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A Baseline Assessment Of Environmental, Health, And Safety Aspects And Impacts Associated With Lithographic And Digital Printing Operations Performed Under Ideal Work Conditions

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A BASELINE ASSESSMENT OF ENVIRONMENTAL, HEALTH, AND SAFETY ASPECTS AND IMPACTS ASSOCIATED WITH LITHOGRAPHIC AND DIGITAL PRINTING OPERATIONS PERFORMED UNDER IDEAL WORK CONDITIONS.

By

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PERMISSION

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ABSTRACT

This work examined various environmental, health, and safety aspects of two comparable printing technologies i.e. offset lithographic and electrophotographic digital printing, and evaluated their impacts on the environment and health & safety of the workers. It also studied the environmental behavior of these technologies with respect to print volume, and provides information to print manufacturers on the same so that they can use this information while deciding on technological selection. An effort has been made to bring attention of the print manufacturers towards the key environmental, health, and safety issues that will help them understand the importance of pollution prevention and safe work operations.

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List of Acronyms

Acronym	Description
$	Dollars
%	Percent
ACGIH	American Conference of Governmental Industrial Hygienists
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
dB	Decibel
EHS	Environmental Health and Safety
EPA	Environmental Protection Agency
g	Grams
GATF	Graphic Arts Technical Foundation
HAP	Hazardous Air Pollutant
HP	Hewitt Packard
Hr:Min:Sec	Hour:Minute:Second
Kg	Kilograms
lb/gal	Pounds per gallon
LMV	Lost Material Value
mg/m^3	Milligrams per metric cube
N/A	Not Applicable
NIOSH	National Institute for Occupational Safety and Health
Nos.	Numbers
NYSDEC	New York State Department of Environmental Conservation
OSHA	Occupational Safety and Health Association
PEL	Permissible Exposure Limit
pH	Negative logarithm of hydrogen ion concentration
PIP	Photo Imaging Plate
TPY	Tons Per Year
TWA	Time Weighted Average
VOC	Volatile Organic Compound

1.0 INTRODUCTION

1.1 Statement of the Topic:

This topic was studied in an effort to evaluate and compare the environmental, health, and safety aspects and impacts associated with lithographic and digital printing processes, and to observe environmental behavior of these technologies with respect to print volume. Two typical comparable presses i.e. sheetfed lithographic and digital were studied for both short-run and long run printing 500 and 3000 sheets respectively, to quantify the amount of waste generated and to evaluate health & safety risk to employees at each operational stage.

Thus, the objectives of this study were:

- To identify and analyze environmental, health, and safety aspects and impacts associated with lithographic and digital printing processes.
- Based on EHS observations and analysis, provide information to print manufacturers on the waste sources and tonnage resulting from the printing operations, and thus create a base for integrating EHS into printing business management strategy.

1.2 Significance of the Topic:

The Printing industry is on the verge of technological change. While the majority of print volume is generated by offset lithography, many print operations are bringing in digital technologies as a complement or even replacement for some offset market segments.

These new technologies enable variable data printing and economically viable short-run jobs. With the advancement and proliferation of digital technologies, the printing industry is looking forward to digital printing as a panacea for some significant technical and regulatory problems that are currently associated with traditional printing methods.

However, issues surrounding the environment and workplace health & safety do not disappear merely because a facility is utilizing digital technologies rather than traditional printing processes. Moreover, digital technology has its own demerits that restrict its use for certain circumstances. It is essential for printers to know and understand how environmental, health & safety impacts of their digital printing compare to traditional printing technologies.

Among the most widely distributed digital technologies including Inkjet, electrophotography with dry toner, and electrophotography with wet toner, latest is believed to be the most competent to offset lithography in terms of high speed and image quality **(The Print Extension Inc., par.1)**. Therefore, out of these technologies, electrophotographic wet toner technology is focused here in comparison with sheetfed lithographic technology for the study purpose.

1.3 Reason for Interest:

The topic was chosen for two main reasons. First, the printing industry, due to its large market share, great employment potential, and use of a variety of dangerous chemicals, can have significant economic and environmental impact. Second, the majority of the

firms that fall under this category are small and medium in size for which it's very important to know about the environmental, health, and safety impacts of the modern digital technology before they convert to the apparently eco-friendly digital technology.

1.4 Limitations of the Study:

The result of this study depends on several factors, and not all of them were considered here in this study due to resource constraints and feasibility considerations. Therefore, this study is subjected to certain limitations which are as follows:

- The study was performed under normal working conditions and no operational or maintenance problems encountered during the trials. This may not be the same all the time as factors such as operator experience, press condition, etc. govern the press operation. Therefore, the results obtained under these abnormal (i.e. trouble shooting) conditions would be drastically different than what would have expected under normal conditions. The potential impacts that the abnormal operations can have on the environmental health and safety are listed below:
  - Problem in attaining acceptable print quality may consume excess amount of resources such as paper, ink, blanket cleaning solutions, etc. and waste volumes generated from wastage of paper, ink, blankets in digital press, etc.
  - The cleaning of blanket in both presses may expose employees to dangerous VOC and HAP emissions for longer time causing significant health impact.

  - Repeated abnormal operations may psychologically cause the operator to work impatiently putting him at risk. The hazards arising from caution sign ignorance are likely to occur under such situation.
- Due to time and resource limitations, the size of the air monitoring samples was restricted to one sample for each type. Though, this gave the desired results, more precise results could be obtained by conducting more samples for each kind of sampling. Also, the samples were located at specific locations considering the worst case scenario representing maximum concentration levels. To obtain representative samples, the monitors should be located at various workplace zones considering the work activities.

1.5 Definitions:

a. Actual VOC Emission:

This is the actual emission of volatile organic compounds at normal press operating condition.

b. Blanket:

A blanket is an intermediate medium used to carry the ink from the imaging plate to the paper.

c. Blanket Cleaning Paper:

A wipe paper used to wipe the blanket after its cleaned using cleaning solutions.

d. Cleaning Solutions:

Chemical used for cleaning the blanket, plate, and other inked press parts.

e. Emission Factor:

A ratio of amount of pollutant released to the environment to the amount of pollutant present in the chemical.

f. Environmental Cost:

Total cost incurred on the waste management activities.

g. Environmental Health and Safety Aspect:

An environmental health and safety aspect is an element of an organization's activities, products, or services that can interact with the environment, health, or safety of the employee.

h. Environmental Health and Safety Impact:

An environmental health and safety impact is any change to the environment, health, or safety of the employee, whether adverse or beneficial, wholly or partially resulting from an organization's activities, products, or services.

i. Imaging Agent:

A chemical used in digital printing operations to maintain the inks at required viscosity.

j. Imaging Oil:

A chemical used as a carrier in digital printing operations to carry the ink smoothly to the application point.

k. Liner:

This is a thin plastic or fiber sheet used in lithographic printing operations to facilitate the ink application system.

l. Long Run:

It's a whole press operation cycle which requires long time for its completion due to heavy print load. For this project work, the press run aimed at printing 3000 sheets is considered as long run.

m. Lost Material Value:

Lost material value is the value of the material that could have been saved from being a part of waste by practicing pollution prevention practices such as recycling, good housekeeping, good operation control, etc.

n. Makeready Waste:

It's the amount of waste produced in operations performed prior to the normal press run which takes place only when the press is ready to deliver the expected print quality.

o. Opacity:

Opacity refers to the smoke or blue haze that can be emitted from some dryers on heatset lithographic presses; this haze is typically caused by fine particles suspended in the exhaust.

p. Particulate Matter:

Particulate matter is defined as particles of solid or liquid matter in the air, including nontoxic materials such as soot, dust, and dirt, and toxic materials such as lead, asbestos, suspended sulfates, and nitrates.

q. Photo Imaging Plate (PIP):

It is a light sensitive metal plate used in digital press for receiving electrostatic charges to develop an image are that in turn act as a ink receptor and transfer the ink to the blanket.

r. Platemaking Chemistry:

It is a term used to encompass all the chemicals used in the platemaking operation. These chemicals include developer solution, replenisher solution, and plate finisher or gum.

s. Potential VOC Emission:

This is the maximum VOC emission that a chemical can produce if it is allowed to dry completely at high temperature and for longer duration.

t. Plates:

It is an imaging plate used in lithographic printing.

u. Rags:

These are the cotton clothes used for cleaning of lithographic press.

v. Respirable Dust:

Respirable dust is that part of the particulate matter or total dust which is capable of penetrating the gas-exchange region of the lungs.

w. Short Run:

It's a whole press operation cycle which requires short time for its completion due to less print load. For this project work, the press run aimed at printing 500 sheets is considered as long run.

x. Time Weighted Average (TWA):

This is an average airborne concentration of a chemical or an agent to which a person can be exposed to over an 8 hour workday.

2.0 BACKGROUND

2.1 Printing Industry:

The printing industry uses various printing technologies for printing books, magazines, newspapers, business documents, catalogs, forms, annual reports, etc. These technologies include lithography, rotogravure, flexography, screen, letterpress, and digital technologies including inkjet, electrophotography etc. The use of these technologies depends on the quality of the print, number of impressions to be printed, availability of required resources, cost of the equipment, consumables cost per print, and other factors. Though, it's common to use only one technology for the whole business, more than one technology can be found at giant establishments.

According EPA's sector notebook data, one of the most significant characteristics of the printing industry is the large proportion of the small firms. Nearly 84 percent of firms employ fewer than 5 employees. However, this is not true with larger flexographic and gravure printing requiring more employees to handle variety of job activities **(EPA Office of Compliance Sector Notebook Project, 4)**.

In this sector notebook, EPA also focuses on the environmental impacts cause by the printing industry. Printing industry impacts on the environment from all sides. The volatile compounds used in the process contribute to air emissions and cause smog formation and some of these compounds affect on the ozone system and may cause ozone depletion. The wastewater discharge may severely harm the freshwater or marine

ecosystem, whereas the solid waste exaggerates waste disposal problem **(EPA Office of Compliance Sector Notebook Project, 25)**.

As per EPA's report, the printing industry releases 99 percent of its total toxic chemical waste to the air and one percent to land and water. Other TRI industries release approximately 60 percent to air, 30 percent to land, and 10 percent to water respectively **(EPA Office of Compliance Sector Notebook Project, 34)**.

2.2 Lithographic Printing:

Lithographic printing is basically a planographic printing process in which a metal, plastic or paper plate with two separate areas i.e. imaging and non-imaging areas is used to carry ink to the paper. The lithographic printing process is classified in two different subprocesses, depending on how the paper is fed and if the paper is heated **(Rothenberg, Toribio, and Becker, 5)**:

a. <u>Sheet-fed offset lithography</u>: As the name implies, individual sheets are used for image printing and the ink is allowed to dry in an oxidative polymerization process. The technology is normally used for short-run orders. 92 percent of the printing facilities that run lithographic presses have sheet-fed offset lithographic presses **(CTSA)**. The most common products that use this technology are fine art reproduction, books, posters, periodicals, advertising flyers, greeting cards, brochures, and packaging.
b. <u>Web offset lithographic (heatset and nonheatset)</u>: A continuous roll (web) of paper is used and the images are printed on top of it, and the paper is cut into

individual sheets during the post-press operations. These are used for longer run orders. The mot common products that use this technology are business forms, newspapers, periodicals, catalogs, advertising, and books. Only 11 percent of lithographers use the web offset process **(CTSA)**. The heatset process uses a recruiting hot air system to dry the ink, while the nonheatset process uses a type of ink that does not require assisted drying.

2.3 Digital Printing:

Instead of producing full size image as in case of offset printing, digital printing technology uses complex matrices of dots or pixels to produce images. Digital printing technologies are further classified according to their way of producing images. With the advancement in digital world, many technologies are coming in market every day. Of these, the most common ones are **(The Print Extension Inc.)**:

a. Ink jet: This is used in small or big inkjet printers which use droplets of liquid inks for printing. Ink deposition takes place by means of a moving head that allows drops to fall as directed electronically, a vector at a time, left to right and back again.

b. Electrophotographic with dry toner: This is used in large desktop printers and in big copier machines. It involves giving an overall electrical charge, in darkness, to a photoconductor on a cylinder, or drum. Once charged, the drum flashes the light which reflects off the black and grey portion of the image to be copied and discharges the photoconductor to match. The portion where the drum received less light retained the charge and so attracted black toner. The toner is then transferred to a sheet of paper, which in turn was heated to seal the toner.

c. Electrophotographic with inks or wet toner: This is used in large digital printing presses. The ink in this process is actually a liquid oner that can be electrostatically charged to produce high resolution and quality color images. For each color, both a plate and the ink receive a charge, and the ink adheres to the charged area of the drum and gets completely transferred to the paper through the blanket. This process repeats for each individual color.

d. Direct to plate: In this technology, specially made 3 layered plates are burned (imaged or carved with depressed areas) by a high speed laser beam. Each plate is mounted on its own cylinder, and all the plate cylinders are mounted around a single large cylinder, which rotates the paper past each plate in turn. Waterless inks adhere to the depressed portion of the plates and get transferred to the paper directly.

3.0 LITERATURE REVIEW

3.1 Markets Trends in Printing Industry:

The printing industry is undergoing a technological change in which print volumes are migrating from conventional offset lithographic printing to digital printing. Lithographic printing is likely to remain a viable technology for the long term for static, long run jobs **(ref. Frank Romano, private communication)** either as a standalone technology or as a component of hybrid production. The migration to digital technology is partially hindered by the small size and limited investment capital available to many printing companies. Many offset printers are small in size and employ fewer than 10 employees, many of whom are traditionally trained, so conversion from conventional to digital print technologies may be economically cumbersome.

