TITLE: The Meniscus Oscillation of Ink Flow Dynamics in Thermal Inkjet Print

The Meniscus Oscillation of Ink Flow Dynamics in Thermal Inkjet Print Head

Ching-Long Chiu, Chien-Wen Wang, Yi-Yung Wu, Yuan-Liang Lan

K200/OES/ITRI
Bldg. 78, 195-8, Sec. 4, Chung Hsing Road,
Chutung, Hsinchu 31040, Taiwan, R.O.C.
Telephone: 886-3-5918438
Fax: 886-3-5917487
H870876@itri.org.tw

Abstract

Meniscus oscillation usually occurs after jetting drops in Drop-on-Demand inkjet head. It is important for ink refill motion. Ink refill motion affects many jetting performance in inkjet technology. Therefore it is very important to understand ink refill motion process for designing inkjet head dimensions and ink properties, such as nozzle diameter, barrier thickness, ink viscosity and surface tension. This meniscus oscillation is a kind of under-damped oscillation. The refill time is defined, as the time required returning to the initialization, the free surface obeys damped oscillation and oscillates between meniscus mounding and recession when the amplitude of the oscillation reduces to dispersion. This study researches several inkjet heads using computational fluid dynamics simulation. CFD solver, such as FLOW_3D, is used to solve the problem. After calculation, the results are plotted with post-processor such as plot software and output to printers. This paper shows the break-off time, the refill time and operation frequency of the inkjet head.

Keywords: Thermal inkjet, Meniscus oscillation, CFD, fluid dynamics.

1. Introduction

In recent years, an inkjet printer has become the most dominant output device of PC due to its low cost, high print quality and color printing. However, the print quality is closely related to the ink droplet generation process. The ink droplets are usually jetted by a pressure source generated by thermal bubbles or piezoelectric transducers. When pressure is applied to the bottom of the chamber, the liquid inside the chamber is compressed in order to form droplets jetted from the nozzle which is on the top of the chamber. After the droplet breaks off at the nozzle, the chamber is then refilled with ink again.

The refill motion of ink affects many printing performances. In 1977, Beasely[1] calculated the refill motion for a piezoelectric-driven inkjet head based upon a simple mathematical model, and compared with two experimental results. The analysis reveals that the equivalent length is much shorter than the physical length during the refill, and the calculated refill times agree with the experiments observed. 1981, Kyser[2] introduced a new mathematical model which can be applied to the

In *Input/Output and Imaging Technologies II*, Yung-Sheng Liu, Thomas S. Huang, Editors, Proceedings of SPIE Vol. 4080 (2000) • 0277-786X/00/$15.00

known embodiments of jets and shown meniscus oscillation in the refill motion. Saitor[3] used a simplified model under some very simple assumptions to study the refill time and oscillation characteristics. In his study, the neglect of the drop ejection process caused some disagreements with experimental results.

This study uses a Computational Fluid Dynamics (CFD) model to simulate the drop jetting behave of an inkjet head, and to observe the meniscus oscillation of free surface near the exit of the nozzle plate after drop jetting.

2. Numerical description

Simulation of an inkjet head is one of the challenging tasks in CFD. The structure size is quite small, in the order of 10 micrometer, and causes severe truncation errors in the calculated results. Another challenge is keeping track of the free surface between liquid-gas phases. Free surface plays a very important role in our simulations because modeling requires tracking the interface in a more accurate resolution. CFD to be used in this case becomes very complicated, the code has to be capable of capturing the interface accurately. Some packages are capable of dealing the density discontinuity of the free surface by smoothing the interfaces over a few grid cells, but not accounting for the sharp changes. In order to simulate the meniscus oscillation of the inkjet head, the code has to have the capabilities of tracking free surfaces, keeping its sharp changes in one cell distance and evaluating the free surface curvatures.

VOF[4] (Volume Of Fluid) method utilizes a finite difference to represent the free surfaces and interfaces which are arbitrarily oriented with respect to the computational grids. Flow_3D is a CFD solver using the VOF method in two-phase flow. It can track free surfaces very accurately, and has a certain degree of accuracy in surface sharp. The VOF method is a wide-use two-phase flow model to tackle interface between gas and liquid phases. VOF has been implanted into many packages such as SOLA, SOLA-VOF, NASA-VOF and so on. Today, many inkjet manufacturers and developers use those packages to simulate the jetting process.

