An Evaluation of Flexographic Inks on Wide-Web Film

SUMMARY BOOKLET

Office of Pollution Prevention and Toxics

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An Evaluation of Flexographic Inks on Wide-Web Film: Summary Booklet

Design for the Environment Program
Economics, Exposure, and Technology Division
Office of Pollution Prevention and Toxics (7404)
U.S. Environmental Protection Agency

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Developed in partnership with the following associations:

Flexible Packaging Association

napim

fta

California Film Extruders & Converters Association

RadTech International North America

Film & Bag Federation

Contents

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DfE would like to thank many individuals and organizations for their participation in this project, especially:

- The Flexo Project Steering Committee
- The Flexo Project Technical Committee
- Industry Contributors to the Flexo Project Performance Demonstrations

The DfE Partners, particularly the Steering Committee, include the major associations in the flexographic ink industry. These partners are an excellent source of information on both industry trends and concerns. Their willingness to maintain continued partnership with DfE over the years demonstrates their commitment to providing the industry with sound environmental information. Associations are considered essential DfE partners both during a project as well as for industry-wide communication and implementation of project results. Associations are key to sharing information, including incentives to making change and recognition of businesses that have made environmental improvements.

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* These companies voluntarily supplied materials for the CTSA or participated in the performance demonstrations.

For More Information

To learn more about the Design for the Environment (DfE) Flexography Partnership or the DfE Program, or to download any of DfE's documents, visit

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Disclaimer

This document presents findings and analysis of a voluntary, cooperative effort between the flexographic printing industry and the U.S. EPA. This is not an official guidance document and should not be relied on by companies in the printing industry to determine regulatory requirements. Information on cost and product usage in this document was provided by individual product vendors and has not been corroborated by EPA. Mention of specific company names or products does not constitute an endorsement by EPA.

Flexo Publications

Flexographic Ink Options: A Cleaner Technologies Substitutes Assessment (CTSA)
Vol 1: EPA EPA 744-R-02-001-A
Vol 2: EPA EPA 744-R-02-001-B

An Evaluation of Flexographic Inks on Wide-Web Film: Summary Booklet
EPA 744-R-02-002

Developing Cleaner Ink Formulations: A Flowchart for Ink Formulators (brochure)
EPA 744-F-02-003

Options for Cleaner Flexo Inks: Highlights from the Flexo CTSA (brochure)
EPA 744-F-02-004

Reducing VOCs in Flexography (case study)

EPA 744-F-96-013

Learning from Three Companies that Reduced VOC Emissions (case study)
EPA 744-F-96-016

Inside Flexo: A Cleaner Run for the Money (video)
(EPA 744-V-98-001)

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What is the flexo ink study about?

The objective of the CTSA was to develop as complete, systematic, and unbiased a picture as possible of different flexo ink technologies, thereby helping industry incorporate environmental and health information into their ink decisions.

This booklet summarizes the key findings of the Flexography Partnership's recent technical report, *Flexographic Ink Options: A Cleaner Technologies Substitutes Assessment (CTSA)*. The complete CTSA documents a detailed research study comparing the environmental impacts, health risks, performance, and costs of the three main flexo ink systems (solvent-based, water-based, and ultraviolet [UV]-cured).

Where the CTSA details performance, cost, and environment, this booklet focuses on the environmental and health findings of the study, for two reasons:

- First, printers often tend to be less familiar with health and environmental concerns than with cost and performance issues.
- Second, the study found a wide range of environmental, health, and safety concerns for all three ink systems, and it is important for printers to become more familiar with these concerns so that they can reduce exposure and related risks to flexo workers, the surrounding community, and the natural environment. Furthermore, taking such steps has the potential to conserve materials and resources, with the potential to reduce costs.

Flexographic Ink Options: A Cleaner Technologies Substitutes Assessment (CTSA) can be downloaded from the DfE website (www.epa.gov/dfe). For printed copies, contact EPA's National Service Center for Environmental Publications (NCEPI). Ask for:

Vol 1: EPA EPA 744-R-02-001-A
Vol 2: EPA EPA 744-R-02-001-B

This booklet, which summarizes important findings of the flexo ink study, was developed for managers of flexo printing facilities and ink formulators, as well as for other decision-makers about flexo ink products. The booklet, as well as other materials published about the flexo ink study, can help flexo professionals to:

- understand more about comparative chemical risks in inks, including identifying concerns for unregulated chemicals in inks that present opportunities for proactive, voluntary risk management,
- facilitate the use and formulation of cleaner inks, and
- encourage adoption of workplace practices that minimize health and environmental risks from exposure to chemicals of concern, and may reduce the burden of regulatory compliance.

How the Flexo Partnership began

Because flexo facilities use so much ink, collectively they have a major environmental impact. Historically, most flexo inks have been solvent-based, with high levels of volatile organic compounds (VOCs) and other toxic chemicals. The industry has made great progress in addressing environmental and health concerns of inks through reformulation, add-on pollution control devices, and other improvements to operations and materials. However, for the benefit of flexo workers, the surrounding community, and the environment, we need to gain a better understanding of the possible health and environmental concerns of ink chemicals.

Flexo professionals can benefit from a better understanding of the possible health and environmental concerns of ink chemicals.

Because of such concerns, the Design for the Environment (DfE) Program at the U.S. Environmental Protection Agency (EPA) joined forces with the flexo industry on a comprehensive, comparative assessment of environmental and health impacts, cost, and performance of a cross-section of inks.

In designing the study, DfE formed the "flexo partnership" with over 60 participants representing flexo associations, printers, ink suppliers, and universities. The partnership elected to focus on inks because they are a major use and cost category for printers, and because the many small flexo firms might not have the resources or expertise to research the environmental implications of inks. The overarching goal of the partnership was to obtain a broader understanding of the environmental and health impacts of ink chemicals, as well as to encourage the innovation and use of even cleaner, safer inks.

Planning the Flexo Ink Study

The partners agreed to perform a cleaner technologies substitutes assessment for flexo inks. The objective of the CTSA was to develop as complete, systematic, and unbiased a picture as possible of different flexo ink technologies, thereby helping industry incorporate environmental and health information into their ink decisions.

The study compared environmental and health impacts, performance, and cost of the three primary flexo ink systems when printing film substrates on wide-web presses. Because of their long-standing use by flexo printers, solvent-based inks were used as the "baseline," and water-based and UV-cured inks were compared to the baseline inks. When the study began, some project participants wanted to learn whether any ink system showed clear advantages in terms of health, safety, or environmental aspects. Thus, the study looked at the ink systems, as well as analyzing the chemicals and chemical categories of the inks within those systems. The project focused on inks used on film because flexography — particularly the packaging sector — prints a wide variety of products on nonporous substrates. The partners hoped that this choice would help make the findings more directly useful to as many flexo printers as possible.

The research focused specifically on inks printed on film, because of the special technical and environmental challenges for printers presented by this combination, including chemical emissions, worker health and safety issues, and some hazardous waste concerns. The three types of film were chosen because they correspond to important flexo market segments:

- LDPE (low-density polyethelene), used for shopping bags and bread bags,
- PE/EVA (polyethylene/ethyl vinyl acetate) co-extruded film, used for frozen food bags, and
- OPP (oriented polypropylene), used for snack food bags and candy wrappers.

Partners volunteered information about forty-five different ink formulations, which then were analyzed to give a comparative, screening-level assessment of the chemical toxicity, exposure, and health risks across the three ink systems. Altogether, the proj-

What Is Flexo?

Flexography is a large, vibrant industry creating many products that are used every day by virtually everyone. Take a look at these facts about flexo:

- U.S. flexo firms had annual sales of approximately $50 billion in 1999. [1]
- The sector employs about 30,000 people. [2]
- More than 80% of all flexo firms have fewer than 50 employees.
- Flexo has an annual growth rate of about 6%. [3]
- Flexo printing consumed more than 513 million pounds of ink in 2000. [4]
- Flexible film packaging accounts for nearly 20% of the flexo market and is valued at $20 billion annually. [5]

Flexography is used primarily for printing on paper, corrugated paperboard, and flexible plastic materials. Flexo is well suited to printing on flexible and non-uniform surfaces (such as plastic films and corrugated board). Many common products are printed using flexo, such as snack food and frozen food bags, labels for medicines and personal care products, newspapers, drink bottles, and cereal containers.

When the study was conducted, UV-cured inks were not being used commercially to a significant extent to print film substrates on wide-web presses.

ect identified and studied more than 100 chemicals that were found in these ink formulations. The formulas chosen were considered typical ink formulations used in each system. The costs of buying and using these inks were studied, as was the energy consumed in printing with these inks. Also, printed test samples were subjected to 18 distinct performance tests that covered a wide variety of conditions important to many flexo printers. However, the study was not meant to cover every possible ink formulation, performance category, or substrate type. Rather, it gives an in-depth "snapshot" of flexo inks. Nonetheless, the completed study is thought to be the most comprehensive research available on flexo inks, and it is an important resource in undertaking changes that could benefit workers, the environment, and the bottom line.

Notably, the Partnership designed the Flexo CTSA as a *comparative* study, rather than as an *optimization* study, because Project Partners saw optimization as the purview of individual printers. Partners recommended conducting the performance demonstrations at 500 feet per minute, a speed that they felt all three systems could run at with acceptable performance. Printers who run their presses at faster speeds are likely to experience lower operating costs and higher ink use, emissions, worker exposure, and risks than those found in the CTSA. In this sense, the flexo ink study should be considered a conservative assessment.

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What conclusions did the study reach?

The study compared environmental and health impacts, performance, and costs of the three primary flexo ink systems: solvent-based, water-based, and UV-cured inks. Environmental impacts included aquatic toxicity, emissions, energy use, resource consumption, and human health effects. The health impacts included estimated exposure and comparative risks to pressroom and prep-room workers and residents of surrounding communities, as well as safety hazards.

Some water-based and UV-cured ink formulations demonstrated improvements in worker safety, reduced concerns for health and environmental risk, and lower material costs.

Overall findings

No ink system was superior across performance, environmental, health, and cost criteria, although each system had advantages.

The study found a wide range of environmental, health, and safety (EH&S) characteristics of formulations in solvent-based, water-based, and UV-cured ink systems. This highlights the need for the flexo industry to work to identify and develop ink formulations that have superior EH&S profiles while still meeting performance needs.

Performance

Materials, equipment, and process need to be customized for each ink formulation, substrate, and printing situation.

All three ink systems performed acceptably, but each system showed a notable range of results on the 18 performance tests that were conducted. Results sometimes varied depending on the test site or the ink color. Substrate type also played a major role in performance, indicating that the ink-substrate relationship was very important to ink performance. The many variations in performance indicate the importance of customizing materials, equipment, and process for each ink formulation, substrate, and printing situation.

