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Problems in Modern Color Inkjet Recycling

Techniques for Dealing with Loose Nozzle Plates and Air Bubbles

HP's evolution in modern inkjet technology for home and business can be classified by the development of three cartridge generations that each have similar print-head designs. The first generation includes 626, 629, 625, 649 and 6614 cartridges; the second includes 645, 6615, 641 and 1823 types; and finally, the most recent generation includes 27, 28, 56 and 57 cartridges. The second- and third-generation cartridges exhibit problems with loose nozzle plates and air bubbles in the ink chamber; this article presents research-based solutions to these common problems.

The Evolution of Ink Cartridge Design

During development of the first cartridge generation, HP's major effort was to achieve technological progress and create print heads with satisfying printing results. It appears that little time was spent trying to make the recyclers' work more difficult.

Of course, our industry is still suffering from electrical defects and from dried-up pigments in the 629 and 6614 cartridges. But we may assume that the primary objective of using pigmented ink for the 629 cartridge was to get better printing results, and the dried-up ink in the empty cartridges was only a collateral effect (which, most likely, worked well with HP because easy refilling without cleaning was no longer possible). Two of HP's actions that make our work more difficult were the removal of the top filling hole of the 629 cartridge and changing the position of the vent hole. These problems were rather small compared to the modern cartridges and could easily be overcome by our industry.

Observing the design of the second-generation cartridges, we can easily conclude that HP divided its development work. Whereas the black 645 and 6615 cartridges showed a huge technology step forward with significantly higher numbers of print-head nozzles and smaller ink drops, it appears there was very little effort to prevent these cartridges from being refilled. On the other hand, HP seems to have invested time in designing the color cartridges to make the refilling process more difficult.

Some of the most common problems encountered during recycling of the color cartridges are loose nozzle plates, air bubbles within the ink foam and in the channels that lead the ink from the foam to the print head, and ink cross contamination, even in tested and well-sealed cartridges. Often the cartridges are very sensitive to improper handling, so that the recyclers have a more difficult task when choosing the right cleaning and/or refill process. Many companies have even stopped refilling color cartridges because of these problems.

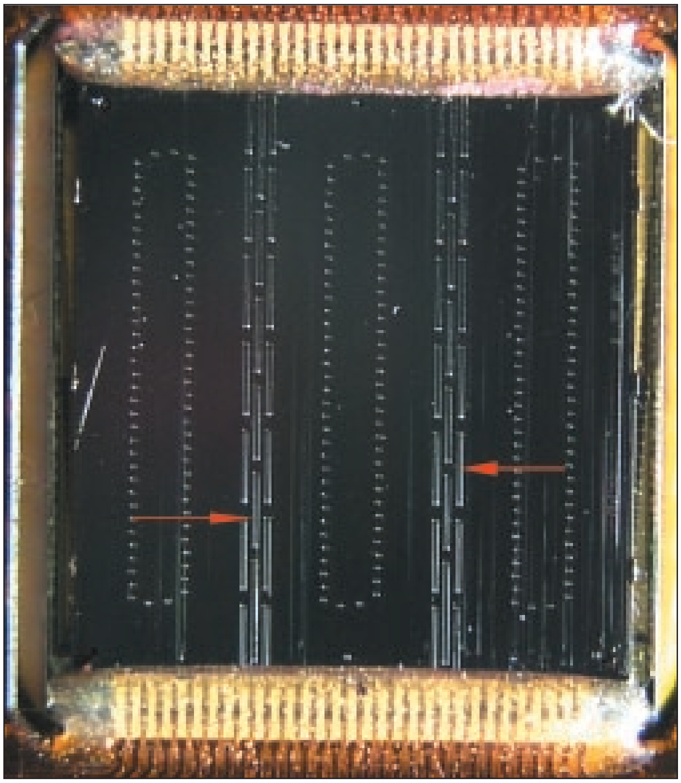

Figure 1. Macro-image of a HP 641 nozzle plate, which is made from palladium and nickel. The nozzle plate has 68 nozzle holes for each color. Additionally, there are two rows of vertical cuts in the nozzle plate (see red arrows).

