A Study of the Ink Reservoir for the Inkjet System

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Abstract

The ink reservoir is a source which provides backpressure in an open-type ink cartridge. The properties of ink reservoir cause tremendous effects on the printing quality of whole inkjet system. It keeps the ink from leaking due to the natural gravity in the non-printing stage. As well as it supplies stable ink output in the printing stage.

In this paper, the property and availability of reservoir material are studied. In particular, the completed processes in design, manufacturing and test of the reservoir for a commercial cartridge are explained. Furthermore, the backpressure mechanism is derived theoretically and experimentally. A backpressure experiment system is introduced here to present the interaction between the ink and the reservoir. The measurement and analysis are not only applied to sponge reservoir material but also fiber reservoir material.

In addition, this paper suggests the issues about reservoir that cartridge manufacturers need to take care during the assembly and the delivery. The changes of external environment also influence the reservoir and may cause the cartridge malfunction. A good reservoir preparation can reduce the negative effects and raise robustness of a cartridge.

Introduction

The ink cartridge of the inkjet printer consists of three major modules. They are print head, cartridge, and backpressure mechanism. The backpressure mechanism can be sorted into two types, closed cartridge and open cartridge.

In a closed cartridge, because its inner space is isolated from the atmosphere, the backpressure mechanism needs to provide certain negative pressure to keep the ink inside from leaking through the nozzle. Also the mechanism has to compensate the differential pressure caused by the consumed ink. A pressure regulator is normally used in controlling the backpressure of a closed cartridge. Its major components are spring, steel ball, and air bag. Most of the pressure regulators are applied to the monochrome/black ink cartridge.

Oppositely, an open cartridge's inner space connects with the atmosphere. Its inner pressure is always equal to the atmosphere pressure. To keep the ink inside from leaking through the nozzle by the natural gravity, the mechanism needs to hold the ink directly. An ink reservoir material is normally used here. Most of the reservoir materials are applied to color ink cartridge.

The properties of ink reservoir cause tremendous effects on the printing quality of whole inkjet system. In printing phase, the reservoir supplies stable and continuous ink output. Therefore, the banding effect won't occur. In non-printing phase, the reservoir holds the ink from leakage.

The criteria of judging the availability of a reservoir material are few because it is difficult to accurately measure the backpressure capability of the ink reservoir material. Hence the major object of this research is to design and define the properties of a good reservoir which can meet the requirements. The ink reservoir material is studied and integrated systematically in this research, including the material property, manufacturing process, specification, test and measurement, theoretical calculation, and experimental method.

Capillarity Theory

Why can a reservoir material provide the backpressure? While the liquid water is put in a long thin tube that has a small than 2.5mm diameter, the concentrating force of the water molecular is less than the adhesive force between the water molecular and the tube wall. Hence the surface tension exists. The backpressure of the reservoir material comes from the adhesive force between the ink and the inner pores' surfaces of the reservoir material. The adhesive force is the capillarity force, can be governed by fluid mechanics in the equation:

$$h = (2 \cdot \sigma \cdot \cos \theta) / (\rho \cdot r) \tag{1}$$

where h (cm) is the natural raising height of the ink absorbed in the reservoir, it's affected by the capillarity force, σ (dyne/cm) is the surface tension of the ink, θ (degree) is the adhesive angle of the ink and the tube wall, ρ (g/cm^3) is the density of the ink, r (cm) is the radius of the long thin tube, it's also the radius of the inner pores in the reservoir material.

In the water-based ink (dye type ink), the adhesive angle (θ) between the ink and the tube wall is close to 08.

That's to say $cos\,\theta$ is close to 1. The equation can be derived into:

$$h = (2 \cdot \sigma) / (\rho \cdot r) \qquad (2)$$

In Equation 2, the surface tension σ and the ink density ρ are fixed as the same ink is used. The rest two variables, the natural raising height h and the radius of inner pores r, are related in inverse proportion. The capillarity force is directly quantified and represented by the natural raising height h. Thus the only parameter which influences the capillarity force is the radius of the inner pores in the reservoir material. Lower r causes higher h. It means the capillarity force larger and backpressure larger; On the other hand, higher r causes lower h, means the capillarity force smaller and backpressure smaller.