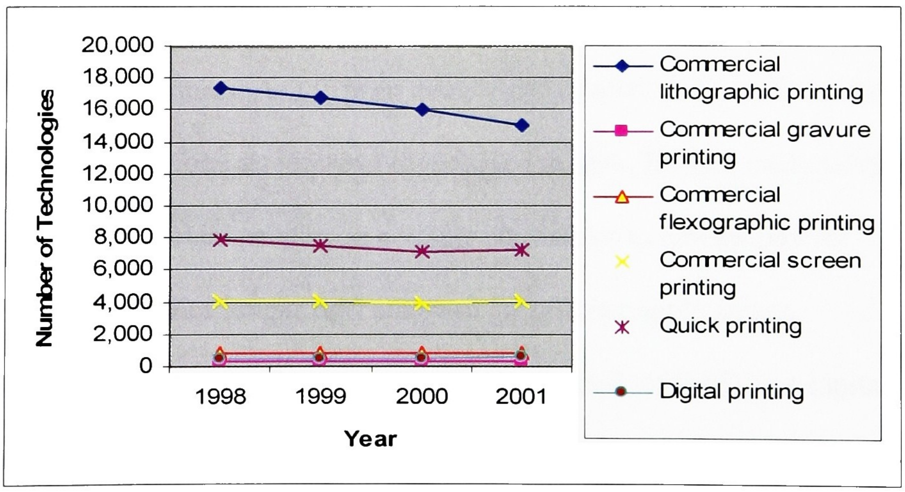
Lithography is by far the most commonly used technology, with a total 15,038 firms using this technology in year 2001 **(US Census Bureau 2001 Economic Census)**. However, the number of firms practicing lithography is declining over time with the availability of new technologies. The dominance of lithographic printing in the industry's recent history may be attributed to the efficient production of multiple and inexpensive copies, very high resolution and print quality, a wide range of coated and uncoated substrates, use of less costly inks than digital printing, and considerable industry experience in color management **(Vince Cahill, 3)**.

However, there are certain barriers for the proliferation of lithographic technology including very limited capability to do variable data printing, prepress setup and

preparation, higher cost per print for short run jobs, the potential to generate significant environmental and health impacts, considerable space requirements, and image size restriction depending on the size of the plate **(Vince Cahill, 3)**.

The digital printing industry, on the other hand is growing at a steady pace, with an increase of 151 press units placed in the United States from 1998 to 2001**(US Census Bureau 2001 Economic Census)**. The driving forces for the adoption of this technology include minimal press setup time, variable data customization, image quality improvements, new screening algorithms, lower costs for short run, minimal space requirements, overall reduction in hazardous materials usage, reduced waste production, and the ability to transmit and collaborate on electronic print files all around the world **(Vince Cahill, 2)**.

Figure 3.1: Major Printing Technology Distribution in U.S.



Like lithography, digital printing has some drawbacks which include slower throughput compared to analog technology, higher cost per impression, the need for specially prepared and coated substrates with some technologies **(Vince Cahill, 2-3)**.

GAMIS (Graphic Arts Marketing Information Service) conducted a study to examine the effects of new printing technologies on the performance requirements for paper substrate **(Business Development Advisory Inc.)**. Highlights of this study are summarized below.

a. Conventional printing technologies will grow at below average rates while digital processes will grow at above average rates over the next five years.

b. The single and two color sheetfed businesses will be increasingly vulnerable to digital processes that can offer faster turn-around on orders, lower costs for short-runs, and variable print capabilities.

c. Electrophotography (EP) is the dominant printing process for cut size papers sold into commercial office, consumer, and commercial printing markets. The breakeven point relative to analog processes in terms of run lengths will continue to progress toward longer run sizes as process improvements reduce operating costs across all formats. As the print quality and relative cost position of the different EP print formats improve for longer run jobs, EP will increasingly be viewed by commercial printers as a viable alternative to lithography for traditional (as well as longer run) commercial printing applications.

d. Digital print processes will continue to attract the bulk of R&D and capital investment spending within the industry but the commercial execution of these investment programs will be slower than expected by some.

3.2 Awareness of Environmental, Health and Safety Issues in the Printing Industry:

Awareness of environmental, health, and safety issues plays an important role in selection of environmental friendly technology. As per one case study, lithographic printers are not familiar with the available government-supported assistance program, and rely greatly on their vendors and suppliers for such information **(Rothenberg, Toribio, and Becker, 20)**. However, amongst the volunteer printers, improvement of environmental, health, and safety conditions was a prime motivator behind reducing VOC emissions.

3.3 Environmental Issues in Lithographic Printing Industry:

Jacobson has listed potential sources of pollution to the air, water, and land commonly found in the lithographic printing industry that may be subjected to permitting and/or special waste disposal and reporting requirements. These issues are summarized as follows.

A. Air Emissions:

a. Volatile Organic Compound (VOC) Emissions:

   Emission of volatile organic compounds is a major environmental issue especially in lithographic printing industry. Insignificant amounts of VOCs may be emitted from plate correction fluids, film cleaner, proofing, plate making, film developing operations, and non-heatset inks. Significant amount of VOCs are generated from fountain solution, cleaning solvents, heatset inks, and paper coating operations.

b. Hazardous Air Pollutant (HAP) Emissions:

   Insignificant amount of hazardous air pollutants may be emitted from film cleaners. Significant amount of HAPs are generated from fountain solution as

ethylene glycol, a hazardous air pollutant, is commonly used in fountain solution. Also, cleaning solvents such as Methyl Ethyl Ketone and other solvents containing glycol ethers, xylene, cumane, etc. emit HAP in significant amounts.

c. Particulate Matter (PM) Emissions:

   Paper dust, spray powder from sheetfed presses and other particulates in the form of condensable organics from uncontrolled ink oil emissions from heatset web presses may be emitted.

d. CO, SOx, and NOx Emissions:

   These emissions are mainly generated from heated web press dryers, boilers, fuel combustion equipments such as heating devices, hot water heaters, furnaces, backup generators, etc., and pollution control devices.

B. Wastewater Discharges:

a. Platemaking Bath Discharges:

   Fixers and developers used in new direct-to-plate platemaking operations have high pH and can be high in BODs and CODs, and total suspended solids. Discharges to the sewer may cause harm to aquatic bodies, and therefore, they must meet the local sewer authority's acceptable ph range. Discharge to any septic system is not acceptable.

b. Film Developing Bath Discharges:

   Fixers containing silver thiosulfate contain silver, a heavy metal, whose discharge is regulated by U.S.EPA. Fixers can be high in BODs and CODs, and total suspended solids. Discharges to the sewer may cause harm to aquatic bodies, and

therefore, they must meet the local sewer authority's acceptable ph range.

Discharge to any septic system is not acceptable.

c. Fountain Solution Discharge:

Waste fountain solution may contain flammable materials such as isopropyl alcohol that are prohibited from all sanitary discharge systems if the flashpoint is below 140 ^{0}F. Acceptability with local POTW needs to be confirmed prior to any discharge. Discharge to a septic system is not acceptable.

d. Water-based coating Discharges:

Waste coating solution may contain flammable materials such as isopropyl alcohol and other solvents in limited amounts that are prohibited from all sanitary discharge systems if the flashpoint is below 140 ^{0}F. Acceptability with local POTW needs to be confirmed prior to any discharge. Discharge to a septic system is not acceptable.

C. Solid/Hazardous Waste Disposal:

a. Spent Fixer:

Spent fixer from imaging section contains silver, even after passing through silver recovery units. If the silver content exceeds 5 ppm, the waste is considered as hazardous waste that needs to be disposed off properly.

b. Used Containers:

Packaging for plate processing chemicals, inks, solvent, blanket wash, etc. may contain product residues and can be of concern if not properly rinsed before

disposal. Therefore, containers should meet EPA's definition of "empty" (i.e. contains less than 1" of material in a 30-55 gallon drum or less than 3% of the dry volume weight) prior to recycling or disposal.

c. Ink Waste:

Most uncontaminated lithographic ink does not meet the definition of a hazardous waste. Some specialty inks may contain regulated metals which render the waste inks hazardous.

d. Cleaning Solvent Waste:

Cleaning solvent mixed with water may also contain excessive suspended solids, excessive color, and/or pH levels that do not meet the local discharge standards.

e. Coating Waste:

Generally, coating waste is not considered as hazardous. However, it may exhibit flammable characteristics or contain an EPA "listed" solvent making them a hazardous waste. Also, it may contain excessive suspended solids, excessive color, and/or pH levels that do not meet the local discharge limits.

f. Solvent and Ink Laden Rags:

Solvent and ink laden rags may exhibit flammable characteristics (i.e. flash point below 140 ^{0}F) or contain EPA "listed" solvent making them a hazardous waste. Many states specifically regulate shop towels and if certain management practices are followed, they are not considered as hazardous waste. These management practices can include:

i. Towels must be unsaturated and pass paint filter or "one drop" test.

ii. Containers must be labeled, covered, and closed.

iii. Must have a contract with industrial launderer.

g. Oil/Lubricants:

In some states, these materials are classified as hazardous wastes and are subject to specific recycling, storage, handling, or disposal requirements. Oils and lubricants containing certain metals or halogens above specific levels are classified as hazardous waste.

3.4 Environmental Issues in Digital Printing Industry:

Unfortunately, very less data is available on the environmental issues pertaining to digital press operations. As per the HP operator manual, the electrophotographic press (i.e. digital HP Indigo press 3000) is subjected to following waste categories.

A. Solid Wastes:

Discarded blankets, PIPs, filter cartridges, and other items are defined as non-regulated solid waste and may be discarded as normal waste in trash cans.

B. Used Oil Waste:

Used oil waste should be discarded or recycled according to local regulations. The following waste materials produced during normal operation of the HP Indigo press 3000 are defined as used oil:

- Used imaging oil collected during line flushing from cooler draining and from ancillary cleaning operations
- HP ElectroInk
- Cotton swabs or rags with imaging oil
- Empty ink cans

3.5 Health and Safety Issues in Lithographic Printing Industry:

The most common hazards in printing industry arise from chemical exposure and access to hazardous parts of moving machine parts. Amongst the hazards caused by chemical exposure, includes occupational asthma, skin diseases, brain damage.

Printing Industry Advisory Committee (PIAC) of Britain produced a leaflet to provide guidance on skin diseases in printing industry. The leaflet highlights the substances and processes that cause skin diseases, particularly dermatitis, and preventive and corrective actions for the same. Printing processes such as cleaning of litho rollers and cylinders, platemaking, correction of litho plates, solvent use, etc. are prime processes with a high occurrence of dermatitis.

The Graphical, Paper, and Media Union (GPMU) discussed more about occupational asthma in its *health and safety* article. Occupational asthma is a result of breathing in substances called as respiratory sensitizers. These substances, such as isocyanates, epoxy systems, and rosin when inhaled can induce changes in body immune system. These sensitizers are mostly found in specialist printing inks, such as textile, glass and metal printing, and specialized adhesives used in screen printing and book binding.

Professor Roberta White and Dr. Susan Proctor of the University of Boston, Massachusetts, warned that brain damage linked to workplace solvent exposure may mimic multiple sclerosis or dementia, with loss of memory, inability to think clearly and depression **(The Graphical, Paper, and Media Union, par.3)**.

Printing Industry Advisory Committee of Britain prepared a summary report on the accident analysis in the printing industry. As per this report, the most critical processes that cause most of the injuries include printing followed by finishing and waste disposal processes. In terms of accident type, handling, lifting and carrying is more concerned followed by contact with moving machinery and slip & fall. From injury type standpoint, finger and hand cut injuries are most critical followed by strain back and finger/hand fracture. Make-ready operations cause more injuries than maintenance/problem fixing operations and normal operations.

Printing Industry Advisory Committee (PIAC) of Britain produced a leaflet in response to large number of accidents that continued to occur during the operation and maintenance of printing presses. This leaflet provides guidance on safe working practices while cleaning and maintaining the sheetfed lithographic press. On detailed analysis, it was found that most of the accidents are caused by the following reasons.

- Inadequate safeguards allowing access to in-running nips.
- Guards failure due to lack of maintenance or removal of guard.
- Control performance deterioration due to lack of maintenance.
- Use of unsafe systems of work for press cleaning.

The leaflet also focused on the potential hazards associated with printing press operations. These hazards include:

- In-running nips between inking and damping roller assemblies.
- In-running nips between the plate, blanket and impression cylinders.
- In-running nips between impression/transfer cylinders.

- Unexpected start-up during multi-person cleaning.
- Absence of nip bars and gap covers.

Reinke, Utsching, and Keller summarized safety hazards and control measures in his article that was drawn from the material contained in Flexography: Principles and Practices. This article recommends use of safety equipments and practices such as emergency stop, lockout/tagout, eyewash or safety shower, spill kit, machine guarding, PPE, fire extinguisher, and labeling on hazardous materials and wastes. The article also described the sources of fire hazard that include friction heat due to high roller speed; static electricity development on press rollers and flammable chemical containers; and spark/flame generating from metal part striking or power tool use.

OSHA documented major ergonomics related work injuries and causes in its report to one of the inspected facility. These include body injuries resulting from stretched repetitive actions in binding section, lifting of heavy stacks of prints & pallets, bending actions, pushing and pulling of heavy jacks, stacking materials at elevated shelves, etc.

3.6 Health and Safety Issues in Digital Printing:

Information with regard to health and safety hazards in digital printing is very scanty. Print manufacturers derive most of the information on health and safety hazards from material safety data sheets supplied by chemical manufacturers and operator's manual provided by the press manufacturers. In the HP Indigo 3000 press operator's manual, HP

highlighted hazards associated with concerned press parts and their actions. Cautions related to these hazards are summarized and listed below:

- Require electrical isolation and lockout during service and maintenance of press.
- Post safety signs on walls in the printing area to warn of fire hazard.
- Do not locate spark-producing equipment within 7.6 m distance of the press.
- Place fire extinguishers where imaging oil and HP ElectroInk will be used or stored.
- Use gloves and safety glasses while performing maintenance operations to prevent exposure to ink or imaging oil causing skin & eye irritation.
- Provide eye wash while handling inks and imaging oil.