This article intends to contribute to a better understanding of the above-mentioned main problems in refilling color inkjet cartridges, by presenting the results of scientific microscopic investigation of HP color print heads. The results indicate that there are adequate technologies available to overcome a significant number of the difficulties, and also describe how to produce reliable refilled color cartridges.

Why do Nozzle Plates Loosen?

Taking a look at the nozzle plate of a 641 cartridge, we observe three groups of 68 nozzle holes for each color. See Figure 1.

Additionally, there are two rows of vertical cuts in the nozzle plate. With higher magnification using Scanning Electron Microscopy (SEM), more details can be seen. Figure 2 shows one row with three parallel cuts and some nozzles. The cuts start from the extremities of the nozzle plate and are about 1 millimeter long and 20 micrometers wide. Each cut has wider ends of about 30 micrometers in diameter, which is also the diameter of the nozzles in this cartridge. Furthermore, there are marks around all of the nozzles and cuts, which probably originate from the pressure of the fixing tool during nozzle-plate manufacturing. It is likely that the cuts and nozzles were made by a microscopic stamping process, as indicated by the fixing tool marks.

Comparing the nozzle plate surfaces from both sides, there is a significant difference to be noted in Figure 3. Whereas the outer edges of the cuts and nozzles are sharp in Figure 3a and 3b, the inner edges are smoothly rounded in Figures 3c and 3d. This materials removal was probably made by micro-etching. As an additional detail in Figure 3d, fixing marks can be seen which originate from the structural polymer (counter part) on which the nozzle plate normally is glued.

But why did HP construct the nozzle plates with cuts and nozzles that are rounded on the inner side? For example, microscopic observation rev-ealed that there are no existing functional print-head parts in the regions of the cuts. One possible explanation for the existence of the cuts could be that they might lower mechanical stresses within the metallic nozzle plate caused by temperature variations during printing. But this would still not explain the existence of the inner rounded edges. On the other hand, the model presented in Figure 4 (on the next page) shows that the rounded edges significantly contribute to nozzle plate loosening during the normal printing process.

A schematic cut through a part of the print head is represented in Figure 4a. The nozzle plate with nozzles and cuts is fixed on a structural polymer layer that also acts as a strong glue to adhere the nozzle plate. During normal printing, the print head suffers microscopic vibration due to the repeated vapor bubble implosions within the ink firing chambers. As there is a difference in mass between the heavy metallic nozzle plate and the much lighter polymeric structure layer, the vibrations cause alternating tension stresses between the nozzle plate and the polymer layer. See Figure 4b. Now — due to the rounded nozzle shape — there is a sharp inner edge between the nozzle plate and the polymer layer. See Figure 4c.

It is well known in materials science that sharp edges are preferred areas for stress concentration. That is the reason why the

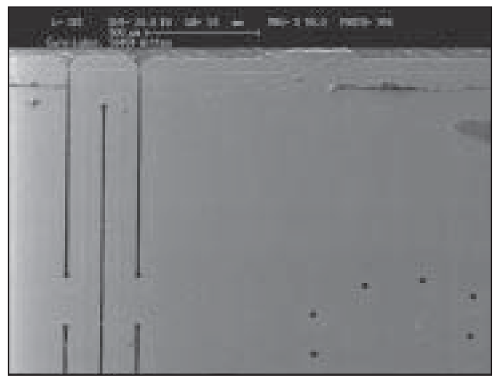

Figure 2. SEM image of a 641 nozzle plate. Some nozzles and one row of three parallel cuts at higher magnification.

