Flexographic Printing-
Generic Scenario for Estimating Occupational Exposures and Environmental Releases
-Draft-

U.S. Environmental Protection Agency
Office of Pollution Prevention and Toxics
Chemical Engineering Branch
1200 Pennsylvania Avenue
Washington, D.C. 20460

April 1999

DRAFT
FLEXOGRAPHIC PRINTING GENERIC SCENARIO
(April 1999)

This generic scenario is based on research that was conducted by Eastern Research Group (ERG) in the spring and summer of 1998. The purpose of the study was to develop a Cleaner Technologies Substitute Assessment (CTSA) for U.S. EPA's Design for the Environment (DfE) initiative. Research for the CTSA included contacting industry representatives to acquire realistic process descriptions, occupational exposure patterns, and printing ink formulations (many of which contained TSCA Confidential Business Information).

The CTSA determined that there are three primary ink formulations, each having slightly different characteristics: solvent-based, UV-cured, and water-based. Additionally, ink consumption rates vary depending on the color. The colors analyzed were: white, green, blue, magenta, and cyan.

The scope of the CTSA was to estimate occupational exposure, both inhalation and dermal, and fugitive and stack air releases from volatile chemicals used in flexographic printing operations. While the CTSA recognized that there could be releases of volatile chemicals to land or water from these operations, they are unlikely except in the event of equipment cleaning and container residue. The CTSA assumed that 100% of the volatile chemicals will evaporate during the process or remain on the substrate. Therefore, liquid and solid releases are not specifically addressed.

The methodology used in the Chemical Engineering Branch (CEB) Engineering Manual for estimation of exposures and releases from open surfaces was used as a basis for modeling. Several discussions and meetings were held with industry, ERG, and EPA personnel to develop the default values needed to conduct the modeling during a "typical" flexographic printing operation. Specific details and assumptions are discussed in the CTSA.