3.7 Regulatory Review:

In an email response through PRINTREG- An email service provided by PNEAC (Printers' National Environmental Assistance Center), **Jones** discussed more about the printing regulations pertaining to lithographic printing.

> **"In terms of regulations for lithographic printing operations, there are no national or federal regulations that are universally applicable. At one time EPA was developing these types of regulations, but suspended work on a document called the Control Techniques Guidelines for Offset Lithography. However, this document has served as a basis for many states to develop and impose regulations designed to reduce VOC emissions from lithographic printing operations."**

Most of the states including Georgia, Virginia, etc. have following regulations:

a. VOC emissions from ink usage:

   No requirement applies to sheetfed lithographic process.

b. VOC emissions from fountain solution usage:

   Any person who owns or operates any type of sheetfed lithographic press shall meet one of the following requirements for the fountain solution used on that press:

   i. Maintain the as applied VOC content of the fountain solution at or below 5.0 percent: or

   ii. Maintain the as applied VOC content of the fountain solution at or below 8.5 percent, by weight, and refrigerate the fountain solution to 60^0 F or less.

c. VOC emissions from cleaning solutions usage:

   Any person who owns or operates any type of sheetfed lithographic press shall meet one of the following requirements for each cleaning solution used for blanket and ink roller cleaning on that press:

   i. Maintain the as applied VOC content of the cleaning solution at or below 30 percent, by weight: or

   ii. Maintain the as applied VOC composite partial vapor pressure of the cleaning solution at or below 10 mm of Hg at 20^0 C (68^0 F).

New York State Regulations:

In SBAP newsletter, **Coyle** has focused on an article regarding environmental issues concerning offset lithographic printing operations. In this article, he discussed about the requirements that are mandatory and are required by DEC (Department of Environmental Conservation) regulations, largely Part 234-Graphic Arts and Part 201-Permits and Registrations. Summary of these regulations is described below:

A. Part 234 - Graphic Arts:

a. Applicability:

   All lithographic printing processes located in the New York City Metropolitan Area are subjected to the VOC control requirements listed in this session. This area is defined as all of the City of New York, and Nassau, Suffolk, Westchester, and Rockland counties. Outside this area, only Major sources (those emitting more than 25 tons of VOCs per year) are subjected to this requirement.

b. Requirements:

   i. All presses that put in operation before September 1, 1988 are required to use a fountain solution that contains 15 % or less VOCs, by weight; or install an air cleaning device to reduce VOC emissions from the dryer exhaust by at least 90%.

   ii. All presses that put in operation on or after September 1, 1988 are required to use a fountain solution that contains 10 % or less VOCs, by weight; or install an air cleaning device to reduce VOC emissions from the dryer exhaust by at least 90%.

   iii. No specific requirements for VOC content of inks and clean-up solvents.

iv. All presses regardless their date of installment, must keep all VOC containing materials in closed containers.

v. All facilities subjected to this standard must maintain the opacity of their exhaust below 10% for any consecutive 6-minute period.

B. Part 201 - Permits and Registrations:

a. All lithographic printing processes located in the New York City Metropolitan Area at least required to be registered with DEC. Facilities with VOC emissions more than 12.5 tons/yr are required to obtain a State Facility Permit.

b. Facilities located outside New York City Metropolitan Area can get an exemption from any permit requirements if their daily VOC emissions are less than 20 lbs. However, these facilities need to maintain records that document the VOC emissions. Facilities with VOC emissions more than 12.5 tons/yr are required to obtain a State Facility Permit.

C. Recordkeeping Requirements:

a. All printing operations, regardless of their size or location, must maintain usage records of VOC-containing materials, including fountain solution concentrates, clean-up solvents, blanket washes, and inks.

Health and Safety Regulations:

OSHA regulations for printing industry are covered in general industry standards i.e. standards 1910. As per **OSHA**, the most frequently cited standards in printing industry include:

- 1910.147 The control of hazardous energy (lockout/tagout)

- 1910.1200 Hazard Communication
- 1910.212 General requirements for all machines
- 1910.106 Flammable and combustible liquids
- 1910.219 Mechanical power-transmission apparatus
- 1910.157 Portable fire extinguishers
- 1910.134 Respiratory protection
- 1910.095 Occupational noise exposure
- 1910.132 General requirements, Personnel Protective Equipments (PPE)

3.8 Job Hazard Analysis:

OSHA produced a booklet to help employers, foreman, and supervisors to identify the hazards associated with their business processes. OSHA outlined five major steps to conduct systematic job hazard analysis task. These steps are as follows:

- Involve your employees in job hazard analysis process.
- Review your accident history.
- Conduct a preliminary job review.
- List, rank, and set priorities for hazardous jobs.
- Outline the steps or tasks i.e. breakdown each job into sub-steps and perform analysis task on each single step.

3.9 Case Study: Assessment of Occupational Safety and Health in the Printing Industry.

Hellenic Institute of Occupational Safety in conjunction with the Athens Labor Center conducted a project aimed at assessing the safety and health conditions in the small and medium sized printing sector **(European Agency for Safety and Health at Work)**. Physical and chemical parameters in the workplace including solvents, metals, dust, noise, lighting, heat stress, ergonomic and safety hazards were examined and the information was disseminated in small and medium sized printing industry. The physical and chemical parameters were determined in five different areas/processes which are as follows:

- At the printing press during printing
- At the printing press during cleaning
- At the binding section
- At the packaging section
- In storage areas

For the determination of heavy metals (lead, cadmium, cobalt, and chromium) a review of the literature was conducted to obtain information of the type of inks and their use in printing industry. Gravimetric measuring techniques were used for determination of inhalable and respirable fractions of particulate matter. The results indicated number of problems with respect to safety and health in some areas of the industry. These include higher bronze dust concentrations, higher noise level, eye irritation potential, risks from fire, explosion, electrical equipment, unguarded machinery, etc.

4.0 METHODS AND MATERIALS

4.1 Methodology Development:

To date, there is no standard methodology available for conducting an experiment to assess the environmental & health aspects and impacts of lithographic and digital printing presses. Thus, an empirical methodology was developed based on the literature review, engineering knowledge, mass balance concept, and practical considerations. The methodology is subdivided into following 4 sections.

4.1.1 Determination of Print Run Length:

Since the evaluation parameters of the study were known to vary with the total output quantity, two different runs (i.e. short run and long run) were conducted on both presses. Based on the literature review and discussion with press operators and mangers, the short run was limited to 500 prints and long run was limited to 3000 prints.

4.1.2 Determination of Comparison Basis:

Selective parameters or metrics were considered to check the behavior of both the presses in comparison with each other. These metrics include:

a) Economic metrics, such as total cost and cost per print.

b) Environmental metrics, such as resource utilization efficiency, environmental impact, environmental cost, and lost material value.

c) Health & safety metrics such as, indoor air quality and noise levels.

d) Scope for improvement.

4.1.3 Design of Experiment:

Having the parameters or metrics to be determined identified, the experiment was designed systematically to give quantities necessary to calculate the metrics values. The design of experiment is summarized in the following stepwise format. (Please refer to Appendix E).

a. Study the manufacturing process.
b. Prepare flow diagram indicating all resource input and output points.
c. Prepare list of input (resources used) and output (waste streams) parameters to be measured.
d. Explore methods of measurements. Consider sensitivity of measuring devices, effect of temperature and humidity on measurement accuracy, etc. Also, decide when the measurement to be taken i.e. before or after the press run.
e. Involve press operators actively and inform them about their roles.
f. Determine image size to be printed and image quality to me attained.

4.1.4 Experimentation:

The experimentation activities were listed prior to the actual experiment. These activities are as follows:

a. Measurement of pre-experimental parameters:
    - Weight of containers of ink, solvent, cleaning solution, fountain solution, and coating solution.
    - Weight of individual sheet of paper, dry rags, plastic bags, empty containers to be used for waste collection.

- Size of imaging oil tank and the level of imaging oil in the tank.

b. Start the press run.

c. Measurement of pos-experimental parameters:

   - Weight of containers of ink, solvent, cleaning solution, fountain solution, and coating solution.
   - Weight of wet rags, waste ink, waste solvent, and ink mix.
   - Weight of ink liners & plates in offset press and blankets & PIPs in digital press.
   - Level of imaging oil in the tank.
   - Weight of waste blanket cleaning paper and clean blanket paper of same size.
   - Paper count on the press.

4.2 Practicing Methodology:

Two representative sheetfed presses commonly used in the industry, the Heidelberg SpeedMaster 74 and the HP Indigo 3000 were chosen for this study. Currently practiced direct computer-to-plate technology was used for platemaking operations.

In order to assess the overall environmental and health aspect and impact of the two printing technologies, the following metrics were utilized:

4.2.1 Resource Utilization/Wastage Measurement:

1. *Paper:* Paper count was preferred over other measurement techniques such as weight measurement considering the sensitivity of the paper in absorbing

moisture from the atmosphere. The paper count was then multiplied by the average weight of a single sheet of paper calculated from manufacture data and individual sheet weight measurements. Data on total number of sheets printed and prints wasted as make-ready waste was directly taken from the press counter.

2. *Ink/Solvent/Cleaning Solution:* Weight measurement techniques were used to measure ink, solvent, cleaning, coating, and fountain solution. Initial and final weights of the containers were taken to estimate the resource consumption and waste generation.
3. *Imaging Oil & Imaging Agent:* Volumetric measurement techniques were used to measure imaging oil and imaging agent. For the imaging oil measurement, imaging oil tank size (Length x Breadth) was measured. This area was then multiplied by the level difference caused due to utilization of the oil. The Imaging Agent used in the HP Indigo process was measured volumetrically prior to its use.
4. *Plate/Liner/Cleaning Rags/Blanket Cleaning Paper/Blanket/PIP:* Weight measurements were taken for evaluating the offset plate, ink reservoir liner, cleaning rags, offset blanket cleaning paper, HP blanket, and HP Indigo PIP (Photo Imaging Plate) plate. Rags were separated and used for cleaning different parts of the press. For the blanket cleaning paper measurement, an equivalent length of blanket clean paper was cut and measured.
5. *Platemaking Chemistry:* Chemical inventory data for 3 month period was used to calculate the amount of developer, replenisher, and finisher used in the process.

4.3 Air Emission Monitoring:

1. *Particulate Matter Emissions:* The National Institute for Occupational Safety and Health (NIOSH) method 500 and method 600 were used for total dust and respirable dust monitoring respectively. Two types of sampling were conducted on each press. Due to time and resource limitations, the sample size was limited to one sample for each type of sampling.

   a. Area sampling or total dust sampling:

   For the area sampling, the samples were taken at the locations where the maximum concentration of dust was anticipated. For the lithographic press run, the sampler was fixed directly above the coating powder application zone. (Photo 1) For the digital press run, the sampler was placed near the exhaust end of the press (Photo 2). The air was sampled at the rate of 2.0 lpm (liters per minute) for the period of 30 minutes.

   b. Personal sampling or respirable dust sampling:

   For personal sampling, the samplers were placed within the breathing zone of the operators where they spend most of their time. For the lithographic press run, the sampler was attached near the press outlet zone. (Photo 3) For the digital press run, the sampler was attached near the computer monitor of the controller station (Photo 4). The air was sampled at the rate of 2.5 lpm (liters per minute) for the period of 1 hour.

Photo 1: Total Dust Sampling for Lithographic Press

Photo 2: Total Dust Sampling for Digital Press

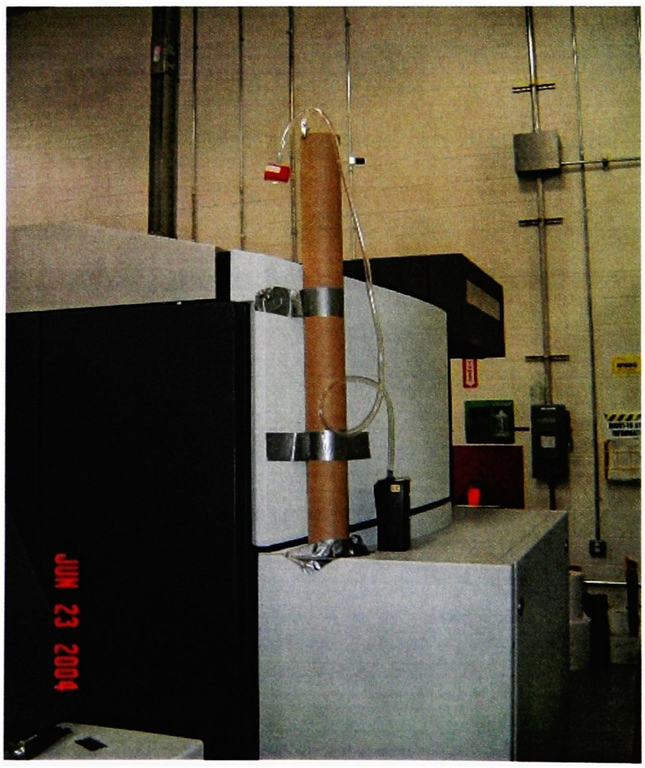


Photo 3: Respirable Dust Sampling for Lithographic Press

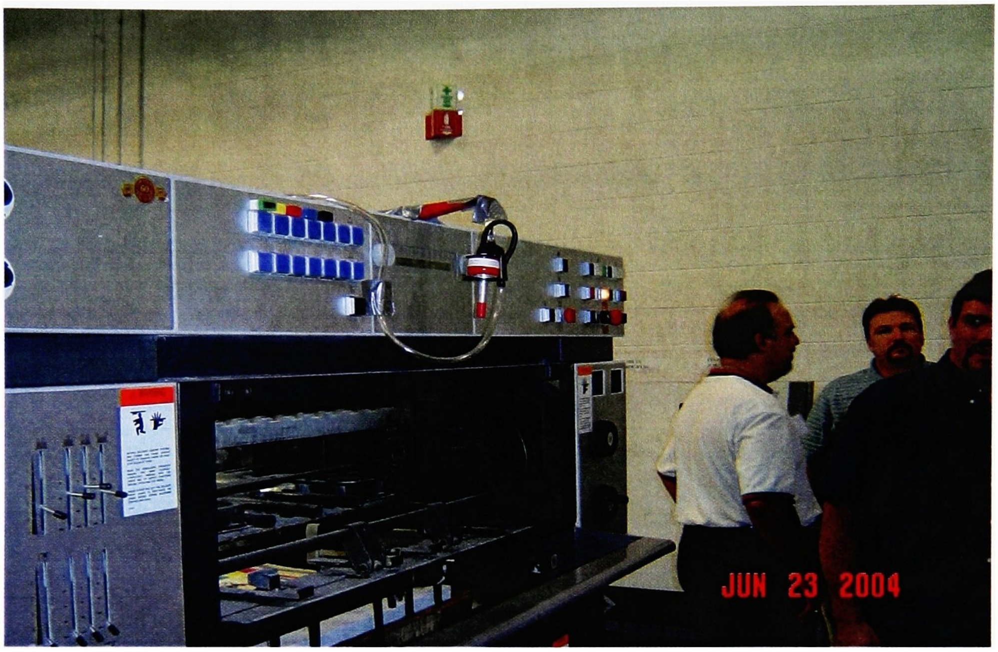


Photo 4: Respirable Dust Sampling for Digital Press

2. *Volatile Organic Compound (VOC) Emissions:* The NIOSH 1500/1501 standard was used for VOC monitoring. VOC sampling was conducted for both area and personal sampling in a manner similar to the particulate matter sampling. Due to time and resource limitations, the sample size was limited to one sample for each type of sampling.

