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Flexible Tubing Selection for UV Ink Transfer Based on Quantitative Test Results

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New technological opportunities have been created by the booming growth of 3D printing technology and steady rise of Wide Format, Packaging, and Coding Printers in the market today. There are many subsets of technology and methods that fall under these growth areas of Digital Printing, yet one commonality between Wide-Format and 3D printing (specifically material jetting and binder jetting) is that both engage in photopolymerization of energy cure inks, primarily UV cure inks. Despite having chemistries far more aggressive than aqueous or solvent-based inks, free-radical UV cure ink is widely utilized because of the strengths it offers; including rapid cure time, versatility in pigments, finishes and compatible substrates, and long storage life. These advantages are compelling enough to design a printing system entirely around the use of UV based inks. However, this presents a challenge for the fluid transfer components, namely tubing, which need to have a balance between properties including **UV blocking, chemical resistance, and flexibility**.

To design system components for these UV ink systems, Saint-Gobain Life Sciences collaborated with printer manufacturers, printhead manufacturers, ink manufacturers, assembly-focused integrators, and experts in the field to understand the needs, wants, and limitations for flexible tubing and other components used to transfer UV inks. These inks are designed to dispense at a specific viscosity when heated to dispensing printhead nozzle temperatures of 40-50°C (104-122°F), which enables strong bonding to the type of substrate for which they're intended. For this reason, the ink viscosity and glass transition temperature are critical to performance. In many 3D printing systems, high viscosity on the range of 300cP is desirable, while for Wide Format there is a need for very low viscosity inks, typically between 60-70cP depending on the system and the substrate. Viscosity can be tailored to a point with solvents, however, the environmental requirement for low VOCs and low molecular weight components led to the usage of small acrylic monomers such as vinyl methyl oxazolidinone (VMOX) and isobornyl acrylate (IBOA). Diluents such as VMOX, IBOA, and others as shown in Figure 1, used by themselves or in combination, will comprise between 15 wt.% to 75 wt.% of a UV ink's overall composition.

Shorthand ID	Chemical Name	Notes
IBOA	Isobornyl acrylate	Prevalent use in the industry today; 10 wt.% - 15 wt.% typical load. There is risk of a future EU ban.
HDDA	1,6-hexanediol diacrylate	Prevalent use in the industry today; 20 wt.% - 25 wt.% typical load.
VCAP	N-vinyl-ε-caprolactam	Prevalent use in the industry today; 25 wt.% - 30 wt.% typical load. There is risk of a future EU ban.
VMOX	Vinyl methyl oxazolidinone	"Green" eco-friendly diluent made by BASF and growing in popularity currently. This is the 'new VCAP'.
VEEA	2-(2-Vinyloxyethoxy) ethyl acrylate	SNUR currently in place with EPA.
ACMO	4-acryloyl morpholine	Uniquely water-soluble.

Figure 1. *Most common diluents used in UV ink compositions today.*

These recipe components can attack transfer tubing, by way of significant swelling or other means of degradation, including delamination of multi-layer constructions. Therefore, it is critical to select the right materials, develop the specific formulation or multi-layer construction if needed, and follow the industry protocols for screening and qualification. IBOA is particularly aggressive towards most polyolefin materials and VCAP is particularly aggressive towards most fluorinated materials. With many soft and flexible plastics, such as thermoplastic polyurethanes or platinum-cured silicones, it is common to see chemical attack when exposed to UV ink formulations strictly due to the aggressive nature of the small monomer diluent content.

UV Blocking Studies:

Both Wide Format and 3D printers that utilize UV cure inks are designed and manufactured with enclosed chambers around the ink dispensing nozzle and entire printbed with the intent of providing protection. The chamber offers containment of fumes and volatile components, and with a distinct orange tint, protects the eyes of operators and other users in proximity to the printer's UV lights. The technology behind the orange tinted films does not translate to many ink system components, including tubing. It is critical that UV ink transfer tubing provides complete UV blocking so that the ink does not cure prematurely, which could lead to clogs and other problematic issues in the print system.

