The Ink Cartridge as a Major Component of an InkJet System

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Abstract

The ink cartridge is one of the four major components of an inkjet system. The three others being the ink itself, the substrate and the printhead. The major manufacturers in the industry each have their own method of a supply system. Hence, many different cartridge systems are presently found in the market. Every one of these systems have both advantages and drawbacks.

In this paper, the systems of the different cartridges are explained. Special emphasis is given to the relevant parameters of backpressure, flow resistance, cartridge yield and cartridge reliability. Furthermore, a measurement system for the backpressure is described, as well as the resulting curves found from the different cartridge designs. By measuring the backpressure, the static and dynamic pressure curves describe both the capillary force of the reservoir and the flow resistance of the ink in the system. This method of measurement is not restricted to cartridges using foams, but delivers useful information of all types of reservoir designs.

In addition, this paper discusses different applied solutions to cope with changes in ambient temperature and air pressure, both of which affect several ink cartridge designs.

Introduction

The triumvirate[1] of ink, printhead, and substrate is the topic of many publications. This article is intended to demonstrate that it is necessary to extend the definition to include four elements: ink, ink reservoir, printhead, and substrate.

Fundamentally, we will learn that the reservoir and its characteristics play a decisive role in the function of the entire ink system (the printer). In order for the print result to be satisfactory, the ink reservoir characteristics must be in full harmony with the entire system. Thus, on one hand, the ink reservoir has a significant influence on the print quality, while on the other hand it also influences delivery characteristics, ease of manipulation, storage stability, shelf life, etc., of the entire ink system.

An ink reservoir can be described according to various properties. For the ink delivery aspect, for example, the physical characteristics such as flow resistance and the system backpressure, which is created by the ink reservoir, are extremely important. The amount of ink contained in the reservoir and the amount of ink available for use can also be classified under this heading.

The geometric properties of an ink reservoir include, among others, its dimensions, its post-assembly position, and the amount of physical space it occupies within the unit. For the usability of an ink reservoir, the storage conditions, characteristics influencing its distribution, the level of user friendliness in replacing the ink supply, etc., are of great significance. Below we will first discuss in greater deal the effects of the system backpressure.

Backpressure

A printhead contains between 50 and 500 nozzles measuring between 15 and 50 µm. This could very easily lead to a situation in which the ink supply drains out through the ink jets. A backpressure within the ink system as compared to the atmospheric pressure can prevent this from happening.

But the balance between preventing run-off from the ink system (greatest possible system backpressure) on one hand, and on the other hand reducing the refill time within the firing chambers (relatively low system backpressure) is important. The refill process is controlled by the ink meniscus at the printhead nozzle and the ink viscosity. If the backpressure within the ink reservoir were too strong, this could cause the ink meniscus to become detached, and the system would drain itself.

The relationship between the backpressure within the ink system and the function of the entire printing process is illustrated in Figure 1. This figure depicts the way in which the maximum amount of ink flow per time unit is determined by the system backpressure. The larger the system backpressure becomes, the smaller the ink droplet size becomes, thereby decreasing the achievable ink flow volume. When the system backpressure eventually reaches –27 mbar, the ink meniscus becomes detached and the entire system fails.

A backpressure level that is too low—or indeed an excess of pressure within the ink system—would, on the other hand, lead to a flooding of the nozzle plate. This would result in a random deflection of ejected ink droplets, or in the failure of ink jets. If the pressure within the system is increased still further, then the ink system would drain itself through the nozzles.

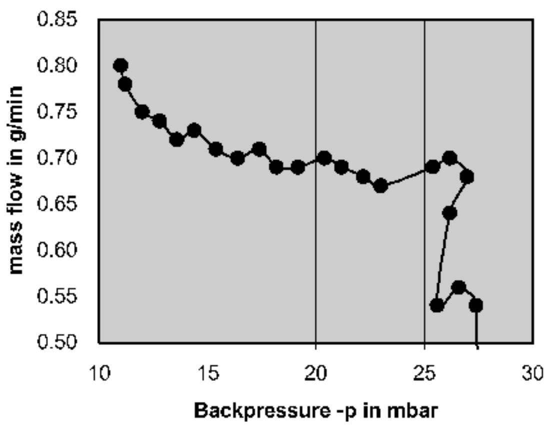

Figure 1. Relationship between backpressure and the function of the printhead

It is, then, vitally important that the level of pressure exerted by the ink reservoir on the entire printing system be precisely adjusted! In this process, the geometric ratios within the printing unit must be considered. If it is possible to situate the ink reservoir below the print head, then the ink level differential Δh will automatically create a hydrostatic backpressure Δp within the system:

$$\Delta p = \rho \bullet g \bullet \Delta h \quad (1)$$

In this equation, ρ represents the density of the ink and g represents the gravitational acceleration.