   a. Area sampling or non-breathing zone VOC sampling: For area sampling for the lithographic press, the sampler was fixed at the top of the ink tank. (Photo 5)For the digital press, the sampler was placed near the exhaust end of the press (Photo 6). The air was sampled at the rate of 0.2 lpm (liters per minute) for the period of 20 minutes.

   b. Personal sampling or breathing zone VOC sampling: For personal sampling, the sampler was attached to the shirt collar of the operator and the sample was taken at the time of press cleaning considering the worst case scenario. (Photo 7a and 7b) For the digital press, the sampler was attached near the computer monitor of the controller station (Photo 8). The air was sampled at the same rate and for the same period as that of the area sampling.

Photo 5: Non-breathing zone VOC sampling for Lithographic Press

Photo 6: Non-breathing VOC zone sampling for Digital Press

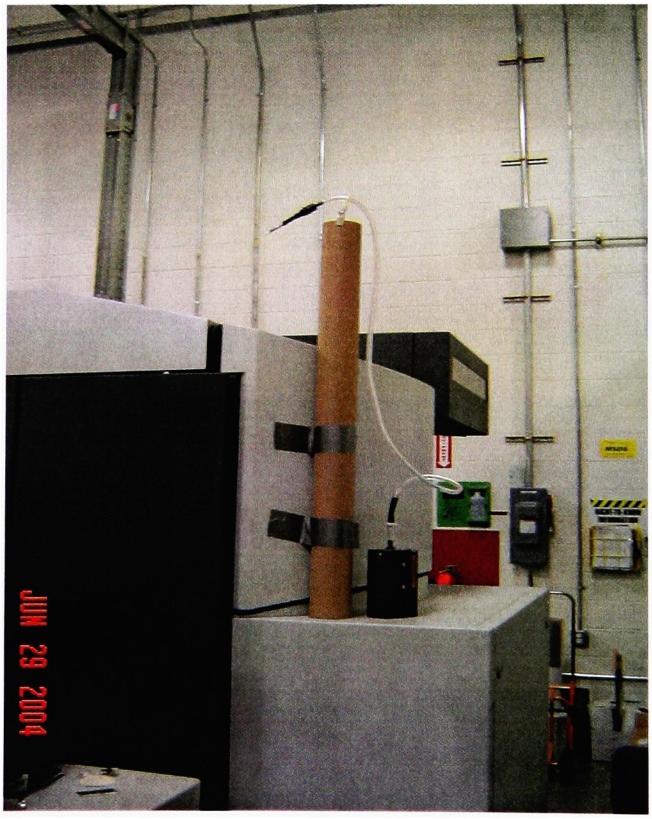
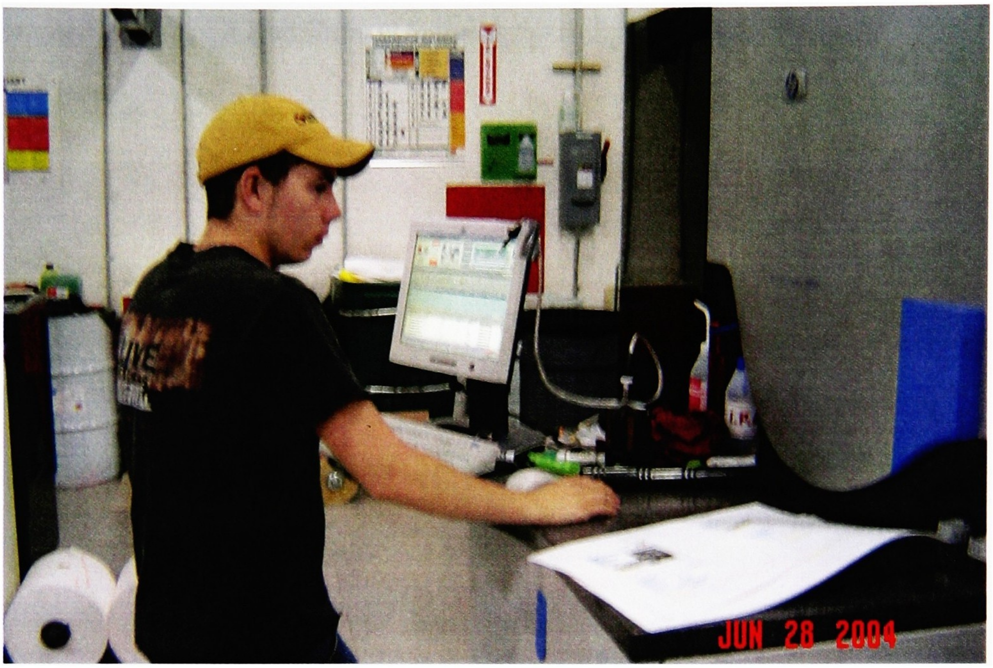


Photo 7 a: Breathing zone VOC sampling for Lithographic Press

Photo 7 b: Breathing zone VOC sampling for Lithographic Press

Photo 8: Breathing zone VOC sampling for Digital Press



4.4. Noise Monitoring:

Noise monitoring was carried out using a Q-300 noise dosimeter. Typically, the noise monitoring should be done for 8 hour period. However, in this case, monitoring was performed only for the duration of the press run because these presses are not operated continually. The procedure to use the noise dosimeter is as follows:

- Charge the battery and check the calibration of the dosimeter before starting the monitoring.
- Clip the microphone of the sampler to the top and end of the shoulder away from the neck of the operator. Avoid any errors due to operator's voice being counted. Clip the meter onto the operator's belt and, if possible, take out the microphone cable underneath the operator's shirt to prevent it from catching on other objects.

- Begin the study by pressing RUN/PAUSE key. Perform normal press operations with the meter ON. At the end of the monitoring period, again press the same RUN/PAUSE key.
- Review the digital information by pressing LEVELS, DOSE, AVE, TIMES, keys.

4.5. Job Hazard Analysis:

Job hazard analysis was performed as per the guidelines given in OSHA 3071 guidebook. The task of job hazard analysis was processed in the following manner:

- Teams of people with diverse experience were formed. The teams member list includes myself (an EHS Graduate Student), Professor from Print Media Department, and the press operators. The team members were informed about the whole job hazard analysis methodology and the purpose behind practicing it.
- The printing job was then broken down into constituent process steps and the team conducted a walk-through around the press and other work zones to identify the potential hazards associated with each process steps. Information regarding accident history, near misses, etc was gathered from the operators.
- Brainstorming to identify potential hazardous parts, motions, actions, etc. were performed and summarized properly.

4.6 Computation Methods:

4.6.1 Method for VOC and HAP Estimation:

Potential and actual volatile organic compounds (VOC) and hazardous air pollutants (HAP) emissions were calculated from the press run results. Potential VOC or HAP

emission is a product of VOC or HAP content of the chemical and the amount of the chemical used, whereas the actual VOC or HAP emission is the product of potential VOC or HAP and emission factors corresponding to chemical type and application practice. Emission factor is based on two main factors i.e. temperature of the system through which the chemical is flowing, and the exposure of the chemical to the atmospheric conditions. Higher the temperature, higher the emission factor, and vise versa. Similarly, greater the exposure to the atmosphere, higher the emission factor, and vise versa.

The emission factors used in this study are based on Graphic Arts Technical Foundation (GATF) guiding document **(Jones),** and are summarized in the table 4.1.

Table 4.1: VOC and HAP Emissions Factors:

No.	Description	Emission Factor
1	Lithographic Ink	0.05
2	Ink and other chemicals used in Digital Press	1.0
3	Cleaning Solutions applied without using rags	1.0
4	Cleaning Solutions applied using rags	0.5
5	Aqueous Coating Solution	1.0
5	Other	1.0

4.6.2 Method for Computing Platemaking Chemistry Usage:

Amounts of platemaking chemicals spent and total numbers of plates developed over a period of 3 months were obtained from the inventory data and chemical uptake rate for

each chemical was calculated. These values are then used in platemaking chemistry usage calculations.

a. Chemical Uptake Rate of a chemical (kg/m^2) = Total amount of chemical spent in 3 months (kg) / total area of plates developed in 3 months (m^2).

b. Chemical Usage (kg) = Chemical Uptake Rate (k/ m^2) x Area of plate to be developed (m^2).

4.6.3 Method for Computing Total Paper Weight Quantities:

Paper weight quantities, such as total paper utilization or waste are based on the average weight of single sheet of the paper. Average weight of the paper is determined by taking weight measurements of individual sheet of paper and averaging them. Also, manufacture data is used to crosscheck the results. Total quantity of paper in weight units are then calculated using following mathematical expression.

Quantity of paper printed/wasted (Kg) = Average weight of single sheet of paper (Kg) x Total number of sheets printed or wasted.

4.6.4 Method for Computing Lost Material Value:

Lost Material Value is calculated by multiplying total quantity or volume of material lost during manufacturing by its unit material cost as listed in Appendix D. The mathematical expression used in calculating these costs are as follow:

Lost Material Value (Dollars) = Waste Volume (kg or number) x Unit material price (Dollars/kg or number)

5.0 RESULTS

Press trials were conducted on both the lithographic and the digital press, and various observations & measurements (as listed in section 4.1.4) were made before, during, and after the actual press run. The results derived from these observations and measurements are elaborated below.

5.1 Resource Utilization:

Table 5.1: Resource Utilization in Lithographic and Digital Press:

No.	Parameter	Lithographic Press		Digital Press	
		Short Run	Long Run	Short Run	Long Run
1	**Paper Usage:**				
	a. Well-Printed Sheets (Nos.)	500	3000	500	3000
	b. Wasted Sheets (Nos.)	1442	1057	24	600
	Total (Nos.)	**1942**	**4057**	**524**	**3600**
2	**Ink Usage:**				
	a. Cyan Ink Usage (g)	450	625	75.77	377.47
	b. Black Ink Usage (g)	450	625	33.67	241.65
	c. Yellow Ink Usage (g)	450	625	37.70	507.57
	d. Magenta Ink Usage (g)	450	625	96.18	394.13
	Total (g)	**1800**	**2500**	**243.32**	**1520.82**
3	**Fountain Solution Usage (g)**	3960	4800	N/A	N/A
4	**Aqueous Coating Solution Usage (g)**	300*	1800	N/A	N/A
5	**Cleaning Solution Usage:**				
	a. Solvent Usage (g)	770.00	770.00	N/A	N/A
	b. Inkote Usage (g)	39.38	39.38	N/A	N/A
	c. Plate Cleaner Usage (g)	91.62	91.62	N/A	N/A
	d. Plate Desensitizer Usage (g)	80.85	80.85	N/A	N/A
	f. Lithotine Usage (g)	29.18	29.18	N/A	N/A
	g. Cleaning Rags Usage (g)	1744.67	1744.67	N/A	N/A
6	**Platemaking Chemistry Usage:****				
	a. Developer Solution (g)	379.68	379.68	N/A	N/A
	b. Replenisher Solution (g)	382.73	382.73	N/A	N/A
	c. Finisher Solution/Gum (g)	264.16	264.16	N/A	N/A
7	**Imaging Oil Usage (g):**	N/A	N/A	258.43	1981.00
8	**Imaging Agent Usage (g):**	N/A	N/A	3.14*	18.87

*** Indicates values derived from long run results.**

**** Values calculated from process chemical inventory data. (Refer to section 4.6)**

Referring to table 5.1, it can be seen that the paper usage in the lithographic press is greater than the paper usage in the digital press for both the short and long runs. However, the paper usage in the lithographic press is 3.7 times the paper usage in digital press for short run, compared to mere 1.1 fold difference for long run. In the lithographic press, the ink requirement increases by 1.4 times for the long run compared to 6.25 fold increment in the digital press. However, compared to lithographic press runs, the total mass of ink used in the digital press for both runs remains low.

5.2 Waste Generation:

Referring to table 5.2, it can be seen that the paper wastage in the lithographic press is greater than the corresponding paper wastage in the digital press. The principle component of this paper wastage is in the makeready stage. Ink waste contributes significantly to the overall waste generation in the lithographic process. The ink wastage in the digital press run was minimal, as the unused ink is usually recycled. However, one thing must be noted here that the digital press generates ink waste during the regular maintenance that the offset press doesn't. This little amount of waste generated from the digital press cleaning operations is hard to evaluate and correlate with print volume. Therefore, its not taken into account here. Waste generated from the cleaning and platemaking processes in the lithographic press run was assumed to be constant for both the short and long runs, since the setup and cleanup procedures are independent of run length.

