Hazards and Risks at Rotary Screen Printing (Part 6/6): Control of Chemical Hazards via Cleaner Production Approaches

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Abstract
This-current-study examined occupational-chemical-hazards, at a-finishing-department (printing-section), of a-textile-mill, via questionnaire/checklist-surveys; document-analysis; site-visits, and walk-thorough-investigations. The-study revealed that: absolute-majority, of the-respondents, reported, that they do routinely-handle and use hazardous-chemicals; 90.9 % alleged that they had been-exposed-to the-organic-dusts; 72.7% reported that some-workers did not use personal-protective-equipment, even if provided; 63.6 % indicated that there were some-workstations, without local-exhaust-ventilation; 45.5 % of the-workers recorded, that hazardous-chemicals can-be-substituted for less-hazardous-ones, while the-rest said: ”I do not know”; and 36.3 % stated, that they were using hazardous-chemicals, while not been-trained in their-proper-use and handling. It-was-also-observed, severally, that: the-departmental-floor had spilled-off-chemicals, from the-machines; in-roller-cleansing, workers used to-dip a-cleaning-rag, into an-unlabeled-container of cleansing-solvent, which was left-open, all-the-time; and that shop/towel rags, used to-clean-up of machine-parts and spills, of-chemical-substances, during printing-operations, were-routinely soaked, washed, and then, re-used. Overall, the-study revealed, that workers could-be-exposed to numerous-hazardous-chemicals, particularly, highly-volatile-solvents. In-addition, lack of Democratic-control, and lack of training and awareness of safer-approaches, to-hazardous-chemicals, as-well-as unsafe-working-practices, were identified. To-eliminate, or to-reduce workers’ exposure to-chemicals, and to-protect the-environment, this-study provided numerous-general-recommendations (under Engineering and Administrative-control-methods), applicable to any-textile-printing-industry, as-well-as proposals, specifically-tailored to the-subject-department. The-recommendations were, largely, based on the-following-approaches of Cleaner-Production, such-as: input-substitution; better-process control; equipment-modification; on-site recovery/reuse; and good-housekeeping-practices. In-addition, areas for further-research was identified. Moreover, informative-synopsis on: Complex, and simple-definition for a-hazardous-chemical; The-United-Nations Globally-Harmonized-System of Classification and Labeling of Chemicals (GHS); Volatile-Organic-Pollutants; Materials Safety Data Sheets (MSDS); Rotary-printing machine, its-operation, chemicals, involved, and their-hazards and emissions, were-offered. The-study is believed, to-be important, not only for the-target-department and the-management, of-the-mill, but also for the-textile-printing-industry-professionals.

Keywords: VOC, MSD, MSI, MSDS, ventilation, air pollution, water pollution, flammability, PPE.

1. Introduction.
1.1. Occupational-hazards
An-occupational-hazard is a-hazard, experienced in the-workplace. Occupational-hazard refers-to both; long-term (e.g., increased-risk of developing cancer, or heart-disease), and short-term-risk (e.g., physical-injury), associated-with the-workplace-environment.

In-general, industrial-workers may-be-exposed to the-following-six-main-types of hazards, depending upon their-occupation (Sudha & Meenaxi, 2014): (1) Physical-hazards: Heat, cold, lighting, noise, visible ultra-violet-radiation, temperature, humidity, and ionizing-radiation; (2) Chemical and mineral-hazards: Dust, vapors, fumes, gases, solvents, metals, and their-compounds; (3) Biological-hazards: Various-blood borne-diseases, sharps/needle sticks, bacteria, moulds, in-health-care, and other-works; (4) Mechanical-hazards: Tripping-hazards, traumatic-injuries, housekeeping-injuries, steps and faults of moving-equipments; (5) Ergonomic-hazards: Posture-force (pushing/ pulling), repetition, vibration, pressure on the-body, work-organization (poorly-designed-work-process and tasks) and work-environment; and (6) Psycho-social-hazards: Low/high-workload-demand, pace /work; little and no control, over what work entails, no social-support, relations-harassment and discrimination, or physical or mental-treats of violence; and no flexibility, for time-off, among-others.

In-particular, according to IHDO (2000), occupational-hazards, related to printing, are: (1) Accident-hazards (Slips, trips, and falls, in-particular on wet-floors or cluttered-passages, or when carrying loads; Blows from falling-objects, in-particular, from overhead-conveyers; Blows and contusions, from moving-machinery; Entanglement between cylinders and rollers, between strong-webs and reels, at reel-up-stands (printing-machines), folding-machines, and other-moving, or rotating-machinery, or equipment; Cuts and amputations, by-blades and other-sharp-edges; Cuts and lacerations, to-the-fingers and hands; Fire-risks from flammable-materials, in-particular, organic-solvents; Electric-shock or electrocution, caused by contact with faulty-insulation or portable-electric-tools, in-particular, during maintenance or repair-operations. (2) Physical-hazards
Printing up to 24–36 colors are available, although most designs involve less than eight colors, and rotary printing (e.g., a blade or a roller), through the open mesh of the screen, onto the fabric, which is temporarily gummed to a print-table, with a moving rubber blanket (Sonderstrom, 1996). Machines capable of continuous processing of a flexible substrate, as it is transferred, between two moving rolls of material (Morse, 2011). The idea of rotary-screen printing was first proposed, in 1947, in Portugal, but the initial commercial machine was first introduced, by Stork (Holland), at the ITMA-show, in Germany, in 1963 (Ullmann, 2008). Conceptually, the idea is to take a flat-screen and simply shape-it into a roll, by sealing the ends, of the flat-screen, together. This simple modification converts a semi-continuous process (of flat-screen printing) to a continuous one (of rotary-screen printing).

The design motif, for each color, is developed as open mesh, on the rotary-screen, by the use of film, laser, or black wax engraving systems. A separate color is supplied, to each rotary-screen, and pushed by a squeegee (e.g., a blade or a roller), through the open mesh, of the screen, on-to-the-fabric, which is temporarily gummed on-to a print-table, with a moving rubber blanket (Sonderstrom, 1996). Machines capable of continuously printing up to 24–36 colors are available, although most designs involve less than eight colors, and rotary-
screen-printing, on textile-materials, up-to 5m, in-width, can be carried-out, at speeds up to 80m/min (Horrocks & Anand, 2000).

On-the-other-hand, Nirmala (2013) identified possible-hazards in-printing, such-as: (1) Flammability: The thickening-systems contain up to 40% solvents, and are highly-flammable; (2) Air-emissions: Solvents in this-print-system will be flashed-off, from the-oven, during drying and curing; (3) Sludge: Can-have environmental-problems with ground and groundwater-contamination; (4) Formaldehyde (apply to the-aqueous-based printing-systems) is a sensitizer and an irritant, that may-produce reactions, sometimes, violent, in-workers, who are exposed to-it, either; by-inhaling the-air, around the-printing-machine, as it-is operating, or by coming into-contact-with the-printed-fabric. These-reactions may range from-simple eye-irritation to-welts, on the-skin, and severe-difficulty with breathing. Besides, according to OSH (2004), screen-printing is associated with: (1) UV-cured-inks (N-vinyl-pyrrolidone (NVP) and Michler’s-Ketone, causing cancers, and harm to the-unborn-child; (2) other-inks Ketones print-system will-be flashed-off, from the-oven, during drying and curing; (3) pastes (KemI, 2009), as well-as NPEOs (chemicals, with particular-toxicity) (Nirmala, 2013). Problems with ground and groundwater-contamination; (4) Pollution, at the-source, rather than after it has-been-created; (3) Polluters must-prove that a-substance, or activity will-do be-extend to-cover the-entire-lifecycle, of a-product or service. Some CP-techniques include (e.g., cyclohexanone) and aromatic-hydrocarbons (e.g., toluene, xylenes), causing fire-hazard and dermatitis. In-addition, (3) Strong-alkalis (e.g., concentrated-sodium or potassium hydroxide) are used in cleaning of screens, in-screen-printing. They are corrosive-to-skin, eyes, and mucous-membrane. Kerosene, white-spirit (contain n-hexane); chlorinated-hydrocarbons (e.g., dichloromethane); and ketones (e.g., methyl-ethyl-ketone (MEK) are used in cleaning-rollers, cylinders, and blanket-restoring. These can cause fire-hazard; and dizziness, drowsiness, and other-effects-on the-central-nervous-system. Use of n-hexane, and methyl-n-butyl-ketone, in-particular, can lead to-peripheral poly-neuropathy (Assmuth et al., 2011). In-addition, preservatives are also-used in printing-pastes (KemI, 2009), as well-as NPEOs (chemicals, with particular-toxicity) (Nirmala, 2013).

Furthermore, exposure to-organic-solvents, in rotary-screen-printing, through inhalation, and skin-contact, in-the-workplace, can result in degreasing of the-skin, leading to: dermatitis, irritation, or sensitization of the-skin, and respiratory-tract. Long-term health-effects may damage internal-organs, such-as liver, kidneys, and lungs, after absorption into-the-body. Organic-solvents may-also-cause central-nervous-system-damage, and depression, with such-effects-as: drowsiness, in-coordination, inattention, and impaired-balance (KemI, 2009).

For-example, an-outbreak of organizing pneumonia (OP) occurred among textile-printing-sprayers, in-factories in the-Autonomous-Community of Valencia, Spain. OP is a-clinic-pathological-entity, characterized by histological-evidence of intra-luminal-polyps, of connective-tissue, in the-distal pulmonary-air-spaces, contrasting with minor-interstitial-fibrosis, together with distinctive-clinical and radiographic-features. An-epidemiological-investigation-proposed that the-lung-disease was-caused by spraying-procedures of aerosol of Acramin-FWN, to-distal-airways and pulmonary-parenchyma (Romero et al., 1998). This-study focused on rotary-screen printing-process and associated-with-it chemical-hazards and potential-risks. Toxicity of the-printed-garments (to-customers) is outside of the-scope of this-concise-study.

1.4. Cleaner Production (CP).
CP is neither a-legal, nor a-scientific-definition, but rather a-broad-term, that covers what some-countries, or institutions, call ‘pollution-prevention’, ‘waste-minimization’, ‘eco-efficiency’, or ‘green-productivity’ (UNIDO, 2002). CP is also-related to other-sustainability-concepts, such-as: zero-emissions; environmental-sound-technologies; life-cycle-assessment; and green-procurement.

According to Fresner et al. (2009), CP is a-preventative-approach to-managing the-environmental impacts of business, processes, and products, to-reduce waste, environmental and health-risks; minimize environmental-damage; use-energy, and resources, more-efficiently; increase business-profitability and competitiveness; and increase the-overall-efficiency of production-processes. CP is applicable to all-businesses, regardless of size or type. CP is a-continuing-process, which can-be-applied to production-processes; products; or services; or it can-be-extend to-cover the-entire-lifecycle, of a-product or service. Some CP-techniques include changes in: (1) technology; (2) input-materials; (3) operating-practices; (4) product-design; (5) waste-use; (6) maintenance; and (7) packaging.

The four-elements of CP are (Yacoub & Fresner, 2006): (1) The precautionary approach - potential polluters must-prove that a-substance, or activity will-do no harm; (2) The preventive approach - preventing pollution, at the-source, rather than after it has-been-created; (3) Democratic control - workers, consumers, and communities, all have-access to-information and are involved in decision-making; and (4) Integrated and holistic approach - addressing all material, energy, and water-flows, using life-cycle-analyses.

According to ‘Introduction to Cleaner Production (CP): concepts and practice’, by UNEP, CP consists of several-approaches, such-as: (1) Input-substitution (substitute input-materials, by less-toxic; or by renewable-materials; or by adjunct-materials, which have a-longer-service life-time, in-production); (2) Better-process-control (modify: operational-procedures and equipment-instructions, and process record-keeping, in-order-to-run the-processes more-efficiently, and at-lower-waste and emission generation rates); (3) Equipment-modification (modify the-existing production-equipment and utilities, in-order-to-run the-processes at-higher-efficiency, and lower-waste and emission-generation-rates); (4) Technology-change (replacement of the-technology; processing-
sequence; synthesis-pathway, in-order-to-minimise waste and emission-generation, during production; (5) On-site recovery/reuse (reuse of the-wasted-materials, in the-same-process, for another-useful-application, within the-company); (6) Production of a-useful by-product (consider transforming waste into a-useful-by-product, to-be-sold, as-input, for companies, in-different-business-sectors); (7) Product-modification (modify the-product-characteristics, in-order-to minimise the-environmental-impacts, of the-product, during, or after, its-use (disposal), and to-minimise the-environmental-impacts of its-production); and (8) Good-housekeeping (take appropriate managerial and operational-actions to-prevent: leaks; spills; and to-enforce existing-operational-instructions).

This-study utilized CP-approaches.

1.5. Research purpose

The-textile-industry has-been condemned, as being one of the-world’s worst-offenders, in-terms of pollution. Chemical-companies market a-vast-range of products, such-as: dye-formulations, colorants, and finishing-chemicals, to-the-textile-industry. On-the-other-hand, there has-been a-growing-awareness, globally, of the-damage, caused, to-the-environment, by the-indiscriminate-use of dyes and chemicals, some of which are very-toxic, and, even, mutagenic, or carcinogenic (Starovoytova & Odido, 2014).

For-example, research by Starovoytova & Odido (2014), revealed, that various-chemical-substances, used in-textile-mill, were harmful/toxic, carcinogenic, probably-carcinogenic, and water-polluting. Furthermore, it was-identified, that two, out of three, compounds, classified as-carcinogenic to-humans, were-used, in the-mill, either; as chrome/metal/complex-dye, itself, or as its-mordants.