To be effective, UVA and UVB spectrum ranging from 280-400nm wavelengths must be fully blocked. The industry standard to achieve this level of UV blocking in tubing components is to utilize UV-absorbers, such as carbon-based black additives, into the tubing material.

UV-vis transmission spectra have been compared between a tube without UV blocking additives and **Tygon® Ink 1000** to quantify the light blocking capabilities of a UV-blocking tubing (Figure 2). The UV-absorbing species covers the full wavelength range of UV and visible light. To further examine the effectiveness of UV-blocking on inks, small tubing sections were filled with clear or yellow UV-curing ink and sealed with barbed fittings (Figure 3). After the samples were irradiated inside a UV curing oven with a broad UV spectrum, the assembly was opened and checked for evidence of cured ink. It was quickly discovered that the ink in a clear tubing without UV-blocking was cured and fully or partially hardened depending on the ink, and the ink in Tygon® Ink 1000 was still fully liquid indicating the UV light had been effectively blocked. When examining the cross-section area, the inks were cured on the clear tubing whereas Tygon® Ink 1000 shows no evidence of solidified ink.

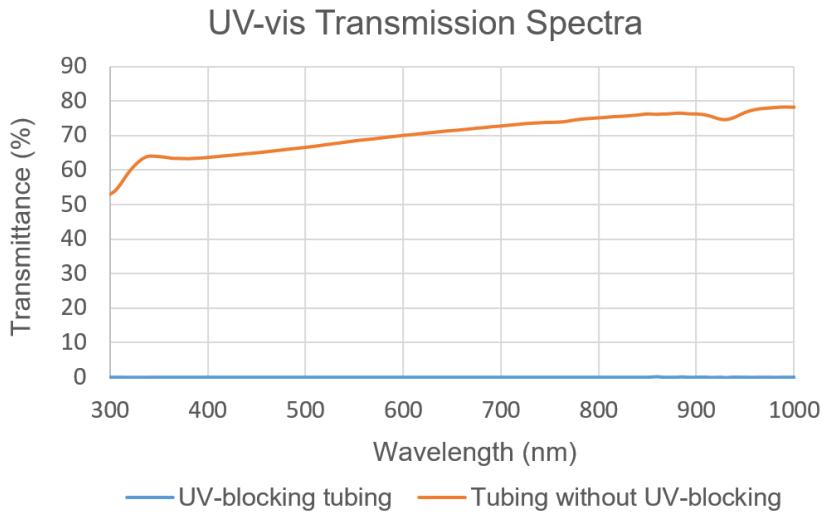

Figure 2. *UV-vis transmission spectra of a UV-block tubing (Tygon® Ink 1000) and a regular clear tubing without UV blocking additives.*

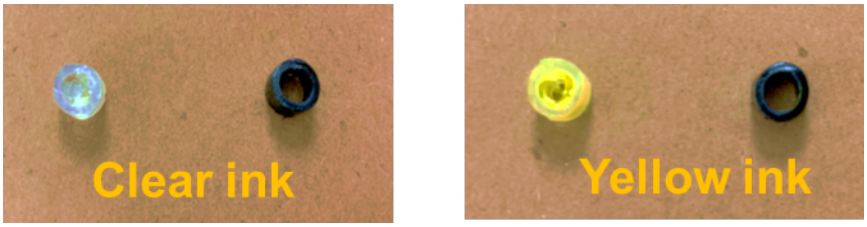

Figure 3. *Left: cross-sectional area of the tubing after filled with clear ink and irradiated with a UV curing lamp. Right: cross-sectonal area of the tubing after filled with yellow ink and irradiated with a UV lamp.*

Chemical Soaking Studies:

There is a desire within the Digital Printing industry to have a “one size fits all” solution when it comes to ink transfer tubing. This is something that Saint-Gobain can provide, based on the results of the extensive testing shown below.