Table 5.2: Waste Generation in Lithographic and Digital Press:

No.	Parameter	Lithographic Press		Digital Press	
		Short Run	Long Run	Short Run	Long Run
1	**Paper Waste:**				
	a. Waste Paper (Nos.)	7	0	0	179
	b. Make Ready Waste (Nos.)	1435	1057	24	421
	Total (Nos.)	**1442**	**1057**	**24**	**600**
2	**Ink Waste:**				
	a. Skin Ink Waste (g)	439.43	439.43	N/A	N/A
	b. Excess Ink from Ink Tank(g)	772.70	994.56	N/A	N/A
	c. Ink on Spatula (g)	52.46	59.84	N/A	N/A
	d. Ink on Liners (g)	65.87	65.99	N/A	N/A
	Total (g)	**1330.46**	**1559.82**	N/A	N/A
3	**Liner Waste (g):**	187.3	187.3	N/A	N/A
4	**Press Cleaning Waste:**				
	a. Waste Blanket Cleaning Paper (g)	116.60	116.60	N/A	N/A
	b. Waste Ink & Solvent on Rags (g)	705.95	705.95	N/A	N/A
	c. Waste Coating & Solvent on Rags (g)	278.01	278.01	N/A	N/A
	d. Waste Ink & Solvent in Wash Tray (g)	225.08	225.08	N/A	N/A
	e. Waste Aqueous Coating Solution (g)	767.17	4603.00	N/A	N/A
	f. Plate Cleaner/Preserver (g)	172.47	172.47	N/A	N/A
	f. Inkote (g)	39.38	39.38	N/A	N/A
	g. litholine (g)	29.18	29.18	N/A	N/A
5	**Press Repair Waste:**				
	a. Blanket Waste (g)	N/A	N/A	448.52	448.52
	b. Metal Stripes Waste (g)	N/A	N/A	94.24	94.24
	c. Impression Paper Waste(g)	N/A	N/A	49.62	49.62
	d. PIP Plate Waste (g)	N/A	N/A	0.00	53.67
6	**Platemaking Chemistry waste:****				
	a. Developer Solution (g)	379.68	379.68	N/A	N/A
	a. Replenisher Solution (g)	382.73	382.73	N/A	N/A
	a. Finisher Solution/Gum (g)	264.16	264.16	N/A	N/A

** Values calculated from process chemical inventory data. Since all the chemicals used in the platemaking operation gets disposed off, the amount of waste generated is equal to the amount of chemicals used.

5.3 Work Environment Conditions:

Results obtained from laboratory analysis of samples collected for particulate matter and VOC monitoring are summarized in table 5.3. Both particulate matter and VOC emission levels are well below the required air quality standards listed in table 5.3(a). The particulate matter emission was found to be almost same in both the presses. In the breathing zone, the VOC emission from the lithographic press was found to be almost double the VOC emission from the digital press. Overall, the indoor air quality is within normal levels for both technologies.

Table 5.3(a): Indoor Air Quality Monitoring Results:

No.	Parameter	Offset Press		Digital Press		Standard Level
		Short	Long	Short	Long	
1	**Particulate Matter:**					
	a. Total Particulate Matter (mg/m^3)	< 0.8	< 0.8	< 0.9	< 0.9	15.0[a]
	b. Respirable Particulate Matter (mg/m^3)	< 0.3	< 0.3	< 0.3	< 0.3	5.0[b]
2	**VOC as n-Hexane:**					
	a. VOC emission outside breathing zone (mg/m^3)	7.2	7.2	483.0	483.0	N/A[c]
	b. VOC emission in breathing zone (mg/m^3)	120.0	120.0	74.0	74.0	400.0[d]

a. OSHA Time Weighted Average Permissible Exposure Limit (TWA-PEL) for total dust **(29 cfr 1910.1000 Table Z-1)**.

b. OSHA Time Weighted Average Permissible Exposure Limit (TWA-PEL) for respirable dust **(29 cfr 1910.1000 Table Z-1)**.

c. New York State Department of Environmental Conservation (NYSDEC) has a threshold limit of 5 tons per year (5 TPY) for VOC emission. No standard exists for VOC emission rate. However, the actual VOC emission figures from table 4.5 shows that the VOC emissions from both the presses are well below 5 TPY (i.e. around 20 kg per day)

d. OSHA and ACGIH have set emission limits for each individual VOC, and therefore, no standard exists for the total VOC Exposure limit. Therefore, exposure limits for each individual VOC listed in MSDS relevant to cleaning operations are studied. Except Glycerol and Phosphoric Acid which account for

2% of VOC components, all VOCs have ACGIH TLV-TWA limit of 100PPM (nearly 400mg/m3) or above.

Except the peak noise level of 147.7 dB in offset press which crossed 140 dB OSHA limit sometime during the operation, noise levels in both the presses are acceptable with respect to the standards listed in table 5.3(b).

Table 5.3(b): Noise Monitoring Results:

No.	Parameter	Lithographic Press	Digital Press	Standard Level
1	Peak Noise Level in dB	147.7	120.6	140.0 [a]
2	Time Weighted Average (TWA) in dB	63.1	61.9	90.0 [b]
3	Average Sound Level in dB	70.0	68.1	N/A
4	Run Time (Hr:Min:Sec)	3:05:35	3:23:00	N/A

a. OSHA peak noise level

b. OSHA Time Weighted Average Noise Level

5.4. VOC and HAP Emissions:

Cleaning solutions used in offset press cleaning are a major source of VOC generation, contributing nearly 66% and 58% of total VOCs from the short and long runs respectively. Inks and Imaging oil are also major VOC contributors in the digital press, contributing nearly 42% & 57% for the short run and 37% & 62% for long run operations as shown in table 5.4(a).

Only lithographic presses generate HAP. The digital press has zero potential for HAP emission as there is no hazardous chemical usage. The HAP emission from the use of fountain solution varies with print volume. The HAP emission level from the platemaking operation is independent of print volume (Table 5.4(b)).

Table 5.4(a): Potential and Actual VOC Emissions:

Chemical Type	Lithographic Press				Digital Press	
	Potential VOC Emission (g)		Actual VOC Emission (g)		Actual VOC Emission (g)*	
	Short	Long	Short	Long	Short	Long
Inks	238.32	330.98	11.92	16.55	180.61	1115.24
Imaging Agent	N/A	N/A	N/A	N/A	2.76	16.60
Imaging Oil	N/A	N/A	N/A	N/A	245.50	1882.00
Fountain Solution	93.17	112.94	93.17	112.94	N/A	N/A
Coating Solution	13.8	82.8	13.8	82.8	N/A	N/A
Platemaking Bath Solution	108.95	108.95	108.95	108.95	N/A	N/A
Cleaning Solution Applied With Rags	824.41	824.41	412.21	412.21	N/A	N/A
Cleaning Solution Applied Without Rags	37.10	37.10	37.10	37.10	N/A	N/A
TOTAL (g)	**1315.75**	**1497.18**	**677.15**	**770.55**	**428.87**	**3013.84**

* Same as potential VOC emissions. (Refer to section 4.6)

- N/A indicates that the metric is not applicable for the corresponding chemical type.

- Potential VOC emission is the maximum VOC emission that the chemical can emit if it is allowed to dry completely at high temperature for long period, whereas the actual VOC emission represents the emission value corresponding to the normal press operating conditions.

Table 5.4(b): Potential and Actual HAP Emissions:

Chemical Type	Lithographic Press		Digital Press	
	Actual HAP Emission (g)*		Actual HAP Emission (g)*	
	Short	Long	Short	Long
Fountain Solution	75.97	92.10	N/A	N/A
Platemaking Solution	76.24	76.24	N/A	N/A
TOTAL	**152.21**	**168.34**	**N/A**	**N/A**

<u>Note:</u> HAP emission values are based on the HAP content of the chemicals used. Since most of the MSDS represent range of HAP content rather than the exact values, average values are taken for calculation.

* Same as potential HAP emissions.

5.5 Environmental Cost Estimation:

Waste disposal costs were calculated by multiplying waste quantities by corresponding unit waste disposal costs listed in Appendix C. The waste disposal costs are summarized in table 5.5(a).

Table 5.5(a): Waste Disposal Cost for Lithographic Press:

No.	Waste Category	Total Waste Quantity		Waste Disposal Cost ($)	
		Short Run	Long Run	Short Run	Long Run
1	**Paper Waste Disposal:**				
	a. Waste Paper (kg)	0.22	0.00	0.020	0.000
	b. Make Ready Waste (kg)	44.34	32.66	-0.733	-0.540
	Total			**-0.713**	**-0.540**
2	**Ink Waste Disposal (kg):**	1.331	1.560	**6.071**	**7.118**
3	**Fountain Waste Disposal:***				
	a. Fountain Concentrate Waste (kg)	0.097	0.118	0.443	0.538
	b. Fountain Substitute Waste (kg)	0.085	0.103	0.388	0.470
	c. Wastewater (kg)	3.782	4.585	17.255	21.110
	Total			**18.086**	**22.118**
4	**Press Cleaning Waste:**				
	a. Waste Blanket Cleaning Paper (kg)	0.117	0.117	0.011	0.011
	b. Waste Rags (nos.)	13	13	1.820	1.820
	Total			**1.831**	**1.831**
5	**Waste Aqueous Coating Solution (kg)**	0.767**	4.603	**0.000**	**0.000**
6	**Platemaking Waste Disposal:**				
	a. Developer Waste (kg)	0.380	0.380	0.000	0.000
	b. Replenisher Waste (kg)	0.383	0.383	0.000	0.000
	c. Finisher/Gum Waste(kg)	0.264	0.264	0.000	0.000
	Total			**0.000**	**0.000**
7	**Liner Waste Disposal (kg):**	0.187	0.187	**0.017**	**0.017**
8	**Plate Waste Disposal (kg):**	1.461	1.461	**1.767**	**1.767**
	Total Environmental Cost			**27.039**	**32.311**

* Recirculation of fountain solution has not taken into consideration.

** Value calculated from long run result.

<u>**Note:**</u>

- Negative (-) values indicate revenue from recycling activities.
- Underlined values indicate conversion from basic unit (i.e. Numbers) to current unit (Kg). Average weight of single sheet of paper used in lithographic press is 30.89 g. (Refer to section 4.6.3)

From these figures, it can be seen that the fountain waste cost is the most significant, followed by ink waste cost. Fountain waste and ink waste disposal accounts for around 67% and 22% of total waste disposal cost for the short run and long run with negligible difference between run lengths. In the table, negative values are shown for the sheets which are recycled, but the total cost of these sheets is not recovered fully, even though the recycled material is efficiently sorted to maximize value.

Table 5.5(b): Waste Disposal Cost for Digital Press:

No.	Waste Category	Total Waste Quantity		Waste Disposal Cost ($)	
		Short Run	Long Run	Short Run	Long Run
1	**Paper Waste Disposal:**				
	a. Waste Paper (kg)	0.00	2.99	0.000	0.272
	b. Make Ready Waste (kg)	0.38	6.99	-0.006	-0.115
	Total			**-0.006**	**0.157**
2	**Press Repair Waste:**				
	a. Blanket Waste in kg(no.)	0.112(1)	0.449(4)	0.010	0.040
	b. Metal Stripes Waste in kg(no.)	0.023(1)	0.094(4)	0.002	0.008
	c. Impression Film Waste in kg(no.)	0.050(1)	0.050(1)	0.005	0.005
	d. PIP Plate Waste in kg(no.)	0.000(0)	0.054(1)	0.000	0.005
	Total			**0.017**	**0.058**
Total Environmental Cost				**0.011**	**0.215**

Note:

- Negative (-) values indicate revenue from recycling activities.
- Underlined values indicate conversion from basic unit (i.e. Numbers) to current unit (Kg). Average weight of single sheet of paper used in digital press is 16.58 g. (Refer to section 4.6.3)

As shown in table 5.5(b), the digital press involves negligible waste disposal costs and waste disposal liabilities.

5.6: Lost Material Value:

Table 5.6(a): Lost Material Value in Lithographic Press:

No.	Waste Category	Waste Volume		Loss Material Value ($)	
		Short Run	Long Run	Short Run	Long Run
1	**Paper Waste:**				
	a. Waste Paper (kg)	0.22	0.00	0.425	0.000
	b. Make Ready Waste (kg)	44.34	32.66	85.709	63.132
	Total			**86.135**	**63.132**
2	**Ink Waste Disposal (kg):**	1.331	1.560	**12.788**	**14.988**
3	**Fountain Waste Disposal:***				
	a. Fountain Concentrate Waste (kg)	0.097	0.118	0.377	0.459
	b. Fountain Substitute Waste (kg)	0.085	0.103	0.389	0.472
	c. Wastewater (kg)	3.782	4.585	0.000	0.000
	Total			**0.766**	**0.931**
4	**Press Cleaning Waste:**				
	a. Waste Blanket Cleaning Paper (kg)	0.117	0.117	0.342	0.342
	b. Waste Rags (nos.)	13	13	NA	NA
	Total			**0.342**	**0.342**
5	**Waste Aqueous Coating Solution (kg)**	0.767**	4.603	**4.561**	**27.374**
6	**Platemaking Waste Disposal:**				
	a. Developer Waste (kg)	0.380	0.380	3.655	3.655
	b. Replenisher Waste (kg)	0.383	0.383	4.020	4.020
	c. Finisher/Gum Waste(kg)	0.264	0.264	2.002	2.002
	Total			**9.677**	**9.677**
7	**Liner Waste Disposal (nos.)**	4	4	**1.600**	**1.600**
8	**Plate Waste Disposal (nos.)**	4	4	**54.240**	**54.240**
	Total Lost Material Value			**170.109**	**172.284**

* Recirculation of fountain solution was not taken into consideration.