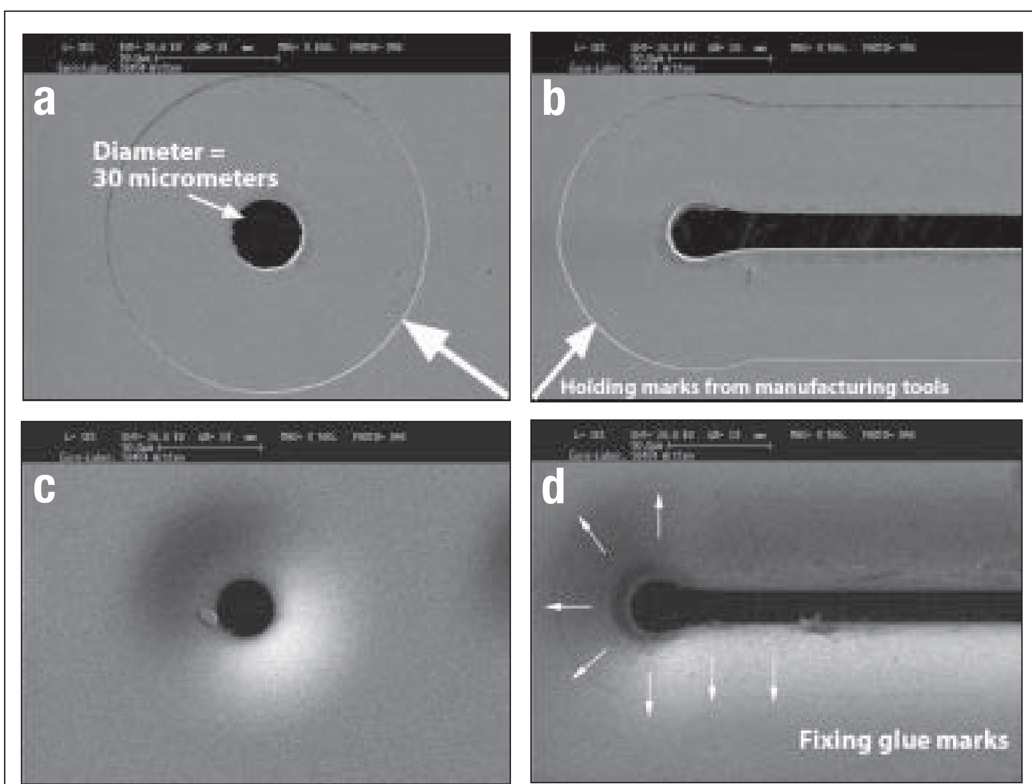

Figure 3. SEM images of a 614 nozzle plate presenting a nozzle and a cut. Figures 3a and 3b. View from the outside of the cartridge with sharp edges at nozzle and cut, and showing holding marks from a manufacturing tool. Figures 3c and 3d. View from inside (towards the print head) showing clearly that the inner edges are rounded. Note that the magnification of Figure 3a is higher, which is what makes the nozzle hole seem to be larger than in the other images.