For printer and printhead manufacturers, the industry standard for tubing qualification is to subject the tubing to a full immersion ink soak for 4 weeks at 40°C; any tubing that experiences more than 5% weight gain is deemed not chemically resistant enough to install as a long-term use component. Figures 4 and 5 below display the results of a range of commercial tubing products designed for UV ink transfer for both a full immersion soak and a cap-and-fill soak. The cap-and-fill method is where only the inner surface of the tubing is exposed to the fluid. A, B, and C are widely used products in this market today. Overall, Saint-Gobain’s new product offering, **Tygon® Ink 1000**, performed well in this diluent testing showing strong chemical resistance in both the full immersion and the cap-and-fill testing.

It is important to note as well that these tubing products were tested in 100% diluents, as opposed to UV ink solutions, so the expectation is that these results capture more severe levels of chemical attack than would be experienced by soaks with the inks themselves. This may be the reason for some of the surprising results for the product from Competitor A, which were almost completely stripped of the black color during the tubing soak (Figure 6) in VCAP. Additionally, we saw the liner of the commercially available ink tubing product from Competitor C was drastically “bleached” after the cap-and-fill test in VCAP (see Figure 7).

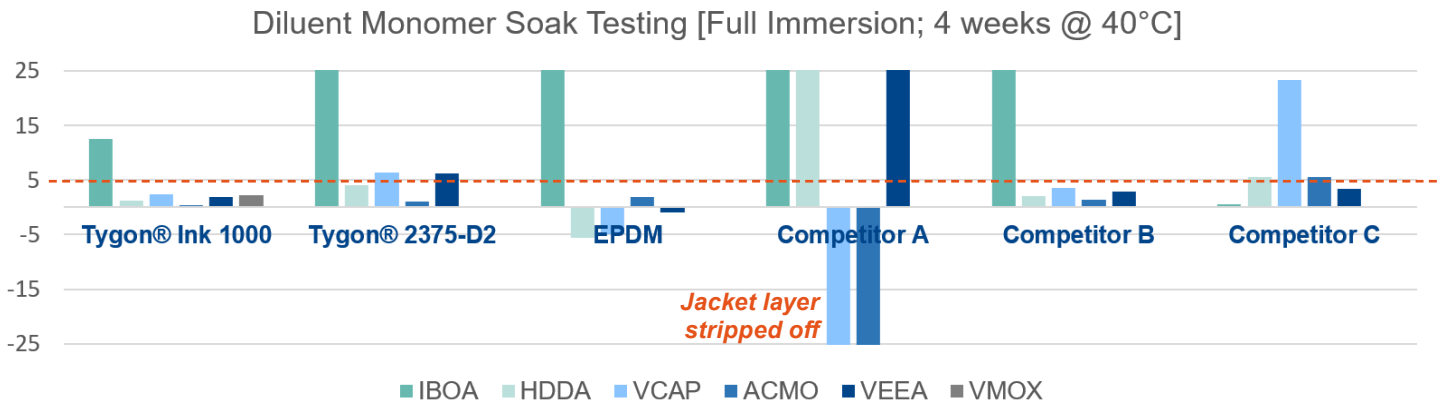

Figure 4. *Diluent Monomer Soak Testing (Full Immersion)*

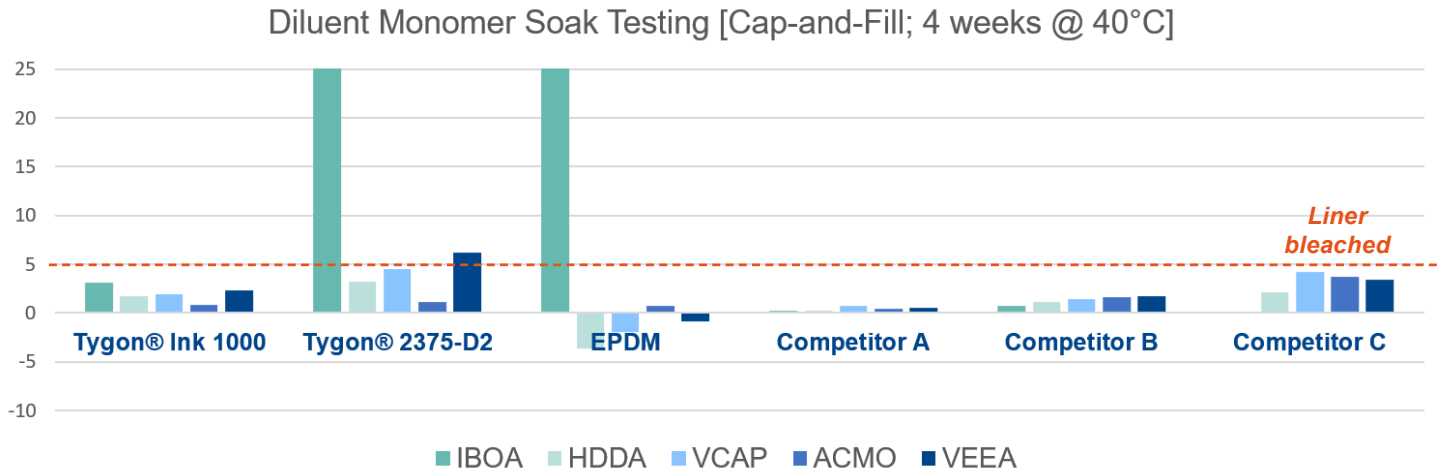

Figure 5. *Diluent Monomer Soak Testing (Cap and Fill)*

Figure 6. *Photo of the tubing from Competitor A after 1 week soaking in VCAP.*

Figure 7. *Photo of the bleached liner of the tubing from Competitor C after cap-and-fill testing with VEEA and VCAP. Note: both ends of the tubing were protected with a barbed fitting, so the near-edge area was not exposed to the diluents and therefore not bleached.*

Tubing Flexibility Studies:

