Transformer Manufacturing-
Generic Scenario for Estimating Occupational Exposures and Environmental Releases
-Draft-

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Generic Scenario: Transformer Manufacturing

Background

Transformer and coil production in the United States and Canada in 1988 was valued at nearly $5.0 billion produced by companies for commercial sale and for internal consumption. This sum does not include transformer and coil production by companies that consume all products internally and that do not sell to the commercial market. Sales for the 690 identified companies ranged from $100,000 to $440 million. Transformers manufacturers range from small, independent shops with limited product variety to large plants that are owned by major corporations. Transformer manufacturing consists of discrete processes that are described in this scenario.

Production Processes

Winding: The process whereby magnet wire, generally copper, is wound into coils. Winding is performed manually or with a variety of specialized semiautomated and automated winding machines. Insulation materials, such as tapes or molded plastic shields, are added to the coils during the winding process. Chemical usage during winding is negligible. Waste consists of scrap magnet wire that is recycled for metal content.

Termination of magnet wires: Electrically connects the wires of the windings to bobbin terminals, to lugs, or to color-coded lead wires. Termination can be performed at any of several stages of the manufacturing process. Tin-lead solder, using rosin flux, is the most common termination method. Soldering is performed with solder irons, by dipping in solder pots, or by directing a fountain of molten solder over the wires to be terminated. The first two processes are performed manually or automatically, whereas the latter process generally is automated. Automatic soldering of terminated wire often is combined with automatic winding equipment to form a coil finishing system.

For most small transformers, termination occurs immediately after winding when the coil wire, which was wrapped around solder-plated terminals during the winding process, is soldered to the terminals. The magnet wire used in these applications generally is insulated with a polyurethane film that is burned off by the solder during termination. Manual soldering typically is performed continuously over 8-hour shifts.

If the wires have been immersed in any impregnating materials or if higher-temperature wire insulation is used, these materials must be mechanically removed (e.g., with wire brushes) before solder can be applied. Solder is then applied directly to the exposed copper wire and terminals. Mildly activated rosin fluxes generally are used, because coils offer many areas where stronger acid fluxes could be entrapped and cause corrosion problems. Isopropyl alcohol is used in liquid form as a solvent to maintain the desired flux viscosity and to clean flux application equipment.

Solder operators work at benches for a continuous 8-hour shift. During this time, they handle solder in wire or bar form and, if they are using a solder pot, skim oxide (dross) from the top of the pot. The dross is recycled for metal content. They use isopropyl alcohol and wipes for cleaning and thinning flux. They are exposed to fumes from soldering (e.g., burnt rosin and magnet wire insulation) and lead in the solder, although exhaust systems generally are used to pull fumes away from the operators.

Flux residue removal: Sometimes performed using alcohol or halogenated hydrocarbon solvents such as trichlorotrifluoroethane. Components to be cleaned are placed in stainless steel baskets and lowered into vapor degreasers. The solvent must be compatible with the magnet wire insulation and molded plastic bobbins and must evaporate completely and quickly from the coil. Operators are exposed to vapors from solvents when baskets are lowered into and removed from the degreasers, although not continuously. Other solvent-related maintenance activities, such as adding solvent or draining sumps, also expose operators.

Assembly: Involves mating core materials to the coil and fixing them in place. Cores are built up using two ferrite core halves or a set of laminations that are stacked up in various configurations. Core assemblies are "locked" together by mechanical fasteners (e.g., clips or bolts), welding, or adhesives. The most common adhesives are two-part epoxies that are applied manually using syringe-type applicators. The two adhesive parts are mixed using packaging that avoids operator contact. During application and handling of bonded cores, skin contact is possible, although operators can wear gloves or rubber finger cots to minimize contact. It is not uncommon for adhesive application to be performed continuously over an 8-hour shift by operators. Wastes include cured adhesives and dispensing materials.

