The Numerical Study on Size Effects of the Inkjet Print Head

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Abstract

Increasing printing speed is one of the most-demanding needs for printer users. To achieve this, one should accelerate the ink refill after ink was jetted out. This depends on the proper design of the ink feed path of the print head. The ink feed path consists of nozzle plate, ink chamber, ink feed channel etc. All the shapes and sizes of these parts are important in design process. Nozzle diameter, nozzle plate height, chamber size, feed channel length and height are the key parameters for design. This work used computational-fluid-dynamics (CFD) method to study the size effect of these parts. The numerical schemes, the volume-of-fluid (VOF) method has been used due to its capability to deal with the interface between gas and liquid. Finite volume method is used as basic numerical scheme. The simulation can help engineer to find an better performance of the structure, which is consistent with the experiments.

Introduction

The inkjet printer, especially the thermal inkjet printer, is very popular in recent years. People use printers to print a large number of documents and graphs. Nowadays, a faster printing speed is one of the most-demanding needs for printer users. Therefore, researchers should find a better design of the inkjet print head to achieve a faster printing.

In the inkjet print head, the shape and size of the ink chamber and the ink feed channel are the key factors to influence the ink-jetting behavior. The traditional method of designing the structure of the print head may need many trial-and-error experiments. This method needs many cycles of fabrications, tests, and observations. If a suitable computer aided design is available, the development process of the print head can be faster than before.

This work uses CFD technology to simulate the flow field inside the thermal inkjet print head. However, there are some difficulties in the simulation of the thermal inkjet print head, such as the complex coupling of heat transfer, bubble behavior, and liquid flow. Thus we assumed a velocity profile to simulate the thermal-bubble effect on the heater. For correctness of the result, the velocity profile was determined by comparing the droplet velocity of some experimental results.

Model and Numerical Scheme

Simulation of an inkjet print head is one of the challenging tasks in Computation-Fluid-Dynamics (CFD). The size of the structure is quite small, about the order of 10 micrometers, which often causes severe truncation errors in the results. Another challenge is tracking the free surface interface between the liquid and gas phase. Free surface interface plays an important role in the simulation because the model requires tracking in a more accurate resolution. CFD was used because the tracking is very complicated and the code has to be capable of capturing the interface accurately.

Volume of Fluid (VOF) method resolves the transient motion of the gas and liquid phase using the Navier-Stokes equations, and accounts for the topology changes of the interface induced by the relative motion between the gas and liquid phase. The VOF method utilizes a finite difference to represent the free surfaces and interfaces that are arbitrarily oriented with respect to the computational grids. The VOF defines a volume fractional function F that indicates the fraction of the computational cell filled with liquid, and uses a donor-acceptor algorithm to track the interface. There exists a free surface interface while the value of F is between zero and unity in a cell. Although VOF can locate the free boundary nearly as well as a distribution of marker particle method and needs less information-stored space, 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

$$\frac{\partial F}{\partial t} + F\nabla \bullet \vec{V} = 0 \quad . \tag{1}$$

The mass and momentum equations can be considered to be conservation and homogeneous, so

$$\frac{\partial \rho}{\partial t} + \nabla \bullet (\rho \vec{V}) = S_c \ , \quad (2)$$

and
$$\frac{\partial \vec{V}}{\partial t} + (\rho \vec{V} \bullet \nabla)\vec{V} = -\nabla P + \nabla \bullet \tau_{ij} + S_m \ , \quad (3)$$

where ρ is the density, t is the time, P is the pressure, $\vec{V}$ is the velocity vector, F is the volume fraction function, τ_{ij} is the viscous stress tensor, and S_c, S_m are the source terms. These equations are solved with some physical models using the commercial solver FLOW_3D of Flow Science, Inc.

The 3D flow models are shown as Figure 1, which are model A to model D. Model A is a single ink-feed-channel model. It is similar to the early product of HP 51626A. Engineers design model B to D as double ink feed channels. For simplification, the shape of the nozzle is designed as a cylinder, not a bell shape.