Health concerns

None of the ink systems was predicted to pose clear concerns for health risks to people in surrounding communities. However, all ink systems contained chemicals of clear concern for health risks to flexo pressroom and prep-room workers, as well as safety hazards.[1]

About 25% of the chemicals studied showed clear concerns for systemic or develop-

The study's health findings reinforce the need for adequate ventilation and for flexo workers to wear appropriate gloves and other personal protective equipment when working with inks. The findings also underscore the importance of developing improved formulations that reduce the EH&S concerns of ink chemicals.

[1]Pressroom workers were exposed via both inhalation and dermal routes; prep-room workers, however, were exposed via the dermal route only.

mental risks to workers under the conditions of the study. Chemicals showed risk concerns to workers via both inhalation (breathing) and dermal (skin) exposure routes. The study shows that it is *not* reasonable to assume an ink product is "safe" or "risk free" without knowing more about the chemicals in the product as well as the hazards associated with those chemicals and expected exposure to the product.

Aquatic toxicity

It is important to store and use chemicals properly, to avoid accidental releases that may end up in water systems. Inks and their wastes should never be put down the drain.

Over half of the ink chemicals studied showed a high or medium hazard to aquatic environments.

It is important to store and use chemicals properly, to avoid accidental or intentional releases that may end up in water systems. Inks and their wastes should never be put down the drain. Caution should be taken as well with equipment cleaning.

Consumption of materials

The UV-cured systems consumed the least ink and press-side additions.

The solvent-based ink systems used, on average, about twice the materials (inks and press-side additions) as the water-based inks and four times the materials as the UV-cured inks.

Ink-related emissions

Even with oxidizers, the solvent-based ink systems had higher VOC emissions than the other two systems, on average.

As expected, water-based inks had a much lower VOC content than solvent-based inks. Interestingly, despite the fact that they used oxidizers, the solvent-based systems generated considerable uncaptured emissions, leading to much higher total ink-related emissions. The water-based systems were, however, the only ones in the study that contained listed hazardous air pollutants (HAPs). Because many inks and press-side additions (especially those in solvent-based and water-based inks) contain VOCs and HAPS, reducing the use of these materials may also lower the amounts of pollutants, both uncaptured (fugitive) emissions in the pressroom and stack emissions that are released outside the facility.

Energy consumption

The water-based systems consumed the least energy.

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

The water-based ink systems had the lowest releases of energy-related emissions.

Releases of polluting air emissions were associated with the facility's energy source. Emissions were highest for the UV-cured systems, because they depended entirely upon electricity, which releases more pollutants per unit of substrate printed than does natural gas. So, even though the UV-cured systems used only slightly more energy than the water-based systems, they contributed a larger share of pollutants based upon that energy use. By knowing more about the environmental impacts that can be attributed to the printing process a flexo facility uses, printers can plan ways to appropriately reduce energy use and related environmental releases. Employing more energy-efficient technologies may benefit a facility by reducing production costs, lowering energy-related emissions, and improving the facility's public image.

By knowing more about the environmental impacts that can be attributed to the printing process a flexo facility uses, printers can plan ways to appropriately reduce energy use and related environmental releases. Employing more energy-efficient technologies may benefit a facility by reducing production costs, lowering energy-related emissions, and improving the facility's public image.

Operating costs

Press speed was the most important driver of operating costs.

UV-cured inks in the study had the highest operating costs due to the higher cost of materials and energy, whereas water-based inks had the lowest costs. The UV-cured inks cost 29-46% more than the water-based inks, whereas the solvent-based inks cost 1% to 39% more than the water-based inks. Although the water-based systems had the lowest energy and capital costs, they did not use oxidizers, which would have added to these costs.

In addition to these specific findings, the study found press speed to be a critical driver of overall operating costs, because it affected all costs except inks and substrates.

The bottom line

The flexo ink study found that each of the ink systems studied had a range of different advantages, as well as health and environmental concerns. Considerable variation was noted even among different colors within a single ink product line. Thus, selecting the best formulations is just as important for a printer as selecting an ink system. To identify the "right mix" of ink products for a specific facility, flexo professionals need to consider many different EH&S aspects — environmental hazards, exposure to potentially harmful products, safety considerations, and the type of energy used — as well as performance, cost, substrate, press design, and operating conditions.

Selecting the best formulations is just as important for a printer as selecting an ink system.

Acceptable performance is a critical characteristic of any environmentally preferable technology. Printers should work with their suppliers to select cleaner inks that deliver important performance characteristics.

To be a good proactive decision-maker, it is critical to have the best information available. Developing and choosing product formulations with more positive environmental profiles may require extra care and scrutiny, especially when selecting raw materials.

The flexo ink study provides screening-level information about risks to human health and the environment associated with each ink system, and offers a basis for comparison. Chemicals predicted to pose a clear concern for health risk in a screening-level assessment are good candidates for a more rigorous assessment.

The model used for the study showed that there would be little exposure to the general population.

Exposure was "modeled" — that is, it was not based on actual measurements of releases. The study made assumptions about a hypothetical model facility, most of which reflect typical operating conditions. Under a different set of assumptions, the findings might have been different. Some important assumptions follow.

- 30% of VOCs released to air would be uncaptured emissions, and 70% would be stack emissions.
- Solvent-based ink systems would have a catalytic oxidizer with a 95% destruction efficiency.
- Pressroom and prep-room workers would work a 7.5 hour shift, 250 days/year.
- Pressroom and prep-room workers would have routine two-hand contact (no gloves) with ink unless a substance was corrosive.
- Press speed would be 500 feet per minute.

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Which ***chemicals*** showed concerns for health risk?

Chemicals in flexo inks have the potential to affect workers and the wider community around flexo facilities. The study analyzed potential risks under certain operating conditions, and found concerns for pressroom and prep-room workers in all three ink systems. This indicates the need for flexo professionals to take steps to address worker health concerns as well as the opportunity to make improvements in ink formulations. This chapter identifies the chemicals and chemical categories in the flexo inks that were found to have risk concerns under the conditions of the study. First, however, it explains the aspects of risk that the flexo ink study examined.

Information about human health risk

The health risk concerns posed by ink chemicals can be systemic, developmental, or carcinogenic. *Systemic toxicity* refers to adverse effects on any organ system (such as the lungs or the nervous system). *Developmental toxicity* means adverse effects that may occur to a developing organism any time between conception and sexual maturity. Developmental toxicity can manifest itself in a number of ways, ranging from altered growth or structural (physical) abnormalities to death. *Carcinogenic effects* are malignant tumors caused by cancer.

This study examined systemic and developmental effects, but it was not able to identify cancer risks for the ink chemicals because of insufficient quantitative data. Although some chemicals in the study had some evidence of carcinogenicity (such as tumors in experimental animals), none were known to cause cancer when touched or inhaled.

It is important to realize that risk depends both on the toxicity of a chemical and on the amount of it to which people and the environment are exposed. Thus, risk varies for different ink product lines and formulations. Risk also changes depending upon how inks are handled. As an example, if all workers wear appropriate gloves whenever they handle inks, dermal exposure is largely removed (except for accidental spills on other parts of the body), and so almost all dermal risks will 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 match those in a particular printing facility.*

Definitions of risk used in the study

- *Clear concern* for risk indicates that for the chemical in question under the assumed exposure conditions of the study, adverse effects were predicted to occur.
- *Potential concern* for risk indicates that for the chemical in question under the assumed exposure conditions, adverse effects may occur.
- *Low or negligible concern* for risk indicates that for the chemical in question under the assumed exposure conditions, no adverse effects were expected. The criteria for each level of risk are shown in Table 1.

TABLE 1 Criteria for Risk Levels[2]

Level of Concern for Risk	Hazard Quotient	Margin of Exposure NOAEL	Margin of Exposure LOAEL	SAT Hazard Rating*
CLEAR	**>10**	**1 to 10**	**1 to 10**	**MODERATE-HIGH**
Potential	1 to 10	>10 to 100	>100 to 1,000	low-moderate
Low or negligible	<1	>100	>1,000	low

* This column presents the level of risk concern if exposure is expected. If exposure is not expected, the level of risk concern is assumed to be low or negligible.

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, 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 match those in a particular printing facility.*

[2] Hazard Quotient (HQ) is the ratio of the average daily dose (ADD) to the Reference Dose (RfD) or Reference Concentration (RfC), where RfD and RfC are defined as the lowest daily human exposure that is likely to be without appreciable risk of non-cancer toxic effects during a lifetime. The more the HQ exceeds 1, the greater the level of concern. HQ values below 1 imply that adverse effects are not likely to occur.

Margin of Exposure (MOE) is calculated when a RfD or RfC is not available. MOE is the ratio of the No Observed Adverse Effect Level (NOAEL) or Lowest Observed Adverse Effect Level (LOAEL) of a chemical to the estimated human dose or exposure level. The NOAEL is the level at which no significant adverse effects are observed. The LOAEL is the lowest concentration at which adverse effects are observed. The MOE indicates the magnitude by which the NOAEL or LOAEL exceeds the estimated human dose or exposure level. High MOE values (e.g., greater than 100 for a NOAEL-based MOE or greater than 1,000 for a LOAEL-based MOE) imply a low level of risk. As the MOE decreases, the level of risk increases.

Information for some chemicals was incomplete. In these cases, systemic toxicity concerns were ranked by EPA's Structure Activity Team (SAT) according to the following criteria: high concern — evidence of adverse effects in humans, or conclusive evidence of severe effects in animal studies; moderate concern — suggestive evidence of toxic effects in animals; or close structural, functional, and/or mechanistic analogy to chemicals with known toxicity; low concern — chemicals not meeting the above criteria.

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

Although some chemicals in the study had some evidence of carcinogenicity (such as tumors in experimental animals), the study was not able to identify cancer risks for these chemicals because of insufficient quantitative data.

Substantial use of some press-side additives may contribute to potential worker health concerns.

Findings about chemical risk

Under the conditions of the study, certain chemicals in each ink system were predicted to pose a clear occupational risk to workers. Table 2 lists the chemical categories and chemicals showing clear risk concern for workers, as well as exposure routes and toxicological endpoints for each chemical.

Alcohols contained the most chemicals of clear concern for risk in the solvent-based and water-based ink formulations.

Systemic and developmental effects that have been reported in the medical literature (from animal or human studies) in association with use of a chemical are known as *toxic endpoints*. Neurotoxic effects, eye irritation, lung effects, decreased growth, and increased mortality are just a few examples of possible toxic endpoints. Toxic endpoints provide an idea of the kinds of adverse effects on body organ systems that may occur from exposure to a chemical.

All chemical categories except olifin polymers included one or more chemicals that were predicted to pose a risk concern for flexo workers. Ten solvents presented clear risk concerns for workers. This was the largest number of chemicals serving any one ink function. Thus, the solvents in solvent-based and water-based inks deserve scrutiny to determine whether they may present risks to the workers in flexo facilities. Several amides or nitrogenous compounds in water-based formulations presented a clear concern for systemic risks to workers. The acrylated polyols contained four chemicals posing a clear concern for risk in the UV-cured formulations.