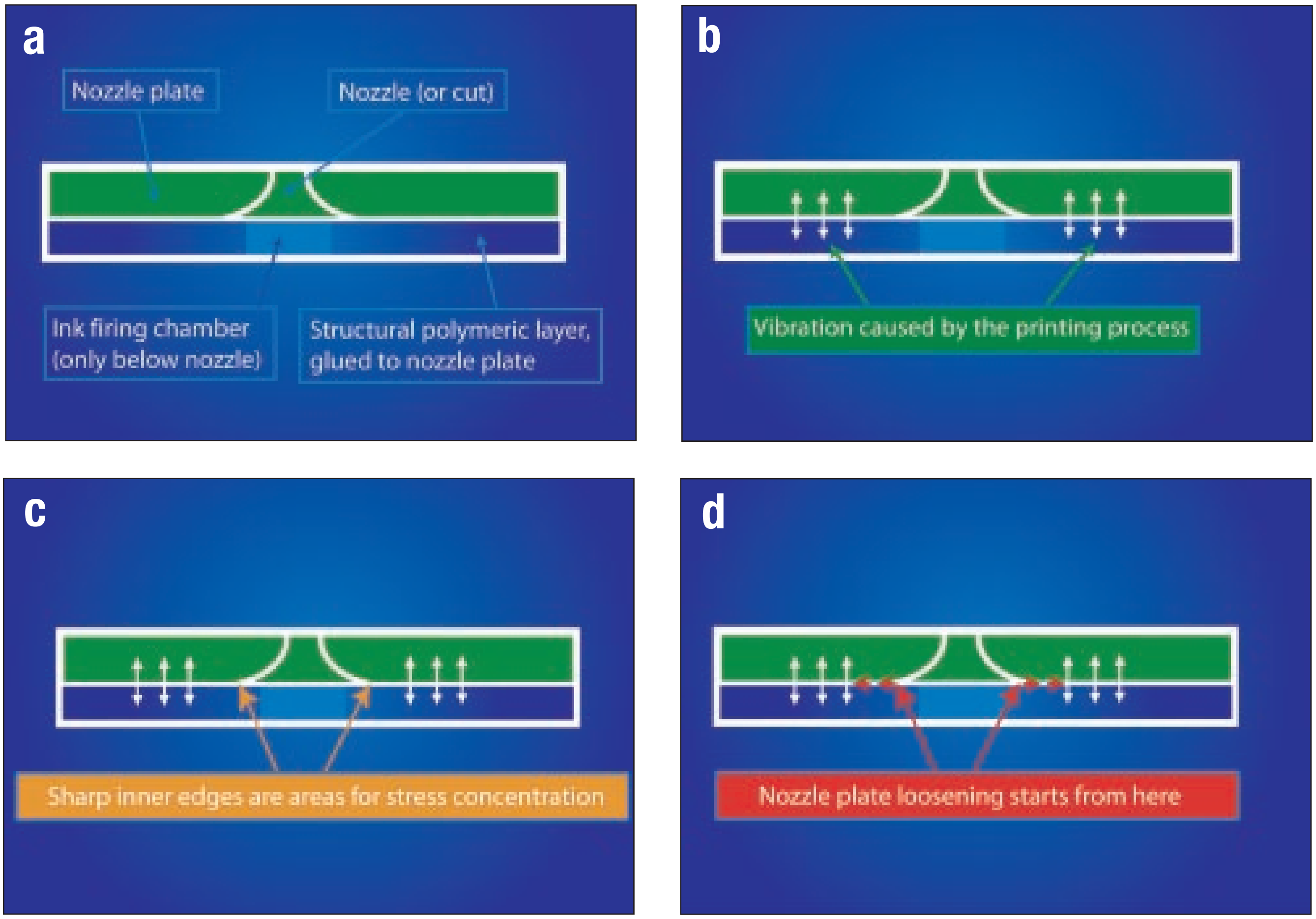

Figure 4. Schematic illustration of the nozzle plate loosening process in four steps (a-d) caused by print-head vibration during the printing process. The result is slow and continuous loosening of the nozzle plate, which initiates around the nozzles and cuts and grows until it reaches the outside of the nozzle plate. Also see the images in Figure 5.

accentuated stress concentration at the inner edges (which is caused by the printing vibration) leads to nozzle plate loosening. See Figure 4d. The important conclusion of this model is that the nozzle-plate loosening process begins around the nozzles and grows slowly toward the nozzle plate extremities, rather than starting at the outside and moving toward the inside.

The beginning of nozzle plate loosening can be detected by observation of surface undulations around the nozzle groups and cuts. See Figure 5.

This model also explains ink cross contamination in well-sealed color cartridges. When the nozzle plate has loosened to the extent that the nozzles of two different inks are interconnected, the different inks will start flowing between the nozzle plate and the structural polymeric layer. This contaminates the other foams and makes the cartridge useless. At this point, the cartridge will still appear to be intact from the outside.

