Improving Inkjet Print Performance with Fumed Silica at the Size Press

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Abstract

A very thin layer of a fumed silica based coating (0.5-1.0 g/m²) applied to plain paper at the size press improves inkjet printing performance. The silica coating behaves as an inorganic sponge with a well defined void and channel structure to absorb ink rapidly for enhancing color qualities, print uniformity and image resolution.

The rapid drying of a print and immobilization of the ink colorant improves many performance aspects when using today's modern high speed printers. A paper with a size press treatment of fumed silica is a novel approach and a cost efficient solution to meet the requirements of tomorrow's printer design. The successful development of both cationic and anionic fumed silica dispersions at high solids content are an essential advancement towards this goal.

Introduction

Fumed metal oxides, based on silica and alumina, are commonly used in coating formulations to produce the high quality photo inkjet media that feature instant dry times, brilliant colors, uniform ink absorption, superb resolution and water fastness. The fractal structure of the aggregated particle is the basis which allows the micro-porous network to be developed within the coating at a finer scale than conventional pigments. It is this structure which provides the essential capillary action needed to transport the ink vehicle quickly away from the paper surface. Liquid absorption via capillary action in a micro-porous system is much faster than the alternative water swellable polymeric systems that rely upon diffusion and solvation. The resulting "instant dry" property, achieved with the micro-porous network, enables the use of high speed printers while maintaining optimum image quality. The ink colorants are absorbed on the surface of the solid particles with pin-point accuracy resulting in both brilliant colors and high resolution.

Fumed Metal Oxides

Fumed metal oxides based on silica or alumina is produced from vaporizable starting materials in an oxygen-hydrogen gas via flame hydrolysis. [1] This is the basis of the AEROSIL® process which was discovered by a Degussa scientist over 60 years ago. Fumed silica (and fumed alumina) consists of primary particles that are approximately 7 to 40 nm in size, depending on the product grade. The primary particles are not isolated, but linked into stable aggregates that can be as large as several hundred nanometers (secondary structure). The particle structure is one of the more distinctive characteristics that set fumed metal oxides apart from other common colloidal systems, such as colloidal silica or alumina.

Fumed metal oxides formed in this process are characterized by very high purity levels and a unique particle structure, as illustrated in Figure 1.

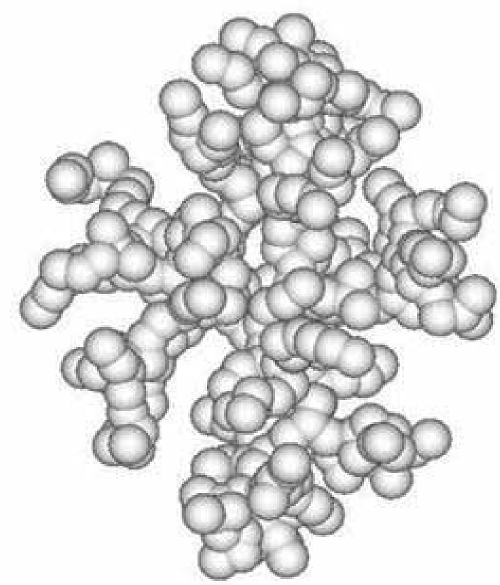

Figure 1. *Computer model for fumed oxides [2]*

With the appropriate dispersing technology, aqueous dispersions of the fumed metal oxide can be made at high solids content allowing a form of fumed silica which is easy to dispense, dose and formulate - without the need for expensive mixing equipment.

The dispersion rheology is an important physico-chemical parameter for the preparation of inkjet coatings. Many of these dispersions exhibit near Newtonian flow behavior. Dispersions at higher solids levels tend to exhibit slight shear thinning, meaning the viscosity is reduced when they are moved or processed. At rest, the viscosity increases again, preventing sedimentation from occurring. The extremely small particle size which allows for a stable, high solids dispersion can also be beneficial for reducing a coating's viscosity at a given solids content. [3]

The dyes used in the formulation of inkjet inks are predominantly anionic. The fumed silica particle, as manufactured, possesses an anionic surface charge which would repel these dyes. The cationic modification to the fumed silica surface (See Figure 2) can now allow an electrostatic bond to be formed between the particle and dye molecule. This further reduces dye mobility if the image is exposed to water or ambient moisture. The development of cationic fumed silica dispersions at high solids offers today's formulator greater flexibility to tailor critical performance advantages. Creating economical inkjet papers to meet tomorrow's printer requirements can be realized with a micro-porous cationic size press treatment.