On-the-other-hand, the-textile-industry consumes a-substantial-amount of water, in its-manufacturing processes, mainly, in-the-dyeing, printing, and finishing-operations. The waste-water from textile-plants is the-most-polluting, of all-the-industrial-sectors, considering-both; the-effluent-composition, and the-volume, generated (Phillips et al., 1999). For-example, another-study, by Starovoytova (2012), have analyzed textile-effluents, and identified, that Chromium-concentration, was higher, than the-standard, by 248%, which contributed, largely, by chrome-dyes. Hexavalent-Chromium, present in-dyes, is regarded as-carcinogenic, to-humans, and, moreover, is-very-toxic to-both; flora and fauna.

According to Talvenmaa (2002), the-dyeing, printing, and finishing-processes, of textile-industry, consume 0.5-0.9 kg of chemicals, per one-kg of fibres, depending e.g., on the-degree of dilution of the-chemicals, used. Chemicals, used during the-textile-wet-processing are rinsed-out, using water and detergents (KemI, 2009), to-the-large-extent, they are not recycled in the-process. According to the U.S. EPA, the-printing-industry releases 99% of its-total Toxic-Release-Inventory (TRI) poundage to-the-air, while the-remaining 1% of releases, are-split-between water and land-disposal. Average VOC-emissions, per-textile-print-line is 130 Mg (tons)/year, for roller, and 29 Mg (tons)/year, for flat and rotary-screen (Allen, 1993).

Besides, workers, engaged in-wet-finishing-processes are frequently-exposed to crease-resistance agents, which may-release formaldehyde, known for its-toxicity. Workers are also-exposed to flame-retardants, including organo-phosphorus and organo-bromine-compounds. The-textile-industries use different-kinds of dyes, including the-most-commonly-used azo-dyes, which are aromatic-hydrocarbon derivatives of benzene, toluene, naphthalene, phenol and aniline. The-solvents, used by the-workers, in different-sections, result in a-major-carcinogenic-effect by direct-contact with the-subjects. Numerous studies have also-emphasized the-occurrence of different-types of occupational-cancers, among textile-industry-workers; and in-particular: Lung-cancer (Checkoway et al., 2014; Wang et al., 2014; Applebaum et al., 2013; Gallagher et al., 2013); Ovarian-cancer (Li et al., 2015; 2013; Ray et al., 2007); Breast-cancer (Wernli et al., 2008b); Endometrial-cancer (Wernli et al., 2008a); Oral-cavity and pharynx-cancer (Kuzmickiene & Stukonis, 2010); Rectum and colon-cancers (De Roos et al., 2005); and Biliary-tract-cancer (Chang et al., 2006), among-others.

Furthermore, chemicals used, in-the-textile-industry, may-cause multi-dimensional-risks, including: environmental, safety, and health-risks, notably to-workers, consumers, but also to-ecosystems, in-regions of production, use, and disposal (Assmuth et al., 2011); in-particular, toxicological-risks, to-humans, and eco-toxicological-risks, to-other-organisms, are intertwined.

In-addition, several-researchers identified and studied a-wide-range of occupational-hazards, which may lead to-accidents. Accidents, frequently, result in occupational-injuries, which can-damage the-reputation of a-company, decrease productivity, and result in large-costs. Besides, injured-employees may suffer not only pain and discomfort, but also more-serious-problems, such-as: a-temporary or permanent-disability, or, even, death (Saxena et al., 2017).

On-the-other-hand, the-workers are the-driving-forces of the-national-economy, and therefore, their-working-lives should-be-protected from occupational-disorders and injuries (Ahasan, 2000). Occupational-safety and health’ objective is not only to-keep the-workers physically-healthy, but also mentally and psychologically-stable (Sudha & Meenaksi, 2014), so that they can remain-healthy, and perform, the-tasks, capably. Occupational-health and safety is a-global-issue and a-matter, requiring urgent-attention and commitment (Leichnitz, 2001;
Phoon, 2001; Manuaba, 2001; WHO, 1995), which should-consider the-local-characteristics of the-occupation, work-practice, and organizational-culture.

The-importance of assessing risks, and taking informed-steps, to-minimize-them, cannot be overemphasized. This-study, therefore, was designed to-examine occupational-chemical-hazards, at the-finishing-department (printing-section) of a-textile-mill.

According to Mansour et al. (2012), considering the-fact that the-textile-wet-processes are recognized as one of the-most-environmentally un-friendly industrial-processes, it-is of extreme-importance to-find alternative, eco-friendly-methods and substances. The-study is moreover-important, as Cleaner-Production approaches are to-be-considered, in proposing appropriate-control-methods and eco-friendly-alternatives.


2.1. Depiction of the-textile-mill, where the-study was conducted.
The-current-study was conducted at Rivatex-East-Africa, Limited (REAL), an-integrated textile-mill, which is fully-equipped to-handle the-entire textile-processing-cycle. Raw-materials utilized, by the-factory, are: cotton, polyester, and viscose. For more-details, on the-mill’s history, structure, and end-products (see Starovoytova, 2017a). The-focus of the-current-study was on printing-section, of the-finishing-department, at the-mill.

2.2. Main-instruments used
Blending of questionnaires and observational-methods, in-occupational-risks and hazards-assessment, has-been recommended, by several-authors (see for-example: Barrero et al., 2009; Descatha et al., 2009; and Barriera-Viruet et al., 2006). In-this-regard, the-following-instruments were used, by the-current-study: document-analysis, a-questionnaire, and observations. Observations were done via a-series of site-visits, and walk-through-investigations, during 3 months-period.

2.3. Focus and design of the-study.
In-order to-conduct a-survey and perform a-document-analysis, the-study was divided-into 3-distinctive parts, which shown in-Figure1.

Figure1: Sequential-parts of the-study (Starovoytova & Namango, 2016).

2.4. Sample size and the-rationale for its-selection
To-evaluate chemical-hazards, among printing-machine-operators, at the-REAL, a-confidential self-report questioner was designed and used, as the-main-instrument, for this-study, with the-sample-size of 12-subjects (representing the-entire machine-operating-staff, at the-finishing-department).

2.5. Data Analysis
This-research complied with the ISO 20252:2006 (E): Market, Opinion and Social-Research Standard; hence, a-preliminary-study was-conducted, at the-factory, using an-initial-version-questionnaire, for determining the-hazards.

To-estimate reliability, the-correlation-coefficient was used, according to Kothari (2004). The-Statistical- Package for Social-Sciences (SPPS-17, version 22)-computer software-program was applied, to-compute the-Cronbach’s co-efficient. Descriptive-statistics was employed to-analyze both; qualitative and quantitative-data.

2.6. Selected-terminology and concepts applied
Analogous to UN, GHS (2005), the-term ‘chemical’ is used-broadly, in-this-study, to-include: substances, products, mixtures, preparations, or any-other-terms, that may-be-used by existing-systems. Moreover, ‘health’
3. Results.

3.1. Validation of the-Questionnaire

Initially, the-EASHW-check-list/questionnaire was modified, to-suit the-specifics of the-study. Upon-valuation, the-general recommendation made, is that the-instrument was-acceptable, with some-minor-editing. Questionnaire-data was-coded, entered into-SPSS, and checked for-errors. Data was analyzed, list-wise, in-SPSS, so that the-missing-values were ignored. Cronbach’s-alpha-test of internal-consistency was-performed, for-some minor-editing.

A-risk is-the-chance, high, medium, or low, that a-hazard will-actually-cause somebody-harm. In-the-case of chemical-exposure, hazard is-the-potential of a-substance to-cause-damage, meaning that a-substance has-an-intrinsic-ability to-cause-harm; it can be said, that the-substance is the-source, or the-root, of potential-harm (Ulbig & Bol, 2010).

Toxicity, for-instance, is-the-hazard of a-substance, which can cause poisoning. Risk, on-the-other-hand, is a-measure of the-probability that harm will occur, under defined-conditions of exposure to a-chemical. If there can be no exposure to a-chemical, no matter how dangerous (hazardous) it may-be, there is no risk of harm. The-relation of risk-to-hazard may-be-expressed as (Duffus & Worth, © IUPAC): \[ R = f (H \times E) = f (H \times D \times t) \]

Where \( R \) is risk, \( f \) is function of, \( H \) is hazard, \( E \) is exposure, \( D \) is dose, and \( t \) is time.

Thus, chemicals, which pose only a-small-hazard, but-to-which there is frequent, or excessive-exposure, may pose as-much-risk, as-chemicals, which have a-high-degree of hazard, but-to-which only limited-exposure occurs.

3.2. Results obtained.

Analogous to previous-study by Starovoytova (2017 b), 12 questionnaires were-administered to-the-entire staff (machine-operators) of the-finishing-department, printing-section; the-response-rate (RR), for this-study, was 92% (11 duly-completed questionnaires).

3.2.1. Demographic-Characteristics.

Table 1 shows the-demographic-characteristics of the-respondents.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S D</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>25.375</td>
<td>10.23</td>
<td>24 - 43</td>
</tr>
<tr>
<td>Duration of Employment (years)</td>
<td>2.75</td>
<td>2.18</td>
<td>1 - 8</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>169.07</td>
<td>11.84</td>
<td>146 - 182</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>65.375</td>
<td>9.80</td>
<td>54 - 85</td>
</tr>
</tbody>
</table>

3.2.2. Actual-responses to the-questionnaire

The-following were the-answers, to-the-questionnaire (presented in-the-decreasing-order): (1) 100 % of the-respondents reported, that they have-been-using hazardous-chemicals (clarification-examples, provided, in-the-questionnaire, were, that hazardous-chemicals were assumed, to-be, those, classified as: toxic, harmful, corrosive, irritant, sensitizing, carcinogenic, mutagenic, or toxic-to-reproduction); (2) 90.9 % of the-respondents, alleged that they have-been-exposed to the-organic-dusts, e.g., from raw-cotton and/or cotton-yarns; (3) 81.8 % reported, that new-workers were told, about risks, from the-dangerous-substances, while the-rest provided no answer. The-
same-share of the respondents, however, also-indicated, that they have never been introduced-to, or referred-to MSDs, to-get-the-information on toxicity and proper-handling of the-chemicals, they handle; (4) 72.7% reported, that some-workers did not use personal-protective equipment, such-as: gloves, gogles, face-shields or respirators, even if this-is provided; (5) 63.6 % stated, that: (a) they were aware of the-dangers, posed by the-chemicals, they are using, while the-rest disagreed; and (b) there are some-workstations, without appropriate-collective preventive-equipment, such-as local-exhaust-ventilation; (6) 45.5 % of the-workers stated, hazardous chemicals can-be-substituted for less-hazardous-ones, while the-rest said: “I do not know”; and (7) 36.3 % reported, that they were using hazardous-chemicals, while not been-trained in their-proper-use and handling.

It-was also-observed, severally, that the-floor had visible, and in-some-cases, substantial-amount of spilled-off chemicals, from rotary-screen-printing-machines, which pose direct-danger to-workers, particularly those, without personal-protective-equipment, such-as gumboots, goggles, and masks; this may-lead-to MSDs and/or MSIs. It was also-witnessed, that shop-towels/rags, used to-clean-up spills of chemical-substances, during printing-operations, were-routinely soaked, washed, and then, re-used.

4. Analysis of the-results and Discussion.

4.1. Hazardous-chemicals: definitions, classification and exposure-routes

100 % of the-respondents reported that they do-use hazardous-chemicals, on a-daily-basis. To-bring more-light on this-type of a-chemical/Substance, the-following-section provided its-definitions and classification.

According to Safe-Work Australia (2015), a-hazardous-chemical means any-substance, mixture, or article, that satisfies the-criteria, for a-hazard-class, in the Globally-Harmonised-System of Classification and Labelling of Chemicals (GHS), including a-classification, referred-to in-Schedule 6 of the-WHS-Regulations, but does not include a-substance, mixture, or article, that satisfies the-criteria, solely for one of the-following-hazard-classes: acute-toxicity-oral - Category 5; acute-toxicity-dermal - Category 5; acute-toxicity-inhalation - Category 5; skin- corrosion/irritation - Category 5; acute-toxicity (oral); respiratory or skin-sensitization; organic peroxides; oxidizing solids; oxidising solids; pyrophoric solids; self-reactive substances; toxic gases; toxic liquid; toxic solids; volatile solids; precursors; and (3) Communicating hazard-information, as-well-as protective-measures, on-labels and Safety Data Sheets (SDS).

Workers can-be exposed to a-hazardous-chemical, and any-waste, intermediate, or product, generated-from the-use of the-substance, if they: work-with it, directly; are in-the-vicinity, of where it-is used, or likely-to-be generated; enter an-enclosed-space, where it-might-be-present; disturb-deposits of the-substance, on surfaces (for-example, during-cleaning) and make-them-airborne; and come-into-contact with contaminated-surfaces. Chemicals may-enter the-human-body through 4 different-means, such-as: (1) inhalation (breathing-in the-vapors); (2) ingestion (swallowing the-chemical); (3) injection (by-some-mechanical-means, under-the-skin); or (4) absorption (skin-contact). Inhalation and absorption routes are common; chemicals, however, can-be-also-ingested, accidentally, through contact with food or drink, and material can-be-injected, by mishandling of pressurized-equipment, like airless-sprayers (Safe-Work-Australia, 2015).

UN, GHC (2005), classified-exposures, that might-be caused by chemical-exposure, as-follows:(1) Physical-hazards (Explosives; Flammable-gases; Flammable-aerosols; Oxidizing-gases; Gases, under-pressure; Flammable-liquids; Flammable-solids; Self-reactive-substances; Pyrophoric-liquids; Pyrophoric-solids; Self-heating-substances; Substances, which, in-contact with water, emit flammable-gases; Oxidizing-liquids; Oxidizing-solids; Organic-peroxides; and Corrosive to-metals); (2) Health-hazards (Acute-toxicity; Skin-corrosion/irritation; Serious-eye-damage/eye-irritation; Respiratory or skin-sensitization; Germ-cell-mutagenicity; Carcinogenicity; Reproductive-toxicology; Target-organ systemic-toxicity – single-exposure; Target-organ systemic-toxicity–repeated-exposure; and Aspiration Toxicity); and (3) Environmental-hazards (Hazardous to the-aquatic-environment; Acute-aquatic-toxicity; Chronic-aquatic-toxicity; Bioaccumulation-potential; and Rapid-degradability).