Sponge Type Reservoir

The sponge type reservoir material is made from polymer material and vesicant. While manufacturing, the heating process decomposed the vesicant into air bubbles spreading in the polymer material and made the polymer foamed. The air bubbles become inner pores after cooling process. Therefore, the porous sponge forms. Commonly used foamed polymers are Polyethylene (PE), Ethylene-Vinyl-Acetate (EVA), Polystyrene (PS), Polypropylene (PP), Acrylonitrle-Butadiene-Styrene (ABS), Polycarbonate (PC), Polyethyleneterephthalate (PET) and Polyurethanes (PU) rubber.

Most of the ink cartridges use foamed PU rubber as the sponge reservoir material, especially the Polyether. It has good advantages of flexibility, hydrolysis resistance, chemical resistance, mechanical strength, porous uniformity, processing stability and ink absorption.

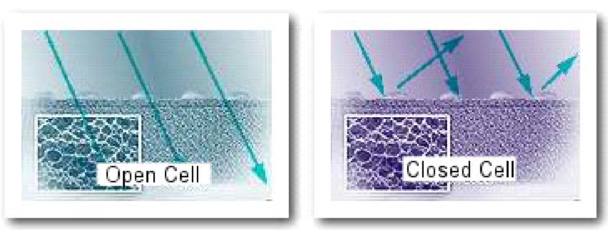

Figure 1. Open Cell Structure and Closed Cell Structure

For the two kinds of porous sponge, open cell structure and closed cell structure (as Figure 1), only the open cell structured sponge can be applied to the ink cartridge. Each cell has channel connecting to each cell in the open cell structure sponge. The ink absorption ability of the reservoir comes from the ink delivery between cells through the channels, as well as the dispersing ability. The character makes the sponge reservoir have the capability of reserving and releasing ink.

Many forming methods can be used to make the foamed polymer material, e.g. injection, extrusion, compression and pour. The compression forming method is most applicable one for making the sponge reservoir. Its scenario is putting the polymer material and vesicant in a mold cavity, then compressing and heating the mold. The foaming quality is controlled by the process parameters of pressure, temperature and duration. After cooling and solidification, the soft flexible porous sponge forms. Post-processes like cutting and thermal compressing on the side direction are necessary to get a rigid, easy to assemble, smaller pores and good capillarity sponge product.

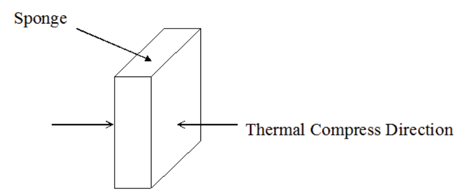

Figure 2. Scheme of the Thermal Compression

The normal sponge has specifications in characterizing the physical property like density, foaming expansion rate, tensile strength, compressing residual distortion rate, Shore hardness, pore number and so on. For the sponge reservoir product after thermal compression, the specifications are stricter than normal sponge.

1. Density: 0.06~0.15 g/cm^3

The density of a sponge reservoir product means the proportional increased density of the sponge after thermal compression. It can be defined by dividing the real weight by the appearing volume.

2. Availability: 70~90%

The availability is the ratio of the releasable quantity and the poured quantity among the ink absorbed by the capillarity. Higher availability means less ink residue in the reservoir. In another word, less ink is wasted. That's why the availability is the most important character for a commercial reservoir design.

The availability can be measured by the backpressure experiment. First, calculate the total output ink quantity under the maximum negative pressure the nozzle can endure (normally 26 mbar), then divided by the total original supplied ink quantity.

3. Void Ratio: 85~95%

The void ratio is the ratio of the porous volume and the appearing volume of the sponge reservoir. In another word, it's the ratio of the pores in the sponge reservoir. Higher void ratio means higher amount of ink that every unit of sponge can hold.

Normally the void ratio can be measured through an experiment. First, clamp and press the sponge tightly. Then have the sponge merged in the water as the sponge was fully compressed. Release the sponge within the water and make sure every pore in the sponge is fully of water. Finally, measure the weight of the wet sponge. The weight and the volume of the absorbed water can be measured by comparing the weight of the wet sponge and the dry sponge. Thus the volume of the pores is measured, and the void ratio can be calculated.

4. Compression Ratio: 1st Compression Ratio 3.0~5.0; 2nd Compression Ratio 1.05~1.4

The compression ratio follows the equivalent principle, i.e. the total compression ratio of the sponge reservoir is equal to the product of all compression ratios.