The use of press-side additions, such as solvents and additives, increased the worker risk concern for many of the solvent- and water-based ink formulations. In particular, propanol and propylene glycol methyl ether in solvent-based systems, as well as ammonia, propanol, isobutanol, and ethyl carbitol in water-based systems, presented potential or clear worker risk concerns when used in the volumes observed during the performance demonstrations.

TABLE 2 Flexo Ink Chemicals Showing Clear Risk Concerns for Flexo Workers (under conditions of the CTSA)

Chemical	Function in Ink	Exposure Route*	Toxic Endpoints**
Acrylated polymers (found in UV system)			
Glycerol propoxylate triacrylate	UV reactive compound	derm	tissue necrosis, decreased body weight, neurotoxic and respiratory effects
Acrylated polyols (found in UV system)			
Dipropylene glycol diacrylate	UV reactive compound	inhal, derm	SAT: genotoxicity, neurotoxicity, oncogenicity; developmental and reproductive effects; derm and respiratory sensitization; skin and eye irritation
1,6-Hexanediol diacrylate	UV reactive compound	inhal, derm	developmental effects
Hydroxypropyl acrylate	UV reactive compound	inhal, derm	respiratory effects
Trimethylolpropane triacrylate	UV reactive compound	derm	decreased body weight; skin and neurotoxic effects; changes in clinical chemistry; altered organ weights; respiratory effects
Alcohols (found in all systems)			
Ethanol	Solvent	inhal, derm	blood, liver, neurotoxic, and reproductive effects, decreased cellularity of the spleen, thymus, and bone marrow; dev: fetal malformations
Isobutanol	Solvent	inhal	blood and neurotoxic effects, changes in enzyme levels; dev: cardiac septal defects
Isopropanol	Solvent	inhal, derm	blood and skin effects, tissue necrosis; kidney, liver, neurotoxic, reproductive, spleen, and respiratory effects; changes in enzyme levels and clinical and urine chemistry; dev: fetal death, musculoskeletal abnormalities, fetotoxicity
Alkyl acetates (found in all systems)			
Butyl acetate	Solvent	inhal, derm	changes in serum chemistry, fluctuations in blood pressure; dev: fetotoxicity, musculoskeletal abnormalities
Ethyl acetate	Solvent	inhal	blood, cardiovascular, gastrointestinal, kidney, liver, neurotoxic, and respiratory effects; decreased spleen and liver weight; increased adrenal, lung, and kidney weight
Amides or nitrogenous compounds (found in all systems)			
Ammonia	Multiple	inhal, derm	skin and eye irritation; corneal, liver, spleen, and respiratory effects
Ammonium hydroxide	Multiple	inhal, derm	eye effects, nasal irritation, respiratory effects
Ethanolamine	Multiple	inhal, derm	respiratory irritation; kidney, liver, neurotoxic, and respiratory effects
Hydroxylamine derivative	Multiple	inhal, derm	SAT: genotoxicity, dermal sensitization, developmental toxicity

TABLE 2 Flexo Ink Chemicals Showing Clear Risk Concerns for Flexo Workers

Chemical	Function in Ink	Exposure Route*	Toxic Endpoints**
Ethylene glycol ethers (found in water system)			
Alcohols, C11-15-secondary, ethoxylated	Solvent	derm	Overall concern; severe skin irritation, eye irritation, lung effects
Butyl carbitol	Solvent	inhal, derm	blood and skin effects, liver effects
Ethyl carbitol	Solvent	inhal, derm	decreased food consumption, bladder, blood, kidney, liver, neurotoxic, reproductive, and spleen effects; dev: sperm, liver, brain, and birth weight in offspring***
Hydrocarbons — low molecular weight (found in solvent and water systems)			
n-Heptane	Multiple	inhal	auditory and neurotoxic effects, altered serum chemistry
Inorganics (solvent and water systems)			
Barium	Solvent	derm	decreased body weight, increased arterial blood pressure, reproductive and respiratory effects; dev: reduced survival, decreased weight gain, blood effects
Organic acids or salts (found in solvent and water systems)			
Dioctyl sulfosuccinate, sodium salt	Additive	derm	death, gastrointestinal and neurotoxic effects; dev: body weight effects; (SAT) derm sensitizer to humans***
Organophosphorous compounds (found in solvent and UV systems)			
Phosphine oxide, bis(2,6-dimethoxybenzoyl)(2,4,4-trimethylpentyl)-	Multiple	derm	neurotoxic, food consumption and body weight, adrenal, blood, skin, and liver effects***
Organotitanium compounds (found in solvent system)			
Isopropoxyethoxy-titanium bis (acetylacetonate)	Additive	derm	SAT: neurotoxicity, genotoxicity, oncotoxicity, and developmental/reproductive toxicity. Skin, eye, mucous membrane irritant
Titanium diisopropoxide bis(2,4-pentanedionate)	Additive	derm	SAT: irritation of the eyes, skin, and mucous membranes. Moderate concern based on release of hydrolysis products: 2,4 pentanedione, inorganic titanium, and isopropanol. 2,4 pentanedione: concern for neurotoxicity, mutagenicity, oncogenicity, and developmental/reproductive toxicity. Inorganic titanium: concern for mutagenicity and oncogenicity. Isopropanol: concern for liver, neurotoxic, reproductive, respiratory, and spleen effects; changes in enzyme levels and clinical and urine chemistry; fetal death, musculoskeletal abnormalities, fetotoxicity, blood and skin effects, tissue necrosis at application site, increased kidney and liver weight.

Chemical	Function in Ink	Exposure Route*	Toxic Endpoints**
Titanium isopropoxide	Additive	derm	irritation of the eyes, skin, and mucous membranes. Moderate concern based on release of the hydrolysis products, inorganic titanium and isopropanol. Inorganic titanium: concern for mutagenicity and oncogenicity. Isopropanol: concern for liver, neurotoxic, reproductive, respiratory, and spleen effects; changes in enzyme levels and clinical and urine chemistry; fetal death, musculoskeletal abnormalities, fetotoxicity, blood and skin effects, tissue necrosis at application site, increased kidney and liver weight.
Pigments — organic (found in all systems)			
C.I. Pigment Red 23	Colorant	derm	blood, kidney, and stomach effects***
Pigments — organometallic (found in all systems)			
D&C Red No. 7	Colorant	derm	thymus and reproductive effects, changes in clinical chemistry, kidney effects, decreased thymus weight***
Propylene glycol ethers (found in solvent and water systems)			
Propylene glycol methyl ether	Solvent	inhal, derm	increased mortality; blood, developmental, liver, neurotoxic, reproductive, respiratory, and skin effects; altered organ weights; and decreased growth

These chemicals were predicted to pose risk concerns under the specific conditions of this study; they might be associated with different risks, or with no risk at all, under different conditions.

Abbreviations: dev = developmental effects. All endpoints not specifically indicated as developmental are systemic.

SAT = Structure Activity Team and acute data reports.

*Only pressroom workers were assumed to have exposure via inhalation (inhal). Both prep-room and pressroom workers were assumed to have dermal exposure (derm).

**Toxicological endpoints are the potential effects on organ systems (e.g., cardiac, respiratory) that have been reported in the medical literature and other reports in association with use of a chemical. A reported association does not mean that the effect is necessarily caused by the chemical.

***Reported effects may have been observed from a different exposure route.

Aspects of inks to learn more about

- Press-side additions
- Cleaning products
- Air emissions (VOCs and HAPs)
- Safety hazards (e.g., flammability, ignitability, reactivity, corrosivity)
- Environmental hazards
- Health risks to workers
- Health risks to community
- Energy consumption and opportunities for conservation
- Solid wastes
- Unregulated chemicals
- Untested chemicals

The databases and resources listed at the back of this booklet identify chemical substances by specific chemical name. It is important to obtain the correct chemical identification information, which includes Chemical Abstract Service (CAS) names and numbers when doing research on chemical formulations.

Ways to reduce health risks of flexo inks

Inhalation risks to flexo workers can be managed to a great extent by ensuring good ventilation in the pressroom and prep-rooms, and by creating and enforcing clear policies for use of masks and respirators. Dermal risks can be managed by making sure that all workers wear the right gloves whenever they are handling inks, press-side additions, or cleaners.

Many of the substances analyzed in the study were found in multiple ink formulations and are likely to be found in other inks as well. Risks posed by ink chemicals can continue to exist as long as toxic chemicals are present and being used. Therefore, whether choosing among the ink systems or choosing an ink formulation, it is important to consider the EH&S impacts of the chemical substances that make up a formulated product. The flexo ink study can serve as a first step in bringing a more positive environmental profile into the printing shop.

Health considerations are as basic to good printing as are performance and cost. Identifying chemicals that have lower toxicities provides important opportunities to remove these chemicals from formulations before they can enter the workplace and the environment. In addition, moving to chemicals with reduced impacts will increase environmental and health benefits. Possible benefits of switching to a cleaner ink formulation may include

- reduced health and safety risk concerns for workers and the community,
- fewer regulatory requirements,
- greater customer satisfaction,
- increased efficiency,
- a move to innovative technologies, and
- lower operating costs while maintaining high quality standards.

Flexo professionals play an important role in minimizing the impacts of ink chemicals. This responsibility extends beyond the walls of facilities to the greater community and the environment. Ensuring that workers wear appropriate protective gear is just the starting point. Only a very small percentage of the perhaps 80,000 chemicals available for commercial use today have been adequately tested for health and environmental hazards. More than half of the chemicals in the flexo ink study had no little or no published toxicological data available at the time of the study. Many chemicals that are not regulated by any U.S. government organization were predicted to present a clear or possible risk concern to workers under the conditions of the study.

The inadequacy of much chemical data points to the importance of learning more about the categories and specific chemicals in flexo inks and related products. It is important to support research on untested and inadequately tested flexo ink chemicals, especially those with clear or potential risk concerns and those produced in high quantities. Very little basic toxicity information is publicly available on most of the commercial chemicals made and used in the United States. Without this basic hazard information, it is hard to make sound judgments about what risks these chemicals could present to people and the environment.

Flexo professionals can and should work to identify and use formulations that will help protect workers and the environment. The DfE Program encourages printers, ink manufacturers, and distributors to actively engage in a dialog on "*getting the right mix*" in flexo facilities. Printers and suppliers need to work together to evaluate inks, identify possible alternatives, and compare current and alternative ink products. This may yield benefits for printers and formulators, as well as providing benefits for workers and the environment.