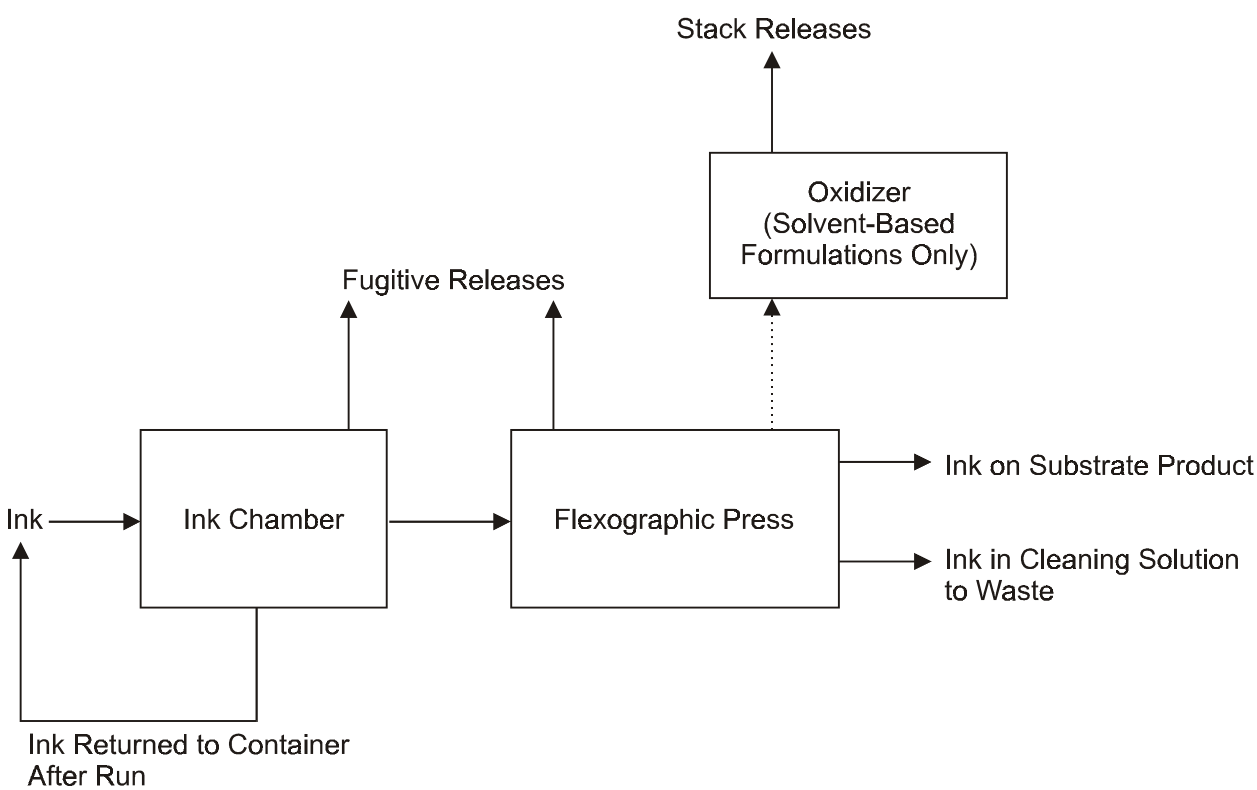
PROCESS DESCRIPTION

Printing ink is typically received at a flexographic facility in 55 gallon drums and is pumped into a dispensing system or poured into 5 gallon ink cans in the ink preparation room. Each 5 gallon can is capped and carried to the press where it is opened and poured into an enclosed ink sump at press side. The ink can itself may alternatively serve as the sump. The ink is then pumped from the ink sump to an enclosed chamber which may or may not empty into an open drain pan.

Next, the press is prepared for production (i.e., the makeready process). During makeready, a sample of the substrate is run through the press to allow for correction of the printing quality and the sample is then recycled or disposed. The substrate is then run through the press for the actual production run. At the conclusion of the run, the unused ink is pumped out of the ink chamber back into the sump. The "ink consumed" during makeready and production (i.e., the difference between the amount of ink added to the ink chamber and the amount removed from the ink chamber at the end of the run) either remains on the rollers, is released to the air, or is printed onto the substrate. For purposes of the CTSA, "ink consumed" includes only the ink printed on the substrate or released to air (all other releases, including container residual were considered negligible and were outside the scope of the study). Following a production run, the ink rollers and ink chamber are cleaned with solvent (for solvent-based and UV-cured inks) or water (for water-based inks). The solvent cleaning solution may be reused and is eventually disposed as a hazardous waste and incinerated or burned for energy recovery. The water cleaning solution may be reused and is eventually disposed as a hazardous or non-hazardous waste.

Ink consumption rates vary by color of the ink; white inks have significantly higher consumption rates than the other colors, with green and blue inks having slightly higher consumption rates than magenta and cyan inks. Press speed also greatly affects the amount of ink consumed. All estimates in the CTSA assumed a press speed of 500 feet per minute for all three formulation types, which will result in the highest consumption, release, and exposure levels. With this press speed, ink consumption rates are approximately the same between different formulation types. Model runs using industry-supplied data associated with varying press speeds of 336 ft/min, 380 ft/min, and 466 ft/min for UV-cured, water-based, and solvent-based formulations, respectively, show a reduction in ink consumption rates and environmental releases of 32.8%, 24%, and 6.8%, respectively.

Addition of solvents, reducers, extenders, cross-linkers, and other compounds to the printing ink usually causes the volatile content of the ink to rise, resulting in greater environmental releases. Solvents contributed more to this rise in volatility than the other additives. Typically, solvents were added in greater quantities to the solvent-based formulations than to water-based or UV-cured formulations.



A generic process diagram is presented below.

ENVIRONMENTAL RELEASES

This scenario examines the environmental releases that occur during makeready and during the actual production run of the flexographic press. The only releases discussed in this study are air releases, although the only expected significant water releases would be from potential rinsing of spent containers or from equipment cleaning if these wastes are not recycled or collected for incineration as expected.

Environmental release quantities depend on many variables, including the volatile content of the ink mixture, whether exhaust streams contain air control devices, the ink consumption rates, and whether the ink was mixed with additives prior to use.

A mass balance approach and CEB's open surface model were used to calculate releases from inks during flexographic printing. Releases to air are based on the amount of "ink used" and the weight percentages and the vapor pressures of the ink components. The calculations estimate releases from the three types of inks (solvent-based, UV-cured, and water-based) for each of the five colors (White, Reflex Blue, 354 Green, Process Magenta, and Process Cyan).