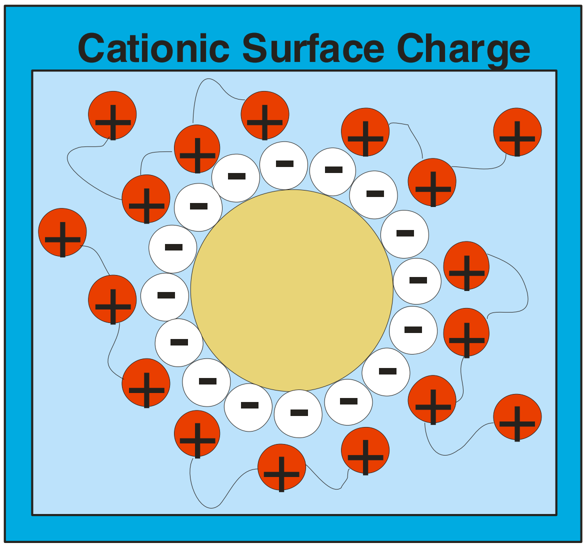

Figure 2. *Schematic of a cationized silica particle*

The Role of Particle Structure

Fumed silica consists of spherically shaped particles. The primary particles do not exist in isolation and they do not have any internal porosity associated with them. In the fuming process, the primary particles are fused together to form a secondary or aggregate structure. This aggregate structure is the reason for their use in micro-porous paper coatings. When mixed into a formulation, the aggregates are not broken down into primary particles and retain their structure. These aggregates are capable of forming an effectively porous network in the coating matrix that is efficient for fluid transport and colorant immobilization. This structure yields excellent results in many applications, even when relatively small quantities are used (See Figure 3).

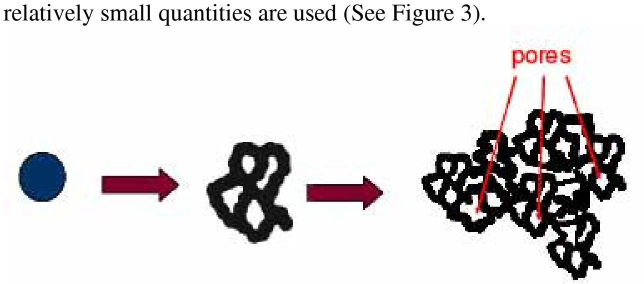

Figure 3. *An illustration of the a) Primary particle size b) secondary aggregate structure and c) Micro-porous coating structure. [4]*

Commercial Inkjet Papers

The "Bright White" type inkjet paper available at various office supply stores is perceived by the general public as being superior to common "office" paper for inkjet printing. The most outstanding feature is, as the name implies, the high brightness value, which when printed deliver high contrast between the image (text) and sheet. In reality, these "Bright White" papers should more properly be seen as simply "office" papers with high brightness values. There is minimal distinction in their performance on an inkjet printer, relative to the less expensive office paper.

At first glance it may seem scant attention was given to improving the quality of the inkjet image. The fact might well be the lack of a viable technical alternative to the polymeric surface treatments which currently dominate at the size press of the paper machine.

At the high end of the inkjet media market, photographic inkjet papers are realizing the benefits of micro-porous coating technology through improvements of ink dry times, water-fastness, color quality and image resolution. [5] Size press treated paper utilizing a fumed silica based treatment can be the basis for producing low cost inkjet papers with truly enhanced print performance.

Experimental Procedure

The puddle size press is a common piece of equipment on many paper machines used to impart a functional treatment. The size press solution is typically of low solids and viscosity. Detailed operation of the puddle size press is beyond the scope of this paper, but in general, the press via hydraulic pressure forces the size press solution into the voids between fibers. Essentially, the puddle press leads to the sheet being saturated as opposed to the surface treatment obtained with coaters.

To simulate the puddle size press in the lab environment, the coating was formulated to 4% solids resulting in a Brookfield viscosity of less than 100 cPs. The coating is comprised of 100 dry parts of a cationized fumed silica (AERODISP® WK 7330, Degussa), 10 dry parts of polyvinyl alcohol (Celvol® 523, Celanese) and 15 dry parts of a cationic polymer (Induquat® 35L, Indulor GmbH). This coating is applied to a multi-purpose printing paper (20 lb Spectrum® DP, Georgia Pacific) with the appropriate wire-wound rod, dried with a heated forced air gun and then dried under restraint using a Laboratory Sheet Dryer (Adirondack Machine Corporation, Model S100). This approach allows the treatment to saturate the sheet, minimize wrinkles and avoid curl, while obtaining low pickup weights. One primary source of error in this approach is in calculating the true amount of treatment applied to the sheets, especially at these extremely low addition levels. The correlation between the rod wire size and coat weight is expected to be linear and is seen in Figure 4.