If, however, the ink reservoir can only be situated above the printhead, then compensation must be made for the hydrostatic pressure which results within this arrangement.

Depending on the printing system, other dynamic alterations are added to these static pressure components. Inks that are highly viscous, for instance, require special attention to the flow resistance within flow channels between the ink reservoir and the printhead. The radius R and the length l of this type of channel connection result, according to Hagen-Poiseuille,[2] in an addition pressure component Δp:

$$\Delta p = \frac{8 \cdot \eta \cdot l}{\pi \cdot R^4} \cdot \dot{V} \quad (2)$$

In addition to these obvious influences, there are others which must be considered as well. As an example, we need only mention the pressure peak which occurs at the transition point of the printhead motion which is caused by the tube components as they move with the print head. This also causes a fluctuation in the backpressure. It is possible that a brief flooding of the nozzle plate can occur, which again can lead to a failure of the printing system.

For achieving optimal print quality, then, it is vitally important to maintain a constant system backpressure. Static pressure components should remain as unchanged as possible, dynamic components should be as inconspicuous as possible, and pressure peaks caused by individual occurrences should be prevented whenever possible.

Backpressure Measurement System

The knowledge of system backpressure is crucial in order to facilitate development of a reliable and finely-tuned ink system. For this reason, this paper is intended to present the construction of a simple system for measuring the backpressure created by the ink reservoir. Figure 2 contains a sketch of the construction.

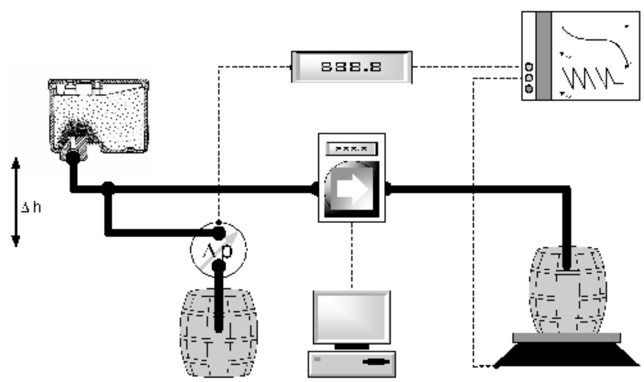

Figure 2. System for measuring the backpressure created by an in reservoir

A pump with a constant volume flow $\dot{V} = const$ empties an ink reservoir. The printhead itself can also be used as a pump. A differential pressure probe is used to record the process of emptying the cartridge. In other words, the differential pressure between the atmospheric pressure and the pressure within the ink system is measured. The volume of ink which has been pumped off is weighed in order to monitor the volume flow. Both signals (pressure, scale measurement) are recorded using a graphical recorder or a specially-programmed software. The pump is controlled by a computer, which allows reproducible alterations in the volume flow to be integrated into the measurement.

Before beginning the measurement process, the system must be thoroughly cleaned from bubbles in order to insure that no air has been introduced into the tubes, which would influence the measurement. The selection of tube connectors is also important; tubes which are too long and thin or a tube branching which is incorrectly positioned can invalidate the results of the measurement. The elevation of the ink reservoir in relation to the pressure probe is also important.

A typical measurement curve resulting from this simple construction is represented in Figure 3. This is a measurement performed on a sponge-type ink cartridge. During the course of this measurement, the cartridge was drained with a constant volume flow. The pump was halted repeatedly, however, in order to measure the current static pressure at the given moment (P1). The dynamic pressure components can be determined at points of higher volume flow (P2). At this point, the rate of delivery was increased to equal the printer's maximum available volume flow (black page). This measurement gives a proportion for the flow resistance, or delivery resistance of the ink cartridge.