The Material Data Safety Sheet (MSDS) and the product label are excellent places to start in understanding the potential impacts of a chemical. However, the MSDS or label may not provide enough information to make a better choice. Often, chemicals are generically described by chemical class or by trade name. Structural and other differences in chemicals of the same general class and makeup may not be apparent from product literature or labels, especially for imported substances. Descriptions in distributor or supplier literature and catalogs may define a chemical type, but not detail an actual chemical structure (e.g., whether a carbon chain is branched or linear — a key distinction from an environmental standpoint since linear chains biodegrade more rapidly than branched). Also, sales materials may only list trade names, often an imprecise descriptor, since a name might remain the same while the actual product composition may change.

Table 3 lists some ways that flexo professionals can reduce risks and improve environmental responsibility related to ink chemicals.

Because any given printing facility may use different inks and have different operating conditions than those of the Flexo CTSA, these chemicals may not pose a clear concern at that facility. However, a facility that does work with chemicals studied by the CTSA should carefully assess their use and potential worker exposure, and manage appropriately.

There are approximately 2,800 high-production-volume (HPV) chemicals for which little data are available. HPV chemicals are those manufactured in, or imported into, the US in amounts equal to or exceeding 1 million pounds per year. To provide important data, EPA challenged industry to provide testing or further information about these chemicals. In response, many of the HPV chemicals have been ponsored by industry, and EPA hopes to have all HPV testing completed by 2004.

The DfE Program has developed an *Integrated Environmental Management System (IEMS) Implementation Guide* that helps businesses plan, set up, and maintain an IEMS. You may download it from the DfE website (www.epa.gov/dfe), or contact EPA's National Service Center for Environmental Publications. The publication number is EPA 744-R-00-011.

TABLE 3
Ways to Reduce Environmental, Health, and Safety Concerns of Ink Chemicals

- Ensure that all workers who handle inks wear appropriate personal protective gear (e.g., butyl or nitrile gloves and respirators as needed) to minimize exposure to chemicals. More information on which gloves to choose for working with specific chemicals can be found at the National Toxicology Program website: http://ntp-server.niehs.nih.gov
- Maximize good ventilation, particularly in ink prep-rooms and pressrooms.
- Develop other safety policies and practices for inks, and ensure that workers follow them.
- Make environmental and health information about ink chemicals more accessible and understandable (e.g., expand MSDSs, provide best practice tips, include chemical information in sales materials).
- Become familiar with environmental and health impacts of chemicals in inks.
- Select the cleanest inks that make business sense.
- Minimize use of hazardous inks as well as press-side additions.
- Ensure that all pollution control devices are maintained properly and work correctly at all times.
- Look at all steps in the printing process throughout the facility to identify ways to improve operations and environmental performance. If not already in process, start developing an **environmental management system**.
- Support further research on ink chemicals.

4

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.

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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.

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.

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

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.

5

Solvent-based inks: Chemical category findings

Although solvent-based inks typically offer excellent quality and dependability, they contain relatively high concentrations of VOCs. Oxidizers destroy most stack emissions that would otherwise be released to the environment, but these devices have no effect on emissions in the pressroom, which may eventually be released to the environment. Also, the solvent-based inks in the study contained several chemicals that, under the conditions of the flexo ink study, were predicted to pose clear risk concerns for workers. This chapter summarizes the flexo ink study's health-related findings for the two solvent-based ink product lines.

A chemical category would typically describe a group of chemicals with shared or similar chemical and toxicological properties. The flexo ink study borrowed from EPA's New Chemical Categories (www.epa.gov/oppt-intr/newchems/chemcat.htm) as a means to group the chemical substances that the partners shared for this study. To determine whether other similar substances would be included in a chemical category, and therefore predicted to express similar health and environmental concerns, category boundary conditions such as molecular structure and weight, water solubility, etc. should be considered.

General population

No chemical categories with *clear concern for risk* to people living near a printing facility were identified in the solvent-based systems that were studied, and most categories presented a negligible concern. The categories of alcohols and propylene glycol ethers (both used as solvents) contained chemicals that showed *potential concern for risk*. Also, the use of press-side additions increased risk concerns for some solvent-based formulations.

Although the general population was not found to be at clear risk concern, the study design made specific assumptions resulting in little exposure to people living adjacent to the facilities. Thus, depending on the conditions at a particular facility, people living near a facility could be at risk for health effects if there were sufficient releases.

Flexo workers

Solvent-based inks had relatively high levels of uncaptured emissions. This is mostly attributable to solvents, which showed clear risk concerns for pressroom workers through inhalation. Because of emissions in the pressroom from solvent-based inks, the study found risk concerns for the following chemical categories:

This highlights the importance of minimizing fugitive emissions through enclosed doctor blades and other equipment and workplace practices.

- Alcohols: systemic and developmental risk
- Alkyl acetates: systemic risk
- Low-molecular-weight hydrocarbons: systemic risk
- Propylene glycol ethers: systemic and developmental risk

Table 8 lists the clear inhalation and dermal risk concerns that were found for workers. Alcohols, alkyl acetates, and propylene glycol ethers showed risk concerns for *both* dermal and inhalation exposure.

Five of the chemical categories in the study contained solvent-based chemicals that showed clear concerns via dermal exposure, and three categories showed clear concerns via inhalation. Two categories — alcohols and alkyl acetates — presented both dermal and inhalation risk concerns.

Chemicals in these categories were predicted to drive worker health concerns. When assessing inks at a flexo facility or developing new formulations, you might start with these categories.

TABLE 8 Clear Occupational Health Risk Concerns for Solvent-Based Inks

Chemical Categories of Clear Risk Concern*	Function in Ink	Exposure Route**
Alcohols	Solvent	dermal, inhalation
Alkyl acetates	Solvent	dermal, inhalation
Hydrocarbons (low molecular weight)	Multiple	inhalation
Inorganics	Multiple	dermal
Organometallic pigments	Colorant	dermal
Propylene glycol ethers	Solvent	dermal

*These chemical categories might be associated with different risks, or with no risk at all, under different study conditions. A category is included in the table if at least one chemical in the category posed a clear risk under the conditions of the study. Not all chemicals in these categories were found to present risk concerns.

**Only pressroom workers were assumed to have exposure via inhalation. Both prep-room and pressroom workers were assumed to have dermal exposure.

6

Water-based inks: Chemical category findings

Four water-based ink product lines were assessed in the flexo ink study. This chapter addresses the health concerns that were analyzed in the study for the general population and for flexo workers.

To be considered "water-based," an ink must contain less than 25% VOCs by volume. However, the range of VOCs in water-based inks can be very large. For example, the VOC content of the water-based inks in the study ranged from 1% to 14%. Some of the water-based inks also contained HAPs.

General population

No chemical categories with *clear risk concern* to people living near a printing facility were identified in the water-based systems that were studied, and most categories presented a negligible concern. Alcohols (functioning as solvents) in two water-based formulations showed *potential concern*, based on toxicological data. The use of press-side additions increased concern for some formulations.

The general population was not found to be at clear risk concern, in part because the study design made specific assumptions that resulted in little anticipated exposure to people living near facilities. For example, the surrounding population was assumed to live a minimum of 100 meters distant from the facility. If in actuality people live closer to a facility than 100 meters, and/or if a facility operates under conditions that result in substantial VOC emissions, neighbors could be at risk for health effects.

Flexo workers

Table 9 lists the chemical categories in water-based inks that were predicted to pose a clear risk concern for workers under conditions of the study. Five categories had chemicals showing clear concerns for health risk via dermal exposure, and three categories contained chemicals showing clear risks via inhalation. Alcohols, amides or nitrogenous compounds, and ethylene glycol ethers showed risk concerns for *both* dermal and inhalation exposure.

Chemicals in these categories were predicted to drive worker health concerns. When assessing inks at a flexo facility or developing new formulations, you might start with these categories.

TABLE 9 Clear Occupational Health Risk Concerns of Water-based Inks

Chemical Categories of Clear Risk Concern*	Function in Ink	Exposure Route**
Alcohols	Solvent	dermal, inhalation
Amides or nitrogenous compounds	Multiple	dermal, inhalation
Ethylene glycol ethers	Solvent	dermal, inhalation
Organic pigments	Colorant	dermal
Organometallic pigments	Colorant	dermal

*These chemical categories might be associated with different risks, or with no risk at all, under different study conditions. A category is included in the table if at least one chemical in the category posed a clear risk under the conditions of the study. Not all chemicals in these categories were found to present risk concerns.

**Only pressroom workers were assumed to have exposure via inhalation. Both prep-room and pressroom workers were assumed to have dermal exposure.

7

UV-cured inks: Chemical category findings

This chapter focuses on health concerns related to the three UV-cured ink product lines in the flexo ink study.

Many chemicals used in UV-cured inks have incomplete toxicology data. More research is needed to better understand possible health and environmental impacts.

Only *uncured* inks only were analyzed in this study, because adequate data about emissions from inks after curing were not available. Given that most of the volatile components of UV-cured inks react chemically during curing and are incorporated into the coating, *it is reasonable to expect (but not known for certain) that air emissions from these inks would be substantially lower in practice.*

The use of UV-cured inks in wide-web flexo was a newly developing technology when the study was designed. Technology advances since that time might result in different findings if the study were repeated today.

General population

No chemicals with *clear concern* to people living near a printing facility were identified in the UV-cured ink systems that were studied, and most chemicals presented a negligible concern. Acrylated polyols in one product line (serving as reactive diluents) contained chemicals of *potential risk concern*. Certain amides or nitrogenous compounds and acrylated polyols also may present a potential risk.

Flexo workers

Table 10 shows the chemical categories in UV-cured inks that were predicted to pose a clear risk concern for workers under the conditions of the study. Chemicals in acrylated polyols (used as UV-curing compounds) were found to pose a clear risk more often than any other chemical category in UV-cured inks. Acrylated polyols and amides or nitrogenous compounds showed clear concern for both inhalation and dermal exposure. The other categories (acrylated polymers, organometallic pigments, and organophosphorus compounds) showed dermal risks only.

Chemicals in these categories were predicted to drive worker health concerns. When assessing inks at a flexo facility or developing new formulations, you might start with these categories.

TABLE 10 Clear Occupational Health Risk Concerns for UV-Cured Inks

Chemical Category of Clear Risk Concern*	Function in Ink	Exposure Route**
Acrylated polyols	UV-curing compounds	dermal, inhalation
Acrylated polymers	UV-curing compounds	dermal
Amides or nitrogenous compounds	Multiple	dermal, inhalation
Organometallic pigments	Colorants	dermal
Organophosphorus compounds	Multiple	dermal

*These chemical categories might be associated with different risks, or with no risk at all, under different study conditions. A category is included in the table if at least one chemical in the category posed a clear risk under the conditions of the study. Not all chemicals in these categories were found to present risk concerns.

**Only pressroom workers were assumed to have exposure via inhalation. Both prep-room and pressroom workers were assumed to have dermal exposure.