Once a-chemical has-been-classified, the-hazard(s) must be communicated, to-target-audiences. The-international-mandate, for the-GHS, included the-development of a-harmonized-hazard communication-system, including labeling, Safety-Data-Sheets, and easily-understandable-symbols, based on the-classification-criteria,
developed for the-GHS. Twenty-four GHS-Pictograms and Hazard-Classes, can-be viewed via UN, GHS (2005).

Regulatory-authorities, in-countries, adopting the-GHS, will-take the-agreed-criteria and provisions, and implement them, through their-own-regulatory-process and procedures, rather than simply incorporating the-text of the-GHS, into their-national-requirements. The-GHS-document, therefore, provides countries with the-regulatory-building-blocks, to-develop, or modify existing-national-programs, which address classification of hazards, and transmittal of information, about those-hazards, and associated protective-measures.

To-better-comprehend the-whole-process of rotary-screen-printing, the-following-section briefly explained the-process, as a-sequential-order of steps.

4.2. Selected-specifics of rotary-screen-printing

Figure 2 shows the-general-arrangement of rotary-screen-printing-machine. This-study focused on the-Octrooi Aangevraagd rotary-screen-printing-machine (model-number 146590).

In-general, there are 5 basic-steps in-printing a-fabric: (1) Preparation of the-print-paste; (2) Printing the-fabric; (3) Drying the-printed-fabric; (4) Fixation of the-printed-dye or pigment; and (5) After-washing/pick-up/curing.

The-preparation of the-printing-paste (ink) is one of the-most-important-steps, in-printing; the-ready-paste must-be-viscous (like paint or pudding). This-quality is called ‘flow’; the-choice of an-agent, to-create this-flow (called a-thickening-agent) is a-critical-component (Lacasse & Baumann, 2004). Ink-preparation, at-the-department, is done in-the ‘color-kitchen’, adjacent to the-main-operational-area. For-direct-printing, a-printing-paste is prepared by-dissolving the-dyes in-hot-water, and adding urea and a-solvent (ethylene-glycol, thioethylene-glycol, sometimes glycerin, or a-similar-substance). This-solution is stirred, into a-thickener, which is easily-removed, by-washing. Small-amounts of oxidizing-agents are also-added. The-dye or pigment is thickened with-starch, or made into-emulsion, which, in-the-case of pigment-colors is prepared with an-organic-solvent. All the-necessary-ingredients, for the-paste are dosed, and mixed-together, manually (like at-the-subject-department), or in-an-automatic-mixing-station. After making the-printing-paste, it-is-essential to-strain, or sieve, all-colors, in-order-to-free-them from lumps, fine-sand, and other-foreign-objects, which would predictably-damage the-highly-polished-surface, of the-engraved-rollers, and result in poor-quality-printing.

Second-step is the-actual-fabric-printing. Rotary-screen-printing-machine consists of: in-feed device, glue-trough, rotating-rubber-blanket (print-table), dryer, and fixation-equipment. The-printing-process is initiated by manually-feeding/positioning, the-fabric, onto the-rubber-blanket. The-fabric moves along, in-continuous-mode, under a-set of cylinder/rotary-screens, which rotate at-the-same-velocity, as the-fabric (Nirmala, 2013). As the-fabric travels, under the-rotary-screens, the-screens turn with the-fabric. Printing-paste/ink is continuously-fed, to-the-interior of the-screen, through a-color-bar or pipe. As the-engraved rotary-screen rotates, the-squeegee-device pushes printing-paste, through the-design-areas, of the-screen, onto the-fabric; only-one-color can-be-printed by each-screen (see Figure 2).

Two-types of dryers are used, for printed-fabric, steam-coil, or natural-gas fired-dryers, through which the-fabric is conveyed, on-belts, racks, etc., and steam-cans, with which the-fabric makes direct-contact. After printing and drying, the-fabric is, often, cooled, by-blowing-air over it, or by-passing-it over-a-cooling cylinder, to-improve its-storage-properties, prior to-steaming, which is the-process of color-fixation, into the-fabric. Temperatures, in-the-steamer, must-be carefully-controlled, to-prevent-damage, from overheating, due to the-
heat-swelling of the-fabric, condensation of certain-chemicals, or the-decomposition of reducing-agents. After steaming, the-printed-fabric must not be stored for too-long, prior to-washing, because reducing-agent-residues may-continue to-decompose (only few-hours is, hence, allowed).

Finally, printed-goods must-be washed, thoroughly, to-remove thickening-agent, chemicals, and unfixed-dyestuff; care should-be taken to-prevent staining of the-uncolored-portions of the-fabric. Washing begins with a-thorough-rinsing, in-cold-water. Afterwards, re-oxidation is carried-out, with hydrogen peroxide, in the-presence of a-small-amount of acetic-acid at 122-140°F, followed by a-soap-treatment, with sodium-carbonate, at the-boiling-point.

After concise-expansion, on the-rotary-screen-printing-process, it is logical to-look, closely, at the-different-chemicals, commonly-used, in-the-process, alongside with their-potential-impacts.

4.3. Chemicals, used in printing

Chemical-substances are being-used, extensively, in-rotary-screen-printing, either; for the-printing-process, itself, or for the-obligatory-cleaning of machine-parts/elements.

Printing-ink, a-compulsory-component, of rotary-screen-printing, is complex-mixture of chemical compounds, with composition, varying, based on their: (1) solvent-bases (oil or water); (2) drying-mechanisms (absorption, evaporation, oxidative-polymerization, etc.); and (3) adopted-printing processes (in-particular, the-printing-ink-types).

A-printing-ink is, normally, made-up of 4 main-components: (1) The-coloring-matter (dyes or pigments); (2) The-binding-agent; (3) The-solvent; and (4) The-auxiliaries.

The coloring-matter used, can-be either; dyestuffs, or pigments. Coloring-matters, which are soluble, or could-be made-soluble, in-water, are known as dyes, while the-insoluble-ones, are pigments. The-dyes used, for printing, mostly-include vat, reactive, naphthol, and disperse-dyes, which have-good-fastness properties. Pigments are, by large, chemically-inert and insoluble (Allen, 1993), and, hence, in-most-cases, an-acrylic-co-polymer is used to ‘glue’ the-pigment-particles, to-the-fabric-surface, and, often, organic-solvents are used (such-as benzene or toluene). The-pigmented printing-paste must physically-bind with the-fabric, so it must-contain a-resin, which holds the-pigment in-place, on-top of the-fabric. For-example, black-inks usually-contain carbon-black, whereas white-inks contain titanium-dioxide, calcium-carbonate, zinc-oxide, clay, etc. Colored-pigments can be organic or inorganic. Organic-pigments are, mostly, synthetic-colorants of aromatic-hydrocarbon-origins, such as benzene, naphthalene, or anthracene, containing chromophoric-groups =C=NH, -CH=N- and -N=N-. Inorganic-colored-pigments usually-contain metals, such-as: lead, chromium, copper, mercury, and iron, among-others.

Binders are, in-general, ‘self-cross-linking polymers’ based, mainly, on acrylates, and, less-commonly, on butadiene, and vinyl-acetate, with solid-contents of approximately 40-50% (Ullmann, 2008).

Solvents are usually-added, in-the-formulation of the-thickeners. White-spirit is a-commonly-used organic-solvent, as is water. The-organic-solvent-concentration in print-pastes may vary from 0% to 60%, by-weight, with no consistent-ratio of organic-solvent-to-water.

The most-important auxiliaries are the-thickening-agents. Printing-paste normally contains 40-70% thickener-solution (Lacasse & Baumann, 2004). Typical-thickening-agents are starch-derivatives, flour, gum-Senegal, gum-Arabic, and albumen. A starch-paste is made from wheat-starch, cold-water, and olive-oil, boiled, for thickening. In-addition, other-auxiliaries, generally-used, for-printing, are (Ullmann, 2008): Oxidizing-agents (e.g. m-nitrobenzenesulphonate, sodium-chlorate, hydrogen-peroxide); Reducing-agents (e.g. sodium - dithionite, formaldehyde-sulphoxylates, thiourea-dioxide, tin(II) chloride); Wetting-agents (nonionic, cationic, anionic); Discharging-agents, for discharge-printing (e.g. anthraquinone); Humectants (urea, glycerine, glycols); Carriers (creosotinic-acid, methyl-ester, trichlorobenzene, n-butylphthalimide, in-combination with-other-phthalimides, methylnaphthalene); Retarders (derivatives of quaternary-amines, leveling-agents); Resist-agents (zinc-oxide, alkalis, amines, complexing-agents); Softeners; Resins; Metal-complexes (copper or nickel-salts of sarscicine, or hydroxyethylsarcosine); and Defoamers (e.g. silicon-compounds, organic and inorganic-esters, aliphatic-esters, etc.).

Other-substances, possibly-present, in printing-industry-activities include (Guidance Note for printing 6/16, 2004; EPA RCRA Hazardous Waste Resources; Environment Australia, 1998): Water-based inks and coatings (such-as: Ammonia, Zinc, etc.); Water-Solvent-based-inks (Ethyl-benzene, Ethylene-glycol, Glycol-ethers, Toluene, diisocyanates); Solvent-based- inks and coatings (Hexane, Methyl-ethyl-ketone (MEK), Methanol, Propylene Oxide, Xylenes, Methyl-isobutyl-ketone (MIBK), Isopropyl Alcohol, Ethyl Acetate, Ethanol, Propyl Acetate, Butanol, 2- Butoxyethanol); Acetone-Pigments (Barium, Cadmium, Chromium, Copper, Lead Chromate, Manganese, Zinc); Ink-solvents (n-Butyl-alcohol, Isophorone); Ink-catalysts or retardants, for drying (Manganese, Methyl-Chloroform-1,1,1, Trichloroethane, Xylenes); Component in cleaning-solvents (Benzene, Cumene, Cyclohexane, Ethyl-benzene, Hexane, Methyl Chloroform-1,1,1, Trichloroethane, Methyl-ethyl-ketone, Methylene-Chloride, Naphthalene, Toluene, Xylenes, 1, 2, 4 Trimethylbenzene, Isopropyl Alcohol); Component
in cleaning-solvents fountain-solution additive (Diethylene-glycols, Ethylene-glycols, Glycol-Ethers, Phosphoric-acid); Component in copper-plating-solution (Ethylene-glycols, Methylene Chloride); Adhesives/Spray adhesives (Cyclohexane, Hexane, Methyl Chloroform-1,1,1, Trichloroethane, Vinyl-Acetate, Isopropyl-Alcohol); Plasticizer, in inks and coating (Dibutyl-Phthalate); Film-developing (Diethanolamine, Formaldehyde, Hydroquinone, Phenol); Plate-developer (Perchloroethylene, Phenol); Film-cleaner (Hexane, Methylene-Chloride); Cleaners / Etching (Nitric-acid, Phosphoric-acid, Perchloroethylene); and Blanket/Roller Wash (Cumene, Ethylbenzene, Naphthalene, Methanol, Methyl-Chloroform-1,1,1-Trichloroethane, Methylene-Chloride, Toluene, Xylenes).

Moreover, phthalates, known for their-toxicity, are used in-textile-printing; Swedish-authorities, for example, found that the-use of PVC-based printing-colors is common (Stockholms Stad, 2009), and 12 out of 13 investigated-printer-shops also used colors, containing phthalates. The-most-commonly-used phthalates, in textile-dyes are butyl-benzyl-phthalate (BBP) and di-isononyl-phthalate (DINP) (KemI, 2009; Environment Agency, UK, 2008).

The-list of chemicals/substances, given, in-this-section, is for illustrative-purpose, and, by no means, exhaustive, nevertheless, it is a fair-indicator of the-spectrum of the-chemicals, commonly-used, in-printing.

The-severity of exposure of employees, to-hazardous-chemicals, is affected by: (a) the-nature and the-form, of the-substance; (b) frequency and duration of exposure; (c) rate of generation, of the-hazardous-chemicals, and their-concentration, in the-atmosphere; and (d) effectiveness of safety-measures, in-minimizing the-exposure. For-example, the-physical-form of a-chemical-substance has a-pronounced-effect on the-extent of the-hazards of the-chemical. Gases, vapors, fumes, aerosols, dusts, airborne-particles, and powders, increase their-risk of: entering the-human-body, as-well-as fire, and explosion. Attention, hence, should be-paid to any-possible side-reactions and by-products.

Other-environmental and health-hazards, in-printing-textiles, are resulted from the-equipment cleaning-operations, which use both; water, as-well-as different-substances.

4.4. Cleaning

After printing-run, the-screens, and the-whole-application-system (pumps, squeegees, hoses, pipes, etc.), have-to-be cleaned-up, at each-change of color, or pattern, while a-considerable-amount (approximately 10 liters) of printing-paste still-remains, in-the-system. The-remaining-paste is, largely, in-the-tubes, which run-between the-paste-reservoirs and the-screens. Besides, rotary-screen-printing-machines are equipped with both; washing and gluing-devices. In-both-devises, the-continuous-rubber-belt, after pulling-away the-fabric, is moved, downward, in-continuous-mode, over a-guide-roller, and washed-with water, and rotating-brushes, to-remove the-printing-paste-residues and the-glue, if necessary. After this, the-belt is sent-back, to-the-gluing-device.