VOF has defined a function F whose value of unity at any point occupied by fluid and zero otherwise. The average value of F in a cell then represents the fractional volume of the cell which is full of fluid, while a zero value indicates that the cell contains no fluid. There exists a free surface while the value of F is between zero and one in a cell. Although VOF can locate the free boundary nearly as well as a distribution of marker particle method[4], and has the advantage of a minimum of stored information, the method is worthless unless an algorithm can be devised for accurately computing the evolution of the F field. The time dependence of F is governed by,

$$\frac{\partial F}{\partial t} + u\frac{\partial F}{\partial x} + v\frac{\partial F}{\partial y} = 0 \tag{1}$$

Eqn.1 describes that F moves with the fluid, and is the partial differential equation of marker particles. Thus, the VOF method provides a simple way to track the free surface.

3. Results and Discussions

The simulation of Inkjet head has some difficulties such as the criterion of the bubble formation under the condition of super heating and the free surface capturing. The treatment of the thermal bubble growth of an inkjet head belongs to the super-heating model. So far, there are no commercial packages can deal with super-heating. In fact, it is a big challenge for the inkjet simulation. This study introduces a solid piston to substitute for the thermal bubble, which is a pressure source for inkjet jetting process. Fig.1 is the contour of computational domain for Flow_3D. The computational domain is an two-dimensional, axisymmetric inkjet head which the radius of the nozzle plate is 30 μm and 50 μm in thickness. The height of barrier (or ink supply channel) is 30 μm. For the convenience of calculation, the solid bottom including a movable piston has been set as 2 μm thickness. The void region is 500 μm in length, 52 μm in radius. The piston has a specified velocity as a function of time shown in Fig.2. The boundary conditions are given as follows: symmetry in central line, wall condition in bottom, continuative condition on the top exit and one atmosphere pressure condition on the right. The viscosity coefficient and surface tension coefficient are 3.5 cps and 50 dyne/cm^2, respectively.

Fig.3 shows the variation of the interface height in the axial direction for the case in which the nozzle radius is 30 μm and the height of barrier is 30 μm. The lowest point of 27 μsec is the break-off time of the droplet. This figure shows that the oscillation of the free surface. Table 1 shows the computational results for four kinds of nozzle radii and four kinds of barrier heights. From the results, we found that the smaller the nozzle radius, the less the break-off time. Besides, the barrier height does not influence the break-off time if the nozzle radius is kept constant. The results of the refill time show that the larger the nozzle radius, the longer the time.

Some of the results do not obey this tendency, we found that small satellite droplets separated from main droplet or second droplet collide back to the free boundary after jetting. This may cause slightly large oscillation on the free boundary and destroy the natural frequency of damped oscillation. We observe from experiments that there are usually a small amount of ink deposits around the muzzle. Perhaps, the residual ink around the muzzle may have the similar phenomena compared with the simulation results. The reason is that the smaller droplet has opposite momentum while separating from the larger droplet and has larger buoyancy effect.

Table 1 also shows the oscillation frequency of the results. Almost the frequencies are larger than 2kHz and smaller than 3kHz. This shows the structure can work at 3kHz.

From the above results, we use several kinds of nozzle radii and barrier heights to calculate the break-off time of the droplet and the ink refill time. The results show that CFD can use to simulate the behaviors of inkjet heads. Although there are some differences in the break-off time and the refill time, the operation frequencies of the inkjet heads still work about 2kHz. Here, the design operation frequency is 3kHz.