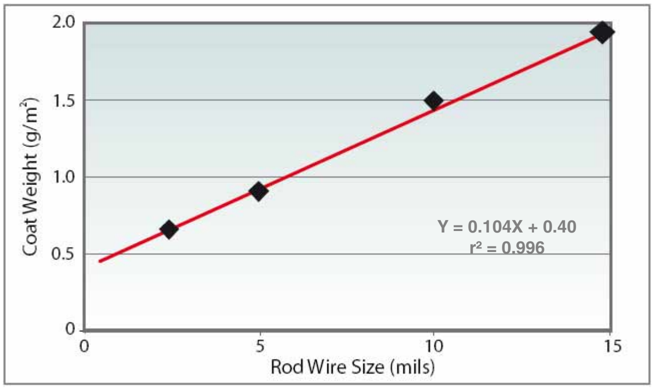

***Figure 4.** Correlation between Rod Wire Size and Coat Weight*

Image Quality Measurements

Unless stated otherwise, data used in this work were derived from measurements obtained with a "Personal Image Analysis System" (QEA, Inc). The treated papers were printed on two common desktop inkjet printers:

1) Hewlett-Packard Photosmart 8250 and
2) Epson Stylus Photo R200

These printers were selected for their distinctly different ink sets and printing mechanisms employed, relative to each other. The Epson inks typically contain higher concentrations of organic solvents which make the printer a more discriminating test platform to observe and measure changes in printing properties. Minor changes in the ink chemistry can result in obvious print quality differences particularly when the rate of ink absorption is affected.

A print pattern was created which contains various elements needed for quantifying print attributes such as optical density, color gamut area, print mottle and grain, color-color bleed and dot circularity.

Results and Discussion

Color Quality

Optical densities have been averaged for the primary colors, Cyan (C), Magenta (M), Yellow (Y) and Black (K) and plotted against coat weight for the two inkjet printers. As seen in Figure 5, the density values increase in a linear fashion with coat weight.

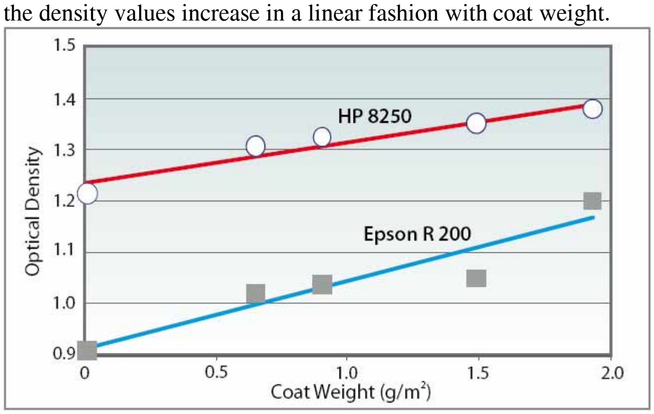

***Figure 5.** Effect of Coat Weight on Averaged Optical Density Values*

Color gamut area is a calculated from the CIELAB a* and b* values for the colors cyan, magenta, yellow, red, green and blue. It is indicative of the potential color palette available in a printing system. Higher values indicate the capability of generating more colors and printing those colors more accurately. As seen in Figure 6 the color gamut area expands with increasing treatment weights.

The increased performance in these color qualities is achieved when the ink resides at or near the surface of the sheet or if the coating is transparent. The unique structure of fumed silica aids in immobilizing the colorant near the surface. The small aggregate size of fumed silica helps to maintain transparency, enabling vivid colors and detailed images.

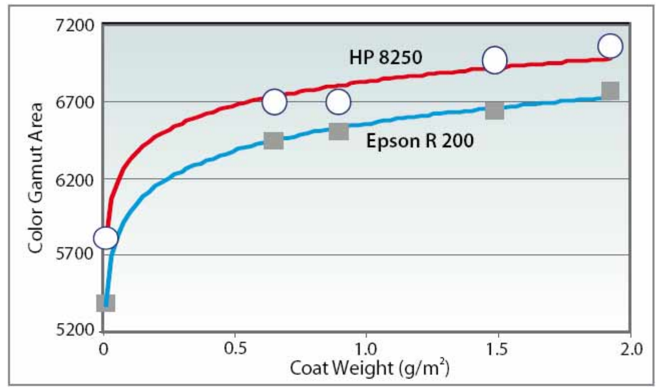

***Figure 6.** Effect of Coat Weight on Color Gamut Area*

Print Uniformity

When ink is absorbed too slowly or unevenly by the coating, the image may appear "spotty" or mottled. In spite of high color values (e.g.; optical density, gamut) that might be obtained, the resulting print would be unacceptable.