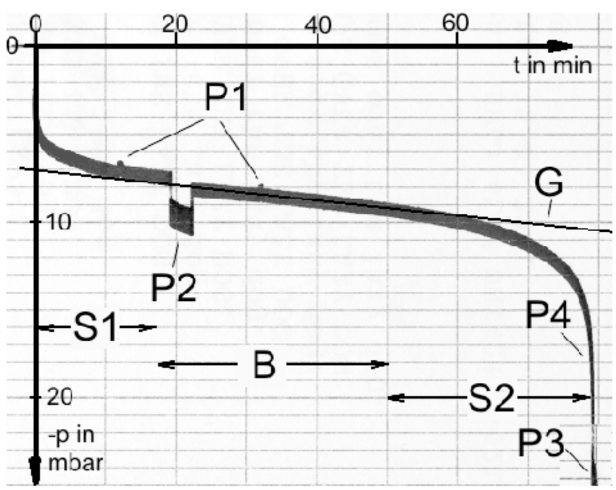

Figure 3. Pressure curve of a sponge-type ink cartridge

The linear portion (B) of the pressure curve is caused by the change in hydrostatic pressure. The fluid level within the ink reservoir decrease when delivery of ink continues. This decreases the hydrostatic pressure in a linear fashion (G).

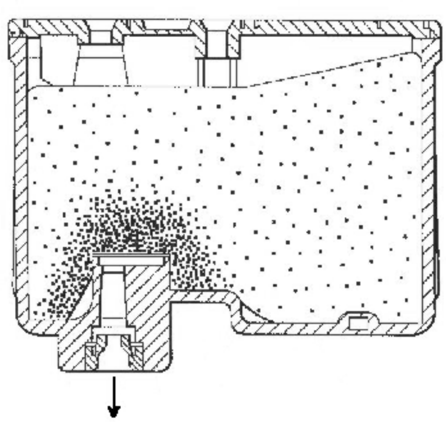

Figure 4. Sponge-type ink cartridge[3]

The backpressure climbs rapidly at the end of the pressure measurement curve (P4). At this point, there is no longer any ink contained within the system and the filter enclosed within the cartridge locks. Air can only be drawn through the wet filter when the differential pressure is sufficiently great (P3). The locking pressure of the filter is determined in this manner.

Important properties of the system can be determined through investigation of this simple pressure measurement curve.

Overview of Ink Reservoir Systems

Various ink systems have been developed over the course of time. We will now clarify the application of the measurement system described above by means of tests using industry-standard ink reservoir systems.

Sponges are important tools for storing ink. Figure 4 depicts the construction of a typical sponge-type ink cartridge. We will now address the question of how a sponge creates a backpressure. A sponge contains many small pores (Figure 5). Each of these pores functions as a tiny capillary which can absorb ink.

The wetability of this sponge material determines the extent to which the sponge can be filled with ink. This condition[4] is described by Equation 3.

$$\Delta h = \frac{2 \cdot \sigma \cdot \cos\alpha}{\rho \cdot g \cdot r} \qquad (3)$$

where Δh is the height of the liquid within a capillary, σ the surface tension, α the wetting angle and r the diameter of the capillary.

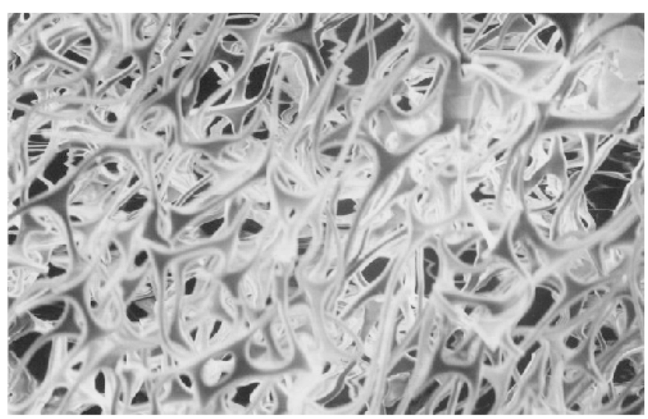

Figure 5. Melamine foam, magnification 300x

If the ink wets the sponge well, and if the system is not force-filled, then the highly absorbent tiny capillaries begin to fill themselves. If the ink does not wet the sponge well, which means that a forced filling is required, then the large capillaries are filled first.

In order to save time, sponge ink cartridges are often force-filled. In this type of system, the ink is distributed through a process which brings the sponge to the most energetically advantageous condition. In other words, when an ink has a high degree of wetability, the ink will preferably be stored in the small capillaries. In order for ink to be drawn from this sponge, it is necessary to develop a differential pressure which is sufficient to empty—initially—the largest filled capillaries. This "unwetting," or draining, proceeds through increasingly smaller pores which, as per the equation above, oppose with an increasing capillarity (Figure 3, S1).