References

1. J. D., Beasley, "Model for Fluid Ejection and Refill in an Impulse Drive Jet," Photographic Science and Engineering **21**, pp. 78-82, 1977.
2. E. L., Kyser, L. F. Collins, and N. Herbert, "Design of an Impulse Ink Jet," Journal of Applied Photographic Engineering 7, pp.73-79, 1981.
3. K. Saitoh, "A Simple Model of Ink Refill Motion in Inkjet Printing," 7th IS&T's International Congress on Advances in Non-Impact Printing Technologies, Portland, Oregon, Volume II, pp.120-123, 1991.
4. C. W. Hirt, and B. D. Nichols, "Volume of Fluid (VOF) Method for the Dynamics of Free Boundaries," Journal of Computational Physics **39**, pp.201-225, 1981.

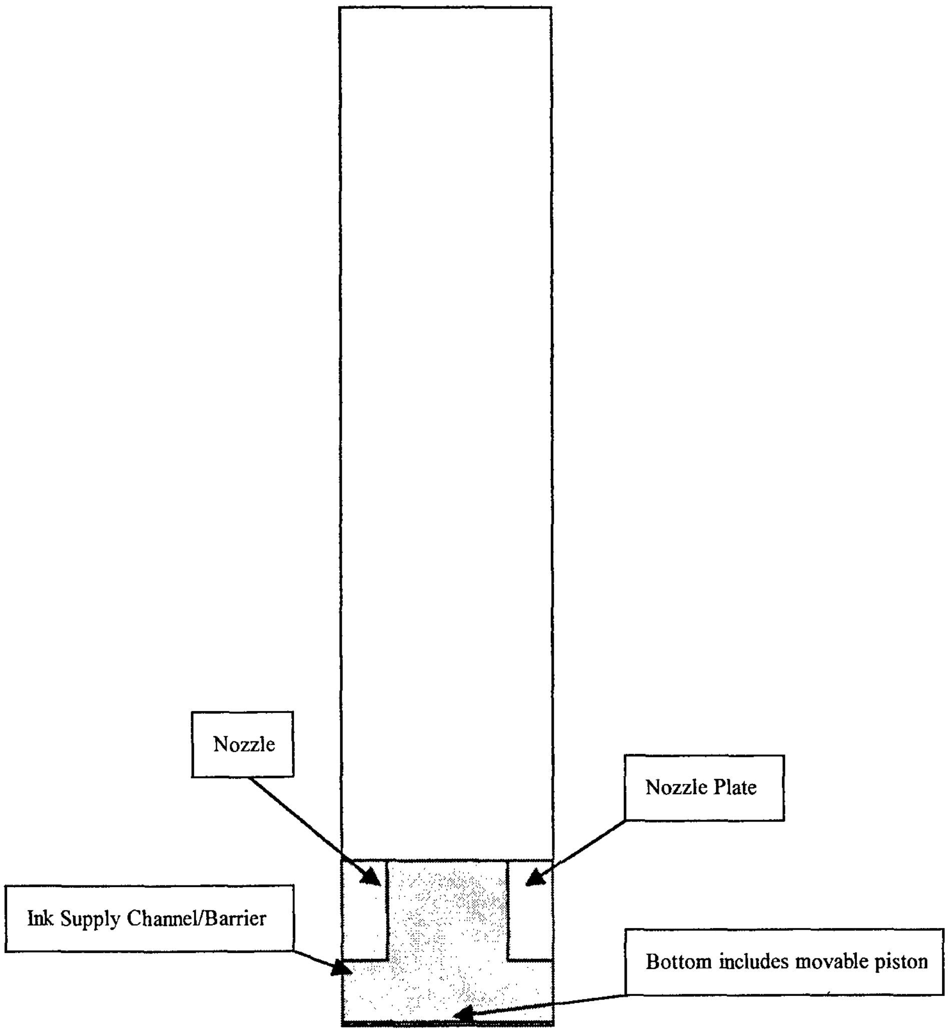

Fig.1 2D computational domain