If using plastisol-inks, in-order-to-emulsify the-ink, for easy-removal, from screens, squeegees, flood-bars, spatulas, and work-surfaces, it-is-necessary to-use some-solvent. Solvents, used to-clean printing-equipment include: Dichloromethane (methylene-chloride-synonym); Tetra-chloroethylene; Ethylene-glycol; Glycol-ethers; Methanol; Methylene-chloride; Acetone; n-Butanone; n-Butyl-acetate; Ethyl-acetate, Hydrocarbon-solvent (white-spirit), 1-Propanolltram; Methyl-ethyl-ketone (MEK); Naphthalene-Phenol; Toluene; and n-Xylene (MDNR, 2004; Nousiainen & Sundquist, 1979), among-others. In-addition, blankets, used to-transfer the-ink-filled-image, to-fabric, are cleaned-with-washes, that contain glycol-ethers and 1, 1, 1- trichloroethane (TCA). These-solvents are potentially-hazardous/toxic; for-example, OSH (2004) reported an-outbreak, of peripheral-polyneuropathy, among offset-printers, caused by contact with n-hexane, a-main-ingredient of the-solvent, used for cleansing printing-rollers. Moreover, according to MDNR (2004), many-waste-solvents are hazardous-wastes (ignitable, toxic, reactive, or corrosive); some-used-solvents are on the-F and U-list.

On-the-other-hand, the-type of solvent used, depends, largely, on the-equipment, to-be-cleaned. For-example, a-blanket-wash must dissolve-ink, quickly, and dry, rapidly, with minimal-wiping. In-contrast, a-solvent, that is intended to-clean a-chain of ink-rollers must evaporate-slowly, to-insure that it does not flash-off, before it has worked its-way, through all-the-rollers. In-addition, the-belt should-be washed, to-remove the-residues of paste and adhesive. All of these-components must be washed, thoroughly. It-is-common-practice to-squeeze the-color, from the-screens, back into the-printing-paste-mixing-containers, before washing them (ResiteX, 2008).

Cleaning, in-the-department, involved washing, of the-printing-system, and cleaning of the-floors. It was observed, that cleaning of rollers, was-done, manually, by workers, using solvent-wetted-rags. For-convenience, uncovered-container, of organic-cleaning-solvent, was kept, close to-the-printing machine, causing evaporation of VOCs, to the-workplace. Moreover, the-containers were not labeled, hence workers were, most-likely, unaware of potential-safety and health-hazards, of the-containing-liquid, and, hence, were using the-solvent, without any-precautions. Some-fabric-designs require up-to 20 different-colors; hence, 20 rollers have-to-be cleaned, consequently increasing the-exposure to VOCs. It should-be noted, that the-risk of absorption, of a-solvent, into the-body, depends on: the-particular-chemical, its-concentration, and frequency, duration, and mode...
of exposure.

With regard to general cleaning operations, UNIDO (2002), recommended to avoid: (1) APEO detergents and replace them, with more biodegradable alternatives; and (2) solvent-based products, and carriers, containing chlorinated aromatics. Besides, it was recommended to select less hazardous process materials, such as cleaning solutions, with no hazardous constituents. Other alternatives include low volatility cleaners / coating materials (e.g., VOC composite vapor pressure less than 10 mm Hg at 20°C), and water- and vegetable oil-based inks.

In addition, the towels/rags, used for cleaning, could also be characteristic hazardous waste, particularly if they can burst into flames. The shop towels/rags are hazardous waste, and hence, they should not be hand-washed and reused, but must be disposed of, at a permitted hazardous waste treatment, storage, or disposal facility. And lastly, all the containers should be properly labeled (see the importance of and details on labeling via UN (2012).

The study also proposed to utilize ‘Process and equipment modification’ approach of CP, e.g., to install automatic blanket washers, to eliminate manual cleaning, thus minimizing the risk of exposure, of workers to organic solvents.

From the above information, on the chemicals, involved in the printing operations, two ingredients of major concern, were identified as inks/pastes, and solvents; the following section provided a closer look at the two.

4.5. Inks

There are two main types of printing paste/ink used: (1) Pigmented emulsions: Pigmented emulsions are suitable for all fiber types, they are able to dry, by evaporation, at room temperature, and are able to be cured at 320°F, for 2-3 minutes, which achieves washing, and dry cleaning fastness. A typical formulation of a pigment-emulsion printing paste is: White spirit -62%; Binder -15%; Water -10%; Pigment -dispersion -5%; Plasticizer; characterized by virtually 100% volatility; (b) Liquid plasticizer (i.e., dialkyl phthalate or di-iso-octyl phthalate); (c) heat and light stabilizers (i.e., liquid barium/cadmium/zinc, combined with epoxy plasticizer); and (d) high proportion of extender, to improve wet-on-wet properties (Ullmann, 2008; Lacasse & Baumann, 2004).

Both ink types have their advantages and limitations, as well as related hazards. For example, solvent-based inks (e.g., inks, containing ethanol, isopropanol, ethylene glycol, xylene, toluene, cyclo hexane and petroleum distillates) are considered the least environmentally friendly, due to the highly volatile solvents, given off, during printing and drying. The petroleum based binder used in many solvent-based inks, could be replaced with renewable resources, such as vegetable oil or soy. Besides, relatively new entry, on the market, is called ‘Eco Solvent’ inks; where ‘eco’ means ecological; however, these inks, generally, contain glycol-esters or glycol-ether-esters (both, however, derived from mineral oil, hardly a renewable resource or an ecologically sound process). Discharge inks are now also available, in formaldehyde free formulations, such as the Oasis Series, by Wilflex, making them safer (Saxena et al., 2017).

With plastisol printing pastes, both; PVC and phthalates, are chemicals of concern (as carcinogens), many companies, hence, are offering phthalate free plastisol inks. In addition to non-phthalate plastisols, there are some new acryl based screen printing inks, that are sometimes referred to as non-PVC and non-phthalate plastisols. Acrylic inks, however, are more costly, than standard plastisols, and are, substantially more expensive, than standard water based inks. New inks have also been developed, such as latex, resin, and UV curable inks. Dr. Nicholas Hellmuth, of FLAAR (http://www.wide-format-printers.org/), wrote in his blog, that there is a potential, that resin inks could be considered better, than water based inks.

4.6. Solvents

Screen inks also contain solvents, such as: aliphatic and aromatic hydrocarbons (e.g., white spirit, trimethylbenzenes), ketones (e.g., cyclohexanone), alcohols (e.g., diacetone alcohol), and certain glycol ethers and their esters (e.g., 1-methoxy-2-propanol and 2-butoxyethanol acetate), among others. Large rotogravure printing facilities may consume more than 200 tons of solvents, per year. The solvents, used in the printing pastes, are typically, respiratory, skin, and eye irritants; at times, they can also cause abnormal changes in chromosomes (OSH, 2003). There has been particular concern about the health effects, of some glycol ethers, and their acetal derivatives. Short term health effects range from loss of concentration, mild headaches, and nausea, to more severe headaches, vomiting, or even unconsciousness. In the long term, kidney and liver damage may result, from such absorption (Chemical Safety in the Workplace, 2001).

In addition, solvents are, generally expensive, hence, their consumption should be reduced. To reduce the
amount of solvent, used, it can be: recovered, reused, or on-site-recycled. Recover solvent, from shop-towels/rags, for reuse or recycling, can be done, by using gravity-draining, through false-bottom-containers, or by hand-wringing. On-the-other-hand, most on-site-recycling, of solvent, is done with a distillation-unit called a-still. Used-solvent is put in the-still and heated, to the-boiling-point. The-solvent-vapor is then cooled, producing nearly-pure-solvent. There are also recycling-units, which filter the-used-solvent. The-author was informed, that off-site recycling-facilities are not available, in-Kenya. Reusing-Solvent can be done by using the dirty-solvent as a first-rinse, for dirty-equipment; settle-out the-solids in-used-solvent, by simply putting the-used-solvent, in a-container, and leave-it, undisturbed, until the-solids settle-out. Siphon-off the-liquid-solvent with a-drum-pump. Eventually, however, the-solvent may be too-dirty, to reuse; in-such a-case, it should be recycled; disposing of used-solvent, however, should be a-very-last-resort.

Solvents are now available, that are ‘more’ environmentally-sensitive, than the-traditional petroleum-based-solvents. Companies are beginning to market biochemical-cleaning-solutions, inks, and additives, to-replace current-solvents (for-example: terpene-d-limonene (derived from citrus-fruit), coconut-oil, soybeans, seaweed, and fatty-amides)(O Eco-textiles, 2012).

In-this-regard, the-study recommended, that the-purchasing-department should-ask their-supplier(s) if non-hazardous-solvents are available, and if so, they should choose, for purchase, the-least-toxic-solvent, that will do the-job, and also the-one with the-lowest VOC-content-possible.

On-the-other-hand, some of the-chemicals, used, in-printing-operations, will remain-affixed to-the-fabric, the-rest will manifest in hazardous-emissions to air, to water, and as solid-waste. In-addition, the-intrinsic-nature of some-chemicals makes them to be-highly-flammable and, even, explosive. The-next-sections, hence, discussed these-issues.

4.7. Volatile-organic-compounds (VOCs) and hazardous-air-pollutants (HAPs); and their-control

According to MDNR (2004), many-inks and cleaning-solvents, used in the-printing-industry, contain chemicals, referred-to-as Volatile-organic-compounds (VOCs), and/or hazardous-air-pollutants (HAPs). VOCs are chemicals, which evaporate into-the-air, and then react-with-sunlight, to-form urban-ozone (photochemical-smog). Smog has serious-health-effects on the-human-respiratory-system, such-as: coughing, headaches, nausea, and permanent-lung-damage. HAPs are chemicals, that-are-believed to-cause-cancer, and in-addition, birth-defects, nerve-disorders, and other-chronic and acute-diseases. Many VOCs are also HAPs.

VOC-emissions, to-air, constitute approximately 98 to 99% of all-toxic-releases, in the-printing-industry (KEMI, 2014). The-most-significant-sources of VOCs-emissions, in-printing-activities, result from evaporation of the-fountain (e.g., isopropyl-alcohol and ethanol) and cleaning (e.g., organic-solvents), that are used in-fabric-printing. EPA (2003), for-example, has-determined, that textile-coating and finishing-operations, are a-source of hazardous-air-pollutants (HAPs); the-principal source of which is the-use of solvents.

Other-sources of VOCs include: lacquering, with solvent-based-lacquers; binding; coating; and drying-operations; as-well-as ink-storage, and mixing; and press-proofing. VOCs (alcohols) may-also be emitted, during the-screen-cleaning-operation, in-screen-printing, and from the-developing, and drying-operation, during cylinder-etching, in-gravure (KEMI, 2014). Besides, when rotary-screens are made, or repaired, at the-printing-workshops, volatile-solvent-based-adesives and varnishes can-create solvent-vapor-hazards. If epoxy-adesive is used, to-secure rotary-screens, to-their-end-rings, there is a-risk of skin-contact, until the-adesive is completely-cured (Chemical-Safety in-the-Workplace, 2001). According to World Bank Group (2007), solvent-vapors may-contain toxic-compounds, such-as: acetaldehyde, chlorofluorocarbons, dichlorobenzene, ethyl-acetate, methyl-naphthalene, and chloro-toluene, among-others. Other-substances, with significant-air-emission-potential are used in-printing-processes, including: ammonia, formaldehyde, methanols, and other-alcohols, esters, aliphatic-hydrocarbons, and several-monomers, among-others.

Moreover OSH (2003) identified, that Volatile-Organic-Compounds (VOCs) can-contain traces of decane (which is carcinogenic), 1, 1, 1-trichloroethane (can-cause skin-irritation), iso-octane, toluene (can-cause fatigue, drowsiness, throat, and eye-irritation), xylene (can-cause kidney-failure and menstrual-disorder), and benzene (carcinogenic, and potential-teratogenic). Besides, screen-printing-inks, containing ketones, or aromatic-hydrocarbons, can affect liver, kidneys, central-nervous-system, and can-lead-to cardiac-arrhythmia.

Furthermore, EPS (1997) provided some-specific-examples, of petroleum-derived-substances, released into-the-environment, by textile-printing-industry, with their-potential-effects on human-health and environment, as-follows: (1) Toluene, primarily-used, as a-solvent, is also-used, throughout-printing, for cleanup-purposes. It contributes to the-formation of ozone, in-the-atmosphere; studies have shown, that unborn-animals were harmed, when high-levels of toluene were-inhaled, by their-mothers; (2) Ethylene-glycol mono-n-butyl-ether was used to-represent all-glycol-ethers, because it is the-most commonly-used glycol-ether, in-printing. It-can-leach into-ground-water, and react with photo-chemically-produced hydroxyl-radicals. For-humans, even-moderate-exposure may-cause central nervous-system-depression, including: headaches, drowsiness, weakness, slurred-speech, stuttering, staggering, tremors, blurred-vision, and personality-changes. These-symptoms are misleading,
and hence, a-worker, in-the-absence of an-accurate-occupational-history, may-be-wrongly-diagnosed with schizophrenia or narcolepsy; and (3) Methyl-ethyl-ketone contributes to the-formation of air-pollutants, in the-lower-atmosphere; breathing ‘moderate-amounts’ for short-periods of time, can-cause adverse-effects on the-nervous-system, ranging from headaches, dizziness, nausea, and numbness, in the-fingers and toes, to unconsciousness; repeated-exposure to-moderate to-high-amounts, may-cause severe-damage of liver and kidney.

The-evaporation and inhalation, of VOCs of potentially-hazardous-chemicals, during, printing, can-be at any-processing-stage, where alcohols, or solvents, evaporate into-the-work-environment (examples are shown as red-arrows, in Figure 3). Highly-volatile-solvent-vapors are released, during printing, and will-be-present, throughout the-printing-production-area. Also, the-fabric will-continue to-off-gas-solvents, after the-material has-been-printed, especially if it has-been-rolled-up.

Although some-mineral-spirits evaporate, in the-early-stages, of the-printing-process, the-majority of emissions, to the-atmosphere, is, actually, from the-printed-fabric drying-process, which drives-off volatile-compounds (shown as a-grey-arrow, in Figure 3, coming-out from the-drying-chamber-stack, through the-vent to-the-Atmosphere).