** Value calculated from the long run result.

Lost material value (LMV) i.e. the value of the resources lost in producing the product. This is calculated by multiplying quantity of material lost by its unit purchase price listed in Appendix D. These values for the lithographic press are summarized in table 5.6(a).

The paper contribution to LMV is significant, with nearly 51% and 37% of the total LMV for the short and long runs respectively. The plate and ink contributions are around 32% and 8% of total LMV for both the short and long press runs.

The lost material values for digital press are tabulated in table 5.6(b). Blanket waste accounts for a huge portion of total lost material value in both short and long press runs. Paper waste shares very little portion of total lost material value.

Table 5.6(b): Lost Material Value in Digital Press:

No.	Waste Category	Waste Volume		Lost Material Value in Dollars	
		Short Run	Long Run	Short Run	Long Run
1	**Paper Waste Disposal:**				
	a. Waste Paper (kg)	0.00	2.99	0.000	5.776
	b. Make Ready Waste (kg)	0.38	6.99	0.734	13.503
	Total			**0.734**	**19.279**
2	**Press Maintenance Waste:**				
	a. Blanket Waste (no.)	1	4	800.000	3200.000
	b. Metal Stripes Waste(no.)	1	4	0.000	0.000
	c. Impression Film Waste (no.)	1	1	1.683	1.683
	d. PIP Plate Waste (no.)	0	1	0.000	600.000
	Total			**801.683**	**3201.683**
Total Lost Material Value				**802.372**	**3220.962**

5.7: Job Hazard Analysis:

The results derived from the information gathered during walkthrough survey and brainstorming performed over entire press operations are summarized in table 5.7.

Table 5.7: Job Hazard Analysis Results

No.	Hazard Category	Potential Health & Safety Impact in Lithographic Press	Potential Health & Safety Impact in Digital Press
1	Cutting Hazard	▪ Sharp plates handling, lifting, mounting, dismounting, and bending may cause finger skin cut. ▪ Sharp paper handling may cause hand skin cut.	▪ Use of Small but sharp blade for blanket cut may cause finger skin cuts. ▪ Sharp paper handling may cause hand skin cut.
2	Burn Hazard	▪ Handling of hot plate with more than 270 degree centigrade temperature after baking may cause severe hand burn. ▪ Maintenance work on IR dryer when its hot can cause moderate skin burn.	▪ Blanket cleaning or replacement, paper jam repair work, impression paper replacement, PIP replacement, pre-transfer erase unit handling, etc. may cause severe skin burn.
3	Chemical Hazard	▪ Chemical splashes may potentially harm eyes and cause skin burn during opening developer bath covers. ▪ Chemical splashes due to fountain recirculation pump operation can cause eye irritation. ▪ VOC exposure during press cleaning can cause eye irritation.	▪ Eye irritation due to hand contact after working on repair works without gloves. ▪ VOC exposure while press operation with open front cover can cause eye irritation.
4	Struck By Hazard	▪ Lifting of heavy developer bath cover may impound on feet and can cause damage to the finger bones. ▪ Uncontrolled release of heavy paper tray at both inlet & outlet end of the press can cause severe damage to the feet bones.	▪ None

5	Struck Against Hazard	▪ None	▪ Operator may bang up his head or shoulder and while getting up after working at ink & imaging agent chamber.
6	Slip Hazard	▪ Spills of solvent and other cleaning solutions on press platform and floor can harm body parts, such as hand, shoulder, back, head, etc. ▪ Spill of platemaking chemistry on floor can cause body injuries explained above.	▪ Spill of ink, imaging oil, imaging agent, or other cleaning or repairing solutions on floor can harm body parts, such as hand, shoulder, back, head, etc.
7	Pinch Point Hazard	▪ Pulling out sheets from delivery end of the conveyor belt during press run may cause finger pinch and bone damage, in worst case. ▪ Accidental entrapment of fingers at the exposed feed end of the paper separator can cause moderate finger pinch causing skin injury. ▪ Uncontrolled upward and downward movement of the paper lifting mechanism at the press feed end may cause moderate finger or feet pinch causing skin injury. ▪ Plate mounting bar can cause severe finger pinch during plate mounting operation causing bone damage. ▪ Cleaning ink rollers with unfolded rags may severely cause severe bone damage due to hand or fingers crushing. ▪ Accidental access to pump blades while draining the fountain tank may result in chopping of the finger tips.	▪ Nip points at blanket roller, PIP rollers, and impression roller can severely damage finger bones while carrying repair works. ▪ Catch tray wheel (Rotor B) can shear finger skin and damage finger bones if accessed carelessly. ▪ Air circulation fan, if assessed with front door open, can shear finger tips severely or cause body injury due to entrapment of clothing in fan.

8	Trip Hazard	▪ Unsafe boarding, stepping, or walking on the press platform can cause body injuries.	▪ Unsafe walking or crossing over the power cords and hydraulic tubes can cause body injuries.
9	Ergonomics	▪ Manual loading of papers at feed end can cause backbone and mussel injuries.	▪ None
10	Fire Hazard	▪ Spark due to built up static on motors used for hydraulic oil circulation may catch fire, if volatile chemicals are kept around.	▪ Spark due to high voltage on parts near the oil filter while changing oil filter can cause fire.
11	Abrasion Hazard	▪ None	▪ Performing or observing other operations at paper feed end can cause minor skin abrasion. ▪ Minor skin abrasion or injury while loading paper on spring loaded paper tray.
12	Radiation	▪ None	▪ Laser radiation could be harmful if the laser path gets reflected by reflective material or during cleaning of writing head. The laser doesn't discharge when the doors are opened.
13	Electrocution Hazard	▪ None	▪ Access to live parts can cause body electrocution.

6.0 ANALYSIS AND DISCUSSION

6.1. Resource Utilization Efficiency:

From the resource utilization and waste generation results obtained from table 5.1 and 5.2, the efficiency of consumables used i.e. paper and ink is calculated and summarized in table 6.1.

Table 6.1: Resource Utilization Efficiency

No.	Resource Type	Resource Utilization Efficiency (%)**			
		Lithographic Press		Digital Press	
		Short Run	Long Run	Short Run	Long Run
1	Paper	26.16	73.95	95.62	83.28
2	Ink*	26.09	37.61	100	100

* Ink loss in blanket and trays is not taken into consideration

** Percentage of resource used in the final product. For example, in lithographic press 26.16% of total paper used for short run gets used in final product. These figures can vary depending on the experience of the operator, especially in case of lithographic press.

From table 6.1, it can be seen that the paper usage is significantly greater for the lithographic process compared to the digital process, due primarily to the materials consumption involved in makeready. Overall, the digital press has been shown to be superior to the sheetfed offset press in terms of material utilization.

Though the digital press calculations indicate 100% efficiency in ink utilization, actual ink consumption for the long run is much more than the expected figure based on extrapolation from the short run values. If we analyze the performance of the digital press in terms of ink consumption for both the short and long runs, it can be seen that the actual

consumption of yellow ink is much more than the expected figure corresponding to short run value (Table 6.2). This is because of paper jams that required frequent blanket cleaning followed by blanket quality check up using yellow ink. Yellow ink is used as a background to highlight any deficiencies in blanket cleaning. This loss of efficiency was included in the calculations since in the real world of production press operation; such events are not an uncommon occurrence.

Table 6.2: Analysis of Ink Consumption in Digital Press:

Ink Type	Short Run Usage (g)	Expected Long Run Usage (g)*	Actual Long Run Usage (g)	Difference (g)**
Cyan	75.77	454.62	377.47	77.15
Black	33.67	202.02	241.65	-39.63
Yellow	37.70	226.20	507.57	-281.37
Magenta	96.18	577.08	394.13	182.95

* Values extrapolated from the short run results. Since the print volume for long run is 6 times that of short run, a multiplication factor of 6 is considered in the above calculations.

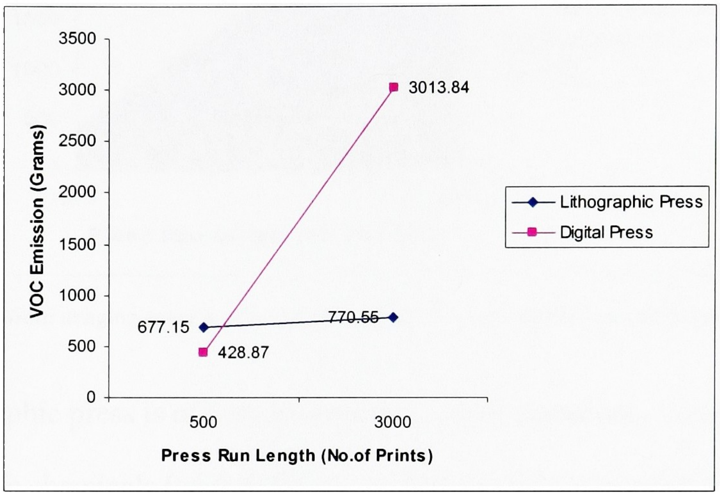
** Difference between actual long run usage and expected long run usage. Negative values indicates that the usage of ink in excess of ideal usage calculated based on short run usage values.

6.2. Environmental Impact:

Although the VOC emissions from both the presses are well below the regulatory emission standards described in table 5.3(a) and 5.3(b), the digital press operations cause much more impact on the environment than the lithographic press for long run operations (Figure 6.1). In the digital press, the imaging oil is a major source of VOC emission, and has higher VOC content (95%) than the sheetfed press inks (Avg.13.24%). Also, its usage increases proportionately with the increase in number of prints, whereas the ink usage in lithographic press increases only slightly when increasing run length.

Additionally, the emission factor (i.e. percentage fraction of material emitted into the atmosphere) for the inks (0.05) is 20 times less than the emission factor for imaging oil (1.0).

Figure 6.1: VOC Emissions in Lithographic and Digital Printing



Another contributing factor to the gradient difference in figure 6.1 is that the major portion of VOC emissions for lithography remain constant with run length, as they are associated primarily with the cleaning and platemaking operations. For the digital press, the VOC emissions increase proportionately with the print volume (Figure 6.3).

Figure 6.2: VOC Emissions Distribution in Lithographic Press

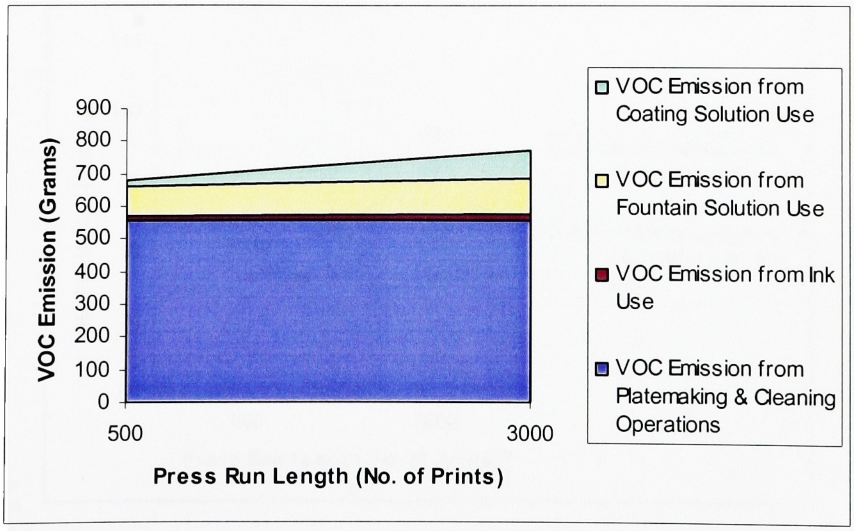
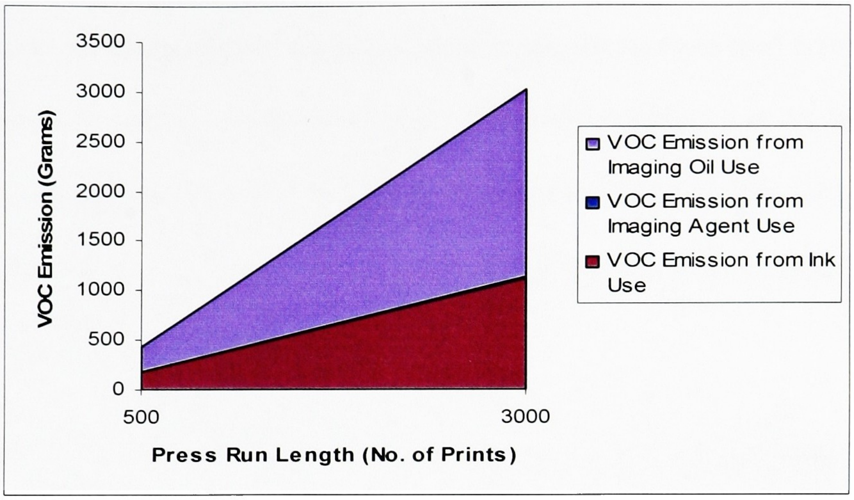


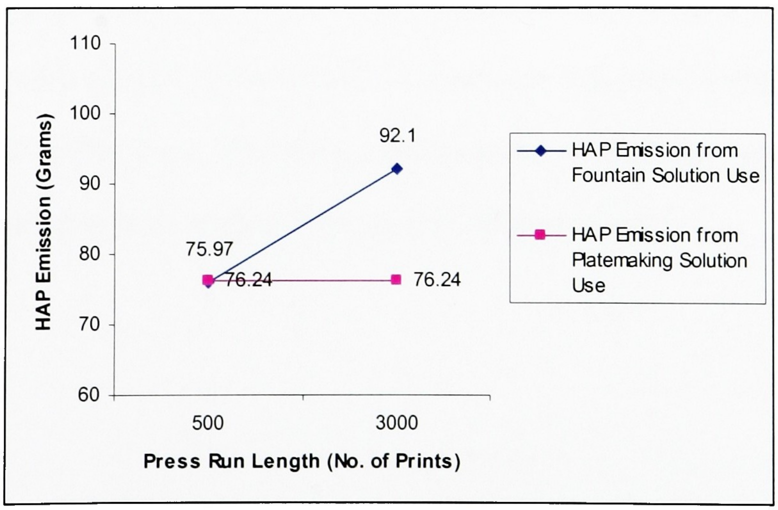
Figure 6.3: VOC Emissions Distribution in Digital Press



* VOC Emission from imaging agent is very minor, and therefore, not clearly represented in the above graph.