The following variables and corresponding default values should be used in the mass balance to calculate air releases of volatile chemicals (those with vapor pressures greater than 0.001 torr):

Variables/default values for the calculations presented below (if applicable) are:

- PMN: weight percent of PMN material in flexographic ink/100; variable with each formulation (additive concentrations typically ranged between 1% and 5%, never exceeding 10%);
- NS: number of sites using flexographic ink with PMN material; variable, can be calculated from use rate calculation below;
- FP: number of flexographic presses in operation per site; assume 4 as default;
- CE: capture efficiency of the stack; assume 70% as default;
- DE: destruction efficiency of the air controls; assume 95% for solvent, 0% for water and UV;
- ICR: ink consumption rate; assume 20 kg/hr as default;

- H: 7.5 hour shifts per worker;
- Sh: 3 shifts per day;
- DOP: 300 days of production per year;
- IR: worker breathing rate; 1.25 m^3/hr; and
- Cm: mass concentration of respirable materials in the air (mg/m^3, estimated below).

1. Use Rate

Generic (kg PMN/site/yr) = PMN × ICR × FP × H × Sh × DOP

= PMN × 20 kg/hr × 4 presses × 7.5 hours × 3 shifts

= PMN × (1,800) kg/site/day

<OR>

= PMN × 20 kg/hr × 4 presses × 7.5 hours × 3 shifts × 300 days/year

= PMN × (5.4×10^5) kg/site/year

2. Environmental Releases

Liquid Waste: Following a production run, the ink rollers and ink chamber are cleaned with solvent (for solvent-based and UV-cured inks) or water (for water-based inks). The solvent cleaning solution may be reused and is eventually disposed as a hazardous waste and incinerated or burned for energy recovery. The water cleaning solution may be reused and is eventually disposed as a hazardous or non-hazardous waste. These releases were not estimated in the CTSA.

Solid Waste: Solid wastes were not estimated in the CTSA.

Fugitive Air Emissions: Fugitive air emissions were assumed identical regardless of the type of ink formulation (water-based, solvent-based, or UV-cured).

Generic (kg PMN/site/day) = PMN × ICR × FP × H × Sh × DOP × (1-CE)

= PMN × 20 kg/hr × 4 presses × 7.5 hours × 3 shifts × 0.3
= PMN × 540 kg/site/day

Stack Air Emissions: It was determined that flexographic processes involving solvent-based ink formulations typically include air pollution control devices while those utilizing water-based and UV curable formulations do not. Therefore, an additional term must be included for the air pollution control system for solvent-based inks.

(i) Solvent-based formulations

Generic (kg PMN/site/day) = PMN × ICR × FP × H × Sh × CE × (1-DE)

= PMN × 20 kg/hr × 4 presses × 7.5 hours × 3 shifts × 0.7 × 0.05
= PMN × 63 kg/site/day

(ii) UV-cured and water-based formulations

Generic (kg/PMN/site/day) = PMN × ICR × FP × H × Sh × CE

= PMN × 20 kg/hr × 4 presses × 7.5 hours × 3 shifts × 0.7
= PMN × 1,260 kg/site/day

Water Emissions: None assumed. Although not specifically addressed in the CTSA, any water used for cleaning or other purposes is typically treated and disposed of as liquid waste. **[Franklin, we need to discuss this]**

WORKER EXPOSURE

The CTSA assessed occupational exposure for workers in the ink prep room separately from those in the printing room. The CTSA also determined that typical press speeds utilized in flexographic processes do not generate appreciable misting. Increased press speeds (above 500 feet per minute) may result in inhalation exposure to mist, this should be evaluated on a case-by-case basis.

Number of Workers and Duration of Exposure:

Typically, one worker per shift will be required in the ink prep room and eight workers per shift will be required in the printing room (two workers per press, four presses per site). Facilities operate an average of three shifts per day; therefore, a typical facility will require a **total of 27 workers**.

Each worker will incur similar dermal exposures but the inhalation exposure will vary as discussed below.

Ink prep room workers are typically exposed for four hours per shift while printing workers are exposed fro 7.5 hour shifts.

Facilities are expected to operate 300 days per year.