Figure 3: VOCs-emissions in printing

Depending of the-run, the-air-emissions-level can be substantial; for-example, OhI & Wegman (1978), identified, that Ethylene-glycol-monomethyl-ether, Mono-chlorobenzene, Phenol, Pigments, Dyes, Monochlorobenzene, during-use, of a-printing-paste, in a-textile-printing-plant, in Massachusetts, U.S.A., the-average airborne-level of monochlorobenzene, originating from cleaning-agents, was reported as 15.0 ppm (69 mg/m$^3$), which is higher, than the-relevant-standard.

4.8. Control-methods
4.8.1. Engineering and Administrative Approaches
Engineering and Administrative-control-measures are the-two main-preventive-approaches, used to-control hazards.

Engineering-controls are physical-in-nature, including mechanical-devices, or processes, that eliminate, or minimize the-generation of chemicals, suppress, or contain-chemicals, or limit the-area of contamination, in the-event of spills and leaks (Safe-Work Australia, 2012). Engineering-controls include: (1) Substitution--replacing a-hazardous chemical, process, or piece of equipment, with a-less-hazardous-one; (2) Isolation--using an-enclosure, a-barrier, or distance, to-separate workers, from hazards(see Starovoytova, 2017c); and (3) Ventilation--mixing fresh-air, with contaminated-air, in a-work-area, or preventing release of airborne-hazards, by removing them, at-the-source.

The-primary-consideration is to-adopt appropriate-preventive-measures, in-order-to-directly-remove the-hazards, at source, via elimination or substitution. If such-measures are not feasible, segregation of the-chemicals, or the-processes, or other-control-measures should-be taken. The-use of personal-protective equipment should only be considered a-supplementary-means, or as the-last-resort, to-minimize workers’ exposure to-the-
Substitution is the replacement of a-hazardous-chemical, with a-chemical, that is less-hazardous and presents lower -risks, for-example, by: substituting a-less-volatile-material, to-control a-vapor-hazard may-cost-less, than the-installation and maintenance of a mechanical-ventilation-system; substituting a-highly-flammable-liquid with one that is less-flammable, or combustible; using hazardous-chemicals with a-single-hazard-class, rather than those with multiple-hazards; substituting high-hazard-chemicals, like: carcinogens, mutagen, reproductive-toxicants, and sensitizers, with less-hazardous-chemicals; using diluted-acids and alkalis, rather than concentrates; and using a-product, in either-paste, or pellet-form, rather than as dust or powder (Safe-Work Australia, 2012).

Substitution/replacement, in-particular, in-this-study, can-be-used, to-do any of the-following--Substitute a-hazardous: (1) Chemical, such-as, for-example: lead-based-pigment, with a-less-hazardous-chemical, such-as a-non-toxic, or less-toxic, pigment; (2) Process, such-as solvent-based-cleaning, with a-less-hazardous-process, such-as steam-cleaning; and (3) Piece of equipment/tool, such-as a-broom (which can create a-dust-hazard), with a-more-efficient(in dust removal) piece of equipment, such-as a-wet-vacuum-cleaner.

Isolation involves separating people, from the-chemicals, or hazards, by distance or barriers, to-prevent, or minimize exposure. Examples of isolation include: Isolate workers, from chemicals; use of closed-systems, such-as those used during the processing and transfer of flammable-liquids, in petroleum-refineries; or the-use of glove- boxes or glove-bags; placing a-process, or a-part of it, within an-enclosure, which may also-be-fitted-with exhaust- extraction, to-remove contaminants; isolating operations, in one-room, with access restricted to-properly-protected- personnel; placing operators in a-positive-pressure-cabin, that prevents airborne-contaminants entering; distancing workers from hazardous-chemicals, and any-potential-hazards, generated by their-use (Safe-Work Australia, 2012).

Administrative-control-measures, on-the-other-hand, aim to-limit worker’s time, spent close-to the-hazard, hence, reducing their-exposure; via for-example: implementation of safe-work-practices, scheduling of frequent-breaks, or rotating-shifts, among-others (OSH, 2004).

Administrative-control-measures include: (1) Reducing the-number of workers, exposed to the-chemical (for-example, by restricting worker-access to certain-areas); (2) Reducing quantities of hazardous-chemicals, through inventory-reduction (e.g., by ‘just in time’ ordering, rather than storing large-quantities of hazardous-chemicals, and timely-disposal, of hazardous-chemicals, which are expired, or no longer required; (3) Cleaning-up spills immediately; (4) Providing washing-facilities, for rinsing-off chemicals (e.g., hand-washing, eye-washing, safety-showers, laundering of clothes).

4.8.2. Specific-controls of VOC
To-reduce exposure to VOCs, KEMI (2014) proposed selection of materials, or processes, with no, or low-demand-for VOC-containing-products, for-example: (1) Reduction in the-use of solvents, containing benzene, toluene, and other-aromatic-hydrocarbons, as-well-as acetic-acid; (2) Use of water-based-inks, and vegetable-oil-based-inks (e.g., soy, linseed, canola), and ultraviolet (UV)-curable-inks; (3) Use of fountain-solutions / cleaning-solutions, with low-volatility-components (e.g., with benzene-content less than 0.1%, toluene, and xylene less than 1%) or vegetable-oil-based cleaning-agents, as-substitutes for organic-solvents, reducing, or replacing, isopropyl-alcohol; (4) Use of cleaning-agents, based on soap, or detergent-solutions, and vegetable-oils, esterified with-alcohol, for solvent-free-cleaning-operations, wherever possible; (5) Use of press-cleaning-solvents, with minimum-flash-points of 55°C (e.g., low-volatility hydrocarbon-mixtures, non-VOC-citrus, vegetable-oils and their-esters); (6) Replacement of dichloromethane (methylene-chloride) for the-removal of dried-ink; (7) Use of water-based and UV-curing-lacquers; (8) Substitution of solvent-based-adhesives, with adhesives, with a-lower-solvent content, UV-drying-systems, or water-based-adhesives, or thermo-foiling; (9) Implementation of waterless-offset-printing; (10) Reduction of the-etching-depth of the-plate, in rotogravure (e.g., thermal-laser-direct-imaging, instead of diamond-stylus, or chemically-etching, with ferric-chloride), when items can-be-printed with soy/vegetable-based-ink; and (11) Use of dry-ice-blasting-processes, for cleaning.

In-addition, they recommended avoiding, or minimizing, VOC-losses, through process-modifications, and solvent-vapor-recovery, including: (1) Adoption of automatic-wash-up-systems and automatic-blanket wash-systems; (2) Implementation of solvent-recovery and recycling-systems, including in-line-filters, for fountain-solutions, and distillation-units, for solvents; and (3) Quality-control of storage-containers and drums, containing volatile-materials (e.g., inks, paints, and solvent-laden-cleaning-rags), ensuring that they are kept-closed, and segregated in a-ventilated-room/area (KEMI, 2014).
Also, implementation of secondary-controls, was recommended, as-necessary, to-address residual-emissions, including: (1) Activated-carbon-adsorbers (not suitable for ketone-based-inks); (2) Use of heat-set afterburners / recuperative / regenerative-thermal-oxidizers (compatible with most-inks, for rotogravure and flexography, but energy-intensive); (3) Use of catalytic/regenerative-catalytic-oxidizers (suitable for facilities, dedicated to long-term-production, for specific-items, but not suitable, for certain-inks, with chlorinated-solvent-additives); (4) Incineration of exhaust-gases, if using solvent-based-lacquers; (5) Developing and implementing a-solvent-management-plan, that includes procedures, for reduction in-the-use of solvents, via: (a) Verification of compliance with emission-limits, providing a-quantification of the-solvent-emissions, from all-sources (including solid-wastes, wastewater, and air-emissions); (b) Identification of future-reduction-options, including implementation-schedule; (c) Record-keeping, on annual-solvent-consumption and solvent-emissions. Besides, recovery of VOCs, through vapor-recovery-units, and use of a-fully-closed-loop-system, especially if cleaning with halogenated-organic-solvents cannot be avoided (e.g., for fabrics that are heavily-loaded with silicone-oils); Using appropriate control-technologies (e.g., installation of scrubbers with activated-carbon slurries; installation of activated-carbon-adsorbers; or incineration of extracted-vapors in a-combustion-system) (KEMI, 2014).

World Bank Group (2007) recommended prevention and control-techniques, to-reduce VOC-exposure-hazards, include the-following: (1) Use of hoods and enclosed-equipment; (2) Use of well ventilated-rooms, with a-slight-positive-pressure, for process-control-operators; (3) Use of shift and task-rotation-strategies; (4) Install of extraction and air-recycling-systems, to-remove VOCs, from the-work-area, with use of appropriate-abatement-technologies (e.g., scrubbers, employing activated-carbon absorbers) or routing the-extracted-vapors, to-the-combustion-system; and (5) Use of personal-protective equipment (PPE), such-as respirators, as necessary.

Typical-safe-work-procedures, that reduce the worker’s exposure to VOC-emissions, should-include the-following: (a) ensuring the-time, spent near the-hazard, is kept-to-minimum; (b) keeping containers, of printing-inks and solvents, closed, when not in-use; and (c) avoiding-skin-contact with printing-inks and solvents; (d) simple-personal-hygiene (e.g., washing-hands, before-food, can-reduce the-risk of exposure to-chemicals, via ingestion-route. For-example, vapor-emissions, resulting from transfer, can-be minimized by: the-use of enclosed-transfer-systems, and vapor-recovery-connections; keeping-lids-open, only for the-minimum-period, required for transfer; minimizing exposed-surface-areas; avoidance of splash-filling; minimizing the-temperature of liquids, being transferred; and providing extraction-ventilation, for all-sources of vapor (Safe-Work Australia, 2012).

Additional-steps, to-reduce the-emissions, to-air, include: Decreasing emissions of organic-solvents, by changing to water-based-products; Using scrubbers, to-collect particulate-matter; Pre-screening chemicals, using the-Material-Safety-Data-Sheets, to-ensure that chemicals are not toxic; and Identifying sources of air-pollution, and quantifying-emissions (UNIDO, 2002).

In-particular, gravure-printing cylinder-making may-be sources of emission of some-toxic-compounds, including hexavalent-chromium, hydrochloric-acid, and isocyanates. Recommended-prevention and control-strategies for these-types of emissions, include: (1) Installation of baffle-separators, with aerosol-screens to-limit-emissions of hexavalent-chromium (Cr VI), from chromium-plating-baths; (2) Maintaining hydrochloric-acid-concentrations at 10%, by-volume, in de-chroming-baths, and plugging the-ends of the-cylinders, to-avoid the-interior-exposure to hydrochloric-acid (HCl), thus minimizing HCl-emissions; (3) Avoiding, or minimizing, emissions of isocyanates, generated during the-handling, loading, and mixing-processes, involving coatings, containing isocyanate; the-handling and storage of isocyanate-contaminated-wastes; and printing/coating, and drying-processes, involving coatings, that contain isocyanate; Prevention and control-techniques include: (a) Use of automatic-pumps to-transfer liquid-isocyanates, from drums/storage-containers, to-process-containers; (b) Selection and use of isocyanates, containing less-volatile, isocyanates; and (c) Use of enclosed-mixing and storage-containers (KEMI, 2014).

Furthermore, to-avoid, or reduce, fugitive-air-emissions, from chemical-spills, the-study recommended improved-work-practices, via good-housekeeping-practices. The-goal of good-housekeeping is to-contain and remove hazards, and requires the-following: Proper-storage and handling; Proper clean-up-procedures; and Prompt-removal and correct-disposal of chemical-wastes. For-example, storage-areas should-be well-ventilated (with recommended 5 air-changes, per-hour), to-prevent the-accumulation of fumes and vapors (SHS, 2015).

On-the-other-hand, VOCs are the-primary-air-pollutants, for which printers are regulated. Regulated-air-emissions come, primarily, from inks, cleanup-solvents, adhesives, coatings, dyes/pigments, etc. (MDNR, 2004). For-example, The-Environmental-Protection-Agency’s (EPA’s) Office of Air-Quality-Planning and Standards (OAQPS) has-developed a-National-Emission-Standard for Hazardous-Air-Pollutants (NESHAP) under Section 112 of the-Clean-Air-Act (CAA) Amendments, of 1990, to-limit air-emissions, from the-production of coated, printed, dyed, slashed, or finished-fabrics.

Furthermore, Health and Safety Executive (2005); and Enroth (2001), stated, that Occupational-health and safety-performance should-be-evaluated, against internationally-published-exposure-guidelines, including: the-Threshold-Limit-

Figure 3 also-shows, that some-fugitive-VOC-emissions, were-released to-wastewater. A-closer-look at wastewater, from printing-operations was, therefore, presented in the-next-section.

4.9. Wastewater/ printing-effluent, and control of water-pollution.

Compounds, which contribute to the-aquatic-toxicity, of textile-printing-effluent include: salts; metals (incorporating heavy-metals); surfactants; toxic-organic-chemicals; biocides; toxic-anions (UNIDO, 2002), as-well-as suspended-solids, solvents, and foam (UNEP, 1996). In-addition, high-concentrations of certain-chemicals can-disrupt the-pH-balance, at the-treatment-plant, and disrupt the-bacterial-systems, essential to the-sewage-treatment-process; moreover, combinations of mixtures with low-flash-points can-cause flammability-concerns, in the-sewage-system (UNIDO, 2002). Additional serious-problems arise, in-printing with-reactive-dyes, where large-quantities of urea, is used to-swell cellulosic-fibres, bringing-about disaggregation of the-dyes, an-increased-solubility of dyes, retarded-evaporation of water, during-drying, and increased-condensation of water, on-prints, during steaming (The-Textile-Industry, 2000; UN, 1996).