It is only possible to empty a sponge pore if it is ventilated; that is, if the removed ink can be replaced by incoming air. This takes place reliably if the capillary in question is one which is located at the boundary between ink-filled and air-filled pores. Another possibility for ventilation exists if the ink within the sponge can be distributed in such a way that an equilibrium of volume can be created.

When ink continues to be removed from a sponge, the backpressure continues to increase (S1, S2). However, the pressure curve displays a broad range of backpressure which is nearly linear (B). This section is created by the large number of pores which in fact represent the nominal pore size of the sponge. As a result of the manufacturing process, however, sponges actually contain pores of various sizes, resulting in larger and smaller pores as well.

The sponge curve described above plays also a significant role in systems other than straightforward sponge ink cartridges. Sponges are also used in dual-chamber systems.

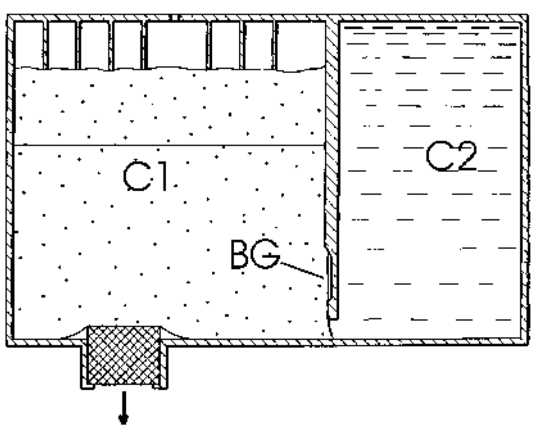

Figure 6. Dual-chamber ink cartridge with sponge[5]

A dual-chamber ink system of this type is illustrated in Figure 6. The ink cartridge contains a primary chamber (C1), which is filled by a sponge, and a secondary chamber (C2) containing free ink. The sponge-filled chamber is ventilated and, simultaneously, the ink is drawn from this chamber. The pressure measurement curve resulting from this is depicted in Figure 7. The constant pressure area (B) is striking. This curve segment is not influenced in any way by the hydrostatic pressure. The bubble generator alone determines the level in this segment.

The bubble generator (BG) is a type of one-way vent, which allows air entering the liquid chamber above a defined backpressure threshold. In the model described here, the bubble generator is created through grooves in the intermediary wall in conjunction with the sponge in chamber 1.

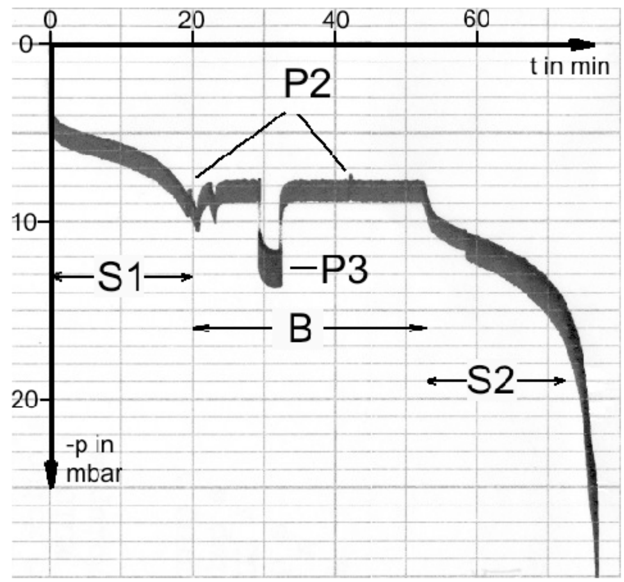

Figure 7. Pressure curve of dual-chamber ink cartridge

The bent curve segment at the beginning (S1) and end (S2) of the measurement is a result of the sponge in chamber 1. In the first section of the curve (S1) the bubble generator is not yet functioning, since its ventilation pressure has not yet been reached. In the second segment (S2) there is no longer any ink remaining in the liquid chamber. For this reason, the ink must now be drawn exclusively from the sponge.