Considering the results of the research work described earlier, some conclusions can be made to get better results when refilling color cartridges. First, there is no way to repair loose nozzle plates because they are a functional part of the microscopic print-head structure, and the inner print-head parts cannot be glued together

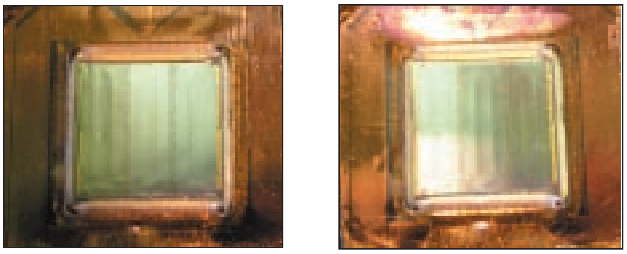

Figure 5. The beginning of nozzle plate loosening can be detected by observation of surface undulations around the nozzle groups and cuts.

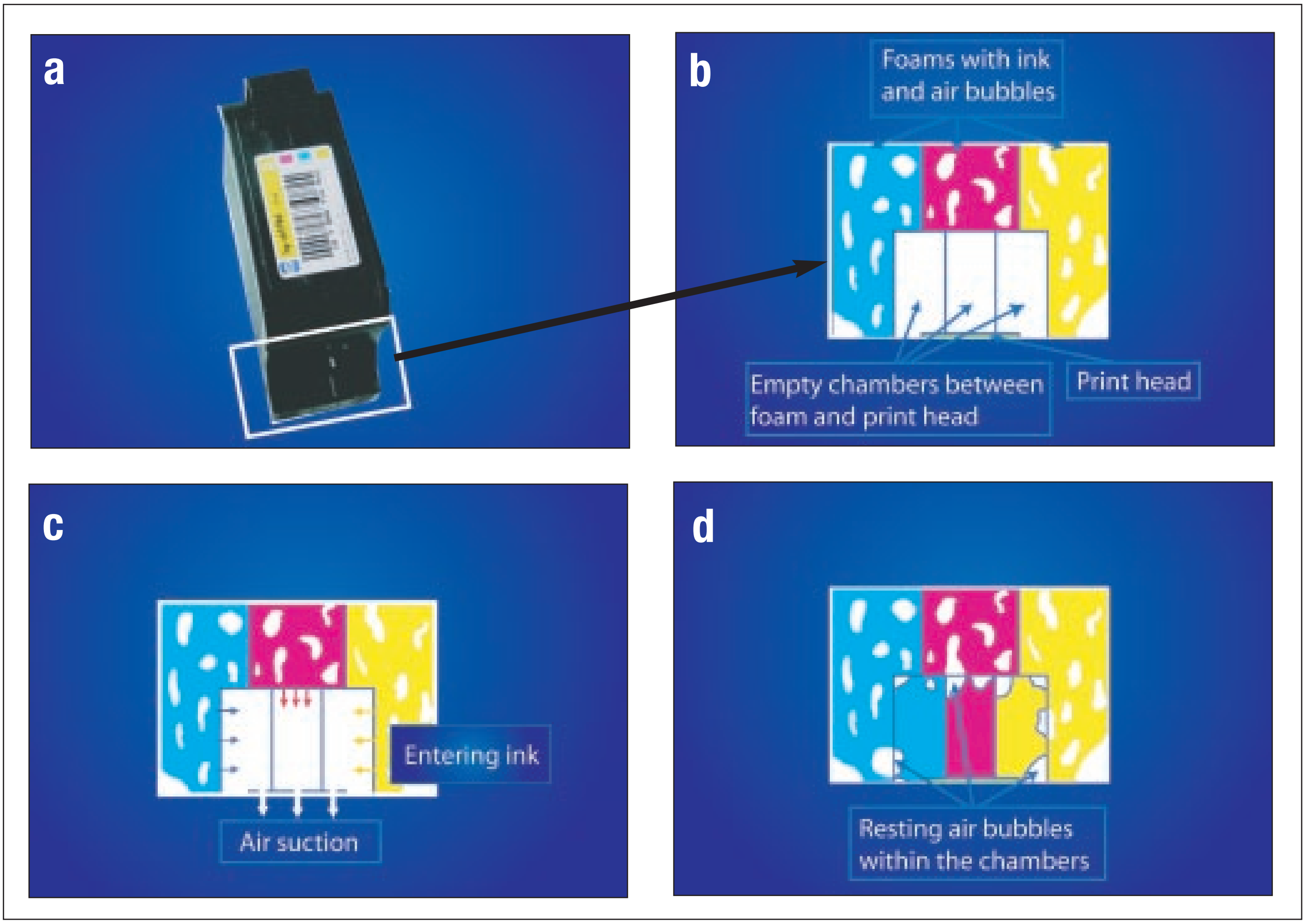

Figure 6a. Schematic illustration showing the inner bottom part of an HP 6578 cartridge. Figure 6b. After filling the cartridge under normal air pressure, the foams contain ink and some air bubbles, and the chambers that lead the ink to the print head are filled with air. Figure 6c. Air suction after or during the filling process causes the ink to enter into the chambers. Figure 6d. As a final result, there are remaining air bubbles within the foam and chambers that cannot be completely removed by air suction.

again, due to their microscopic dimensions. For example, fixing the nozzle plate by applying glue on the outer extremities (outside corners) will not help guard against the natural loosening and self-destruction progress during the second cartridge life cycle. This is why special attention should be paid when buying empties. A meticulous examination of the nozzle plates can help to detect cartridges in which the loosening process has already started. A lens with magnification of about 10 times will help to discover the surface undulation defects. Of course, to get good results, an experienced inspector is necessary.

Centrifuging as a Cartridge Testing Tool

An important and very useful tool in examining empties is a centrifuge. Besides promoting the emptying, cleaning and ink decontamination of the cartridge foams, a centrifuge can be a good tool for testing to determine if the nozzle plate is already loose. A variable-speed centrifuge is best, so that it can be adjusted to the different sensibility of each cartridge type. The cartridges should be mounted with the print head positioned towards the outside of the centrifuge. By using this method with moderate speed, only cartridges that were already damaged during their first life cycle will lose their nozzle plates — these are the ones that would not have worked until the end of the next life cycle anyway. In other words, the centrifuge is used as a testing machine for loose nozzle plates. Without centrifuging (that is, mounting the cartridge into a centrifuge with the print head towards the centrifuge's center axle), you cannot know if the nozzle plate is already loose inside and if the cartridge will print until the end of the next life cycle. This method has been used successfully for several years.

Air Bubbles Within Foam Cartridges

Most recyclers are very familiar with the following problem: The refilled color cartridge shows good print-test results and is sold to the end user. The cartridge works well for several days and then suddenly stops printing — the ink flow of at least one color has stopped. See Figure 6a.