TSCA Section 5 and Acrylate Esters

A Significant New Use Rule (SNUR) was proposed for acrylate esters, which are found in some flexographic ink formulations. However, EPA withdrew the proposed SNUR after receiving, under the terms of a voluntary agreement, toxicity data from acrylate manufacturers that determined that neither triethylene glycol diacrylate nor triethylene glycol dimethacrylate were considered carcinogenic. As a result, EPA no longer supports the carcinogen concern for acrylates as a class. However, EPA may still regulate and maintain health concerns for certain acrylates on a "case-by-case" basis when they are structurally similar to substances for which EPA has supporting toxicity data or when there are mechanistic/toxicity data supporting the concern. Data from experimental studies show some acrylates can cause carcinogenicity, genotoxicity, neurotoxicity, reproductive and developmental effects, and respiratory sensitization. For dermal exposure, EPA continues to recommend the use of protective equipment, such as impervious gloves and protective clothing, for workers exposed to new or existing acrylates and methacrylates. For inhalation exposure, NIOSH-approved respirators or engineering controls to reduce or eliminate workplace exposures should be used. EPA continues to evaluate the acrylate chemical category for ecotoxicity.

8

What workplace safety hazards were found?

Flexo inks and press-side additions may present safety hazards to workers and the community. To compare the relative safety of ink systems, the inks in the study were rated for flammability, ignitability, and reactivity.

Findings on workplace safety hazards

As is true for almost every industry, flexo inks may contain chemicals that present safety hazards in the workplace. Table 11 lists the workplace safety hazards of the inks in the study.

- Because **solvent-based inks** generally have higher amounts of solvents, they posed workplace hazards for both flammability and ignitability. They had an average flammability rank of 3, which means they can easily be ignited under almost all normal temperature conditions. They also were rated as ignitable (can be ignited under 140°F). None were reactive.
- The **water-based inks**, which contained varying percentages of flammable solvents, were less flammable on average than solvent-based inks. However, the range was wider, and some water-based ink formulations were as flammable as solvent-based formulations. No water-based inks were ignitable or reactive.
- Reactivity and flammability data were only available for one of the **UV-cured inks**, which was rated as slightly flammable and slightly reactive. None of the UV-cured inks were ignitable.

How to use these findings

The safety of inks in the study varied by ink system, and water-based inks showed an especially wide range of flammability rankings. It is therefore not appropriate to assume that an ink necessarily shares the common characteristics associated with

TABLE 11 Workplace Safety Hazards of the Flexo Inks

	Flammability (ranked 0-4)*	Ignitability (yes/no)	Reactivity (ranked 0-4)*
Range across solvent-based inks	3	yes	0
Range across water-based inks	0-3	no	0
Range across UV-cured inks	1	no	1

* A rank of 0 indicates a very safe product, whereas a rank of 4 indicates a highly unsafe product.

Water-based inks showed an especially wide range of flammability rankings.

other inks in the same system. It is important to check the safety rankings for all inks used and stored in the facility.

Also, following systematic procedures for safely preparing, operating, and cleaning press equipment will help to avoid serious injuries and health problems to employees. An effective process safety program identifies workplace hazards and seeks to eliminate or reduce their potential for harm. As part of any safety program, printers should

- follow all safety guidelines and rules,
- clearly post all relevant MSDSs,
- become aware of the safety hazards for all chemicals used and stored in the facility,
- have emergency evacuation and notification procedures in place, and
- consider whether ink products with lower safety ratings are available and suitable.

9

What aquatic toxicity concerns were identified?

A chemical with aquatic toxicity concerns has the potential to cause harmful long-term effects to aquatic life. This chapter identifies the chemicals that showed medium or high aquatic toxicity in the study.

Findings on aquatic toxicity

For the flexo study, if 0.1 mg of a chemical in one liter of water could cause a problem for aquatic organisms, the chemical was said to have *high aquatic toxicity*. Similarly, if more than 0.1 mg/liter and up to 10 mg/liter would be needed to cause a problem, a flexo ink chemical was said to have *medium aquatic toxicity*.

Each ink system contained chemicals of high aquatic toxicity:

- Solvent-based system: 11 chemicals
- Water-based system: 8 chemicals
- UV-cured system: 12 chemicals

About half of the ink chemicals in the study showed medium or high aquatic toxicity. Eighteen chemicals had high aquatic toxicity, and another 35 chemicals showed medium toxicity. Table 12 lists these chemicals.

It is important to store and use chemicals properly, to avoid accidental releases that may end up in water systems. Inks and their wastes should never be put down the drain.

TABLE 12 Flexo Ink Study Chemicals Showing Aquatic Toxicity

High aquatic toxicity

Amides, tallow, hydrogenated
*Ammonia**
C.I. Basic Violet 1, molybdatephosphate
C.I. Basic Violet 1, molybdatetungstatephosphate
C.I. Pigment Violet 27
*Dicyclohexyl phthalate**
Distillates (petroleum), hydrotreated light
*2-Ethylhexyl diphenyl phosphate**
Glycerol propoxylate triacrylate
*n-Heptane**
1,6-Hexanediol diacrylate
2-Isopropylthioxanthone
4-Isopropylthioxanthone
*Mineral oil**
Resin acids, hydrogenated, methyl esters
*Styrene**
Thioxanthone derivative
Trimethylolpropane ethoxylate triacrylate

Medium aquatic toxicity

Acrylic acid polymer, acidic #1
Acrylic acid polymer, acidic #2
Alcohols, C11-15-secondary, ethoxylated
*Ammonium hydroxide**
2-Benzyl-2-(dimethylamino)-4′-morpholinobutyrophenone
*Butyl acetate**
C.I. Pigment Blue 61
C.I. Pigment Red 48, barium salt (1:1)
C.I. Pigment Red 48, calcium salt (1:1)
C.I. Pigment Red 52, calcium salt (1:1)
Citric acid
D&C Red No.7
Dioctyl sulfosuccinate, sodium salt
Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide
Dipropylene glycol diacrylate
*Ethanolamine**
*Ethyl acetate**
Ethyl 4-dimethylaminobenzoate
1-Hydroxycyclohexyl phenyl ketone
Hydroxylamine derivative
*Hydroxypropyl acrylate**
Isopropoxyethoxytitanium bis(acetylacetonate)
Methylenedisalicylic acid
2-Methyl-4′(methylthio)-2-morpholinopropiophenone
Phosphine oxide, bis(2,6-dimethoxybenzoyl) (2,4,4-trimethylpentyl)-
*Propyl acetate**
Resin, acrylic
Solvent naphtha (petroleum), light aliphatic
Styrene acrylic acid polymer #1
Styrene acrylic acid polymer #2
Styrene acrylic acid resin
Tetramethyldecyndiol
Titanium diisopropoxide bis (2,4-pentanedionate)
Trimethylolpropane propoxylate triacrylate
Trimethylolpropane triacrylate

*Regulated under one or more federal environmental/health statutes.

Because it was not expected that the inks or their wastes would be released to the aquatic environment, water releases and subsequent related risks were not assessed. If any of these inks are ever released untreated to water, however, there could be aquatic risk concern. In fact, four of the chemicals listed in Table 12 — ammonia, butyl acetate, dicyclohexyl phthalate, and styrene — have been regulated under the Clean Water Act.

As Table 12 shows, only about 20% (11/53) of these chemicals are regulated by federal laws that protect the environment. Thus, even though the other chemicals in the table were found to exhibit high aquatic toxicity, no specific restrictions exist on their use.

How to use these findings

About half the chemicals in the flexo ink study were identified as having high or medium toxicity to the aquatic environment. Toxic chemicals were found in every ink system, and the majority of them are not federally regulated. Ink chemicals and wastewater containing ink products can be accidentally spilled or released to the environment. For these reasons, it is up to flexo professionals to take the initiative. To help reduce exposure, and consequently risk, to aquatic environments:

- Never pour inks or ink-related products (such as press-side additions or wash water) down the drain.
- Minimize the use of chemicals that have been found to be toxic to the environment.
- Keep in mind that some unregulated chemicals may still pose hazards to the environment.
- Consider and use alternatives to toxic ink chemicals when available.
- Support research to identify environmentally benign inks and ink chemicals.

Inks in the study

The ink systems

The study examined the three main flexo ink systems: solvent-based, water-based, and UV-cured. To investigate whether any one ink system showed clear advantages in terms of health, safety, or environmental aspects, the study compared the three ink systems and looked at the chemicals and chemical categories in the individual inks.

The primary difference among the ink systems is the method used for drying or curing the ink. Solvent-based and water-based inks are dried by evaporation, whereas UV-cured inks are cured by chemical reactions. Flexo inks contain components that are responsible for several main functions, including solvents, colorants, resins, additives, and (for ultraviolet inks only) UV-curing compounds.

Solvent-based inks

Solvent-based inks are generally considered the industry standard for ease of use and quality of printing, and they are widely used in flexo. However, because these inks dry by evaporation, the solvents usually contain significant amounts of VOCs, which have notable health and safety concerns. VOCs are usually very flammable, and they contribute to the formation of ground-level ozone (a component of smog), which causes respiratory and other health problems. Solvent-based ink systems are equipped with oxidizers and other pollution-control devices to destroy VOCs.

Water-based inks

Although the primary solvent in water-based inks is water, these inks can and usually do contain VOCs, up to a maximum of 25% by volume. They may also contain one or more of the 188 hazardous air pollutants that were listed in the 1990 Clean Air Act. Depending on their HAP and VOC content, water-based inks may or may not have fewer health and environmental concerns than traditional solvent-based inks. (Note that in some locations and for some water-based inks, oxidizers must be used to destroy VOCs and most HAPs.) Also, again depending on their VOC content, water-based inks show a range of flammability. Some of them are not at all flammable, but others are as flammable as some solvent-based inks.

UV-cured inks

UV-cured inks are the newest ink system to make major progress in flexo. The use of UV inks has been steadily increasing, especially for narrow-web labels and tags. Chemicals in UV-cured inks form solids and bond to the substrate when they are exposed to ultraviolet light, whereas solvent-based and water-based inks dry by evaporation. Because of this difference, UV-cured inks do not contain traditional solvents, so they may have very low VOC content. However, they do contain many chemicals that have not been tested comprehensively for environmental, health, and safety impacts.

Functional components of flexo ink chemicals

Chemical components allow ink to adhere to a substrate. These components can be divided into five basic functional categories:

- Solvents
- Colorants
- Resins
- Additives
- UV-curing compounds

Some chemical categories are called “multi-functional.” A category with this label contains multiple chemicals that serve different functions. Thus chemical A might be a solvent and chemical B an additive. Each chemical was assigned to only one functional category.