Only the lithographic press is of concern regarding HAP emissions, since the digital press uses no hazardous chemicals (table 5.4(b)). As with the VOC emissions, HAP emission levels do not increase significantly with increase in print volume. HAP emission levels increases by only 10.60% with a concomitant 500% increase in print volume. This can be attributed to fountain solution consumption, as the HAP emission from the platemaking solutions is independent of print volume.

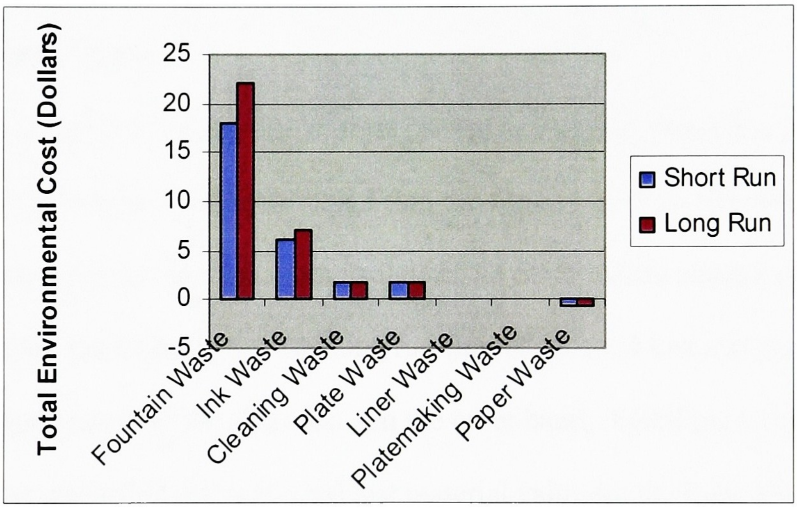
Figure 6.4: HAP Emissions Distribution in Lithographic Press



6.3 Environmental Cost:

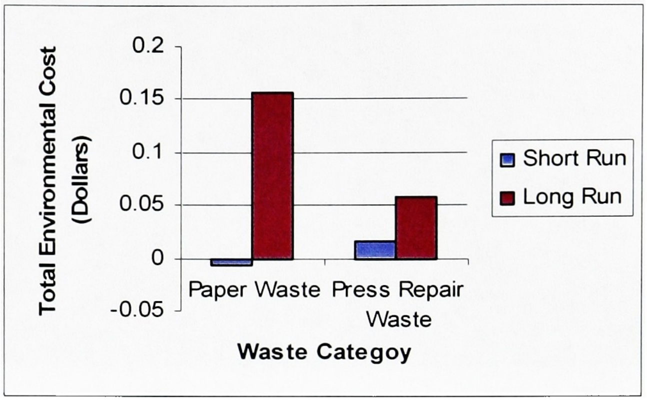
The fountain waste disposal cost is a major contributing factor to overall environmental cost in lithographic printing (Figure 6.5). The reasons for this high cost are both the high volume of waste and the waste disposal costs themselves. Fountain solution waste is treated expensively as hazardous waste. However, this cost does not increase significantly with increase in print volume.

Figure 6.5: Environmental Cost Distribution in Lithographic Press



In comparison, the overall environmental cost is much less for the digital press than for the offset press (Figure 6.6). Although this cost increases with print volume, it remains lower than for the offset press. Therefore, it can be said that the digital press shows advantages in terms of waste disposal, irrespective of print volume.

Figure 6.6: Environmental Cost Distribution in Digital Press



6.4 Lost Material Value:

Considering lost material value, digital press proved to be more expensive over offset press for both the long and the short runs. From the figure 6.7, it can be seen that except for the lost material value for the coating solution, no other values change significantly with print volume for lithography. The long run figures for total lost material value show only a 1.28% increase over the short run. On the other hand, digital press experienced nearly 3 fold increase (301.43%) in total lost material value for the long print run. Also, total lost material values in digital press for short and long run are respectively 4.7 and 18.7 times more than the total lost values in offset press (Figure 6.8).

The higher figures in digital press may be attributed primarily to the costly material usage for consumable components, including the blanket and PIP plate which must be changed at frequent intervals. The usage of these materials in digital presses increases with the run length, giving rise to the steep gradient in figure 6.8. On this basis, the economic viability of the digital press compared with the offset press under these conditions may be compromised.

Figure 6.7: Lost Material Value Analysis in Offset Printing

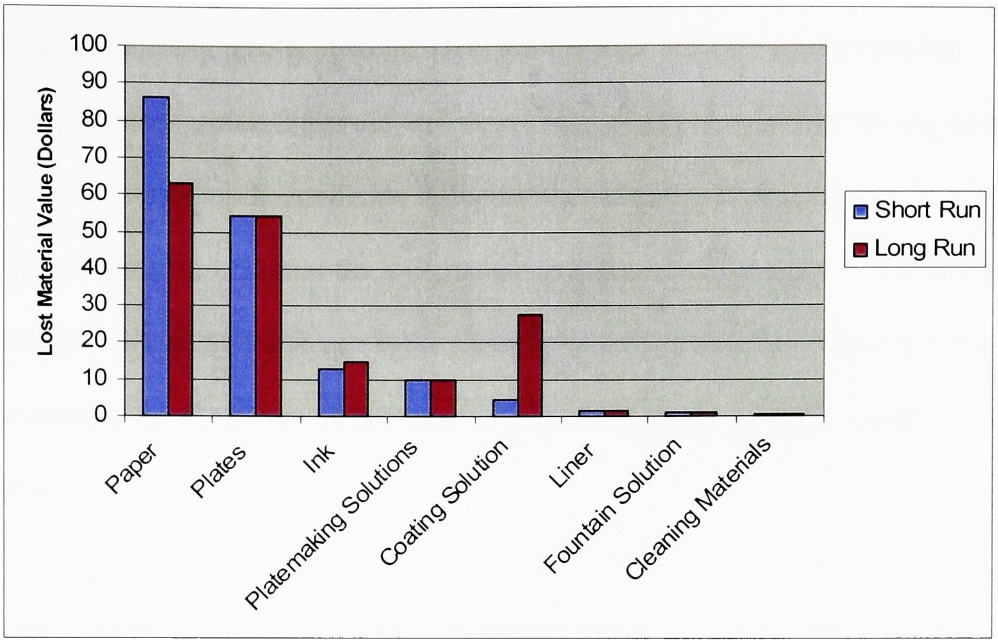
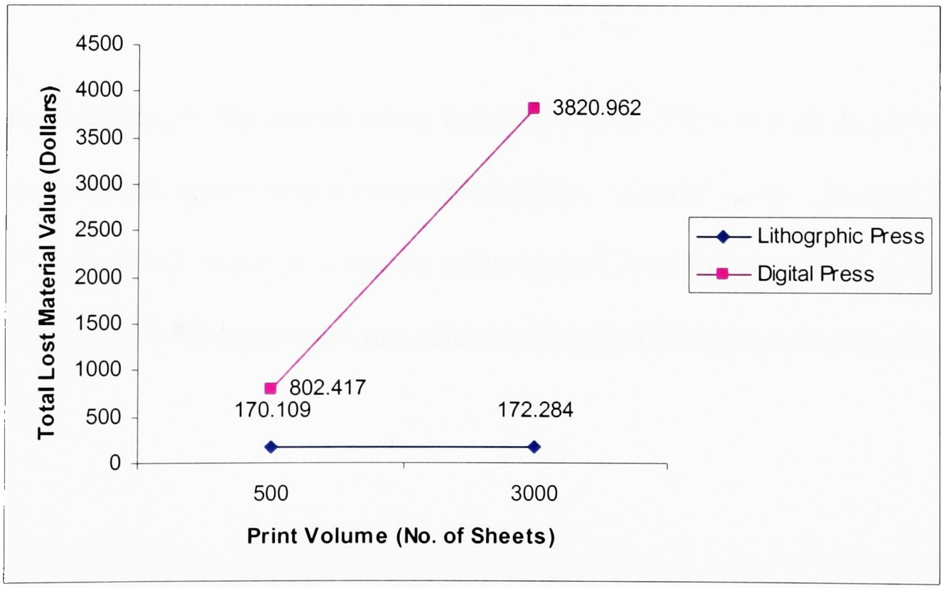


Figure 6.8: Lost Material Value Analysis for Offset & Digital Press



6.5 Health and Safety Impact:

Air and noise monitoring results obtained from both presses indicate a safe working environment, as the exposure limits are well below the limits prescribed by the regulatory agencies. However, there is a significant difference in overall VOC emission level with the offset press showing 1.6 times the VOC emissions from the digital press. The main contributing factor for this difference is the cleaning operation that takes place in offset press after every run, which has the potential to expose the press operators directly to the VOC source.

Noise levels in both the presses are within acceptable limits, except for the peak noise level (147.7 dB) in the offset press which crossed the 140 dB OSHA limit during the operation. The peak level was not exceeded by the digital press.

The factors contributing to the overall safety impact are quite different with these two technologies, including factors which cannot be directly compared. Only a primary comparison was conducted here as complete safety impact assessment requires sound statistical data based on all parameters that affects safety, and thus, was out of scope for this project.

7.0 CONCLUSION

In summary, it can be said that, digital printing sounds attractive for short run. For long run, digital press would be more attractive from environmental, health, and safety standpoints provided that the imaging oil is replaced with low VOC solution serving the same purpose. However, it won't be feasible from print cost, quality, and run time points of view.

On safety front, it becomes very complex to compare these two technologies because of the diverse nature of the hazards associated with these technologies. Therefore, it's a trade off between environmental impacts of digital printing versus health and waste management issues of offset printing.

Thinking in terms of scope for improvement, it seems that the digital printing has a great potential to improve its environmental behavior as compared to lithographic press as it has to deal only with the imaging oil which is the root cause for the VOC emissions. On the other hand, lithographic press has to deal with variety of chemicals to improve its environmental behavior.

From the analysis of the results, it can be definitely concluded that for a short print run, digital press proves superior to lithographic press on environmental and health front. However, this is not exactly true for long print run as the lithographic press stands very well against digital press on VOC emission issue. On the other hand, digital press proves

superior from worker's health and waste management view points. However, the environmental impacts of digital press operations vary significantly with regard to print volume, which is not the case for offset press.

The environmental and health impacts associated with lithographic printing industry include increased consumption of natural resources, such as trees, due to inefficient use of paper; health impact resulting from exposure to volatile organic compounds during press cleaning and hazardous air pollutants during platemaking and printing operations; and potential impacts associated with hazardous waste storage and disposal activities. The only environmental and health impact associated with digital printing industry includes the atmospheric volatile organic compounds contribution as a result of imaging oil usage.

Printers interested in conducting similar study for their operations can refer to the methodology flow chart described in Appendix E.

Scope for further research:

The study was performed under normal working conditions and no operational or maintenance problems encountered during the trials. This may not be the same all the time as factors such as operator experience, press condition, etc. govern the press operation. Therefore, in order to obtain representative data and compelling results, more trials needs to be taken to encompass both normal and abnormal work conditions.

Due to time constraints and short print sessions, personal monitoring was not conducted for a full 8 hour shift. In order to obtain time weighted average values for the given parameters, conduct personal monitoring for full 8-hour shift period.

Air monitoring for specific hazardous air pollutants, such as ethylene glycol, 2-butoxy ethanol, etc. can be conducted to measure their concentrations in the work environment. The tests shall be taken near the platemaking operations zone and near the printing press zone.

Due to time and resource limitations, the size of the air monitoring samples was restricted to one sample for each type. However, more samples need to be taken:

- to get precise results about the already identified pollutants;
- to evaluate pollution levels at various locations in the printing premise; and
- to evaluate pollutant levels for additional specific volatile organic compound or hazardous air pollutant.

