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How did the three ink *systems* compare?

The three ink systems were analyzed in terms of health risk concerns for flexo workers and the surrounding population, performance characteristics, environmental impacts (including emissions and material and energy use), and costs.

Every ink product line in the study contained chemicals that showed *clear* risk concerns for workers in the pressroom and prep-room.

Health risk concerns

The flexo ink study assessed possible risks for both dermal and inhalation exposure to chemicals. Each ink system was found to contain chemicals that, under presumed conditions, showed clear health risk concerns for workers who handle inks in the prep-room or pressroom.

General population

No chemicals in the study presented a *clear concern* for risk to the general population (people living near a printing facility), and most chemicals presented a negligible concern. Each ink system, however, had one category with chemicals that posed a *potential concern* for the general population: alcohols (functioning as solvents) in one solvent-based and two water-based formulations, and acrylated polyols in one UV-cured ink formulation (serving as reactive diluents). Based on reports by EPA's Structure Activity Team[3] (SAT), some propylene glycol ethers in one solvent-based ink, amides or nitrogenous compounds in two UV-cured inks, and acrylated polyols in one UV-cured ink may pose a potential risk concern to the general population.

Risk depends both on the toxicity of a chemical and the amount of it to which people and the environment are exposed. Risk varied by the product line, formulation, and how inks were handled. As an example, to help identify cleaner formulations, workers in the study were assumed to not wear gloves. However, if all workers were to wear appropriate gloves whenever they handle inks, dermal exposure would largely be removed (except for accidental spills on other parts of the body), and thus almost all dermal risks would be eliminated. Risk also may vary depending on the quality of pollution control equipment and the pressroom ventilation rate. For all these reasons, *the risk concerns found in the study will not necessarily*

Pressroom and prep-room workers

Every ink product line in the study contained chemicals that, under presumed conditions, showed *clear* risk concerns for workers in the pressroom and prep-room.

One way to compare the relative risk of the three ink systems is to rank formulations by the number or percent of chemicals predicted to pose a clear concern for worker risk. As shown in Table 4, the solvent- and water-based product lines[4] each included an average of 16 chemicals with clear risk concern. The total number of chemicals in an ink product line was determined by adding the numbers of base chemical ingredients and press-side solvents and additives for each formulation within a product line, and then summing the totals for all five formulations. Using this method, a chemical

[3] Information for some chemicals was incomplete. In these cases, systemic toxicity concerns were ranked by EPA's Structure Activity Team (SAT).

[4] A product line is a group of inks that is made by one manufacturer, shares certain printing characteristics, includes multiple colors, and is intended to be used with one ink system. For the flexo ink study, each product line contained five colors—blue, white, cyan, magenta, and green.

TABLE 4 Number of Chemicals with Clear Worker Risk Concern*

Ink type	Product Line	Number of Chemicals*	Toxicological Data**		SAT Data**		Total Chemicals of Clear Risk Concern**		
			No.	%	No.	%	No.	%	Rank***
Solvent-based	#S1	63	15	24%	2	3%	17	27%	5
	#S2	70	14	20%	0	0%	14	20%	10
		71	15	21%	0	0%	15	21%	9
		75	18	24%	0	0%	18	24%	7
Water-based	#W1	43	16	37%	0	0%	16	37%	1
	#W2	48	13	27%	3	6%	16	33%	2
	#W3	62	15	24%	0	0%	15	24%	6
		56	13	23%	0	0%	13	23%	8
	#W4	66	18	27%	0	0%	18	27%	4
UV-cured	#U1	48	1	2%	6	13%	7	15%	12
	#U2	70	16	23%	5	7%	21	30%	3
	#U3	46	0	0%	9	20%	9	20%	11

* Chemicals are counted more than once if found in more than one formulation within the same product line. The number of chemicals may also include site-specific press-side solvents or additives.
** Includes clear concern for risk for systemic or developmental effects via inhalation or dermal routes.
*** The ranking orders the product lines from the highest to lowest percentage of chemicals with clear concern for occupational risk.

was counted more than once if it were found in more than one formulation. For example, ethanol, used in three formulations within a product line, was considered to be three "chemicals." However, if a chemical presented a clear risk concern for both dermal and inhalation pathways in a single formulation, it was counted only once. Similarly, if a chemical presented a clear risk concern for both systemic and developmental effects, it was counted only once.