It is understood in this industry that tubing flexibility is important, perhaps equally as important as tubing chemical resistance to ink solutions, for several reasons. During installation, a tubing must be able to be maneuvered through intricate routings in a printhead and set in place without any kinking or collapsing upon itself, which would otherwise lead to complications in use. It is also common for tubes to be disconnected and reattached to barbed or luer fittings many times during their lifespan, including accommodations for rinses/flushes/cleanouts and the replacement of ink cartridges and other components. Flexibility and flex fatigue must also be considered when the printhead carriage is moving quickly or over a large distance as seen in Wide Format printing. Flexibility can be measured by many different methods; the simplest method is via tubing durometer (hardness). This, however, does not capture the full breadth of flexibility for a tube.

Therefore, measuring the different facets of flexibility including minimum bend radius (Figure 8), maximum force to bend (Figure 9), and force required for fitting insertion (Figure 10) provide the printer operator or integrator installer with a set of parameters to assess “how easy will it be to work with this tubing”. The minimum bending radius is a quantitative measurement of the smallest allowed radius the tubing can be bent around without kinking or otherwise disrupting ink flow by wall collapse. Therefore, the smaller the bend radius, the greater is the material flexibility since it is less likely to kink during assembly or in-use. The maximum force to bend characterizes how easily the tubing will bend or give, which also directly impacts installation difficulty. Ink 1000 meets the desired minimum bend radius and the maximum force to bend in this industry.

Finally, the force required for fitting insertion is a gauge of how much work is required to connect tubing to luer or barbed fittings, which characterizes ‘flexibility’ across the cross section of the tubing. As shown in Figure 10, Tygon® 2375-D2 might be the most favorable product from an insertion perspective (relatively low), however, it is also observed that the tubing has a low retention force. The higher the insertion force, the higher the retention force. **Tygon® Ink 1000** has an insertion force between Tygon® 2375-D2 and other market offerings, providing a more desired balance between insertion and retention forces.