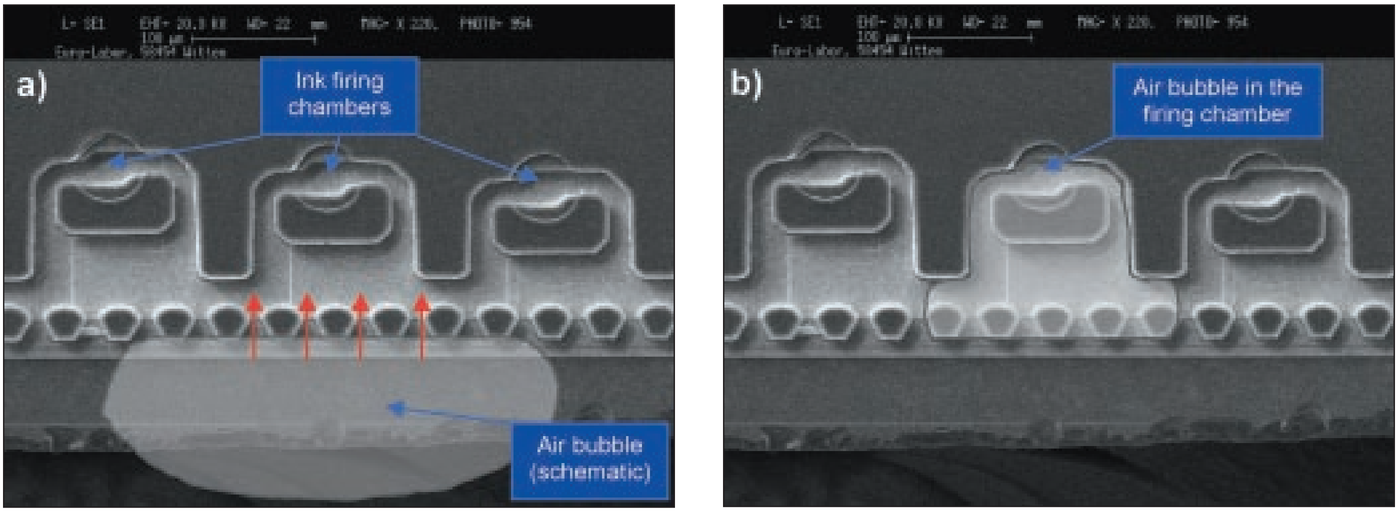

Figure 7. SEM image of three ink firing chambers in a HP 6578 print head. An additional schematic illustration shows how the air bubble coming from the air chambers (shown in Figure 6) enters the print head (a) and causes interruption of the ink flow after entering the firing chambers (b).

Figure 6 on the previous page offer an explanation of what has likely happened:

After manually refilling a color foam cartridge (for example, a HP 6578) under normal environment air pressure, the cartridge is not completely filled with ink. See Figure 6b. In addition to the ink, there are also air bubbles trapped inside. The main reason is that the capillary force within the foam cells is higher than the gravity force, which causes the ink not to fill all of the foam cells uniformly from the bottom to the upper foam volume. Instead of a uniform distribution, the ink flows first into the cells that have the highest capillary force.

For example, the foam is pressed together within the foam chamber, and some areas are under more pressure (higher density!) and consequently have smaller foam cells in which the capillary force is higher. The humidity of the cell walls also plays an important role on the capillary force. Once an area with low capillary force is surrounded by ink, there is no more chance to get ink inside this area because the air in the cells is trapped and cannot get away any more. The air bubble could change its position or form, but it cannot simply disappear. For example, during the future printing process, the air bubble could also move to the print head and cause interruption of the ink flow.

Additionally, the chambers that normally lead the ink from the foams to the print head are also filled with air. These chambers are very big cavities in comparison to the small foam cells, and consequently the capillary force is very low here. So there is no driving force to make the ink leave the foam cells and enter into the chamber, and with empty chambers, the cartridge certainly would not work.

In order to bring the ink down to the print head, many refillers use some suction device to suck the air through the print head nozzles out of the chambers. See Figure 6c. The strong suction force causes the ink to leave the foam cells and to flow inside the chamber. But some of the resting air bubbles in the cartridge foams may also move into the chamber. Furthermore, modern cartridges were designed to have sharp edges within the chamber in which trapped air remains. So the final result is still air remaining within the chambers near the print head.

Under these conditions, there is an initial ink flow to the print head, and consequently the print test shows good results. But later, during printing by the end user, a small portion of trapped air slowly moves down into the print head and interrupts the ink flow. See Figure 7.

To avoid this problem, it is absolutely necessary to fill the cartridge under a strong vacuum condition. A simple additional suc-

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tion pump acting on the print head nozzles during the refill process cannot solve the problem. The result will be the same as described above, unless the cartridge is completely under vacuum before the filling process starts.

It is quite likely that HP uses vacuum technology for filling the new OEM cartridges because there is no other way to avoid the air bubble formation inside the foams and chambers.

But what is the difference between filling under vacuum and under normal air pressure? First, under vacuum, the total inner cartridge volume will be almost free of air before the filling process starts. Then the foams will fill in a similar way as under normal air pressure conditions. At the end of the vacuum-filling process, there will also be some areas inside the foam that do not contain ink. See Figure 8a.

The most important difference is that these bubbles contain vacuum instead of air — also inside the chamber near the print head. Subsequently, as seen in Figure 8b, when air is released into the filled foams, all vacuum areas will suck the surrounding ink inside, and the chambers near the print head will fill with ink coming from the foams. Note that the print head must be sealed during this operation in order to prevent air from entering through the print head.