Washing of fabric, after printing, also results in colored-effluents, which carry unfixed-printing-paste and its-ingredients. For-example, for cotton, percentage of unfixed-dyes (released, into-wastewater) is 5-10% (for azoic-dyes) and is as-high-as 20-50% (for reactive-dyes) (Babu et al., 2007). Besides, printing-blankets or back-grays (fabric-backing-material, that absorbs excess-print-paste), which are washed with water, before drying, may-generate wastewater with an-oily-appearance, and significant VOC-levels, from the-solvents, used in-printing-pastes (World Bank Group, 2007). Considerable-levels of PCDD/Fs have-also-been determined, in some-phtalocyanine-dyes, and in-printing-inks (Krizanec et al., 2006). The-most-toxic, among persistent-organic-pollutants (POPs), are polychlorinated-dibenzo-p-dioxins and furans (PCDD/Fs), often simply-termed as ‘dioxins’ (Marechal & Krizanec, 2012). Some of the-difficult-to-treat printing-wastes include: color-residues, phosphate, nitrogen-containing-chemicals, and non-biodegradable-materials, such-as solvents and surfactants. These-substances can resist effluent treatment, and hence, cause environmental-problems, on-discharge.

In-particular, liquid-waste from the-printing-operations may-include: ink-residues (containing zinc, chromium, silver, mercury, barium, lead, manganese, benzene, dibutyl /ethyl-acetates, etc.); waste, from fountain and cleaning-solutions (e.g., spent-organic-solvents, including trichloroethane, methylene-chloride, carbon-tetrachloride, acetone, methanol); and other-solvents, and container-residues (e.g., toluene, xylene, glycol-ethers, Methyl-ethyl-ketone, and ethanol). Besides, water-based-inks may-contain biocides and photo-initiators. Acid-plate-etching-chemicals, used in-gravure, may contain nitric-acid, perchloroethylene, and butanol. In-addition, copper and chromium-compounds, as-well-as ethylene-glycol, glycol-ethers, and methanol, may-be found, in these-operations. The-rinsing-water, from developing-stencils, in screen-printing, contains reactive-acrylates, is toxic to-aquatic-life, and may-cause nitrification-effects. Rinsing-water, used during cylinder-making in gravure-printing, may-contain copper, chromium, and nickel, and is acidic. Rinsing-water, generated during the-development of the-light-sensitive plate-coating, may contain limited-quantities of de-coating-agents, with a-chemical-oxygen-demand (COD) of approximately 300 mg/l (Krizanec et al., 2006).

In-addition, Marechal & Krizanec (2012) compiled the-summary of main-pollutants, of-wastewater (in-their-study) after the-printing-process (see Table 2).
Table 2: Main-pollutants, in-wastewater, after the-printing-process (Marechal & Krizanec, 2012).

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic dyestuff</td>
<td>Non-fixed dye</td>
</tr>
<tr>
<td>Urea</td>
<td>Hydrotrropic agent</td>
</tr>
<tr>
<td>Ammonia</td>
<td>In pigment printing pastes</td>
</tr>
<tr>
<td>Sulphates and sulphites</td>
<td>Reducing agents by-products</td>
</tr>
<tr>
<td>Polysaccharides</td>
<td>Thickeners</td>
</tr>
<tr>
<td>CMC derivates</td>
<td>Thickeners</td>
</tr>
<tr>
<td>Polyacrylates</td>
<td>Thickeners</td>
</tr>
<tr>
<td>Glycerin and polyls</td>
<td>Anti-freeze additives in dye formulation</td>
</tr>
<tr>
<td>m-nitrobenzene sulphonate and its</td>
<td>Solubilising agents in printing pastes</td>
</tr>
<tr>
<td>corresponding amino derivative</td>
<td>In discharge printing of vat dyes as oxidising agent</td>
</tr>
<tr>
<td></td>
<td>Direct printing with reactive dyes inhibits the chemical reduction of the dyes</td>
</tr>
<tr>
<td>Polyvinyl alcohol</td>
<td>Blanket adhesive</td>
</tr>
<tr>
<td>Multiple substituted aromatic amines</td>
<td>Reductive cleavage of azo dyestuff in discharge printing</td>
</tr>
<tr>
<td>Mineral oils/aliphatic hydrocarbons</td>
<td>Printing-paste thickeners (half-emulsion pigment printing pastes occasionally)</td>
</tr>
</tbody>
</table>

The majority of chemicals, applied to the fabric, are washed-off, and thrown to drain. Therefore, reducing chemical-consumption can lead to a reduction in effluent-strength and, hence, lower-treatment costs, as well as overall-savings in chemical-costs. Various options, for reducing chemical-use are listed, as follows: (1) Reduce metal-content, through careful-pre-screening of chemicals and dyes, for metal-content, and using more environmentally-friendly alternatives, where possible; (2) Eliminate galvanized-plumbing, as reactions with brass fittings can take place in the presence of acids, alkalis, or salts, and lead to the release of zinc; (3) Use biodegradable surfactants, such as linear alcohol ethoxylates; and (4) Replace chlorinated solvents with unchlorinated alternatives (UNIDO, 2002).

Two approaches, to eliminate, or replace urea, in colored effluents, have been suggested: (1) adoption of two-phase flash-printing (World Bank Group, 2007); complete, or partial-substitution of urea, with an alternative-chemical Metaxyl FN-T; and (2) the mechanical application of moisture, to printed-fabric, prior to entering the steamer (The Textile Industry, 2000; UN, 1996). In addition, Barclay & Buckley (2000), proposed large-scale investigations on alternatives to urea, as this increases the nitrogen in the effluent.

On the other hand, several authors have reported the adverse health impacts of textile effluents (see Hiremath et al., 2014; Starovoytova & Odido, 2014; Starovoytova, 2012; Samiya et al., 2007; and Muezzino, 1998). Textile effluent is also a cause of significant amounts of environmental degradation and human illnesses, e.g., about 40% of globally-used colorants contain organically-bound chlorine (a known carcinogen) (Advanced Environmental Technologies, 2011).

Recommended wastewater prevention strategies should consist of: (1) the substitution of potentially hazardous compounds, and the reduction, in volume of wastewater, requiring treatment; (2) Reducing the use of chromium, lead, and barium, in the pigments; and (3) Use alternative coatings (e.g., electrostatic/powder coatings, toxic free alternative paints). If chromium application is required, drag out recovery and reduction, or evaporation, or reverse osmosis technologies, should be used (The Textile Industry, 2000)

In addition, Barclay & Buckley (2000), proposed water conservation approaches, such as: reusing water, from washing the printing blanket; and turning off wash water, when machine is not running. World Bank Group (2007), also recommended use reusing rinsing water left over, from cleaning the printing belt. In addition, Textile waste minimization (2009) proposed to reduce water consumption, in cleaning operations, of printing equipments (e.g., by start/stop control of cleaning of the printing belt, reusing the cleanest part of the rinsing water, from the squeegees, and screens).

Lastly, utilizing ‘Change of technology’ CP approach, a conceptually innovative and relatively new development (Air Dyeing Technology) could be one of the promising solutions, to heavily polluted effluent. According to Kant (2012), air is used, instead of water, in this process, to color textiles. In addition, the process emits 84% less Green House Gases (GHG); and requires 87% less energy. The process is already being adopted by a number of leading textile industries.

Printing-processes, normally, result-in unused (leftover)-inks, spent-solvents, and other-chemicals, applied in the-industry. Some of them could-be hazardous-substances (as discussed in-the-previous-sections), and hence, on disposal, these-substances could become hazardous-waste.

To-be-considered hazardous-waste, however, a-material, first, must be classified as a-solid-waste. EPA defines Solid-waste as: ‘garbage, refuse, sludge, or other-discarded-material (including solids, semisolids, liquids, and contained-gaseous-materials)’. If the-subject-waste is considered solid-waste, one must, then, determine, if it-is hazardous-waste. Wastes are defined as-hazardous, by EPA, if they are specifically named-so, as one of four-lists of hazardous-wastes (listed-wastes), or if they-exhibit one of four-characteristics (characteristic-wastes).

There are 4 different-types of listed-wastes; designated as: (1) The-F-list; (2) The-K-list; (3) The-P-list; and (4) The-U-list. Wastes, on the-P-list are called ‘acute-hazardous’ and are regulated more-stringently, than the-other-types. Moreover, if one mixes any-waste with a-waste, which is on the F, P, K or U list, all of it is considered as hazardous, even if there is only a-very-small-amount of listed-hazardous-waste, in the-mixture.

Characteristic Wastes exhibit one, or more, of the-following-characteristics (EPA, 1998): (1) Ignitability: Ignitable-wastes (e.g., solvents) create fires, under certain-conditions, or are spontaneously-combustible, and have a-flash-point less than 60 °C (140 °F); or solids that catch-fire, easily, and burn so-rapidly, they create a hazard; (2) Corrosivity: A-waste with a-pH less-than, or equal-to, 2.0, or greater, than or equal to 12.5 (e.g., haze-removers), are acids, or bases, that are capable of corroding metal-containers, such-as storage-tanks, drums, and barrels; (3) Reactivity: Reactive-wastes are normally-unstable, react-violently with-water, can-explode, or release poisonous/toxic-gases, fumes, or vapors, when-mixed with-water; and (4) Toxicity: Toxic-wastes (e.g., trichloro-ethylene, in-printing) are harmful, or fatal, when ingested, or absorbed. These-wastes are of defined-concentrations of certain-organic-chemicals, heavy-metals, or pesticides, when tested by the-toxicity-characteristic leaching-procedure (TCLP). When toxic-wastes are disposed-of, on land, contaminated-liquid may drain (leach), from the-waste and pollute ground-water. Toxicity is defined through a-laboratory-procedure, called the-Toxicity-Characteristic-Leaching-Procedur.

The-main-areas of waste-minimization, in-printing, include: raw-material-conservation; product-substitution; process and equipment-modifications; and waste-recovery. Other-options include: Waste-minimization, in-the-design-stages, can eliminate the-need for dyes, containing-metals; Careful-selection of surfactants; Reducing air-emissions, by replacing-solvents with water-based alternatives; Routine and carefulmaintenance of printing- equipment; Training employees, in the-practices of good-housekeeping; Installing automated-color-kitchens; Reusing-left-over printing-paste; Removing-excess-paste, from drums, screens, and pipes, by dry techniques (wiping with a-squeegee etc.) before washing-with water. This reduces the-color-load, discharged to drain; Careful-scheduling, to prevent-expiration of printing-pastes, before use; and replacing conventional-printing-paste with less-harmful-compounds, based on poly-acrylic-acid or poly-ethylene-glycol (Barclay & Buckley, 2000). Besides, shop-towels/rags, contaminated with listed-hazardous-waste, are hazardous-waste; hence they must be managed as hazardous-waste. In-addition, worn-out-screens, and leftover-printing-pastes, could-be hazardous, hence, they cannot be discharged into sewer-line; instead they must be disposed of as a-hazardous-waste (see UN (2012)).

Other-options include: minimizing the-volume of paste-supply-system (e.g., diameters of pipes and squeegees), has major-effects in reducing printing-ink-losses, in rotary-screen-printing (Textile-waste minimization, 2009); EPA-RCRA Hazardous-Waste-Resources proposed to-recycle inks, to-make black-ink. Reformulated-black-ink is comparable to-lower-quality new-black-inks; Dispose of inks, should be by sendingthem to a-fuel-blending-service, that combines these and other-wastes, for burning, at-industrial-boilers or kilns; and transport waste, using a-registered hazardous-waste-transporter, to a-hazardous-waste-treatment-facility. Moreover, potential Pollution-Prevention-Methods include: Dedicated printing-machines to-specific-colors, or special-type of inks, to-decrease the-number of cleanings, required for each-press; Print lighter-colors, first; Squeegee, or wipe-surfaces, clean, before washing, with-solvent; Clean ink-fountains only when-changing-colors, or when there-is a-risk of ink-drying; Isolate inks, contaminated with hazardous-cleanup-solvents, from non-contaminated inks; Use organic-solvent-alternatives wherever-possible, such-as detergent, or soap, nonhazardous-blanket-washes, and less-toxic acetic-acid solvents. Besides, pigments, containing lead, chromium, silver, cadmium, and barium, may-be hazardous-wastes, depending on the-amount of heavy-metals, in the-ink, hence, the-study recommended to-the-management of the-department, to-inquire from their-supplier(s), on nonhazardous substances, to-purchase; and Transporting hazardous-waste, should be by using a-registered hazardous-waste transporter, to a-hazardous-waste-treatment-facility; e.g., most-solvents will-be recycled, or incinerated, there (UN, 2012).

In-addition, the-study recommended to-recover solvent, from shop-towels/rags, for reuse or recycling, by using gravity-draining, through false-bottom-containers, or hand-wringing.
4.11. Reclamation/stripping of screens

Irrespective of the type of inks-used, all printers attempt to reclaim/strip screens, due to the high-cost of the new rotary-nickel-screens. The screen can be stripped (reused) only few times, as each chemical-stripping-process, the screen will be damaged, by the strong-acid, in the stripper. Failure to reclaim screens and ‘ruined’-screens, cost, on-average USD 5,000-10,000, per-year (Ukena, 2005). The process of reclaiming-screens generates solvent-waste and wastewater. Solvent-waste generated from screen-cleaning, and wastewater (containing particulates, comprised of ink-pigment, emulsion, and emulsion-remover) is generated, through the process of emulsion-removal.

Reclaiming screens involves the following-steps: (1) paste removal: All excess-paste, in-the-screen, should be ‘carded-off’ or reused, on another-job. The screen should, then, be-washed, to remove any remaining-paste, because the paste will interfere-with the process of removing the stencil. Screen-cleaning-solvents are a source of VOC-emissions; (2) emulsion removal: The stencil, or emulsion, is removed, by spraying the screen with a solution of water and emulsion-remover-chemicals, which is comprised, mainly, of sodium-metaphosphate, and then, rinsing the solution-away, with fresh-water; and (3) haze or ghost-image removal: Finally, if any haze or ‘ghost-image’ remains, a haze-remover must be applied. Ghost-image is a shadow of the original-image, which remains on the screen, caused by paste, or stencil, caught in the threads of the screen. Some haze-remover products are caustic, and can damage, or weaken, the screen. Haze-removers make screens brittle and tear-easily; therefore, only small amounts should be used (Ukena, 2005).