The 1st compression ratio means the shrunk volume of the sponge reservoir product after thermal compressing by the side direction. The purpose is to increase the stiffness of the sponge reservoir and to reduce the difficulty of inserting the sponge into the cartridge. Furthermore, the diameter of the pores is shrunk and the capillarity can be increased. The 1st compression ratio is always more than 2.0 because of avoiding the uneven distribution within the thermal compression process. However, the 1st compression ratio shouldn't be too large to control the material cost.

The 2nd compression ratio means the volume ratio of the sponge after and before inserting the sponge into the cartridge. The 2nd compression ratio is always small since the purpose is to tighten the contact between the sponge and the side walls of the cartridge and to prevent the air penetrate into the ink pipe and jam the ink channel through the gap.

5. Capillarity: More than 20mm

The quantification of the capillarity can be derived by Equation 1. The capillarity is closely equal to the natural raising height of the absorbed ink in the sponge reservoir.

The measurement of the capillarity is quite straight forward. Put the sponge in to a container with ink and supply the ink continuously. The sponge is saturated while no longer raising of the ink height can be observed. The ink height can be defined as the maximum capillarity.

Fiber Type Reservoir

Fiber is the long thin polymer material which was drawn into a more than 100:1 of length-to-diameter ratio. Most of the fibers are applied to the textile industry. The fiber should possess high tensile strength, high elastic modulus and high wear resistance. These physical properties come from the high molecular chain and the drawing and braiding process. Commonly used fiber materials are Polypropylene (PP), Polyethyleneterephthalate (PET) and Polyamide (PA; Nylon).

The fiber polymer used for fiber type reservoir is braided and gathered after drawing. Because of the excellent ductility and tensile strength, the polymer material can be melted and drawn into thin threads with less than 1 micron diameter. Millions of the thin threads gather into a bundle of polymer fiber. After packing with a Polyethylene (PE) film and controlling the fiber density, the fiber reservoir is finished.

The principle of why the fiber reservoir can store ink inside is the natural capillarity which come from the tiny space between the thin threads. A proper fiber reservoir with certain backpressure can be regulated by controlling the fiber density.

Due to the property of the fiber and backpressure source, the ink delivers only through the fiber thread direction. The fiber reservoir uses natural gravity to guide and supply ink. It is directive. While the ink supply the ink pipe from top to down, the fiber reservoir should store and release ink through top-down direction. Otherwise the ink supply the ink pipe horizontally, i.e. the direction of the ink delivery and the fiber thread are perpendicular to one another, the ink delivery will be difficult and obstructive since the ink's natural gravity is no longer effective. The ink supply is directive and is poor in the side direction. It is a huge restriction in designing fiber reservoir.

Backpressure Experiment

The ink cartridge supplies the ink within the inkjet printer's print phase. When installing a new cartridge onto the printer, the ink will flow down due to the natural gravity after removing the blue tape on the print head. The ink won't leak out in a great quantity because of backpressure caused by the ink reservoir.

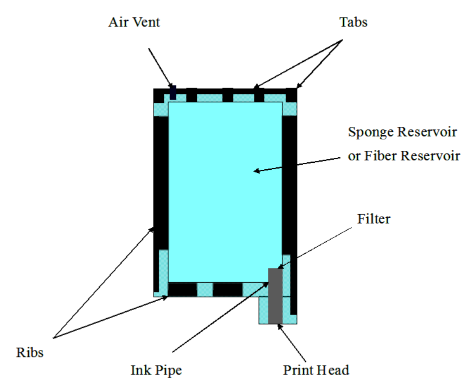

Figure 3. Illustration of the Ink Cartridge

Thermal bubble printer for example, the ink in front of the ink pipe is heated and vaporized into a bubble then jetted out at the moment of printing. Because of the Van der Waal force between the ink molecules, the jetted out ink causes a vacuum attractive force to the remaining ink in the cartridge. This attractive force, can be regarded as another negative pressure from the print head, will balance the backpressure of the ink reservoir. Thus the ink at the bottom of the reservoir can continuously supply ink to the ink pipe. The ink in the reservoir will stably supply ink to the print head from top to down.

The backpressure experiment is to simulate the negative pressure from the print head and to observe the ink supply between different backpressure. The relation of the different reservoir's ink releasing and the different pressure can be understood. Then the reservoir's properties and availability can be studied.