This ranking demonstrates the range of worker health characteristics within any given system. For example, the UV-cured system had the two "cleanest" product lines, as well as the third worst. *Thus, selecting the best formulations is just as important for a printer as selecting an ink system. Printers should work with their suppliers to identify cleaner formulations that meet their performance needs.*

Performance

The performance of the ink systems was evaluated by printing a representative test image at 11 volunteer facilities. Each of the study's nine product lines (two solvent-based, four water-based, and three UV-cured) was printed on three substrates (LDPE, OPP, and PE/EVA). Up to 18 standard performance tests were conducted on each ink-substrate combination to analyze a wide range of capabilities.

Table 5 lists the ink system, color, and substrate combinations showing "best in class" performance for selected tests that were run. Most of these tests do not have industry standards, and for some tests the determination of a better or worse result can depend on the needs of a specific printing situation.

The quality of performance varied widely across ink systems, substrates, and ink formulations. No clear evidence emerged that any one ink system performed best overall. For example,

- Water-based inks outperformed solvent-based inks on both LDPE and PE/EVA substrates. Solvent-based inks performed better than water-based inks on the adhesive lamination test.
- Gloss was highest for solvent-based inks on PE/EVA. Gloss was low on UV-cured inks, despite the fact that high gloss is considered a strength of UV finishes.
- Odors varied in both strength and type across both ink and substrate type.
- Mottle was significantly higher for water-based inks, as well as for blue inks overall. Mottle results for UV-cured inks were better than that of the water-based inks and comparable to that of the solvent-based inks.
- UV-cured inks displayed good resistance to blocking, particularly on PE/EVA and no-slip LDPE.
- UV-cured inks displayed relatively good trapping.
- Coating weight was greater for UV-cured inks, despite lower ink consumption. (This may indicate that UV-cured inks need higher linecount anilox rolls than were used in the study.)

Substrate type was important to quality, and ink-substrate interactions such as wetting and adhesion affected some of the results.

These performance demonstrations were intended to provide a snapshot of the capabilities of the ink-substrate combinations. They are not a substitute for thorough facility-specific testing to determine which ink system or product line performs best for a given printer or print job.

The study's performance tests:

Adhesive lamination

Block resistance

CIE L*a*b*

Coating weight

Coefficient of friction

Density

Dimensional stability

Gloss

Heat resistance/heat seal

Ice water crinkle adhesion

Image analysis

Jar odor

Mottle/lay

Opacity

Rub resistance

Tape adhesiveness

Trap

Uncured residue (UV-cured inks only)

TABLE 5 Selected "Best in Class" Performances on Flexo CTSA Tests

Test	Best Score	Ink System	Substrate	Color	Worst Score* **
Adhesive lamination	0.3040 kg (highest)	solvent**	OPP	N/A***	0.2575 kg (lowest)
Block resistance	1.0 (lowest)	UV no slip	LDPE	N/A	3.2 (highest)
Density	2.17 (highest)	UV high slip	LDPE	blue	1.09 (lowest)
Gloss	59.08 (highest)	solvent	PE/EVA	N/A	32.31 (lowest)
Heat resistance	0 failures (lowest)	solvent**	OPP	N/A	24 failures (most)
Ice water crinkle	no ink removal (least)	solvent,water	LDPE, PE/EVA	N/A	30% ink removal (most)
Image analysis	324 µm2 dot area (lowest)	solvent	PE/EVA	cyan	1,050 µm2 (highest)
Mottle	47 (lowest)	UV no slip	LDPE	green	812 (highest)
Rub resistance, wet	0 failures at 10 strokes	water, solvent	LDPE, PE/EVA	N/A	failure at 2.2 strokes

*This score represents the opposite end of the range of all scores received on this test for all ink systems tested, as an indicator of the wide range in scores on many tests.