The mixture of toxic-chemicals, like Methylene-Chloride, Dichloromethane-Chloride, Formic-Acid, and Phenol, is commonly used, for stripping. These chemicals are extremely dangerous, and prolonged-exposure, via inhalation, or skin-contact, is known to cause adverse effect on the health of textile-printing-workers, in Kenya; In Europe, these chemicals are restricted.

The study proposed an innovative technique, which was introduced, by CST, Germany, in 1999; The NovaJet-machine uses high-water-pressure, about 3000 Bars, to clean the screens. With special nozzles, it is possible to strip the screen, without damaging the nickel-surface. According to BSI (their-local-representative, in Pakistan), this is the only pollution-free machine, for stripping-screens. Additionally, it also consumes very low amount of water, due to closed-filter-system. Water-stripping is not only cost-effective, but it is also the safest procedure for stripping the nickel-screens, without any danger to human health (BSI International).

4.12. Printing paste

World Bank Group (2007), recommended pollution-prevention and control-techniques, including the following: Reduce printing-paste-losses, in-rotary-screen-printing, by minimizing the volume of printing-paste supply, and by recovering and recycling printing paste, at the end of each run; Use transfer-printing for synthetic-fabrics and digital ink-jet printing-machines to produce short runs of fabrics; and Use printing pastes with no or low VOC-emissions (e.g., water-based, APEO-free, and reduced ammonia-content printing pastes). Besides, binders, made of natural wood resin, wax-stand-linseed, or safflower-oils, and chitosan, were tested in order to obtain biodegradable printing paste; promising results were reported, when using chitosan, as a binder, and no solvent was necessary. In addition, since between 5 and 10 different printing pastes are usually required, to print a single pattern (in some cases up to 20 different pastes are applied); in order to reduce losses, due to incorrect measurement, it is recommended the preparation of the pastes is done in automatic stations (see Starovoytova, 2017a), where the exact amount of printing paste required is determined, and prepared, in continuous mode, for each printing position, thus, reducing printing paste waste, at the end of the run.

Besides, due to safety and health concerns, as well as environmental considerations, petroleum-based printing inks are now replaced (in many textile printing processes) by safer UV light or electron-beam curable inks, vegetable-based inks (including soy oil based inks), or aqueous based inks. However, as UV curable materials commonly contain methacrylates, or polyfunctional acrylates, which can cause skin irritation, or sensitization, special care, hence, should be exercised, in using these chemicals.

On the other hand, the rotary screen printing machine, at the department, is equipped with a conventional paste feeding system. A suction pipe leads from the paste vat to a pump, from where a printing hose leads to the squeegee. From here the paste is directed inside the cylinder roller.

Waste ink may contain: chromium, barium, and lead content; and might be contaminated with cleaning solvents, such as: trichloroethylene; methylene chloride; 1, 1, 1-trichloroethylene; carbon tetrachloride; 1, 1, 2-trichloroethane; 1, 2, 3-trifluoroethane; chlorobenzene; xylene; acetone; methanol; methyl ethyl ketone (MEK); toluene; carbon disulfide, or benzene, among others (EPA, 1998). To reduce waste and to recover printing paste, from supply system, in the rotary screen printing machines, the current study proposed a technique, described by Resitek (2008). This technique allows the recovery of the printing paste, remaining in the supply system, of rotary screen printing machines, at the end of each run. In essence, before filling the system, a ball is inserted, in the squeegee, and then, transported, by the incoming paste, to its end. After finishing a print run, the ball is pressed back, by controlled air pressure, pumping the printing paste, in the supply system, back into the drum.
for re-use. The technique is illustrated in Figure 4, showing the ball, during the phase, in which the pump is transporting the paste, back to the drum.

Another possibility, which has also already been implemented, in some companies, is to recover and re-use these residues, for making up new recipes (Resitex, 2008). In addition, the study recommended to recover, and re-use, residual printing pastes, e.g., by making isolation panels building materials (see Yacooub & Fresner (2006)).

Figure 4: Paste recovery system

4.13. Flammable substances and their control

Fire and explosion hazards may arise from the use of flammable substances, or oxidizing agents, which can intensify a fire, by supplying more oxygen. Flammable substances (e.g., petroleum spirit) are often used for preparation of emulsion thickening, in pigment printing. This incurs significant fire hazards, to the workplace, particularly, when the printed fabrics/articles are subsequently baked, at high temperature.

An indication of the flammability of a liquid is its flash point, which is defined as the lowest temperature, at which the liquid gives off flammable vapor, in air, that can catch fire or explode, if exposed to an ignition source. The greater the volatility, the more readily flammable vapor is produced, and the lower is the flash point. Generally speaking, a liquid having a low boiling point will have a low flash point and vice versa.

Ignition of a flammable liquid can occur only when the concentration of its vapor, in air, is within a certain range, called the explosive range (defined by the lower and upper explosive limits), at temperature, above its flash point. This consideration is important in the design of ventilation, to ensure that the concentration of the contaminant is kept well below its lower explosive limit and no ignition sources are nearby (ILO, 1998).

Besides, exothermic reactions will generate heat, spontaneously, and may, therefore, have the following effects: (1) formation of hazardous gases, vapors, or fumes; (2) increase of pressure, in container, causing explosion; (3) rapid bubbling, causing splashes, of hot hazardous fluids; and (4) increase in reaction rate, generating more heat (ILO, 1998). These effects will be further intensified, if there is no effective means to dissipate the heat, evolved, thus resulting in localized heating, and super heating, in part of the reaction mixture. Moreover, some exothermic reactions may auto accelerate, rendering the reaction rate too fast, to be controlled, and hence, putting the workers at danger.

For example, sodium hydrosulphite, a widely used reducing agent, may spontaneously ignite, when wet. The solvent base of resin coatings, or adhesives, which is intended to be easily vaporized, during the drying process, is usually flammable, e.g., white spirit. In pigment printing, the thickening commonly used is oil in water emulsion, in which over 65% of the constituents is flammable solvent (e.g., white spirit). Subsequent evaporation, in oven, can give rise to significant fire and explosion risks (OSH, 2003). To decrease the risk of explosion, due to the flammable solvent, giving out from printed fabrics, in ovens, adequate explosion relief (such as explosion doors, or lightweight explosion panels) should be provided, where technically feasible.

Besides, when heated, the vapor pressure, of flammable and combustible materials, may increase, resulting in higher vapor emissions. Containers of hazardous chemicals should, therefore, be stored away from sources of heat (for example, heaters, or other heating appliances). Heat may also deteriorate packaging, and increase the risk of failure, of the container (Safe Work Australia, 2012).

Furthermore, appropriate emergency equipment should be provided, including, but not limited to: (a) fire-
alarm; (b) fire-fighting-equipment (e.g., fire-hoses, fire-extinguishers, and fire-blankets); (c) emergency-lights and backup, for fume-extraction, in case of power-failure; (d) emergency-showers and eye-washes; (e) first-aid-facilities, e.g., first-aid-kit; and (f) absorbent-material, for cleanup of minor-chemical-spills.

In-addition, where flammable-substances are used, smoking should be strictly-prohibited and open lights, flames, and sparks eliminated. Electrical-equipment should be of certified-flameproof-construction, and machines should be earthed (grounded), to-prevent the build-up of static-electricity, which might lead to catastrophic-sparks, and consequently, fire.

The next-sections were addressing several-matters, arising from the-results, of this-study.


90.9% of the-respondents, alleged that they have been-exposed to the-organic-dusts, e.g., from raw-cotton and/or cotton-yarns. This-finding is in accord with Sudha & Meenaksi (2014), who pointed-out, that there are numerous-health and safety-issues, associated the-textile-industry, including exposure to: chemicals, cotton-dust, organic-dust, and noise. Several-earlier-studies, such as-for-example, by Elwood et al. (1986); Salnaggio (1986); and Crofton (1981), declared, that a-great-number of textile-workers, managing cotton and flax, suffer from various-respiratory-symptoms and show a-failure in lung-function. Saleema et al., (2008) also discovered, that cotton-textile-workers had an-increased occurrence of both; disruptive and restraining-lung-function.

According to Hinson et al. (2014), cotton-dust is present in-the-air, during the-handling and processing of cotton. This-dust may contain-a mixture of many-substances, including: ground-up plant-matter, fibres, bacteria, fungi, soil, pesticides, non-cotton-matter, and other-contaminants. Occupational-exposure to cotton-dust can cause acute-respiratory-symptoms, such as: chest-tightness, broncho-constriction, and respiratory-diseases (including byssinosis, characterized by difficulty, in breathing and tightness-across-the-chest).

U.S.A. department of labor, occupational-safety and health-organization (OSH, 2003) emphases, that following-measures must be included, in every-factory, to reduce the-dust-level: (1) Cleaning floors with a vacuum-cleaner, or method, that cut-down the-spreading of dust; (2) Disposing of dust-away, with as little-scatters as-possible; (3) Using mechanical-method to stack-dump; and (4) Checking, cleaning, and repairing dust-control-equipment and ventilation-systems. In-addition, employers must provide free-annual medical-check-up, including breathing-test, to affected-workers. If workers show significant physical-change, more-frequent check-up must be available to them. Employers are also-required to conduct a training-program, for employees, at least-annually, to create awareness of the hazards, associated with cotton-dust.

Washing the-cotton appears to eliminate the-biological-activity; regrettably, the-washed-cotton does not process well. Steaming the-cotton, on-the-other-hand, can reduce both; the-dust-level and the-biological-activity, of the-dust, without altering the-quality (Nirmala, 2013), and hence, it is recommended, for consideration, by the mill’s management. Besides, engineering-control-measures, including installation of appropriate-type(s) of ventilation, in order-to eliminate, or reduce, the level of hazardous air-borne-contaminants, VOCs, or flammable-vapors, at the source, should be considered.

In addition, this study, recommended to examine the concern of cotton-dust, expressed by the respondents, more deeply, in a further-research.

4.15. Materials Safety Data Sheets (MSDSs)

81.8% of the respondents, indicated that they have never been introduced to, or referred to the MSDS, to get the information, on toxicity, and proper-handling, of the chemicals, they use.

Typical means of hazard-communication, in a workplace, include: labels, MSDS/SDS/PSDS, standard-operating-procedures, placards, notices, signboards, chemicals-catalogue, chemistry-journals, chemical-handbooks, and reputable-online-databases, among others. Hazard-information can also be communicated via "SOP", which refers to a set of systematic step-by-step written-procedures, to be followed, for completing a process or operation (Chemical-Safety in the-Workplace, 2001). Besides, NIOSH sets recommended-exposure limits (REL's), as well as recommends preventative-measures, on specific-chemicals, in order-to reduce, or eliminate negative-health-effects from-exposure to those chemicals. Additionally, NIOSH keeps an-index of chemical-hazards, based on their-chemical-name, Chemical Abstracts Service-Registry-Number (CAS No.), and RTECS-Number (MDNR, 2004).

Limited, yet, essential-hazard-information, about the-chemical, in use, can be found on the-label, of its original-container, whereas more detailed-safety information can be obtained from the suppliers (chemical manufacturers, importers, or distributors) or the respective-MSDS (UNIDO, 2002).

MSDS, Safety-Data-Sheet (SDS), or Product-Safety-Data-Sheet (PSDS), is an important-component of product stewardship and occupational-safety and health. It is intended to provide workers and emergency-personnel with procedures, for handling, or working with that- substance, in a safe manner (UN, 2012). A MSDS provides important source of information about a specific-chemical, used in the-processing-work, especially when the-chemical is used, for the very-first-time. The information includes safe-handling and storage
of the-chemical, first-aid-procedures, potential-effects of contact, and measures to-take, in the-event of a-spill or leak. ISO 11014-1 recommends a standard-format for the-MSDS, which contains the-following-sections: (1) product and company-identification; (2) Hazards-identification; (3) Composition/information on ingredients; (4) First-aid-measures; (5) Firefighting-measures; (6) Accidental release-measures; (7) Handling and storage; (8) Exposure controls/personal-protection; (9) Physical and chemical-properties; (10) Stability and reactivity; (11) Toxicological-information; (12) Ecological information; (13) Disposal-considerations; (14) Transport-information; (15) Regulatory information; and (16) Other-information, including information on-preparation and revision of the-SDS.

According to UN, GHS (2005), minimum-information, for an-SDS, is the-same, as for MSDSs (above), with one-small-adjustment -- ‘product’ (in-number 1, for MSDSs) is stated as ‘substance or mixture’ (in-number 1, for SDSs).

When faced-up with a-toxic-substance, on the-job, workers should-rely on the-MSDSs, to-inform-them of the-substance’s hazards. In-the-case, where the-workers are not informed on the-very-existence of such an-important safety-resource, such-as MSDSs, or MSDSS are not readily available, to the-workers (as in this-study), the-workers, most-likely, will-be unaware of the-potential dangers, and, hence, will not be taking the-necessary-precautions, exposing themselves, to-hazards and risks, associated with the-chemicals, they handle.

According to Starovoytova & Odido (2014), MSDSs are critical-ingredient, for providing reliable-information on toxicity of chemical-compounds and associated-precautions on handling such-compounds. Accurate and full-disclosure of toxic-ingredients is an-important-step towards improving health-outcomes, for workers, in the-industry. Accurate-public-disclosure is a-foundation; particularly in the-area of chemical-substances-management, to-create political and economic-incentives, for industry-change, towards healthier and ‘Green’ manufacturing.

MSDSs, sole-purpose is to-protect workers and provide them with the-proper-procedures, for handling or working-with particular-substances, and should, therefore, be-supplied, for each-individual-substance. When a-substance is bought, the-manufacturer, or the-supplier, should-provide the-purchaser (the-textile-factory) with the-MSDS for it. The-MSDSs should be-received, by the-factory; the-very-first-time substances are delivered. They should-be available in the-manager’s office, the-store-room, or an-appropriate-place, where people can have easy-access, to-them, when needed.