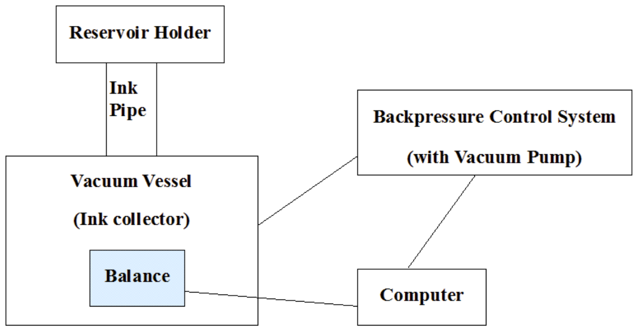

Figure 4. Backpressure Experiment Apparatus

The backpressure experiment apparatus is shown as Figure 4. One major component is a backpressure control system with a vacuum pump inside. It can precisely control vacuum source in 0.1 mbar through the computer. Upper half of the apparatus is a reservoir holder, the experimental reservoir, sponge or fiber, is put here. The ink is poured into the reservoir from the top by a syringe. Lower half of the apparatus is a vacuum vessel. It is tightly assembled and sealed with O-ring. The vessel connects onto the backpressure control system and its vacuum pressure can be controlled by the computer. Inside the vessel, a balance is installed. The balance has 0.05 g precision tolerance and its reading data can be obtained from the computer. As the experiment begins, the ink inside the reservoir is extracted by the vacuum pressure. The ink will flow out through the ink pipe into vessel then drop onto the balance. The ink weight and the related negative pressure are recorded and analyzed by the computer. The reservoir's character is measured.

The backpressure experimental data curve is shown as Figure 5. Different backpressure is defined on the horizontal x-axis and the related ink quantity is expressed on the vertical y-axis. The curve shows the trend of different reservoir materials. The sponge reservoir has steeper slope in the beginning. And it supplies ink concentrating in the beginning, too. The fiber reservoir supplies ink averagely.

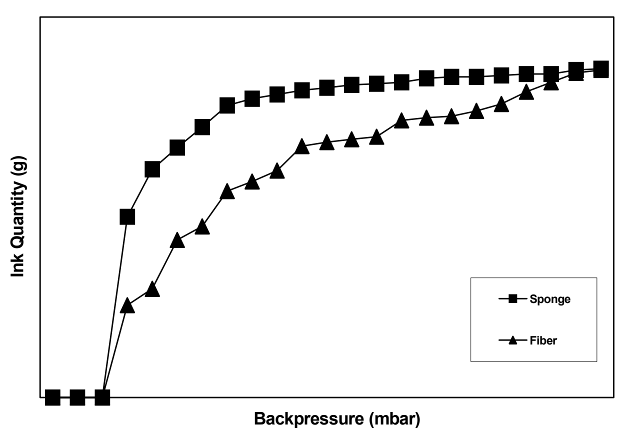

Figure 5. Backpressure Experimental Data Curve

The backpressure that the ink starts to be extracted is the reservoir's maximum backpressure capability. At this point, the capillarity in the reservoir can't resist the negative pressure and the ink starts releasing. 6~9 mbar is a suitable value for most of the ink reservoirs. Too large maximum backpressure capability may cause obstructive ink supply, too small maximum backpressure capability may cause easy leakage.

The maximum reading of the y-axis is the maximum ink quantity that the reservoir can release. It shows the availability of the reservoir. The consumed ink quantity in the reservoir is measured.

Criteria of Designing Ink Reservoir

1. Raw Material Selection

The sponge reservoir requires uniform pore diameters in the raw material. Since the pore diameters directly influence the printing quality. Too many differences between the pore diameters will cause unstable ink supply.

In addition, the sponge material requires good mechanical strength to prevent the sponge from cracks or generating particle as the friction and constriction in installing the sponge into the cartridge. Since cracks easily cause the local ink concentration and the local high backpressure; Particles and broken pieces may block the filter, cause the filter malfunction and discontinue the ink supply.

Furthermore, the sponge material requires wrinkle resistance, antiseptic, anti-static, cleanliness and so on. An inversion experiment should take place after the cartridge was installed and fulfilled with ink. The purpose is to ensure that the ink won't flow back and infiltrate over the sealing line.

