for diffusion. Delay time and pressure have been examined and optimized experimentally. Measurement system modifications would be significant to quantify diffusion, thus measurements were not made. Suffice to say that diffusion is driven by wipe time, thus the wipe should be as fast as possible.

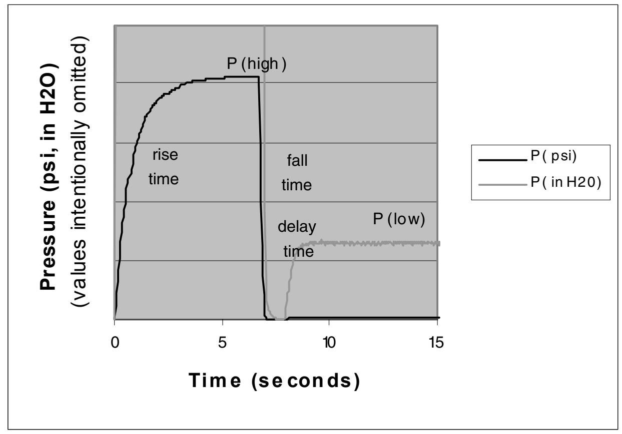

Figure 4. Purge profile

The delay time between the high pressure purge (HPP) and the low pressure assist (LPA) is important due to the negative static pressure at the orifices. External ink will flow into the jets (given by the advection term of Equation 5) at any time that the applied pressure falls below the static negative pressure, and ink is covering the orifice (Figure 3). Experiments were conducted to verify this analysis, the results of which are shown in Figure 5. The horizontal axis is simply the delay time, in seconds, depicted in Figure 4. The vertical axis is the average amount of ink, in grams, that must be jetted to eliminate all traces of ink mixing. As expected, the smaller the delay time, the less ink mixing is present. Obviously, from Figure 5, the delay time should be eliminated if possible.

The required pressure of the LPA is bounded on both sides. If the pressure is too low, ink will flow into the orifices according to Equation 5. If the pressure is too high, ink begins to "ooze" out of the orifices, causing problems for the orifices below. Two solid ink printheads were tested to determine the best operating point for the LPA. The results are shown in Figure 6.

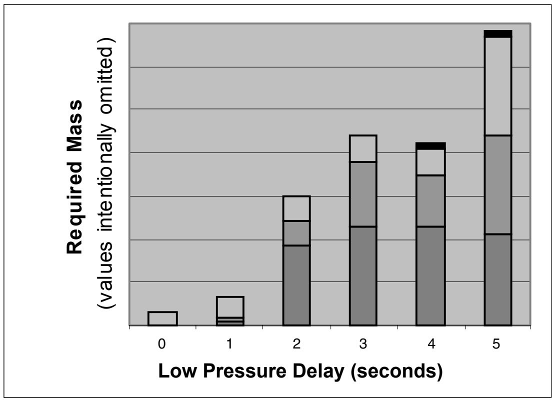

Figure 5. Delay time effect on ink mixing at 1.35" H2O

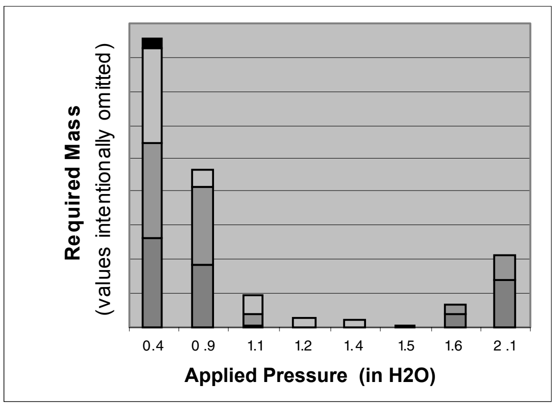

Figure 6. Effect of LPA pressure on ink mixing performance with no low pressure delay

For both printheads of Figure 6, a bathtub curve exists, indicating exceptional ink mixing performance from approximately 1.1 to 1.5 inches of water (pressure). The lower limit is somewhat higher than the negative static pressure at the orifices. This is due to the slight pressure applied by the wiper blade as it cleans the jetstack. The upper limit corresponds to prior experiments indicating that the jets begin drooling at roughly 1.0 – 2.0 in H2O. These data also indicated no corellation to orifice diameter. This is significantly lower than the orifice meniscus strength, and is likely caused by contamination related surface wetting on the faceplate as mentioned previously.

Conclusion

The combination of negative static pressure at the apertures (needed for jet stability) and periodic aperture array maintenance leads to unwanted contamination (in the form of ink or debris) being drawn into the apertures during the maintenance cycle. Experimental results agree well with analytical work, suggesting methods to largely eliminate this problem leading to improved print quality and reliability.

Biography

Rodney Hill graduated from Michigan State University with a Bachelor of Science in Mechanical Engineering in 1990. From there, he went on to the University of Utah for graduate studies in Fluid Mechanics. Rodney graduated in 1996 with a Doctor of Philosophy degree upon completing his dissertation entitled "Boundary Layer Vortex Generation". For the past seven years, Rodney has worked at Xerox Corporation in Wilsonville, Oregon focusing on solid ink printhead technology.