The nozzle is 50µm in diameter, and 50µm in height for each model. The ink feed channel is 30ìm in height. To simulate the thermal bubble effect, we assumed an inlet/outlet flow on the heater. To achieve a good accuracy, we tried many sets of inlet/outlet velocity profiles and chose the one that match the experiments best. The inlet/outlet flow comes from the lower-center of the ink chamber, as shown on the left of the model graphs in Figure 1, which has a size of 42µm X42µm. Figure 2 shows the velocity profile used in this work.

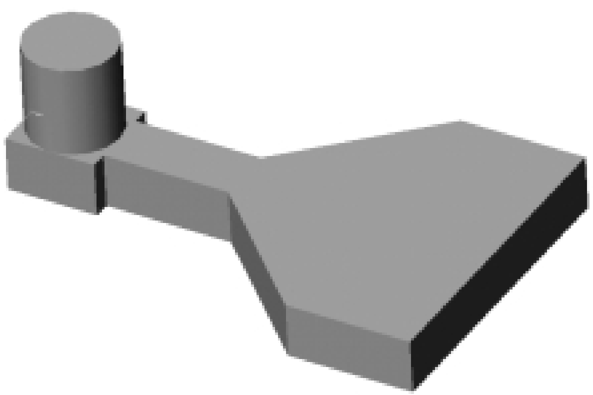

Figure 1a. Model A

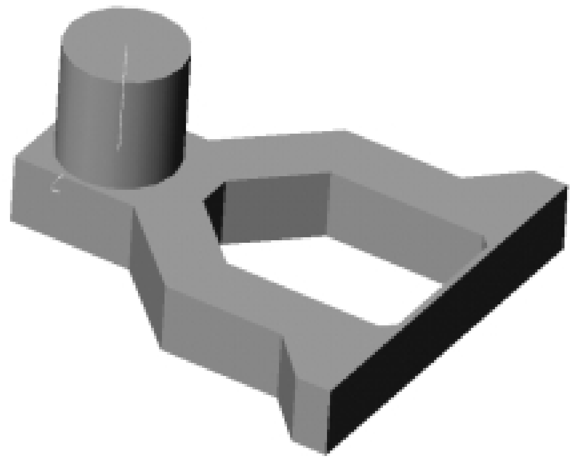

Figure 1b. Model B

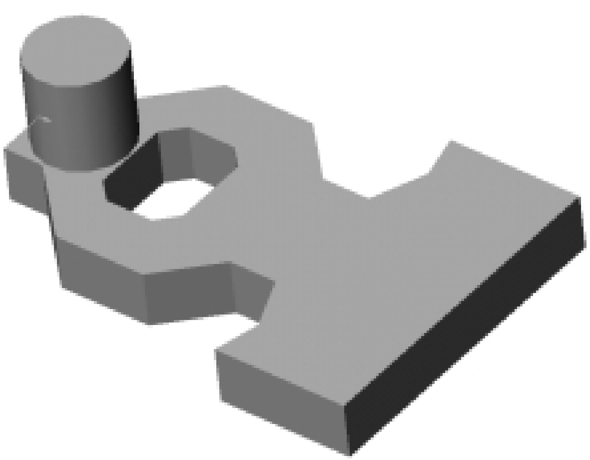

Figure 1c. Model C

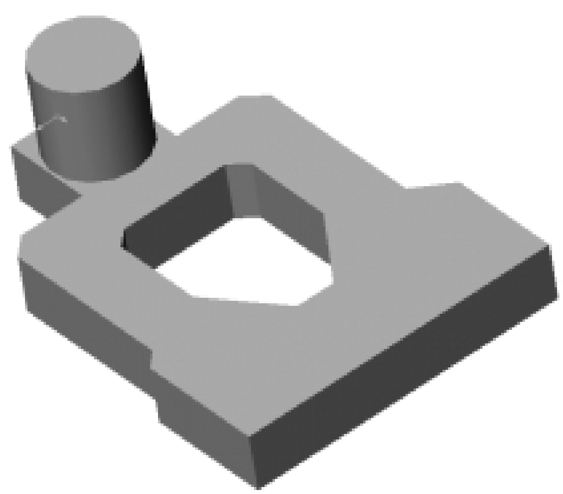

Figure 1d. Model D

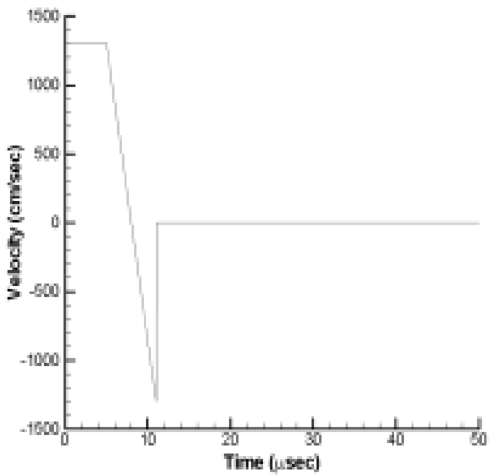

Figure 2. Velocity Profile of Inlet/Outlet

The ink properties are 2.47 cps for viscosity, 1.0 g/cc for density, and 48 dyne/cm for surface tension.

Results and Discussions

Four models had been solved by FLOW_3D using the velocity function and ink properties. Each calculation began from 0ìsec, and ended at 200ìsec, that covers down to 5kHz operation frequency.

Table 1 shows the settling times of the 4 types. The settling time is defined that the speed of the free surface is smaller than 5 cm/sec, which is about 0.5% of the inlet velocity. From table 1, model C has the shortest settling time, and the others have a similar settling time. The shorter the settling time, the higher the operation frequency. Thus the model C has better performance than the others. This is also verified by experiments. We think this could be explained by two reasons. First, from the viewpoint of the structure design, the model C is a double-feed-channel type and therefore there is an island on the opening side of the chamber. With the island, the ink is more difficult to flow outside the chamber. Second, the model C has the largest channel volume and the shortest distance between the chamber and the island.

Table 1. The Settling Time of the Models

Model	Settling Time (μ sec)	Feed Channel Area (μm^2)
A	260	~2100
B	148	~5830.7
C	83	~6064.2
D	144	~5915.7

Figure3a-3d show the velocity vector of the cross section at 15ìm barrier height at the settling time. For the double-feed-channel models B-D, there is a pair of vortexes inside the ink chamber when ink is being refilled. The vortexes will disappear when the free surface interface is settled.

The advantage of the double-feed-channel model is that there is larger flow rate than the single-feed-channel model, since it has a larger channel volume. Thus the double feed channel model has the capability of larger ink supply quantity. However, there are still some other factors causing different settling time between the double feed channel models.

There are two designs of the turning angle in the double-feed-channel models. One is 45 degree turning angle, and the other is 90 degree turning angle. Figure 3b, c, d show that the streamlines of the model with 45 degree turning angle are smoother. And there are few the circulation zones in the channel corners.