The fiber reservoir requires uniform thread diameter and precise volume formed by the PE film. The quantity of the fiber threads should be precisely controlled to handle the fiber reservoir's density. Therefore the capillarity can be fixed as demand.

In addition, the fiber also requires good mechanical strength to prevent the reservoir from blocking the filter by broken pieces and particles and discontinuing the ink supply.

Furthermore, the fiber material requires antiseptic, anti-static, cleanliness and so on.

2. Fitness for the Cartridge Size

The sponge reservoir, because of its soft character, is easy to be wrinkled, cracked or irregular as the inserting into the cartridge. The phenomenon leads to the local high compression ratio and concentrates ink locally. It also reduces the reservoir's availability and discontinues the ink delivery. A fixture can be applied here to get rid of difficulty in inserting a larger size sponge into a smaller size cartridge.

The fixture has separate side walls and its cross section area is smaller than the cartridge's. The sponge is clamped and pre-compressed by the fixture then inserted into the cartridge. After slowly drawing out the fixture, the sponge is properly and well shaped installed in the cartridge. The fixture's and the cartridge's cross section area are always smaller than the sponge's to result in the 2^{nd} compression ratio of the sponge.

Furthermore, the sponge always protrudes out of the cartridge as it's fully inserted into the cartridge. The upper lid of the cartridge compresses the sponge and also provides another direction of the 2^{nd} compression while it covers and seals the cartridge chamber. The sponge seamlessly contacts the cartridge's walls and tightly wraps the ink pipe to prevent air invading.

For the fiber reservoir, the PE film's size should provide tight tolerance with the side walls of the cartridge. Avoid any existing gap to prevent the ink from permeating upward. The upper lid of the cartridge also has to compress the fiber while it covers and seals the cartridge chamber. The fiber reservoir seamlessly contacts the cartridge's walls and tightly wraps the ink pipe to prevent air invading.

3. Interaction with the Ink

The reservoir and the ink coexist permanently. It is an essential principle that the reservoir must cause no chemical or physical reaction with the ink. The experimental method is putting the reservoir with the ink in an environmental test equipment. With 7, 14, 21 and 30 days of accelerative test, the reservoir's appearance and properties are measured and studied.

The change in the reservoir's appearance may imply the poor chemical resistance of the reservoir's polymer material. The change in the ink's conductivity, viscosity and pH indicates the chemical reaction occurring between the reservoir and the ink. The corrosion of the reservoir can be measured by a laser particle analyzer. All chemical and physical tests should be put into practice to ensure the integrity of the reservoir's properties.

4. Environmental Requirement

A good ink cartridge product may damage during shipping and delivery. A tiny bubble which remained in the cartridge during the manufacturing process may expand and block the ink channel or cause ink leakage because of the environmental changes in pressure and temperature. The package and the storage of the ink cartridge should consider the environmental issues. Furthermore, a better ink pouring technology and the 2^{nd} compression should carry out to isolate the air outside.

Conclusion

The difference between the sponge and the fiber can be found in the curve trend of the backpressure experiment. The sponge reservoir begins separate out a large amount of ink at a certain negative pressure. The fiber reservoir provides more stable ink supply. In comparing the two types of reservoir, the fiber reservoir has a better character in resisting environmental changes. It permits larger changes in the backpressure than the sponge reservoir.

The leakage of the ink cartridge comes from the stability in the ink pouring process. No bubble residuum in the cartridge should be assured during the manufacturing phase. Higher maximum backpressure capability should be considered to prevent the cartridge from leakage although higher backpressure capability results in lower availability.

The sponge material is more than three times the cost of the fiber material. Yet the sponge reservoir has a better yield in its manufacturing processes and it provides non-isotropic ink supply capability. The cost of ownership is the usual priority as the same functional requirements. The cost comes into existence not only from the raw material but the manufacturing process, package, handling and storage. Cartridge vendors may choose suitable characteristic reservoirs according to their requirements and capabilities.

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Biographies

Yi-Chia Wen serves in the Opto-Electronics and Systems Laboratories of Industrial Technology Research Institute (OES/ITRI). She received her Mechanical Engineering BS degree at Tamkang University, Taiwan. She started the study in inkjet system since she joined OES/ITRI 2000. Her major research focuses on the commercialization of inkjet system, especially on the experimentation and characterization of reservoir materials. She gained experiences of technical consulting for mass production by involving in many ink cartridge manufacturers' projects.

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