**UV-cured samples were not tested.

***Results were not color-specific.

Materials consumption, energy use, and emissions[5]

Flexo printing, like many industries, consumes resources and releases pollutants to the environment. The study sought to determine the relative impacts of the three ink systems by examining the following:

- Materials used (i.e., inks and press-side additions).
- Energy consumed by press equipment specifically related to inks, including hot air drying systems, catalytic oxidizers, corona treaters, and UV curing systems.
- Pollutants released during the operation of this equipment, including carbon dioxide, carbon monoxide, dissolved solids, hydrocarbons, nitrogen oxides, particular matter, solid wastes, sulfur oxides, and sulfuric acid.

Table 6 shows the average quantity of materials and energy consumed, as well as energy-related pollutants released, for each ink system.

[5]The releases from energy use were estimated using computer modeling, rather than being measured at each facility.

TABLE 6 Materials Used, Energy Used, and Energy-Related Emissions Generated*

Ink System	Materials Used (Ink & Press-side Additions)(lb/6,000 ft^2)	Energy Used per 6,000 ft^2 (Btu)	All Energy-Related Emissions (g/6,000 ft^2)	Ink-Related Emissions (g/6,000 ft^2)
Solvent-based	8.53	100,000	10,000	824
Water-based	4.14	73,000	6,800	158
UV-cured	2.16	78,000	18,000	190

* These calculations assumed a press speed of 500 feet per minute.

Materials consumed

In general, the UV-cured systems used the lowest volume of materials, whereas the solvent-based systems used about four times this amount on average. These results are consistent with the general expectation that less UV-cured ink is needed because nearly all of the ingredients are incorporated into the dried coating, unlike for solvent-based and water-based inks. Also, except for one site, no press-side additions were used with the UV-cured systems.

Ink-related air emissions

For solvent-based and water-based systems, printers often make use of press-side additions. These materials can add to the VOC content of the ink and may pose clear pressroom worker risks. For example, at one of the flexo ink study sites using water-based inks, over half of the emissions resulted from materials added at press side.

Many inks and press-side additions (especially in solvent-based and water-based inks) contain VOCs and HAPs as a percentage of volume. VOC content was highest on average for the solvent-based ink systems. The averaged smog-related emissions from the water-based systems (221 grams/6,000 square feet) and UV-cured systems (300g/6,000ft^2) were considerably lower than those from the solvent-based systems (914g/6,000ft^2). This is because the water-based inks had substantially lower levels of VOCs than solvent-based systems, and the UV-cured inks had almost no VOCs. Therefore, despite the fact that the solvent-based systems used oxidizers, they generated considerable uncaptured emissions, leading to much higher ink-related emissions.

The flexo ink study assumed that solvent-based systems would have oxidizers with a 70% capture rate and a 95% destruction efficiency. If a facility has a higher capture rate (e.g., due to enclosed doctor blades) or higher destruction efficiency, expected emissions would be lower (and perhaps lower than emissions from a high-VOC water-based system).

The water-based systems were the only ones in the study that contained HAPs. Water-based printing systems that do not use oxidizers may therefore release HAPs as both uncaptured emissions in the facility and as stack emissions to the environment outside the facility.

The energy consumption and cost estimates assumed a 50% recirculation rate for solvent-based and water-based ink dryers.

Reducing the amounts of ink-related resources a flexo facility consumes may lower the amounts of pollutants, including VOCs and HAPs, released both inside and outside the facility.

Energy consumed

The solvent-based systems used the most energy to produce the same square footage of image, because they used energy-consuming oxidizers to destroy hazardous compounds. The water-based systems consumed the least energy, because they used neither oxidizers nor UV-curing equipment. The energy used by the UV-cured systems was only slightly higher than that of the water-based inks and was approximately 22% less than that of solvent-based inks.

Energy-related air emissions

Energy used in flexo — both power plants that supply electricity and in some cases at the flexo facility as well— can be a major source of emissions, particularly air emissions. Carbon dioxide (CO_2) is released by power generation. Although not regulated as a pollutant, CO_2 is the most common of the "greenhouse gases," which trap heat in the atmosphere and contribute to global warming. Energy used in flexo printing also generates hydrocarbons, nitrogen oxides (called NOx and pronounced "nox"), carbon monoxide (CO), sulfur oxides, and small airborne particles called particulate matter.