Solvents help deliver the ink to the substrate. The solvent allows the ink to flow through the printing mechanism, and then the solvent evaporates so that the ink forms a solid coating on the substrate. Typically, inks are manufactured and transported in a concentrated form, and the printer must add solvent to the ink to attain the desired viscosity (flow). A solvent must adequately disperse or dissolve the solid components of the ink, but it must not react with the ink or with any part of the press. It must dry quickly and thoroughly, and have little odor.

Colorants give inks their color. The two types of colorants used in printing are dyes and pigments. Dyes can be useful when transparency is desired, and the colors of dyes are often quite strong. However, dyes can be susceptible to attack by chemicals and water, and they can also be toxic. Pigments are small, insoluble particles. Some pigments can also be toxic. In general, pigment-containing inks are more resistant to chemicals and heat and are less prone to bleeding through the substrate than are dye-containing inks. The inks used in this study contained pigments, including those that are based on organic, inorganic, and organometallic structures.

Resins cause ink to stick to the substrate. They also disperse the pigment and give gloss to the finished coating. Resins can provide flexibility, scuff resistance, cohesive strength, block resistance, and compatibility with printing plates. Common categories of resins include nitrocellulose, polyamides, carboxylated acrylics, and polyketones.

Additives are used to improve the performance of inks. Plasticizers enhance the flexibility of resins. Waxes and other slip additives provide lubrication to the dried ink and resist damage from rubbing and scuffing. Wetting agents modify the surface tension to help inks stick to the substrate. Defoaming agents reduce bubble-forming tendencies of water-based inks. Buffers maintain the pH of the ink at a desired level. Inhibitors are used to prevent an unwanted chemical change.

UV curing compounds enable UV inks to chemically change to dry solids that bond with the substrate. Monomers are individual molecular units that can combine to form larger structures known as polymers. Acrylated polyols act as monomers, whereas acrylated polymers can be both monomers and polymers. Oligomers are small polymers that can be further combined to form larger polymers. Photoinitiators, such as aromatic ketones, aromatic esters, and organophosphorous compounds, use UV light to enable a chemical reaction to take place among monomers and oligomers.

Every function is associated with specific categories of chemicals, which are listed in Table 13.

TABLE 13 Chemical Categories by Ink Function

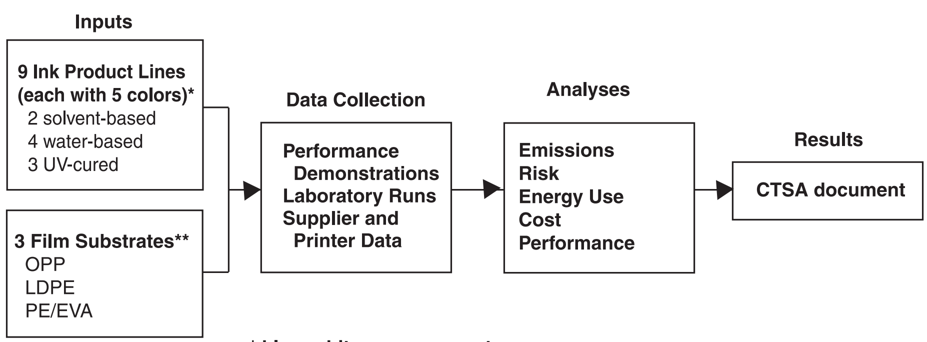
Solvents	Colorants	Resins	Additives	Curing Compounds	Multiple Functions
Solvent-based system					
Alcohols Alkyl acetates Propylene glycol ethers	Organic, inorganic, and organometallic pigments	Polyol derivatives Resins	High-molecular-weight hydrocarbons Organic acids or salts Olefin polymers (waxes) Organotitanium compounds (adhesion promoters) Siloxanes (defoamers and wetting agents)	None	Amides or nitrogenous compounds (slip additives, buffers, inhibitors) Inorganics Low-molecular-weight hydrocarbons
Water-based system					
Alcohols Ethylene glycol ethers Propylene glycol ethers	Organic, inorganic, and organometallic pigments	Resins	Acrylic acid polymers High-molecular-weight hydrocarbons Organic acids or salts Siloxanes (defoamers and wetting agents)	None	Amides or nitrogenous compounds (slip additives, buffers, inhibitors) Inorganics Low-molecular-weight hydrocarbons
UV-cured system					
Alcohols	Organic, inorganic, and organometallic pigments	Polyol derivatives Resins	Aromatic esters (plasticizers) Olefin polymers (waxes) Siloxanes (defoamers and wetting agents)	Acrylated polyols Acrylated polymers Aromatic esters Aromatic ketones Organophos-phorous compounds	Amides or nitrogenous compounds (slip additives, buffers, inhibitors)

Methodology of the flexo ink study

When the study was conducted, UV-cured inks were not being not used commercially to a significant extent to print film substrates on wide-web presses.

The study used a methodology called a Cleaner Technologies Substitutes Assessment (Figure 1). A CTSA systematically evaluates traditional and alternative technologies for the potential risks they pose to human health and the environment, as well as for performance and cost. The objective of this CTSA (the flexo ink study) was to develop a comprehensive and systematic picture of the three primary flexo ink technologies.

FIGURE 1 Study Methodology



* blue, white, cyan, magenta, green.
** OPP = oriented polypropylene. LDPE = low-density polyethylene.
PE/EVA = polyethylene/ethyl vinyl acetate co-extruded film.

The study printed samples using nine ink product lines, each containing five colors (blue, white, cyan, magenta, and green). Altogether, the 45 ink formulations contained more than 100 chemicals. Printing ink suppliers voluntarily provided the ink formulations, which represented the three primary flexo ink systems in use at the time: solvent-based, water-based, and UV-cured. The inks fell into the following categories:

- two solvent-based product lines,
- four water-based product lines, and
- three UV-cured product lines.

This study was not designed to cover every possible ink formulation, performance category, or substrate type. Rather, it gives a "snapshot" of flexo inks at a specific point in time. This is important, because although this booklet identifies issues to consider when thinking about the "best" inks for workers and the environment, each facility and job is unique, and these results should not be generalized. This booklet can help flexo professionals learn more about integrating risk, performance, and cost considerations to both improve operations and reduce environmental impacts.

The general CTSA methodology is described in the DfE document, Cleaner Technologies Substitutes Assessment: A Methodology and Resources Guide. The complete Flexographic Ink Options: A Cleaner Technologies Substitutes Assessment (CTSA) describes the methodology used for this study. You may download these documents from the DfE website (www.epa.gov/dfe).

Performance

The partners included in the study a series of performance demonstrations — brief printing runs of a representative 20” x 16” test image (Figure 2) printed using wide-web presses onto three types of film substrates. Through Flexo Project partners, eleven commercial wide-web printing facilities volunteered as sites for the performance demonstrations. Test samples were printed using a representative image that enabled analysis of 18 performance tests that were considered important to flexo printers. Some tests were conducted during the demonstrations runs, and afterwards the printed images were sent to Western Michigan University, where other performance tests were conducted.

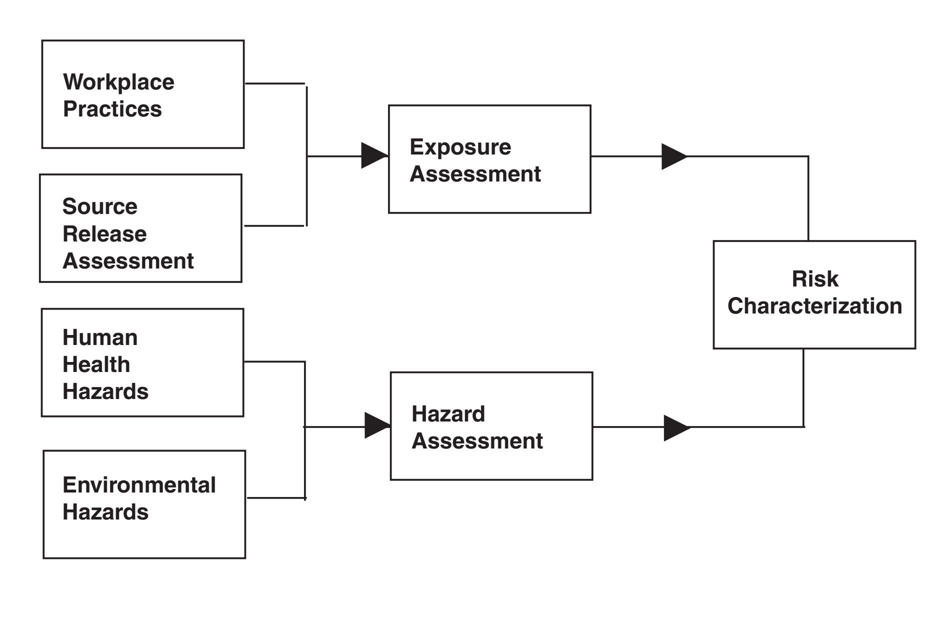
FIGURE 2 Test Image Used in Demonstration Runs (original was run in 5 colors)

Hazards and risks

To analyze the hazards, exposures, and risk concerns of chemicals in the inks, the study used published toxicological data, EPA release and exposure models, and EPA structure-activity analyses. The *release and exposure models* helped to determine the rate at which flexo workers are exposed to ingredients in inks. The study analyzed two routes or pathways by which flexo workers could be exposed to ink chemicals: inhalation (breathing), and dermal (skin). The amount of exposure a worker receives can be affected by chemical components of the inks, methods of handling inks, and exposure route.

The *structure-activity analyses* provided hazard information for chemicals that had not been subjected to toxicological research. Because many ink chemicals have not undergone research about their health and environmental effects, SAT reports were used for many of the flexo chemicals in the study. Figure 3 shows graphically the process that the study used to develop the risk assessment for flexo ink chemicals.

FIGURE 3 The Risk Assessment Process Used in the Flexo Ink Study



Operating costs

The study looked at the costs of buying and using inks that were submitted voluntarily by printing ink suppliers. Sources of information about ink costs included members of the Flexo Partnership Technical and Steering Committees, contributors to the performance demonstrations, and U.S. Census data. Cost categories that were analyzed in the study include materials, labor, capital, and energy. The cost of substrates was not included in the analysis, because the amount of substrate used did not depend on the ink system.

Energy and natural resources

The study looked at the electricity and natural gas that were consumed in printing these inks. Sources of information about the consumption of ink products included

- Members of the Flexo Partnership Technical and Steering Committees
- Contributors to the performance demonstrations
- Energy equipment vendors
- U.S. Department of Energy data

The study also looked at the types and amount of emissions that might be generated by printing with each ink system.

Research assumptions

The study looked at many aspects of printing flexo inks, and thus was complex to plan and implement. In any study design, assumptions are made that will influence the results. For the flexo ink study, some of the important assumptions include the following.