A compensation volume is provided by the situation represented by the bent curve segments. If, for instance, a half-empty ink cartridge becomes warm or subject to a decrease in the atmospheric pressure, then the air contained within chamber 2 expands. This would cause a rise in pressure within the ink system, which could then create an overflowing of the ink into the printer. In order to prevent this, a portion of the sponge in chamber 1 is emptied first, before the bubble generator begins to allow air into chamber 2. The volume of the empty sponge can absorb any ink forced by the expanding air in chamber 2, with no danger of ink overflowing. Of course, it must be considered that the first case deals with an "unwetting" of the sponge, while in the second case the sponge is being force-filled.

In the dual-chamber system described here, the absorbency of the sponge and the pressure threshold of the bubble generator must be precisely coordinated with one another. A sponge curve extended by the bubble generator area is created in this manner.

Design Parameters for Sponge Ink Cartridges

The system balance between sponge material and ink is pivotal in the design of an ink reservoir. Various pressure curves will result, according to the interface tension between the ink and the sponge material. The pore distribution within the sponge will also influence the behavior of the ink reservoir.

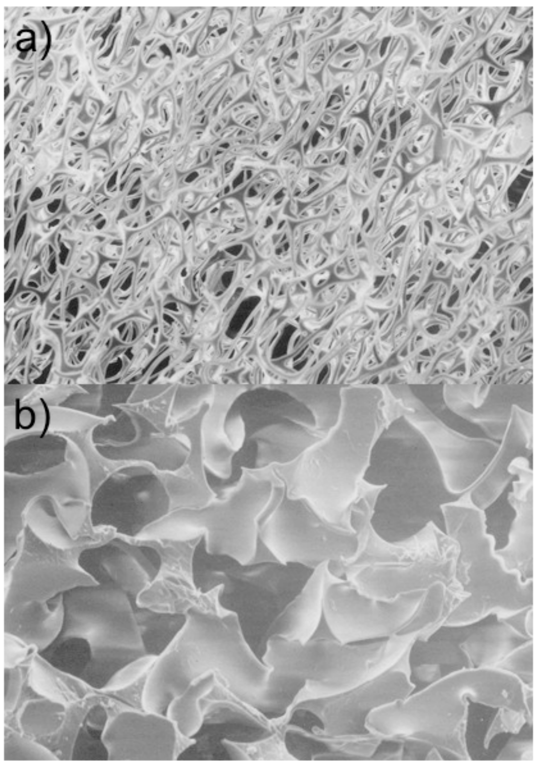

Figure 8. Comparison of sponge materials, magnification 100x: a) Melamine, b) Polyurethane

The SEM pictures of two sponge materials are compared and contrasted in Figure 8. The various materials differ from one another in their pore structures. But the volumetric weight of a sponge also influences the amount of ink that can be stored per sponge volume unit.

The following parameters are critical in the description of a sponge as an ink repository: material density, pore size, pore distribution, chemical composition, compression resistance, temperature stability, wetability, etc.

During the manufacturing process of a sponge, a predefined pore distribution is created. The pores of standard sponges, however, are generally not small enough for use as an ink reservoir in order to engender the desired backpressure. For this reason, sponges are often compressed. This increases the volumetric weight while at the same time also reducing the average pore size.

The effect of compressing the sponge on the backpressure measurement when the same initial sponge material, same ink, and same fill volume are used is represented in comparison in Figure 9. As the compression level of the sponge is increased, the initial pressure is also increased, but so is the steepness of the curve. At the same time the ink mileage—in other words, the volume of deliverable ink—is significantly reduced.

Thus, the sponge compression is an important design parameter in the development of a sponge-type ink reservoir.

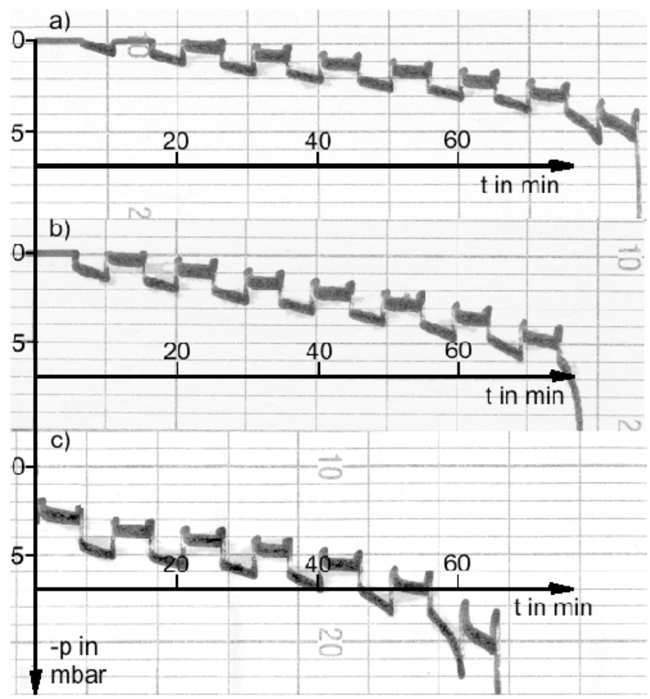

Figure 9. Pressure curves dependent on the compression factor KF: a) KF = 3.6, b) KF = 4.5, c) KF = 5.7