The parameters considered for evaluating complete environmental health and safety aspects and impacts associated with lithographic and digital printing processes were insufficient and/or beyond the scope of this study. However, these uncovered parameters can be used in further research on this topic, and they are as below:

i. Energy Efficiency:

   Energy consideration is important from environmental and cost optimization standpoints. In order to evaluate the energy requirements in both these printing

processes, energy sources or units, such as press motors, hydraulic oil pumps, conveyor belt, infrared light bulb, cooling motors, fans, platesetter light, etc. need to be identified first. The amount of time each energy unit operates need to be noted during the experiment. Energy required for performing each operation would be a product of unit energy consumption (e.g. watts per second) and total time the unit or energy source was operated. Energy efficiency in both these processes would be calculated by dividing total print volume (number of sheets) or tonnage (kg or tonnes) by total energy consumption.

ii. Safety Index:

A safety index is a quantitative metric based on all potential parameters that can have influence on the safety of the employee. Comparing these two presses based on safety considerations is a complex task, and therefore, only qualitative comparison was done here in this report. However, a safety index based on various relevant parameters can be done. Depending on where the press conditions fit in the scoring range, a scoring rating can be assigned for each single parameter. For example, scoring rating for severity of injury can be ranked from 1 to 5, with 1 being not severe and 5 being very severe. The sum of all these rating would be a scoring index for that press. Similarly, scoring index can be calculated for the other press and compared with the other press. Some of the relevant base parameters are as follows:

- Frequency of access to the hazard zone
- Severity of injury
- Toxicity

- Potential number of employees affected
- History of similar incidence

Appendix A

Potential and Actual VOC Emission Calculations (Lithographic Press-Short Run)

SN	Material	Usage	Unit	VOC Content	Unit	Product Unit Weight	Unit	Potential VOC Emission (g)	Emission Factor	Actual VOC Emission(g)
1	**Inks:**									
a	Black Ink	450	g	1.38	lb/gal	9.14	lb/gal	67.94	0.05	3.40
b	Cyan Ink	450	g	0.72	lb/gal	8.78	lb/gal	36.90	0.05	1.85
c	Yellow Ink	450	g	1.81	lb/gal	8.30	lb/gal	98.13	0.05	4.91
d	Magenta Ink	450	g	0.71	lb/gal	8.92	lb/gal	35.82	0.05	1.79
							Total	**238.32**		**11.92**
2	**Fountain Solutions:**									
a	Fountain Concentrate	97.36	g	2.21	lb/gal	9.17	lb/gal	22.44	1.0	22.44
b	Fountain Substitute	85.04	g	6.57	lb/gal	8.00	lb/gal	69.73	1.0	69.73
							Total	**93.17**		**93.17**
3	**Coating Solution:**	300	g	0.39	lb/gal	8.34	lb/gal	**13.80**		**13.80**
4	**Platemaking Solutions:**									
a	Developer Solution	379.68	g	1.015	lb/gal	9.34	lb/gal	41.22	1.0	41.22
b	Replenisher Solution	382.73	g	0.905	lb/gal	9.42	lb/gal	36.77	1.0	36.77
c	Plate Finisher	264.16	g	1.018	lb/gal	8.67	lb/gal	30.95	1.0	30.95
							Total	**108.95**		**108.95**
5	**Cleaning solutions applied using rags:**									
a	Solvent	770	g	6.39	lb/gal	6.67	lb/gal	737.28	0.5	368.64
b	Plate Desensitizer	80.85	g	5.385	lb/gal	7.42	lb/gal	58.62	0.5	29.31
c	Litholine	29.18	g	6.35	lb/gal	6.50	lb/gal	28.51	0.5	14.26
							Total	**824.41**		**412.21**
6	**Cleaning solutions applied without using rags:**									
a	Inkote	39.38	g	94.2	%	7.40	lb/gal	**37.10**	1.0	**37.10**
							Total	**1315.75**		**677.15**

Formulae:

1 Potential VOC Emission (g) = [Material usage (g) x VOC content (lb/gal)] / Product unit weight (lb/gal)

2 Actual VOC Emission (g) = Potential VOC emission (g) x emission factor

Appendix A (Continued)

Potential and Actual VOC Emission Calculations (Lithographic Press-Long Run)

SN	Material	Usage	Unit	VOC Content	Unit	Product Unit Weight	Unit	Potential VOC Emission	Emiision Factor	Actual VOC Emission(g)
1	**Inks:**									
a	Black Ink	625	g	1.38	lb/gal	9.14	lb/gal	94.37	0.05	4.72
b	Cyan Ink	625	g	0.72	lb/gal	8.78	lb/gal	51.25	0.05	2.56
c	Yellow Ink	625	g	1.81	lb/gal	8.30	lb/gal	136.30	0.05	6.81
d	Magenta Ink	625	g	0.71	lb/gal	8.92	lb/gal	49.75	0.05	2.49
							Total	**330.98**		**16.55**
2	**Fountain Solutions:**									
a	Fountain Concentrate	118.01	g	2.21	lb/gal	9.17	lb/gal	28.41	1.0	28.41
b	Fountain Substitute	103.08	g	6.57	lb/gal	8.00	lb/gal	84.53	1.0	84.53
							Total	**112.94**		**112.94**
3	**Coating Solution:**	1800	g	0.39	lb/gal	8.34	lb/gal	**82.80**		**82.80**
4	**Platemaking Solutions:**									
a	Developer Solution	379.68	g	1.015	lb/gal	9.34	lb/gal	41.22	1.0	41.22
b	Replenisher Solution	382.73	g	0.905	lb/gal	9.42	lb/gal	36.77	1.0	36.77
c	Plate Finisher	264.16	g	1.018	lb/gal	8.67	lb/gal	30.95	1.0	30.95
							Total	**108.95**		**108.95**
5	**Cleaning solutions applied using rags:**									
a	Solvent	770	g	6.39	lb/gal	6.67	lb/gal	737.28	0.5	368.64
b	Plate Desensitizer	80.85	g	5.385	lb/gal	7.42	lb/gal	58.62	0.5	29.31
c	Litholine	29.18	g	6.35	lb/gal	6.50	lb/gal	28.51	0.5	14.26
							Total	**824.41**		**412.21**
6	**Cleaning solutions applied without using rags:**									
a	Inkote	39.38	g	94.2	%	7.40	lb/gal	**37.10**	1.0	**37.10**
							Total	**1497.18**		**770.55**

Formulae:

1 Potential VOC Emission (g) = [Material usage (g) x VOC content (lb/gal)] / Product unit weight (lb/gal)

2 Actual VOC Emission (g) = Potential VOC emission (g) x emission factor

Appendix A (Continued)

Potential and Actual VOC Emission Calculations
(Digital Press-Short Run)

SN	Material	Usage	Unit	VOC Content	Unit	Product Unit Weight	Unit	Potential VOC Emission (g)	Emission Factor	Actual VOC Emission(g)
1	**Inks:**									
a	Black Ink	33.67	g	75	%	N/A	N/A	25.25	1	25.25
b	Cyan Ink	75.77	g	75	%	N/A	N/A	56.83	1	56.83
c	Yellow Ink	37.7	g	70	%	N/A	N/A	26.39	1	26.39
d	Magenta Ink	96.18	g	75	%	N/A	N/A	72.14	1	72.14
							Total	**180.61**		**180.61**
2	**Imaging Oil:**	258.53	g	95	%	N/A	N/A	**245.50**	1	**245.50**
3	**Imaging Agent:**	3.14	g	88	%	N/A	N/A	**2.76**	1	**2.76**
							Total	**428.87**		**428.87**

(Digital Press-Long Run)

SN	Material	Usage	Unit	HAP Content	Unit	Product Unit Weight	Unit	Potential HAP Emission (g)	Emission Factor	Actual HAP Emission(g)
1	**Inks:**									
a	Black Ink	241.65	g	75	%	N/A	N/A	181.24	1	181.24
b	Cyan Ink	377.47	g	75	%	N/A	N/A	283.10	1	283.10
c	Yellow Ink	507.57	g	70	%	N/A	N/A	355.30	1	355.30
d	Magenta Ink	394.13	g	75	%	N/A	N/A	295.60	1	295.60
							Total	**1115.24**		**1115.24**
2	**Imaging Oil:**	1981.00	g	95	%	N/A	N/A	**1882.00**	1	**1882.00**
3	**Imaging Agent:**	18.87	g	88	%	N/A	N/A	**16.61**	1	**16.61**
							Total	**3013.84**		**3013.84**

Formulae:

1 Potential VOC Emission (g) = Material usage (g) x VOC content (%) / 100

2 Actual VOC Emission (g) = Potential VOC emission (g) x emission factor

Appendix B

Potential and Actual HAP Emission Calculations
(Lithographic Press-Short Run)

SN	Material	HAP	Usage	Unit	HAP Content	Unit	Potential HAP Emission (g)	Emission Factor	Actual HAP Emission(g)
1	**Fountain Concentrate**	2-Butoxy Ethanol	97.36	g	15	%	14.60	1	14.60
2		Ethylene Glycol	97.36	g	15	%	14.60	1	14.60
3	**Fountain Substitute**	2-Butoxy Ethanol	85.04	g	55	%	46.77	1	46.77
4	**Replenisher Solution**	Ethylene Glycol	382.73	g	10	%	38.27	1	38.27
5	**Developer Solution**	Ethylene Glycol	379.68	g	10	%	37.96	1	37.96
						Total	**152.21**		**152.21**

(Lithographic Press-Long Run)

SN	Material	HAP	Usage	Unit	HAP Content	Unit	Potential HAP Emission (g)	Emission Factor	Actual HAP Emission(g)
1	**Fountain Concentrate**	2-Butoxy Ethanol	118.01	g	15	%	17.70	1	17.70
2		Ethylene Glycol	118.01	g	15	%	17.70	1	17.70
3	**Fountain Substitute**	2-Butoxy Ethanol	103.08	g	55	%	56.70	1	56.70
4	**Replenisher Solution**	Ethylene Glycol	382.73	g	10	%	38.27	1	38.27
5	**Developer Solution**	Ethylene Glycol	379.68	g	10	%	37.96	1	37.96
						Total	**168.34**		**168.34**

Formulae:

1 Potential HAP Emission (g) = Material usage (g) x HAP content (%) / 100

2 Actual HAP Emission (g) = Potential HAP emission (g) x emission factor

Appendix C

Waste Disposal Costs for Lithographic and Digital Press

SN	Waste Category	Disposal Cost ($)	Unit Waste Disposal Cost ($)	Unit
	Lithographic Press			
1	**Paper Waste:**			
a	Waste Paper	165.77 for 2 tonnes	0.091	kg
b	Make Ready Waste	-3000 for 200 tonnes	- 0.016*	kg
2	**Ink Waste:**	1000 per 55 gal drum	4.563	kg
3	**Fountain Waste:**			
a	Fountain Concentrate	1000 per 55 gal drum	4.563	kg
b	Fountain Substitute	1000 per 55 gal drum	4.563	kg
c	Watewater	1000 per 55 gal drum	4.563	kg
4	**Press Cleaning Waste:**			
a	Waste Blanket Cleaning Paper	165.77 for 2 tonnes	0.091	kg
b	Waste Rags	14 for 100 rags	0.14	rag
5	**Aqueous Coating Waste:**	0	0	N/A
6	**Platemaking Waste:**			
a	Developer Solution	0	0	N/A
b	Replenisher Solution	0	0	N/A
c	Plate Finisher	0	0	N/A
7	**Liner Waste:**	165.77 for 2 tonnes	0.091	kg
8	**Plate Waste:**	0.55 per pound	1.209	kg
	Digital Press			
1	**Paper Waste:**			
a	Waste Paper	165.77 for 2 tonnes	0.091	kg
b	Make Ready Waste	-3000 for 200 tonnes	- 0.016*	kg
2	**Press Maintenance Waste:**			
a	Blanket Waste	165.77 for 2 tonnes	0.091	kg
b	Metal Stripes	165.77 for 2 tonnes	0.091	kg
c	Impression Film Waste	165.77 for 2 tonnes	0.091	kg
d	PIP Plate Waste	165.77 for 2 tonnes	0.091	kg

* Negative value indicates recycled value.

Appendix D

Material Costs for Lithographic and Digital Press

SN	Resource Category	Material Cost ($)	Unit Cost ($)	Unit
	Lithographic Press			
1	**Paper:**	60 for 1000 sheets (31kg)	1.933	kg
2	**Inks:**	21.79 for 5 pound	9.608	kg
3	**Fountain Solutions:**			
a	Fountain Concentrate	16.25 for a gallon	3.894	kg
b	Fountain Substitute	16.70 for a gallon	4.585	kg
c	Water	Nil	Nil	Nil
4	**Press Cleaning Materials:**			
a	Blanket Cleaning Paper	13.30 for 10 pound roll	2.926	kg
b	Rags	Recycled	N/A	N/A
5	**Aqueous Coating Solution:**	2.70 for a pound	5.947	kg
6	**Platemaking Chemistry:**			
a	Developer Solution	244.86 for 5 gallon	9.618	kg
b	Replenisher Solution	269.35 for 5 gallon	10.496	kg
c	Plate Finisher	179.27 for 5 gallon	7.584	kg
7	**Liners:**	40 for 100 numbers	0.4	Number
8	**Plates:**	13.56 for a plate	13.56	Number
	Digital Press			
1	**Paper:**	35 for 1000 sheets (16kg)	2.188	kg
2	**Press Maintenance Materials:**			
a	Blanket	3200 for a pack of 4	800	Number
b	Metal Stripes	0	N/A	N/A
c	Impression Film	16.83 for 10 numbers	1.683	Number
d	PIP Plate	3600 for a pack of 6	600	Number

Appendix E

Mass Balance Analysis Methodology

Study the manufacturing process stepwise and list all chemicals used in each process step. Also, list down all energy sources/units used. Ensure that all activities have been covered.

↓

Prepare a flow diagram indicating all material/chemical inputs and waste streams, such as air emissions, waste discharges, solid/hazardous waste, etc. If practiced, show recycling or reuse on the flow chart.

↓

Prepare a list of all inputs (resources used) and outputs (waste streams), and explore methods of measurement for all measurements to be taken.

↓

For convenience, prepare two checklists; one for materials that needs to be taken prior to their usage (pre-run) and other for materials that needs to be taken after their usage (post-run). Discuss on these checklists with the press operators to have their opinion and views, and let them know various points of measurement so that they can ease their operations.

↓

Plan for the required measuring devices and their sensitivity, and check their calibrations.

↓

Take all pre-run measurements. For rags, use labels to separate rags for different purposes. Containers or plastic airtight bags used for measurements should be pre-weighted.

↓

Start the press run and conduct air quality monitoring sampling. Its better to conduct air quality sampling during long run to ease the experiment load.

↓

Mass Balance Analysis Methodology

Note down the rum time of every single electrical equipment. Also, keep an eye on any minor waste that might generate even after make ready stage.

↓

Complete the press run and take all post-run measurements. Techniques used in this study for measuring critical measurements are listed below:

- **Measurement of imaging oil:** Measure the size of the imaging oil container (Length x Breadth) and mark the level before and after the press run to estimate the consumed volume.
- **Measurement of blanket cleaning paper:** After press cleaning, take out the waste blanket cleaning paper and cut an equivalent length of unused blanket cleaning paper and weight it.

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