- At each volunteer test site, the test image was run at a press speed of 300-500 feet per minute for roughly two hours. Press speed under many printing conditions is expected to be different (and in general, higher) than in this analysis.
- When the project methodology was developed, regulations did not require that air pollution control equipment be used with low-VOC inks. Therefore, the energy and cost calculations assumed that an oxidizer was used with solvent-based inks but not with water-based or UV-cured inks.
- Workers could be exposed to chemicals via dermal (skin) or inhalation (breathing) absorption, and the general population could be exposed via inhalation only. Neither population was subject to toxic effects via oral exposure (e.g., drinking or eating contaminated substances).

A "model facility" was designed to use when calculating the risk, cost, and energy consumption figures. A number of assumptions were made about a hypothetical "model facility" in developing the risk assessment. Thus, facilities with different operating characteristics would have different findings.

Thirty percent of VOCs released to air would be uncaptured emissions, and 70% would be stack emissions.

- Solvent-based ink systems would have a catalytic oxidizer with a 95% destruction efficiency.
- Pressroom and prep-room workers would work a 7.5 hour shift, 250 days/year.
- Pressroom and prep-room workers would have routine two-hand contact (no gloves) with ink unless a substance was corrosive.
- Press speed would be 500 feet per minute.

These parameters are important to keep in mind when considering how the results may apply to an actual printing facility.

Environmental resources

The resources listed here are divided into four sections: selected publications, flexo associations, technical assistance organizations, and chemical information sources. Many of these publications can be found on the DfE website (www.epa.gov/dfe), which may also serve as a source of information on other chemical substances. The DfE Program has reviewed many chemical substances in other cleaner technology evaluations, including previous partnerships focused on the activities of screen and lithographic printers.

DfE documents may also be obtained from:

National Service Center for Environmental Publications
P.O. Box 42419
Cincinnati, OH 45242-2419
Phone: 800-490-9198 or 513-489-8190
Fax: 513-489-8695
e-mail: nceipmal@one.net
Internet: www.epa.gov/ncepihom/ordering.htm

Selected publications

Flexographic Ink Options: A Cleaner Technologies Substitutes Assessment
(EPA 744-R-02-001A&B)
Vol. A — 400 pages; Vol. B (Appendices) — 430 pages; February 2002

The CTSA contains detailed information about the study. It includes chapters on risk analysis, 18 performance tests, cost analysis, energy consumption, a benefit-cost analysis, and environmental impacts.

Inside Flexo: A Cleaner Run for the Money (EPA/744-V-98-001)
19 minutes; April 1998

This video provides useful tips to flexo printers for working more efficiently and saving money, while improving the environment. Veteran printers share their success stories in the following areas: (1) managing inks efficiently, (2) printing successfully with alternative inks, (3) making the best use of press return inks, (4) using new cleaning methods that improve efficiency, and (5) improving the bottom line through sound environmental practices.

Flexography Project Case Study #1: Reducing VOCs in Flexography
(EPA/744-F-96-013)
4 pages; March 1997

Highlights the experiences of a flexography printer who successfully reduced VOC emissions and hazardous waste volumes. The case study focuses on the use of water-based ink and cleaning systems, which reduced costs along with environmental and worker-safety concerns. Tambien disponible en español.

Flexography Project Case Study #2: Learning from Three Companies that Reduced VOC Emissions (EPA/744-F-96-016)
4 pages; June 1997

Highlights how three flexo printing facilities went about reducing their VOC emissions. It presents the factors that went into management decisions, the results of switching to water-based inks and of installing an oxidizer, and how ink suppliers, trade associations, and consultants can help printers make decisions and solve problems. Tambien disponible en español.

*High Performance Flexo: Printing with a Cleaner, Greener Image (*Videoconference)
2.5 hours; 2000

This tape includes the entire videoconference, which discussed ways to improve environmental aspects of flexo printing. It is available through the Printers National Environmental Assistance Center (PNEAC) at www.pneac.org.

Printing Industry and Use Cluster Profile (EPA/744-R-94-003)
183 pages; June 1994

This resource provides an in-depth profile of the U.S. printing industry. Demographic information is given for the entire industry, as well as for the specific sectors: screen printing, lithography, gravure, flexography, and letterpress. The profile also presents detailed information about the processes and technological trends involved in each sector.

Integrated Environmental Management Systems Implementation Guide
(EPA 744-R-00-011)
290 pages, 48 worksheets; October 2000

The Guide was developed over three years and has been tested by several small businesses that used it to build an Integrated Environmental Management System (EMS) for their companies. An IEMS integrates worker safety and health concerns along with environmental concerns into a company's cost and performance analysis of products, processes and activities. An IEMS also includes the principles and technical methods of the EPA's Design for the Environment (DfE) Program, which emphasizes reducing risk to humans and the environment, along with preventing pollution and managing resources wisely. The Guide provides clear, step-by-step guidance on implementing an IEMS in a small company.

Integrated Environmental Management Systems Company Manual Template for Small Business (EPA 744-R-00-012)
60 pages; December 2000

The template was developed to help companies document their IEMS. Written as if it were the actual manual of a specific small business, the template helps companies understand how to adapt the procedures to implement an EMS and how to document their IEMS. It contains procedures that are normally documented as part of an ISO 14001-compliant EMS.

Flexographic associations

The following organizations are partners in the DfE Flexography Project:

California Film Extruders and Converters Association

www.cfeca.org

The California Film Extruders and Converters Association (CFECA) is a trade association of manufacturers and suppliers dedicated to representing the broad interests of the plastic film extruding and converting industry in California.

Film and Bag Federation

www.plasticbag.com

The Film and Bag Federation of The Society of the Plastics Industry is a consortium of 60 of the industry's leading manufacturers and suppliers, who work together on issues of interest and concern to the industry. Among its goals are to promote the industry's growth and to provide members with programs, services and the forum for addressing environmental, regulatory and other industry issues.

Flexible Packaging Association

www.flexpack.org

The Flexible Packaging Association (FPA) is the leading trade association for converters and suppliers of flexible materials and allied products for packaging, industrial, and related end-use markets. FPA represents their interests before government, promotes the value of their products, and provides information related to their industries.

Flexographic Technical Association

www.flexography.org

The Flexographic Technical Association is the leading technical society devoted exclusively to the flexo printing industry. Its members come from all aspects of the flexo industry, and include printers, suppliers, graphic trade shops, consumer product companies, designers, end-users, consultants, and educational institutions. Together they provide a wealth of products, services and shared knowledge to the flexographic printing industry.

National Association of Printing Ink Manufacturers

www.napim.org

The National Association of Printing Ink Manufacturers is a trade association that provides information and assistance to its members, to help them better manage their businesses, and that represents the printing ink industry in the United States.

RadTech International North America

www.radtech.org

RadTech International North America, a non-profit organization, is the association for the advancement of ultraviolet and electron beam (UV/EB) technology. RadTech serves as an industry forum, addressing the educational needs of the users and suppliers of UV and EB equipment and materials.

Environmental technical assistance organizations

Several non-profit and government sources of technical assistance and pollution prevention information are listed below.

EPA Small Business Ombudsman

www.epa.gov/sbo/

The Office of the Small Business Ombudsman (EPA SBO) serves as an effective conduit for small businesses to access EPA and facilitates communications between the small business community and the Agency. It also provides a list of state SBOs with expertise on local issues. The EPA SBO reviews and resolves disputes with EPA and works with EPA personnel to increase their understanding of small businesses in the development and enforcement of environmental regulations. The EPA SBO acts as a liaison for the small business community in the development of EPA regulations and standards.

EPA Regional Pollution Prevention Coordinators

http://www.epa.gov/opptintr/p2home/resources/regions.htm

Each region of the United States has a coordinator for pollution prevention (P2) activities. This website lists the contacts and provides a link to a webpage describing activities in each region.

National Pollution Prevention Roundtable

www.p2.org

The National Pollution Prevention Roundtable (NPPR) is the largest membership organization in the United States devoted solely to pollution prevention (P2). The mission of the Roundtable is to provide a national forum for promoting the development, implementation, and evaluation of efforts to avoid, eliminate, or reduce pollution at the source. NPPR holds national meetings; runs its publications program, which includes its quarterly newsletter and many other documents and reports; operates four topic-specific electronic listservs (NPPR [P2 Policy], P2 Tech, P2 Trainer, and P2 Energy); and coordinates roundtable workgroups.

Printers National Environmental Assistance Center (PNEAC)

www.pneac.org

EPA's Office of Enforcement and Compliance Assurance and Pollution Prevention Policy Staff have partnered with industry and environmental experts to develop this environmental assistance center for the printing industry, including compliance assistance and P2 information.

This is a communications-based center linking trade, governmental, and university service providers to efficiently provide the most current and complete compliance assistance and pollution prevention information to the printing industry. The project's staff are located within the partnering organizations. The Great Lakes Information Network is providing support for the two Internet listservs.

Small Business Assistance Program

www.epa.gov/ttn/sbap/

All states have a small business assistance program to help businesses comply with environmental regulations. The EPA Small Business Assistance Program (SBAP) is a forum for state assistance providers to share information, and it provides a list of state SBAPs with expertise on local issues. The SBAP has a website and several publications that provide information to small businesses, as well as contact information for individual state representatives.

Small Business Development Centers

www.sba.gov/sbdc/

The U.S Small Business Administration (SBA) administers the Small Business Development Center Program to provide management assistance to current and prospective small business owners. SBDCs offer one-stop assistance to small businesses by providing a wide variety of information and guidance in central and easily accessible branch locations. The lead organization coordinates program services offered to small businesses through a network of subcenters and satellite locations in each state.

The program is a cooperative effort of the private sector, the educational community, and federal, state, and local governments. The program is designed to deliver up-to-date counseling, training, and technical assistance in all aspects of small business management. SBDC services include, but are not limited to, assisting small businesses with financial, marketing, production, organization, engineering, and technical problems and feasibility studies. The website provides contact information for local representatives.

Manufacturing Extension Partnership (MEP)

www.mep.nist.gov

MEP is a nationwide network of not-for-profit centers in more than 400 locations nationwide, whose sole purpose is to help small and medium-sized manufacturers. The MEP centers, serving all 50 states, the District of Columbia and Puerto Rico, are linked through the Department of Commerce's National Institute of Standards and Technology. With specialists who have experience on manufacturing floors and plant operations, MEPs can perform assessments, provide technical and business solutions, help create successful partnerships, and provide seminars and training programs.

Chemical information

Following are some sources of chemical information to help you better build chemical profiles on flexographic ink ingredients and better understand the health and environmental impacts of flexo inks.