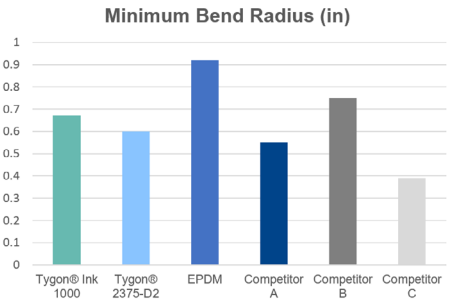

Figure 8. *Minimum Bend Radius Test Results, 4mm ID x 6mm OD*

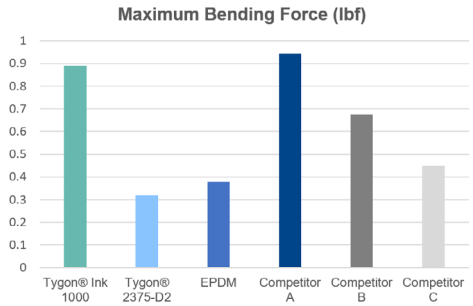

Figure 9. *Bending Force Test Results, 4mm ID x 6mm OD*

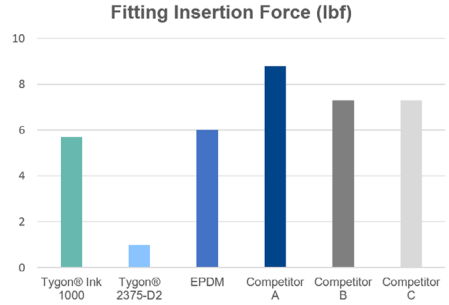

Figure 10. *Fitting Insertion Force Comparison (Ease of Use), 4mm ID x 6mm OD*

Summary:

Figure 11 shows a summary of the desired attributes for UV ink transfer tubing. As shown, **Tygon Ink® 1000** offers the best combination of performance and price.

In conclusion, we at Saint-Gobain have developed a UV ink transfer tubing product in **Tygon® Ink 1000** that is a universal solution for this niche digital printing market. The voice of the customer (VOC) within this market has guided the development of such a product, delivering the desired balance of properties (UV blocking, chemical resistance, flexibility), paving the way to a new standard tubing offering for the UV ink transfer market.

For any technical questions feel free to reach out to **Saint-Gobain's Engineering department**.

	Chemical Resistance		Flexibility	Price
	Jacket	Liner		
Tygon® Ink 1000				
Tygon® 2375-D2				
EPDM				
Competitor A - UV Ink Tubing				
Competitor B - UV Ink Tubing				
Competitor C - UV Ink Tubing				

Chemical Resistance
- : ±5% weight gain or loss (Figure 3)
- : ±5% weight gain or loss (Figure 3), but with visual change (Figure 4, 5)
- : >±5% weight gain or loss (Figure 3)

Flexibility
- : MBR < 0.6 inch (Figure 6)
- : 0.6 inch < MBR < 0.8 inch (Figure 6)
- : MBR > 0.8 inch (Figure 6)

Figure 11. *Overall Product Comparison for UV Ink transfer tubing products.*

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About Saint-Gobain

Saint-Gobain Life Sciences designs and manufactures high-performance components and innovative solutions across a wide range of industries, including biopharmaceuticals, medical, electronics, food and beverage, and more. Supported by deep material expertise and a global manufacturing footprint, our focus on quality and compliance makes us a trusted partner for consistent, reliable and sustainable solutions.

As part of the Saint-Gobain Group, we believe in progress and seek to be a game-changer that improves individual and collective health and wellness. We are convinced that the solutions that meet everyone's essential needs and allow us to live better together, without jeopardizing future generations, are still to be invented. Our commitment to reach this ambitious objective is guided by our shared purpose "MAKING THE WORLD A BETTER HOME."

Saint-Gobain's Industrial & Consumer Solutions (ICS) business unit helps customers achieve safety, performance, and brand assurance through a broad range of capabilities that rely on superior engineering and customer support. Our product applications include those in the food, beverage, habitat, and chemical markets, as well as others. We have helped customers in all of these industries achieve goals in innovation, efficiency, sustainability, and product integrity through customized solutions such as flexible tubing, hoses, fittings, seals, and more.

TYGON® Excellence By Design VERSILON™ Fluid Performance COVISON® Sealed. By Design

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