Inhalation Exposure:

(i) Ink Preparation Room Inhalation Exposure:

Prior to a production run, the potential exists for inhalation exposures for the workers transferring and mixing inks in the ink preparation room due to volatilization of PMN chemicals. **One worker is exposed for four hours per shift.**

Generic (mg/person/day) = $Cm \times IR \times H$

To determine the concentration of respirable materials in the ink preparation room air (Cm), CEB's open surface model can be used. Default values in CEB's inhalation spreadsheet should be changed to use: a ventilation rate (Q) of 7,000 ft^3/min, a 1 ft diameter (z) for the 5 gallon ink cans, and an air velocity above the ink cans of 100 ft/min. For ink preparation room exposures, the medium work inhalation rate of 1.25 m^3/hr and a 4 hour shift should be used. The inhalation exposure can then be read directly from the CEB spreadsheet, or the Cm value calculated from the spreadsheet can be used in the generic equation as shown below:

Inhalation exposure = Cm × 1.25 m^3/hr × 4 hr
= Cm × 5 mg/person/day

(ii) Printing Room Inhalation Exposure:

During the production runs, inhalation exposures occur when workers adjust the 5 gallon ink cans at the press and when workers operate the press. **Two workers are exposed per press for 7.5 hours per shift and there are typically four presses per site**.

Inhalation exposures in the printing room are expected to be substantially higher than those in the ink prep room, primarily because of the higher generation rate (volatilization) associated with the process compared to simple diffusion from an open surface. As a worst case, the mass concentration of PMN chemical in the air can be estimated using the methodology in the CEB Engineering Manual, substituting the fugitive emission rate (previously calculated in the Environmental Release section of this generic scenario) for the vapor generation rate.

CEB's inhalation spreadsheet can be used with a few modification to quickly complete the calculation for Cm. The required modifications are:

- worker exposure = 7.5 hours/day;
- ventilation rate = 7,000 ft^3/minute (both worst case and typical case); and,

- vapor generation rate (g/sec) under the drumming results for both worst case and typical case should be set equal to the fugitive emission rate calculated previously (be sure to enter the value under the g/sec column because the spreadsheet uses these cells to calculate the associated exposures).

Note that hard entering the vapor generation rate in the spreadsheet effectively over rides other calculations that are typically used. Therefore, unless similar modifications are made to the generation rate and ventilation rate (and “Q” for the open surface results column) only the values calculated for exposures under drumming will be accurate. These are the values that should be used.

The CTSA explains that these results represent a worst case scenario and may significantly overestimate the actual exposures. Exposures could be conservatively estimated following the procedure discussed above for inhalation exposure in the ink prep room (using identical default values except for a duration of worker exposure of 7.5 hours/day). This method is expected to underestimate exposure. Using this conservative approach the inhalation exposure could be estimated from the following equation:

Inhalation exposure = Cm × 1.25 m^3/hr × 7.5 hr
= Cm × 9.375 mg/person/day

Dermal Exposure:

Dermal exposure is expected to be similar in all operations and occurs in the ink preparation and printing rooms during the transferring and mixing of flexographic inks. This involves **routine two-hand contact with liquid flexographic inks** and subsequent exposure to the PMN chemicals in the ink. Equations approximating exposure levels are based on data compiled on contact operations as given in Table 4-13 of the CEB Engineering Manual, 1991.

Liquid Dermal Exposure: (1,300 -3,900) mg/day × PMN

REFERENCES

1. Chemical Engineering Branch (CEB). Manual for the Preparation of Engineering Assessments, U.S. Environmental Protection Agency, February, 1991.

2. Fehrenbacher, M.C. and Hummel, A.A. "Evaluation of the Mass Balance Model Used by EPA for Estimating Inhalation Exposure to New Chemical Substances," *American Industrial Hygiene Association*, Submitted for Publication.

3. Engel, A.J. and Reilly, B. Evaporation of Pure Liquids from Open Surfaces. U.S. Environmental Protection Agency, Pre-Publication Draft.

4. Reilly, B. "Memorandum from Breeda Reilly to CEB Staff: Guidance for Preparing PMN Engineering Reports." U.S. Environmental Protection Agency, June 4, 1994.

5. The CTSA Report will be added when final.