ASTDR (Agency for Toxic Substances and Disease Registry).

http://atsdr1.atsdr.cdc.gov

- ToxFAQs. A series of summaries about hazardous substances from the ATSDR Toxicological Profiles and Public Health Statements. Each fact sheet serves as a quick and easy-to-understand guide to the effects of hazardous substances on human health.

  http://www.atsdr.cdc.gov/toxfaq.html

- Toxicological Profiles. Toxicological profiles for hazardous substances found at National Priorities List sites. Profiles include minimum risk levels.

  http://www.atsdr.cdc.gov/toxpro2.html

ChemID. The National Library of Medicine's Chemical Dictionary. Contains over 339,000 compounds of biomedical and regulatory interest. Records include CAS Registry Numbers, molecular formulae, generic names, synonyms, and other references.

http://chem.sis.nlm.nih.gov/chemidplus

ChemFinder. Searchable database of chemical names, synonyms, CAS Registry Numbers, and molecular formulas.

http://chemfinder.camsoft.com

Chemical Right-to-Know (RTK) Initiative, U.S. EPA. Developed to rapidly test chemicals and make the data available to scientists, policy makers, industry, and the public.

http://www.epa.gov/chemrtk

ECOSAR (Ecotoxicity of Structure-Activity Relationships Database). Based on structure analysis, contains estimates of toxicity to fish, invertebrates, and aquatic plants.

http://www.epa.gov/oppt/newchems/21ecosar.htm

ECOTOX Database System. Chemical-specific ecological toxicity databases. Includes AQUIRE, for aquatic toxicity.

http://www.epa.gov/ecotox

International Agency for Research on Cancer (IARC). Overall evaluations of carcinogenicity to humans. List and searchable database of chemicals evaluated as IARC Monographs.

http://193.51.164.11

National Toxicology Program (NTP) Annual Report on Carcinogens. This contains lists of chemicals known or reasonably anticipated to be carcinogenic to humans.

http://ntp-server.niehs.nih.gov/NewHomeRoc/CurrentLists.html

Office of Pollution Prevention and Toxics (OPPT), U.S. Environmental Protection Agency. Databases and software produced by OPPT are valuable tools for obtaining chemical and regulatory information.

http://www.epa.gov/opptintr/opptdb.htm

- EPA's Exposure Assessment webpage includes exposure assessment methods, databases, and prediction models.

  http://www.epa.gov/opptintr/exposure

- Estimation Program Interface (EPI) Suite is a series of physical/chemical property and environmental fate estimation models.

  http://www.epa.gov/opptintr/exposure/docs/episuite.htm

  http://www.epa.gov/opptintr/exposure/docs/epiwin.htm

- Flexography Project website contains many documents to help flexo professionals develop market environmentally improved ink formulations.

  http://www.epa.gov/dfe

RTECs (Registry of Toxic Effects of Chemical Substances). Toxicity data for over 140,000 chemicals. Only available through commercial vendors; URL provides further vendors.

http://www.cdc.gov/niosh/rtecs.html

TOXNET. The National Library of Medicine's Toxicology Data Network. Contains databases on toxicology, hazardous chemicals, and related areas.

http://toxnet.nlm.nih.gov

Toxnet includes:

- CCRIS (Chemical Carcinogenisis Research Information System). Sponsored by the National Cancer Institute, a scientifically evaluated and fully referenced data bank containing some 8,000 chemical records with carcinogenicity, mutagenicity, tumor promotion, and tumor inhibition test results.
- GENE-TOX. Genetic toxicology (mutagenicity) test data, resulting from expert peer review of the open scientific literature for approximately 3,000 chemical substances.
- HSDB (Hazardous Substances Data Bank). Data file that focuses on the toxicology of over 4,500 potentially hazardous substances. Includes human exposure, industrial hygiene, emergency handling, and environmental fate. Scientifically peer-reviewed.
- IRIS (Integrated Risk Information System). An EPA database that contains health risk information on over 500 chemicals. This includes cancer weight-of-evidence classifications and cancer potency factors. These data have been reviewed by EPA and represent EPA consensus.

  http://www.epa.gov/iris

Pollution prevention tips for flexo professionals

Flexo decision-makers have many opportunities to encourage environmental improvements and cleaner, more sustainable operations, including pollution prevention. This involves reducing or eliminating environmental discharges at the source, before they are generated. Pollution prevention requires taking active steps to implement changes in workplace practices, technology, and materials, such as the type of ink used. By reducing the amount of waste produced in the first place, disposal and compliance issues are minimized.

The pollution prevention pyramid shows source reduction at the top. This means that reducing or eliminating environmental problems should be the first and most comprehensive approach to preventing pollution. If a chemical showing hazards or risk concerns cannot be eliminated, then it should be recycled. If it cannot be recycled as is, it should be treated, and only if none of these options exist should it be disposed to a landfill.

Each step in the printing process offers opportunities for pollution prevention. Possible benefits from following pollution prevention practices include cost savings, improved productivity, better product quality, reduced health risk concerns to workers, reduced pressures of regulatory compliance, and of course reduced environmental impacts.

The list that follows includes some obvious and some not-so-obvious suggestions for reducing environmental effects of printing operations. You can probably implement other good ideas that are specific to your facility's operations.

Pre-press

Use Computers for Proofs and Plates: Eliminating all proofs and plates enables printers to skip photographic development and eliminate the use of darkroom chemicals.

Switch from Rubber to Photopolymer Plates: Use of traditional nitric acid baths to etch designs into metal plates may generate wastewater that is low in pH and high in metal content, requiring regulation under the Clean Water Act. Photopolymer plates eliminate this waste stream as well as the metal engravings and wastes generated from the production of conventional molded rubber plates.

Printing and clean-up

Install Enclosed Doctor Blade Chambers: Enclosed doctor blade chambers reduce ink evaporation, which results in better control of ink usage, more consistent color, and improved performance of the inks on press. Making this change to an older press may greatly reduce ink evaporation, thus minimizing worker exposure to hazardous chemicals.

Cover Volatile Materials: By keeping all cans, drums, and open ink fountains covered, printers can reduce odors and worker health risk concerns by minimizing uncaptured VOC emissions.

Use Higher Linecount Anilox Rolls: This enables printers to apply smaller ink droplets closer together, to achieve much finer ink distribution, easier drying, and potentially faster press speeds.

Rework Press Return Ink: Reworking press return ink can increase efficiency, reduce ink purchases, and reduce hazardous waste if contamination issues can be addressed. Ink can be reworked by blending press return ink with virgin ink or other press return inks.

Use Computerized Ink Blending: Software and specialized equipment help printers blend ink, reduce surplus ink, and reuse press return ink.

Print with Four-Color Process: The limited number of inks in four-color process printing can minimize the amount of mixed colored inks used and eliminate residues of unusual colors at the end of each job. With chambered doctor blade systems, the increased use of process printing to produce a broad spectrum of colors has become more easily attainable.

Co-Extrude Colored Film: Films can be co-extruded to have panels of color in a clear field, which eliminates the need for heavy coverage with colored ink.

Run Light Colors First: By running lighter jobs before darker jobs, printers can reduce the number of clean-ups.

Standardize Repeat Print Jobs: Make-ready times and waste materials can be greatly reduced if the press operators knows the anilox roll linecount and cell volume, the sequence of colors applied, ink parameters such as pH and viscosity, and other set-up information.

Standardize Anilox Roll Inventory: This saves time during makeready and reduces waste.

Use Multi-Stage Cleaning: Solvent use can be reduced by using a multi-stage cleaning procedure for the printing decks. This procedure reduces solvent use by reusing solvents that are otherwise discarded. Pre-used solvent is used in the first stage to remove the majority of the ink. In the second stage, a cleaner but still pre-used solvent removes more ink. In the third stage, clean solvent removes any remaining ink.

Install Automatic On-Press Cleaning: When paired with solvent recovery, on-press cleaning systems use much less cleaning solution than hand cleaning, while also having a very short cycle time.

Clean Anilox Rolls Promptly: Prompt attention will prevent the inks from setting, thereby reducing the need for harsh chemicals. Clean rolls also produce more predictable ink densities, potentially reducing on-press waste and improving quality.

Use Alternative Methods to Clean Anilox Rolls: Printers can choose among many alternatives for cleaning anilox rolls to reduce or eliminate the need for traditional cleaning solvents. These alternatives use sonic cleaning, dry ice, lasers, polyethylene beads, and sodium bicarbonate.

Recirculate Warm Press Air: Both solvent-and water-based printers can significantly reduce their energy requirements by recirculating warm air from dryers.

Throughout the printing process

Use Safer Chemicals: Switching to inks, cleaning agents, and adhesives that contain a lower percentage of VOCs and fewer HAPs may reduce risk concerns to worker health and the environment.

Segregate Hazardous Waste: Segregating hazardous wastes allows disposal of pure instead of mixed wastes. Because pure wastes are much easier to treat than mixed ones, they are not only less expensive to dispose of, but also require less energy.

Return Containers: Using returnable containers prevents unnecessary waste generation and results in additional cost savings.

Track Inventory: Tracking chemical purchases and disposal can help to maintain a minimum inventory on the shelf, thus reducing the amount of materials wasted. For example, hazardous waste can be minimized by labeling inks with the date and having a "first-in, first-out" rule, i.e., rotating the inks so that the oldest inks are used first. This avoids disposing of expired ink as hazardous waste. Tracking systems using bar codes take inventory control to an even higher level.

Make a Management Commitment: Management should establish, communicate, and demonstrate its commitment to the concept of pollution prevention, to encourage company-wide source reduction in everyday practice. Management can assemble pollution prevention teams of employees, incorporate pollution prevention into job responsibilities, and provide incentives for employees to prevent pollution.

Train Employees: Pollution prevention training for company personnel may facilitate process changes by educating workers on the need for such change. Training also helps to encourage general source reduction and stimulate pollution prevention ideas by personnel.

Monitor Employee Practices: Periodic monitoring helps ensure that source reduction practices are followed.

Seek Out and Encourage Employee Initiatives: Supporting, encouraging, and actively acknowledging pollution prevention initiatives by company personnel can stimulate innovative ideas for source reduction. This may be especially beneficial because employees who are closest to the process are often in the best position to recommend change.

Develop an Environmental Management System (EMS): An EMS is a set of management tools and principles designed to guide a company to integrate environmental concerns into its daily business practices.

DfE has developed an Integrated Environmental Management System Implementation Guide, which provides technical methods, step-by-step guidance, and worksheets for facilities that want to implement an EMS. You may download it from the DfE website (www.epa.gov/dfe). For a printed copy, contact EPA's National Service Center for Environmental Publications:
Phone 800-490-9198 or
513-489-8190;
Fax:513-489-8695;
e-mail:ncepimal@one.net;
or Internet:
www.epa.gov/ncepihom/ordering.htm

References

1. U.S. Census, 1999 *Survey of Manufactures*.

2. U.S. Census. 1997. *Commercial Flexographic Printing*.

3. *Flexo*, December 1998. "1999 Industry Forecasts," p. 32.

4. National Association of Printing Ink Manufacturers. *2001 State of the Industry Report*, p 4.

5. *Flexo*, January 2001, p. 18.