The capillarity can also be used to imprint a channel preference for the ink flow. If one uses a sponge with a decreasing pore size toward the ink outlet, then, in a static situation, the ink will also have a tendency to move in the direction of the ink outlet. This makes the ink delivery process significantly easier.

Conversely, areas of higher compression within the sponge would have an unfavorable effect on the delivery of ink volume, since islands of ink could form within the sponge which are then cut off from the flow of ink. As a result, the ink stored in those areas would be lost to all printing processes.

The pressure measurement curves of various sponge materials are depicted for comparison purposes in Figure 10. The materials identified here are exclusively different types of polyurethane sponges. The various densities of the raw materials were compensated for through various compression factors. One can identify very clearly the various profiles of the curves and the difference in their length (representing ink yield) when the same ink fill level is applied.

The pressure curve of a sponge cartridge is, obviously, also dependent on the volume of reserved ink. The lower the amount of ink which is contained within a sponge, the higher the level of backpressure the system experiences at start-up. This is one result of the distribution in the size of the capillaries and of the hydrostatic pressure.

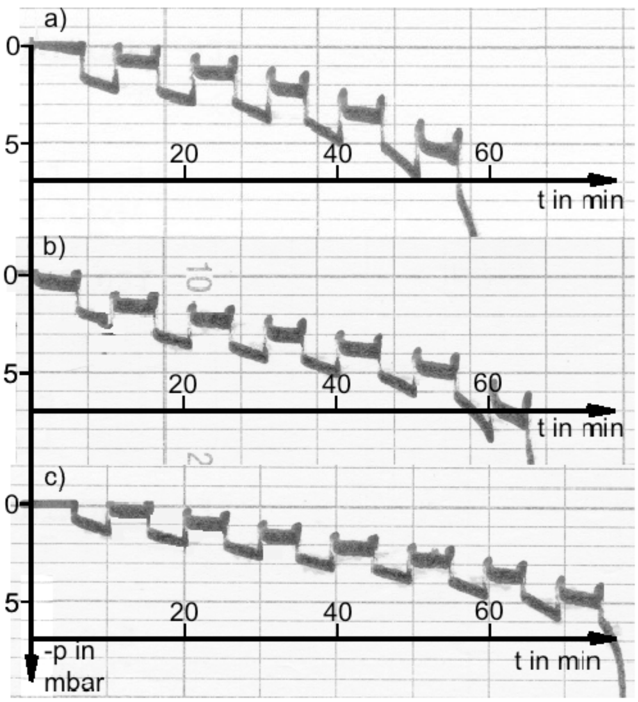

Figure 10. Pressure curves dependent on sponge material: a) Polyester, b) Polyether 1, c) Polyether 2

The filling process itself has also an influence on the behavior at delivery. If a virgin sponge is first completely filled and then drained of enough ink so that the cartridge then contains the ideal amount of ink, then this cartridge will behave differently from a cartridge which was filled initially with the target quantity of ink.

Conclusion

A simple measurement system was introduced within the framework of this paper, which makes it possible to determine the pressure progression of an in reservoir. The pressure curves of various reservoir systems were determined and discussed. The function and the construction of a sponge-type ink cartridge were clarified in detail. Particularly, the dependency of the pressure progression on various sponge parameters was discussed.

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Biography

Mr. Kretschmer is manager of the Inkjet R&D department at Pelikan Hardcopy Production AG, Egg. He joined the company in May 1993 and is involved in new product development, test infrastructure, printhead analysis, product and print quality.

He previously worked for four years at Mannesmann Tally, Germany, an important printer manufacturer. During this time he gained experience in inkjet printing and electrophotography.

As a physicist, he received his diploma at the University of Ulm, Germany. Mr. Kretschmer is author of several patents and publications in the field of inkjet and electrophotography.