Mottle is a measure of coarse scale color density non-uniformity (> 250 um), while grain is a measure of this non-uniformity at a finer scale (< 250 um). In Figures 7 and 8, print mottle and grain, respectively, are seen to be reduced as treatment levels increase. In both cases the use of a micro-porous treatment system is beneficial for image quality. This indicates that fumed silica increases ink absorption uniformity.

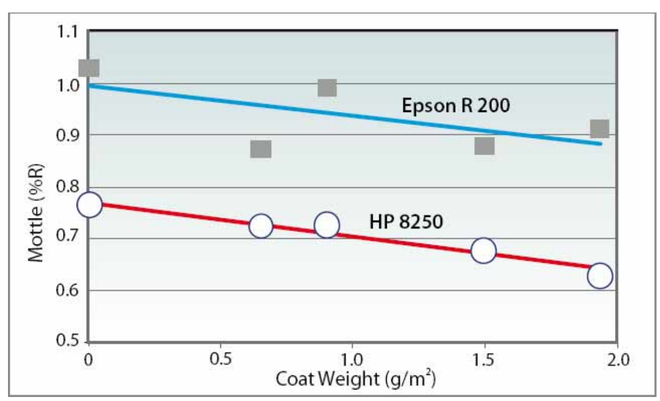

***Figure 7.** Effect of Coat Weight on Print Mottle*

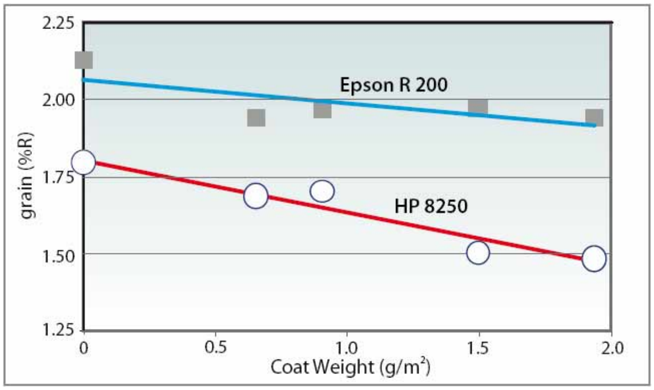

***Figure 8.** Effect of Coat Weight on Print Grain*

Print Resolution

For inkjet printing, the dot is the fundamental print element and the basis for constructing higher level elements such as lines, text characters, graphics and images. The quality of dot formation is a critical indicator of a print's final quality. The circularity of a dot is influenced by the uniformity of ink absorption and fumed silica has a positive influence in this process.

For this element, the aspect ratio (or dot circularity) of printed dots was evaluated. These dots are designed to be 100um in size, where an aspect ratio of 1.0 would indicate a perfectly round dot. As seen in Figure 9, the dot circularity improves as the fumed silica treatment level increases.

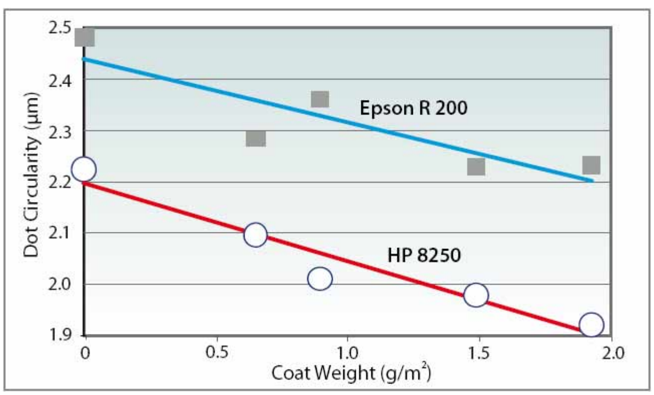

***Figure 9.** Effect of Coat Weight on Dot Circularity*

Line quality is another important consideration for evaluating print quality as it is related strongly with text quality. The amount of line growth, particularly when the ink is capable of "bleeding" into another adjacent color, gives insights on the ink-media interactions.