Impregnation: Generally a batch process in which assembled transformers are immersed in open tanks of liquid impregnant. Baskets lifted by powered hoists commonly are used to transport transformers in and out of the dip tanks and to carts for transfer to curing ovens. If impregnation is performed under vacuum, the transformers are placed in a vacuum chamber and, after air is removed, are immersed in the impregnant. Impregnants are solvent-based, water-borne, or solvent-free and generally are polyesters, polyurethanes, or epoxies. Common solvents used are xylene and toluene.

Impregnation facilities are located in a room physically separated from other operations. Air from the room is exhausted to outside air and curing ovens have their own exhaust systems. Operators are exposed to solvent vapors from immersion tanks and during transport of transformers with uncured impregnant from the immersion tanks to curing ovens. Baskets of transformers are handled with hoists, so some distance is maintained between operators and the uncured impregnant to minimize physical contact. Tank maintenance may be daily and consists of pumping material to drums for disposal and refilling tanks with fresh materials. Some additives, such as catalysts, are added to the tanks by operators.

Polyester varnishes are the most common materials. Solvent varnishes contain solvents such as xylene and toluene. Solventless varnishes are now available that contain styrene and vinyl toluene. Waterborne varnishes contain small amounts of butyl cellusolve (less than 0.5%).

Conformal coating: Coating performed for many small transformers using a variety of coating materials. These materials protect the coil wires, bond cores together, and provide additional electrical insulation between wires. The process generally is performed manually with some mechanical dipping aids in an exhausted work room. The coating is dried in batch or continuous ovens or is simply air dried. Conformal coating materials generally are acrylics or polyurethanes with aromatic solvents such as toluene and xylene. Transformers that are conformally coated generally are hand-dipped to ensure complete coating without coating solderable terminals. Operators are exposed to solvent vapors during immersion and curing of coated transformers and during cleanup of work stations. Protective gloves or finger cots are used to reduce contact with skin. Other activities include adding material to immersion tanks.

Encapsulation: Filling inverted cases that contain transformers. Filling is performed with machines that blend the encapsulant materials and dispense metered amounts when an operator presses a foot switch. The operator manually positions the cases under the dispenser nozzle using holding trays mounted on a sliding table. The process can be automated, particularly for designs that requiring encapsulation to be performed under vacuum conditions. For very small volume production, encapsulating materials can be dispensed with disposable containers that blend the two parts as they are dispensed. Compressed air is used to force the material out of the container. Common encapsulating materials include epoxies, polyurethanes, and silicones, many of which require heat for curing. Ovens used to cure encapsulants usually are exhausted, as are encapsulant-dispensing machines or stations. Encapsulation operators can spend an entire 8-hour shift continuously dispensing materials.

Marking: Identification information usually marked with ink-jet printers that print directly on the transformers or on labels that are applied to the transformers. Rubber hand stamps with air-dry inks also are used. Pad printers that pick up ink from an engraved plate onto a soft rubber pad and transfer it to the transformer are commonly used. Batch and continuous ovens, as well as ultraviolet light, are used to dry or cure inks. A variety of inks are used to mark transformers, including solvent-based inks, UV-curable inks, and two-part epoxy inks. Operator exposure to inks and solvents varies with the printing process. Ink-jet printers result in negligible exposure, whereas both pad printers and hand stamping processes expose operators to inks and solvents during setup, printing, curing, and cleanup. Printing often is a full-time task during an 8-hour shift and is performed in an exhausted work station [1].

Waste Generation, Environmental Releases, and Exposure-Level Calculations

PMN chemicals may be used in many of the steps involved in transformer manufacturing. Specifically, PMN chemicals may be used as (1) solder fluxes and cleaning solvents in the *termination* process,
(2) solvents for *flux residue removal*, (3) epoxies and adhesives in the *assembly* process, (4) impregnants and solvents in the *impregnating* process, (5) coating materials and solvents in the *conformal coating* process, (6) epoxies or other materials for *encapsulation*, and (7) inks, dyes, and solvents in the *marking* process. Each of these process steps involves distinctly different operations that will result in varying amounts of environmental emissions and worker exposure hazards.