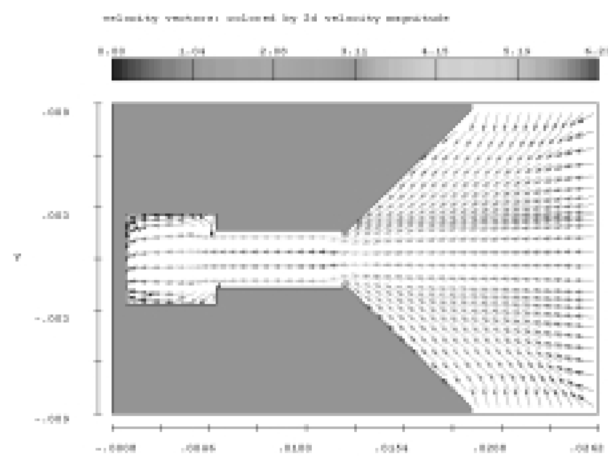

Figure 3a. Velocity vector of Model A

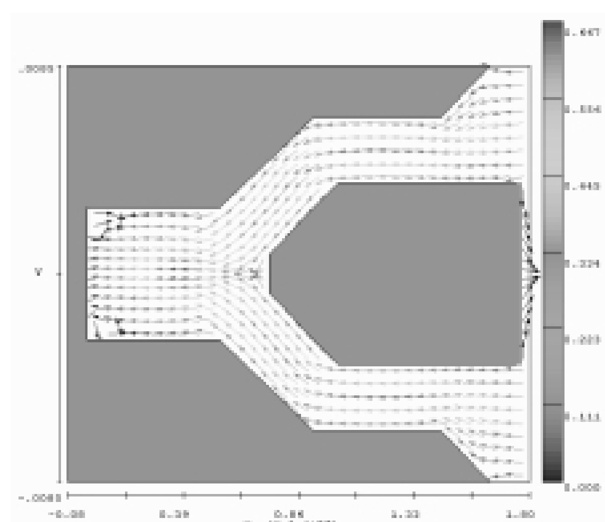

Figure 3b. Velocity vector of Model B

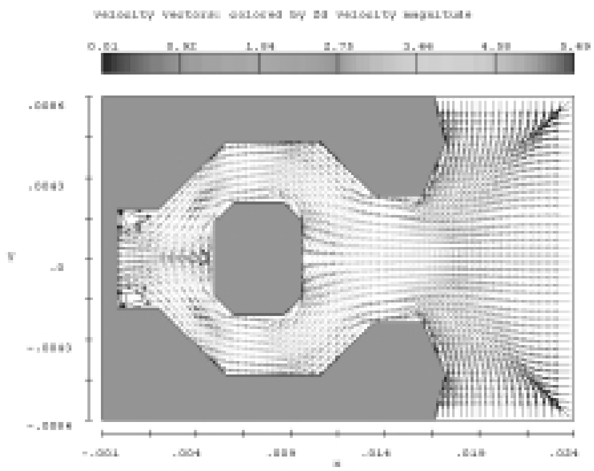

Figure 3c. Velocity vector of Model C

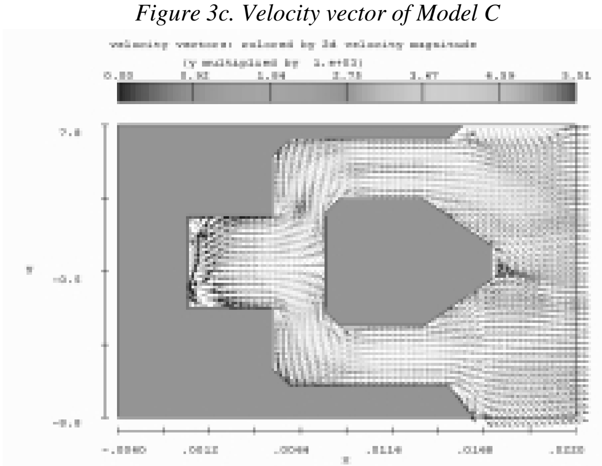

Figure 3d. Velocity vector of Model D

The location of the barrier island is also a key factor. The distances from the barrier island to the opposite wall of the ink chamber are listed in Table 2. The relationship of the distance and the settling time can be found by combining the two tables.

Table 2. The Distance from the Barrier Island to the Opposite Wall of the Ink Chamber

Model	Distance (μm)
A	N/A
B	74
C	52
D	78

Conclusion

The simulation of the inkjet print head is difficult because the model size is very small compared with the cases of the traditional CFD. Since the order of the size is about 10μm~100μm, the computational unit should be set as CGS unit.

This work is a basic study for designing the inkjet print head. The assumed velocity profile instead of thermal bubble model simplifies the computational model. From the results, the double-feed-channel model is a better design than the single-feed-channel model. It has a shorter settling time and better flow state.

The simulation results gave us some hints in designing good ink feed channel.

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Biography

Ching-Long Chiu jointed the Print Head Testing Section of OES/ITRI in 1998. He received his M.S. and PhD from Institute of Aeronautical and Astronautical Engineering of National Cheng Kung University. His interest lies in the field of computational fluid dynamics, numerical simulation of finite element method.

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