Hydrocarbons (from VOCs), NOx, and CO are smog-forming compounds. Smog is related to a number of health problems, including eye irritation, headaches, and asthma. In vulnerable people, smog also can aggravate serious lung and heart ailments. Particulate matter can cause respiratory problems and premature death, as well as impairing visibility and damaging physical structures such as buildings and sculptures.

- For UV-cured ink systems, the releases associated with energy production were higher than solvent-based systems. The releases from energy production were lowest for the water-based systems. These differences occurred because all energy required by the UV systems was derived from electricity — a more pollution-intensive energy source than natural gas, whereas much of the energy used for water-based and solvent-based systems was derived from natural gas, which releases fewer total pollutants per unit of energy.

Operating costs

A number of costs are important to facility profitability and have the potential to highlight differences among ink systems. The study evaluated the costs of materials (ink and press-side additions), labor, capital, and energy. Substrate costs were not evaluated because they are not dependent upon ink use. Input quantities for materials were obtained during the performance demonstrations. Suppliers provided information about costs.

This analysis averages industry information, and therefore it may not reflect the actual experience of any given printing facility in this short-term demonstration. For example, the efficiencies of a long run with familiar products were not achieved. Also, press speed under many printing conditions is expected to be different (and in general, higher) than in this analysis. While this study focused on those costs that typically account for the majority of total costs, other important costs (e.g., waste disposal, regulatory compliance, insurance, storage, clean-up, and permitting) should not be overlooked. In addition, press maintenance and other conditions may affect ink usage, and therefore ink costs.

Highlights of the cost analysis include the following (Table 7):

- Materials were the highest cost category. Water-based inks had the lowest material costs of the three systems, showing a higher mileage than solvent-based inks and a much lower per-pound cost than UV-cured inks.
- The analysis did not consider start-up and clean-up labor, and the press speed was assumed to be the same for all three ink systems. (Labor costs might have differed by ink system if the analysis had captured the costs of preparation, cleanup, etc.) Therefore, labor cost (wages and benefits for two press operators) was identical in the study for all three systems.
- Energy cost (electricity and natural gas) was highest for UV-cured inks. The water-based system showed the lowest energy cost because it assumed no energy use by oxidizers. If oxidizers were to be used, much of the water-based system's cost advantage would disappear.
- Water-based inks had the lowest capital costs (press and other required components), because the water-based printers did not use oxidizers. Solvent-based inks showed higher capital costs because of the expense of oxidizers. Because

TABLE 7 Average Costs of All Systems*

Ink System	Materials (Ink & Press-side Additions)	Labor	Energy	Capital	Total
Solvent-based	$15.29	$5.29	$0.53	$11.87	$32.98
Water-based	$9.55	$5.29	$0.35	$11.41	$26.60
UV-cured	$18.63	$5.29	$1.03	$11.87	$36.82

*Based on running 6,000 square feet and 500 feet per minute.

UV uses lamps to cure inks, this system also had higher capital costs. However, the capital costs of a new press for all three technologies were relatively similar. Therefore, they are likely to be only a small factor in the selection of an ink system.

- Assuming a press speed of 500 feet per minute, total cost was lowest for the water-based system, with the solvent-based and UV-cured systems costing on average 24% and 38% more, respectively. The water-based systems did not use oxidizers, which would have added to the energy and capital costs. Overall operating costs were highest for UV-cured inks, because materials and energy were most expensive.
- Press speed was found to be critical to overall cost because it influences labor, capital, and energy costs. Thus, press speed is likely to be the most significant factor in determining the cost-competitiveness of any ink system.

How to use these findings

Printers and suppliers need to work together to evaluate inks, identify possible alternatives, compare current and alternative ink products, and identify cleaner formulations that meet their performance needs.

The ink systems in the study varied in their risk concerns, performance, emissions, use of materials and energy, and operational costs. The findings show that there may not be one best overall choice of an ink system for all conditions and applications, and that *the choice of formulations within an ink system is just as important as the choice of ink system itself.* In calculating their costs, printers should include all expenses that affect the bottom line, including make-ready and cleanup, waste disposal, storage, permitting and other regulatory requirements, and insurance.

Also, as the study clearly points out, although many individual inks have undergone technical reformulating in recent years to reduce use of some hazardous substances, no ink system is inherently free of human health concerns. See Table 2 for suggested ways to reduce these concerns.