The model shown above explains why the successful refill of foam cartridges can only be achieved by vacuum filling. Note that the vacuum quality plays an important role in the vacuum-fill process. Creating an absolute vacuum is technically impossible. Very efficient turbomolecular vacuum pumps may achieve an almost perfect vacuum, but the cost of such a pump can reach up to $20,000 or more. In practice, most cost-effective vacuum pumps will lead to small volumes of resting air in the filled cartridges. On the other hand, practical experience has shown that ink flow interruption occurs only when the air volume exceeds a critical value, so very small air volumes can be tolerated. R

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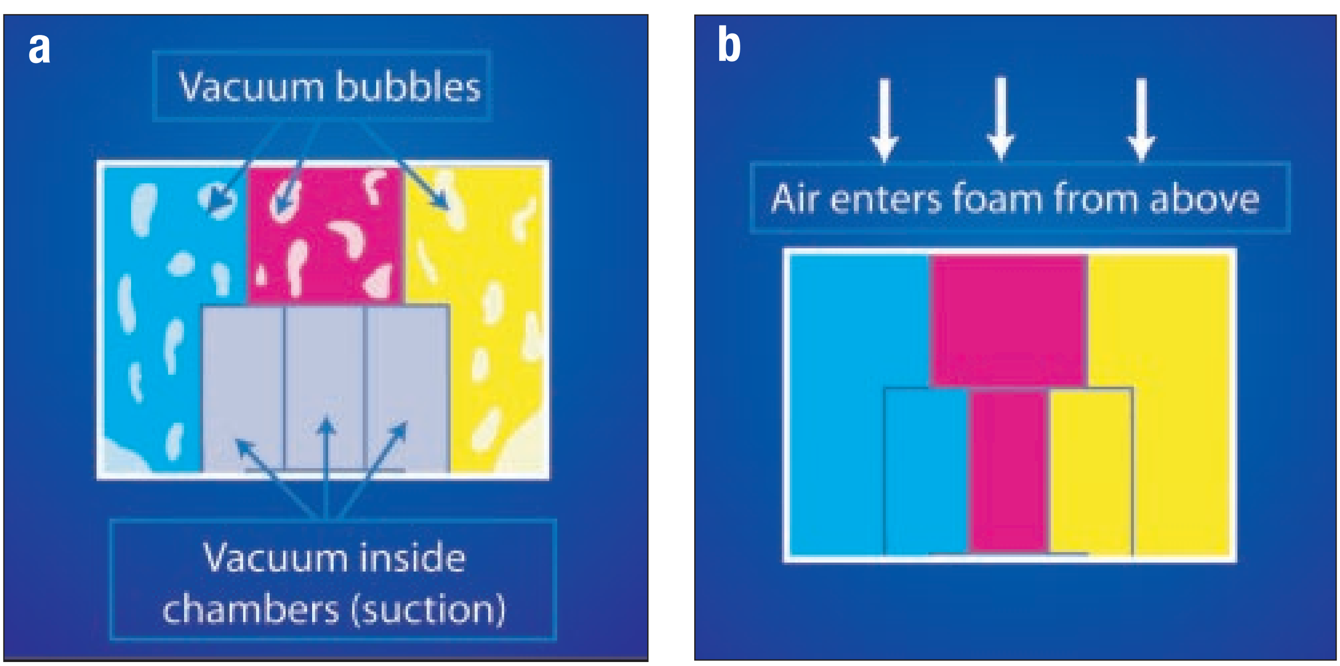

Figures 8a and 8b. Schematic illustration showing the filling process under vacuum. Figure 8a. After cartridge filling under vacuum, the foams contain ink and some small vacuum bubbles, and the chambers that lead the ink to the print head are also under vacuum. Figure 8b. When air is released into the filled cartridge from above, all vacuum areas suck ink inside, and the foams and chambers will be free of air.