It is not within the scope of this study to cover the entire spectrum of operations at a transformer manufacturing facility. A single process step has been selected for in-depth analysis for this generic scenario of the 690 manufacturing plants in the United States, approximately 50% perform impregnation of transformers. To calculate environmental releases and worker exposure, it is assumed that the PMN chemical is used as a component of the impregnant. As stated above, the impregnation involves immersion of assembled transformers in open, and typically large, tanks of liquid impregnant. Following impregnation, the transformers are moved into curing ovens. The impregnation process thus has the potential for significant air, liquid, and waste emissions. In addition, potential worker exposure to impregnant chemicals during transformer handling and tank maintenance operations may be more significant than the potential exposure to PMN chemicals introduced in other process steps.

Assumptions

%PMN : weight percent of PMN chemical in the impregnant
W : weight in pounds of impregnant used per day at the facility = 150 lb/day
D : number of days per year of operation of the facility = 250 days

Environmental Releases (total lb/year at a single manufacturing facility)

<u>Solid Wastes:</u> Solid wastes containing the PMN chemical arise primarily from (1) drippings from transformers during transport, and (2) drippings that collect on the bottom of curing ovens and are periodically scraped out. The volume of waste is approximately 1% of the total impregnant used, W. The amount of PMN chemical that would be released as solid waste from a single manufacturing facility can be estimated approximately as follows:

$$\%PMN/100 * SW * RF * D = ?\ \text{lb/year}$$

where SW is the amount of impregnant solid waste in lb/day generated at the facility, and RF (between 0 and 1) is the fraction of original PMN remaining in the impregnant solid waste. PMN chemicals that are highly reactive or volatile are likely to have a small RF value because they are likely to be removed by the time the impregnant has gelled.

Air Emissions: Air emissions of a PMN chemical component in the impregnant could arise if the PMN chemical is volatile. Such emissions could occur at several steps in the process: (1) in the transfer of impregnant to and from the immersion tanks, (2) during addition of chemicals to the liquid in the immersion tank, (3) directly from the immersion tanks, (4) during transfer of transformers with uncured impregnant from the immersion tanks to the curing ovens, and (5) from the curing ovens during the drying process. These emissions are all fugitive in nature, except for the case of the vented curing ovens that typically have their own exhaust systems. Typical manufacturing plants locate their impregnation facilities in a separate, enclosed environment with their own ventilation systems that vent the fugitive emissions to the atmosphere. Our survey did not find evidence of the use of control devices at impregnation and curing oven vents stacks.

It is difficult to estimate the extent of air emissions for a PMN chemical with the current information available. However, it would be expected that if the PMN chemical is volatile, a large fraction of the air releases would arise from the open-top impregnation tanks and from the curing oven. The amount of PMN chemical that would be released as air emissions from a facility could be estimated as:

$$\%PMN/100 * W * \%Volatilized/100 * D = ?\ \text{lb/year}$$

where %Volatilized is the percentage of PMN chemical that is volatilized during the mixing, impregnation, and curing steps. For solvent varnishes, an open tank can lose as much as 5 gallons of solvent per day to evaporation. An average plant would have at least 3 tanks.

If the air emissions of a known volatile constituent of the impregnant are available through measurements or via emission factor methodology, the potential emissions of a volatile PMN can be estimated by analogy as:

$$\frac{\%PMN}{\%Known} * Q_{known} * P_{PMN}/P_{known} = ?\ \text{lb/year}$$

where %Known in the weight percent in the impregnant of the known volatile chemical, Q_{known} is the estimated annual emission of the known volatile, and P_{PMN} and P_{known} are the vapor pressures of the PMN chemical and the known volatile, respectively. The assumptions that form the basis for the above calculation are discussed in CEB [2].