For the element, the deviation from a nominal line thickness of 280 um is averaged for 12 combinations of primary line colors (K, C, M and Y) on blocks of the four primary colors. As seen in Figure 10, increasing coat weight reduces the degree of line growth.

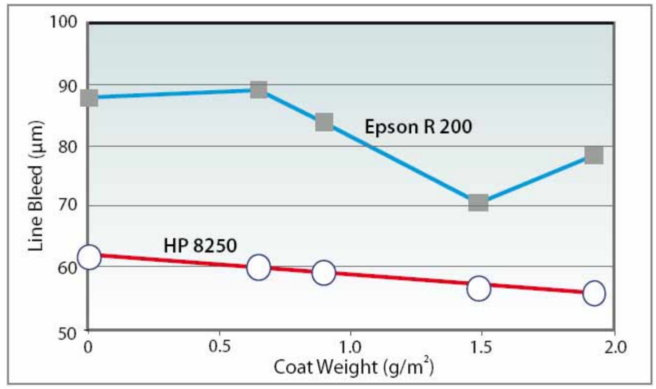

***Figure 10.** Effect of Coat Weight on Line Bleed*

Water-Fastness

An additional benefit realized with the incorporation of fumed silica into a size press treatment is the improvement to ink fastness when exposed to water. For this test, 250 uL of de-ionized water was "dripped" onto a bar of color (C, M, Y, and K) at a 45° angle. The percent reduction from the initial optical density value is calculated as an average of the four colors (Figure 11).

Upon exposure to water or ambient moisture, water swellable systems begin a transition from an elastic solid to a viscous liquid thus allowing the flow of polymer, which contains the ink colorant. The coating containing cationic fumed silica is not as sensitive to this transition. The void and channel structure imposed on the coating along with the associated cationic charge hinders the transport of dyes.

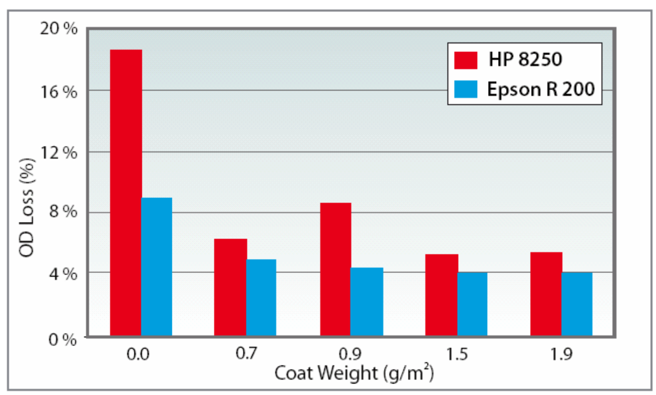

***Figure 11.** Benefit of Fumed Silica Coating for Water-Fastness*

Conclusions

At treatment levels as low as 0.5 – 1.0 g/m² (~11– 22 lbs/ton), a size press treatment with fumed silica enhances inkjet print performance; with many of the properties having improvements of 10 – 20% over an office paper.

The stable, cationized dispersion of fumed silica facilitates the formulation of cationic size press solutions and provides improved resistance to water intrusion.

These benefits are attributed to the small particle size, cationic surface charge and unique structure of fumed silica to enable rapid fluid transport and a strong immobilization of the dye for realizing vivid colors, uniform ink absorption, sharper images and water-fastness, simultaneously.

References

[1] Technical Bulletin Pigments, No. 56 "Highly Dispersed Metallic Oxides Produced by the AEROSIL® Process", Company Publication (Degussa).

[2] C. Batz-Sohn, "Tailor-made Silica and Alumina for Inkjet Media Coatings", Proceedings NIP 20, 805, Salt Lake City, UT. (2004)

[3] Industry Brochure – "Dispersions", Company Publication (Degussa).

[4] A. Storeck, et al; "Novel Inkjet Coating Alumina", Proceedings NIP 22, Denver, CO. (2006)

[5] Technical Information (TI) 1212, "Degussa Synthetic Silica for Inkjet Media", Degussa AG (2004)

Biography

Leo Nelli is a Senior Applications Scientist in Applied Technology with the Aerosil and Silanes business unit of the Degussa Corporation. He joined the company in October 2004 and his present efforts involve identifying new uses for fumed metal oxides for the paper and printing industry. He has over 20 years experience in the paper and printing industry with two issued patents and three currently pending.