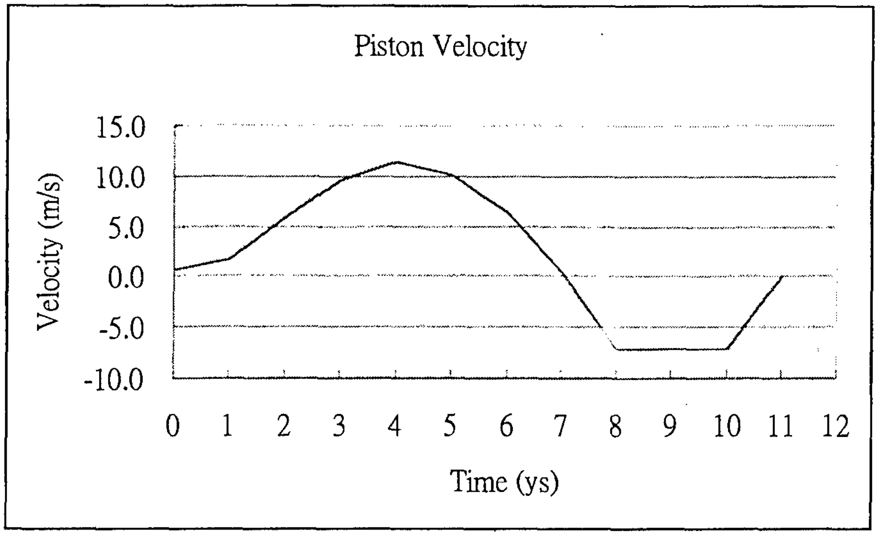

Fig. 2 The piston velocity profile

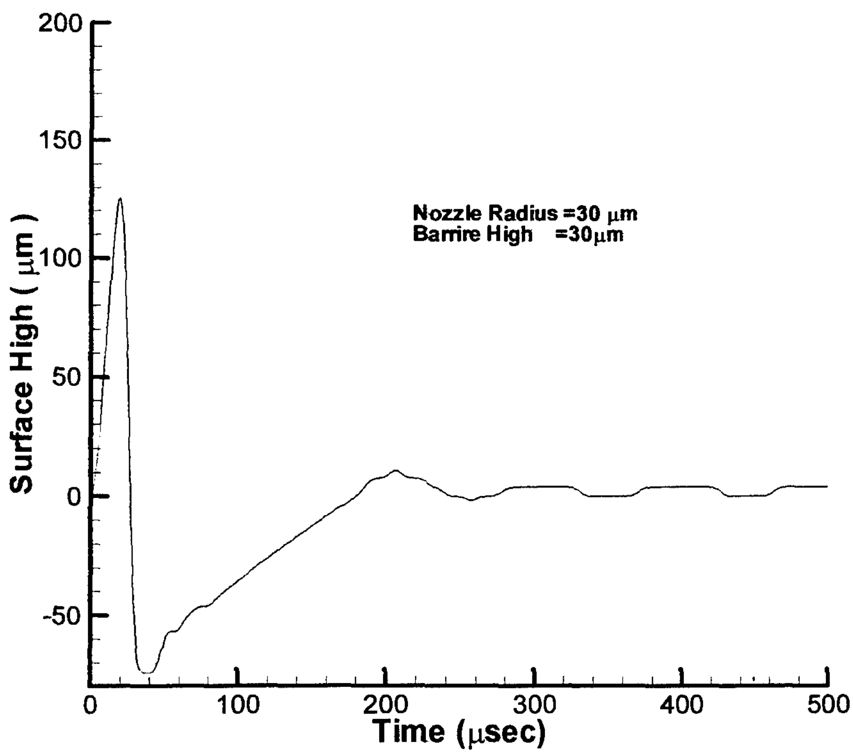

Fig.3 The surface height variation

Break-off Time, μ sec				
Nozzle Radius,, μ m Barrier Height, , μ m	26	28	30	32
25	23	24	29	31
28	22	24	29	28
30	23	24	27	28
34	24	25	27	28
Refill Time, μ sec				
Nozzle Radius, μ m Barrier Height, μ m	26	28	30	32
25	497	331	335	452
28	320	420	366	497
30	327	355	385	361
34	344	355	385	447
Frequency, kHz				
Nozzle Radius, μ m Barrier Height, μ m	26	28	30	32
25	2.01	3.02	2.99	2.21
28	3.13	2.38	2.73	2.01
30	3.06	2.82	2.60	2.77
34	2.91	2.82	2.60	2.24

Table 1 The break-off time, refill time, and operation frequency of several nozzle radii and barrier heights