Water: Liquid waste containing the PMN chemical is expected to arise from immersion tank maintenance operations. In these operations, the immersion tanks are periodically drained of spent impregnant and refilled with fresh liquid. To minimize the need to dispose of liquid impregnant, turnover rates are kept high so that fresh material is frequently added to the tanks. The spent impregnant is transferred into drums for disposal. The amount of PMN chemical released from the disposal of waste impregnant would depend on the extent to which the PMN chemical is retained in the spent material, and may be estimated as:

$$\%PMN/100 * LW * RF * D = ?\ \text{lb/year}$$

where LW is the amount of waste liquid impregnant in lb/day generated at the facility, and RF (between 0 and 1) is the fraction of original PMN remaining in the waste liquid. LW is approximately 1% of the impregnant use rate, W. Highly reactive or volatile PMN chemicals will probably have a small RF value because they are likely to be lost by the time the impregnant is removed from the immersion tanks as spent liquid.

Worker Exposure

Worker exposure to the PMN chemical in the impregnant could potentially occur from various operations within the impregnation process. These include the operations to (1) fill the immersion tanks with impregnant liquid, (2) add the additives to the tanks, (3) load transformers into the tanks and stay in the vicinity of the tanks to oversee the impregnation process, (4) transfer impregnated transformers to curing ovens, and (5) perform maintenance on the immersion tanks. The impregnation is performed in a separate area with a dedicated staff of, on average, three workers. Additionally, one maintenance worker would support the operation.

The extent of worker exposure to the PMN chemical in these process steps would depend on the nature of the process equipment; the volatility of the PMN chemical; and the proximity of the workers to the immersion tanks, impregnated transformers, and curing ovens. Accurate quantification of the various routes for potential worker exposure is difficult with the limited information currently available. For this generic scenario, the various potential routes of worker exposure are discussed qualitatively.

<u>Inhalation (mg/day)</u>: Inhalation of the PMN chemical is not expected to be the most significant route of worker exposure to the PMN chemical. Air flow through facilities impregnation is substantial to remove both volatiles and heat from curing operations.

<u>Dermal Exposure (mg/day)</u>: Dermal exposure can arise from operations involving transfers of the impregnant, addition of chemical additives to the immersion tanks, and mechanical removal of cured impregnant from transformer surfaces such as wires and terminals. Handling of impregnated transformers is conducted using hoists and holding baskets, so that physical contact and dermal exposure from such operations would be minimal. Still, sensitization overtime to epoxy and varnish impregnation is a common problem for workers in these operations.

Dermal exposure from the PMN chemical may be calculated using typical factors for dermal exposure from the types of routine contact operations involved [2]. The operations responsible for the majority of the dermal exposure would be the transfer and mixing of chemicals to prepare the impregnant. If routine contact with the impregnant (and PMN chemical) occurs in these operations with a frequency, FT (number/day), then the dermal exposure is:

$$(1{,}300\text{-}3{,}900)\ \text{mg/m}^3 * FT * \%PMN/100 = ??\ \text{mg/day}$$

Note that these estimates of the extent of dermal exposure would be mitigated if normal operating procedures in the impregnating facility were to involve the use of dermal protective gear, such as gloves. Because impregnant materials may be skin irritants, it is likely that skin protective gear will be used at most transformer impregnating facilities.

Disposal Concerns

The containers used to transport the PMN chemical to the facility are assumed to be recycled, cleaned to remove contamination, and appropriately landfilled or incinerated. All liquid and water wastes are assumed to be reused, reprocessed, or air dried and then disposed of as solid wastes. Solid wastes containing the PMN chemical are assumed to be disposed of using appropriate mechanisms.

Note that release of the PMN chemical to the environment also may occur as a result of the retention of PMN in the cured transformer impregnant. The implications of this release may need to be addressed for the PMN chemical.

References

[1] Technology and Market Assessment. *The North American Electrical and Electronic Transformer and Coil Industry*. Technology and Market Assessment (TAMA) Reports, Lake Zurich, IL. December 1988.

[2] CEB, 1991. Chemical Engineering Branch. *CEB Manual for the Preparation of Engineering Assessments*, Volume 1, Contract No. 68-D8-0112, U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C., February 1991.