Having readily-available-information, on the-hazardous-properties of chemicals, and recommended-control-measures, allows the-production, transport, use, and disposal of chemicals, to-be managed-safely. Consequently, human-health, and the-environment, is protected. Supervisors and workers, should arm-themselves, with up-to-date-information, on the-chemicals, they handle. They should not, however, worry, that they might not pronounce, long-name of a-chemical, correctly; there is a-CAS # (Chemical-Abstracts-Service-Number), that can-be-used, to-look-up the-chemical, and its-possible health-effects. Another-helpful-resource, to-see if the-chemical used, is one of the-most-harmful, which needs to-be-substituted, is “Substitute It Now (SIN) list” at www.sinlist.org.

On-the-other-hand, a-MSDS is product-related and, usually, is not able to-provide information, that is specific, for any-given-workplace, where the-product may-be-used. However, the-MSDS-information enables the-employer to-develop an-active-program of worker-protection-measures, including training, which is specific, to the-individual-workplace, and to-consider any-measures, that may-be-necessary to-protect the-environment.

Besides, all-people, at the-workplace, including those who-may not be directly-involved in using, handling, storing, or generating a-hazardous chemical, should-be considered, for-training, such-as: ancillary or support/services workers (as cleaners, maintenance, and laboratory-staff, are often-exposed to-both; the-hazardous-chemicals they use, in the-course of their-work, such-as cleaning-products, and the-hazardous-chemicals, used in the-workplace, by other-workers), supervisors, managers, contractors, and visitors, among-others.

4.16. PPE
Greater-part (72.7%), of the-respondents, also-reported that some-workers did not used personal-protective equipment, such-as: gloves, goggles, face-shields, or respirators, even, if this-was-provided; the-next-section elaborated on the-issue.

The-main-purpose of using PPE, is to-protect workers against the-risks of hazardous-substances entering their-body, via inhalation, ingestion, or skin-contact. PPE, however, should only supplement, and not replace, the-preventive-control-measures. Appropriate-PPE should be selected, based on physical-nature of the-hazards, and the-routes of entry of the-chemicals, into the-human-body (Chemical-Safety in-the-Workplace, 2001).

PPE should be not only properly-selected, but also, properly-used, and properly-maintained. They should-be inspected, for any-signs of damage, before and after, each-use. PPE should be regularly-cleaned, stored, and kept, in-good-condition. Contaminated-PPE should be appropriately-treated, or disposed, and replacement PPE-sets (in various-sizes) kept readily-available. Wrongly-selected, improperly-used, or maintained, PPE may, in-
fact, do more-harm, than providing expected-level of protection. For-example, a-user may have a-false-sense of security, and hence, is subjected to a-higher-risk of MSDSs or MSIs.

There are many-types of PPE, to-choose-from; the-main-ones were-highlighted as: (1) Protective-clothing (e.g., dust masks, gloves and gumboots) provides skin-protection against chemical-splashes, vapors, particulate-exposures, and other-physical-hazards; (2) Hand and foot protection: Impervious-gloves protect the-hands, of the-workers, from contacting hazardous-chemicals. They should-be made of appropriate-material, which would not be corroded, or damaged, by the-hazardous chemicals, involved in the-operations. If workers have to-work on wet/slippery floors, they should also-wear protective-footwear, preferably of slip-resistant type; (3) Face and eye protection: If there is a-risk of eye-injury, through splashing, suitable-eye-protectors, or face-shields, should-be-worn. Safety-spectacles can-be-fitted with prescription-lenses, if required, while safety-goggles, that completely-enclose the-eyes, provide superior-eye-protection. If protection to the-face, mouth, and nose, is required, in-addition to the-eyes, face-shield should-be-used; (4) Respiratory protective equipment (RPE) protects against exposure to: dusts, gases, fumes, and vapors, in the-color-kitchen, and the-actual-printing-process; but duration of exposure should-be kept as-short as-possible. The-choice, of RPE, depends on the-physical and chemical-nature, of the-exposed-hazard, the-concentration of hazardous substances, and the-duration of exposure. It must fit the-wearer’s face, and its-breathing-resistance should-be-tolerable, to the-wearer. For fire and other-major-emergencies, where asphyxiation or inhalation of toxic-gases is possible, RPE should-compose full-breathing-apparatus (Chemical-Safety-in-the-Workplace, 2001).

Besides, it-is-important to-choose protective-clothing, made of materials, that resist penetration, or damage, by the-chemicals, used. For-example, chemical-resistant-gloves have-to-be used, when handling-chemicals; natural-rubber-gloves, however, are not effective, against hydrocarbon-type-solvents, as they can-penetrate the-rubber and physically-degrade-it. Nitrile or neoprene-gloves, though more-expensive, should-be used, against hydrocarbon-type-solvents. It is-practical, to-always-consult the-MSDSs (if available), of the-chemicals involved, or check the-user-information, provided, by the-particular-PPE-manufacturer.

Respiratory-protective-equipment (RPE) protects workers against exposure to dusts, gases, fumes and vapors, but exposure-duration should-be-kept short. RPE should-be used to-protect the-workers, where engineering-control may not be reasonably-practicable, such-as during: maintenance, cleaning, or emergencies, where hazardous-fumes are generated, from significant-chemical-spillages, or accidental-mixing of incompatible-chemicals. The-choice of RPE depends on the: concentration, duration of exposure, and physical and chemical-nature, of the-hazardous-substances. For fire and other-major-emergencies, where inhalation of toxic-gases, at levels immediately-dangerous, to-health, or life, is possible, RPE should-compose self-contained breathing-apparatus (SCBA). With appropriate-filters, the-following RPE can-protect against airborne-contaminants: (1) air-purifying-respirators – most half-face-respirators equipped with appropriate-filters, provide protection, against contaminants of concentration up-to 10 times, and most full-face-respirators up-to 50 times its-exposure-standard (OEL), when fitted correctly; many powered-air-purifying-respirators that use battery-operated-motor-blower, to-draw air, through filters, have similar-efficiency; (2) airline respirators supply clean-air, to the-mask, helmet, or hood, using an-airline, and the-level of protection, ranges from below 25 to more-than 1000 times, the-exposure-standard, depending on whether a-helmet, hood, or mask, is used (Megtud et al., 2008).

The-study recommended, that: (1) Appropriate-PPE should-be-chose, based on the-particular-chemical-hazards, their/routes of entry, into the-human-body; and (2) PPE, including: eyewear, face-masks, protective-clothing (aprons, gowns, and overalls), gloves, boots, and respirators, should-be-provided, by the-employer, and should-be worn, by the-workers, without fail, to-prevent, or reduce, their-exposure to-hazardous-chemicals.

4.17. Ventilation

63.6 % stated, that there are some-workstations, without appropriate-collective-preventive-equipment, such-as local-exhaust-ventilation. The-working-environment may cause accumulation of hazardous chemicals, in the-atmosphere, if ventilation is inadequate, like in-the-identified, by the-respondents, workstations, particularly at-such-locations, as printing-room, and printing-ink-mixing-area (e.g., in color-kitchen).

There are 4 key-methods of ventilation (OSH, 2004): (1) general-dilution-ventilation; (2) booth ventilation; (3) local-exhaust-ventilation; and (4) push-pull-ventilation. In general-dilution-ventilation, the-contaminated-air is diluted by fresh-air (supplied by electrical-fans or natural-air-currents, through doors, windows, or other-openings, therein. The-contaminated-air is discharged, through relief-openings, or drawn-out, by exhaust-fan. This-method only replenishes fresh-air-supply, for the-whole-work-area, hence, it should-be-used, in-conjunction with other-means of ventilation, in-order-to-remove airborne contaminants, from source. Booth-ventilation is most-effective in the-control of air-borne-contaminants, which restricts the-hazardous-activity to a-designated-area, and prevents the-rest of the-workplace, from being-contaminated. Local-exhaust-ventilation (LEV) allows vapors and particulates be-captured and removed, by forced-air-current, through a-duct, near the-emission-point, before the-contaminants can-be-dispersed, into the-work-area. It is generally-applied to-equipment that cannot
be readily-enclosed, and it may not be suitable, for working with large-pieces of equipment. *Push-pull-ventilation* system is suitable for large-work-pieces, in which fans are used to-blow-vapors, away from the worker’s breathing-zone, towards an-extraction-system.

Basically the-ventilation-methods, to-control inhalation and fire/explosion-hazards, are combined. For-proper-combination, several-factors, related to the-materials used, such-as: the-quantity, frequency of use, volatility, flash-point, explosive-limit, and exposure-limit, should-be considered. Moreover, when LEV or Push-pull-ventilation is adopted, it-is important to-ensure that the-exhaust-current does not pass-through the-worker’s breathing-zone (OSH, 2004).

If door or wall-grilles are engaged, to-provide passive-ventilation, these-should-be-fitted-with-intumescing-seals, where there is a-fire-risk or the-area is used to-store flammable-substances. Where there is-the-potential for accumulation of dense-vapors or gases, low-level-ventilation is recommended. Mechanical-ventilation-systems should-be properly-maintained, to-keep the-systems in-an-efficient working-order and good-repair (in-accordance-with manufacturer’s guidelines) (SHS, 2015).

This-study, recommended to-apply suitable-types of ventilation, to-reduce hazards via inhalation.

### 4.18. Training

36.3 % reported, that they were using hazardous-chemicals, while not been-trained in their-proper-use and handling. *Training* helps employees to-acquire the-necessary-skills and knowledge, which enable them to-follow safe-working-procedures, take appropriate-control-measures, use appropriate personal protective-equipment, and follow emergency-procedures. Training should-also enable employees to-participate, in decision-making, relevant to-workplace-safety and health. The-management, of the-mill, should-ensure, that all-personnel, involving in-printing, including machine-operators, supervisors, store-attendants, cleaners, and emergency-personnel, among-others, are adequately-trained. Training should-be a-continuous-process, so that employees can-learn-about new-developments of workplace-safety, and continue to-improve their-relevant-knowledge and skills. Refresher-training is also-useful and, hence, should-be provided.

Workers should-be informed of-the-following: (1) safety-information about the-hazardous-substances, they could-be-exposed-to; (2) correct-labeling of substances and the-significance of label-details; (3) content and significance of MSDSSs; (4) measures to-reduce the-risks of exposure, to-hazardous-substances, including practice of personal-hygiene; (5) safe-work-procedures on-the-use, handling, storage, transportation, cleaning-up, and disposal of hazardous-substances; (6) information on-the-safe-handling of equipment, including equipment-cleaning; (h) procedures for reporting faults and incidents, including major-spills; and (7) proper-selection, use, and maintenance of PPE; among-others.

Besides, OSH (2004) compiled valuable-resource ‘Guidance Notes on Chemical Safety in Printing Industry’. This-study recommended that management-personnel, at the-department, should-utilize the-valuable-information, provided, in that-document, as-a-point-of-reference, to-establish a-chemical safety-program, tailored-to their-working-processes and environment.

### 5. Conclusion and Recommendations.

This-study illustrated, that rotary-screen-printing is, indeed, a-chemical-intensive-industry, where its-workers being-commonly-exposed to various-hazardous-chemicals/substances, during handling and use (as the-probability of accidental-exposure cannot be eliminated). The-most-notorious-substances are the-printing-inks and solvents; particularly, highly-volatile organic-solvents. Moreover, printing-processes, normally, result-in unused (leftover)-inks, spent-solvents, and other-chemicals, applied in-the-industry. Some of them could-be hazardous-substances (as discussed in-the-previous-sections), and hence, on disposal, these-substances could become hazardous-waste. Such-substances can cause not only serious-health-hazards, but also-present fire and/or explosion-risks, and cause potential-environmental damage, to-both; flora and fauna (particularly, aquatic-life).

The-study also-identified lack of awareness, availability, and proper-management of information on-occupational-chemical-hazards, such-as MSDSSs. In-addition, incorrect, and hence, potentially-harmful, work-practices were observed. Safety and health-measures play an-important-role, in-any-industry. It-is paramount, that the-management take the-necessary-steps, to-protect workers from potential-hazardous situations, e.g., the-workers should-be aware of the-various-occupational-chemical-hazards, in-the-industry.

To-protect workers, and the-environment, from dangerous-exposure, several-general and tailored-recommendations, given in-the-previous-sections were grouped, below, according to CP approaches, as-follows:

1. **Input-substitution** (the-study recommended, that the-purchasing-department should-ask their-supplier(s) if non-hazardous or less-hazardous-substances are available, and if so, they should choose, for purchase, the-least-toxic-one(s), that will do the-job, and also the-one with the-lowest VOC-content-possible. For-example: (a) the-petroleum-based-binder, used in many-solvent-based-inks, could-be-replaced with renewable-resources, such-as vegetable-oil or soy; and (b) phthalate-free plastisol-inks should be preferred to ordinary-plastisol-inks;

2. **Better-process-control** (to-reduce risks of fire and explosion appropriate-emergency-equipment should-
be-provided and smoking should-be strictly-prohibited; to-eliminate, or reduce, the-level of hazardous air-borne-contaminants, VOCs, or flammable-vapors, at the-source, installation of appropriate-type(s) of ventilation should-be considered, and appropriate-PPE should-be-chosen, and used. In-addition the-study recommended, that the-management should establish a-chemical-safety-program, tailored-to their-working-processes and environment, and target all-workers;

(3) **Equipment-modification** (this-study proposed to-install automatic-blanket-washers, to-eliminate manual-cleaning, thus minimizing the-risk of exposure, of workers, to-organic-solvents; and to-decrease the-risk of explosion, due to the-flammable-solvent, giving-out from printed-fabrics, in-ovens, adequate-explosion-relief (such-as: explosion-doors, or lightweight-explosion-panels) should-be provided, where technically-feasible;

(4) **Technology-change** (this-study proposed: (a) a-conceptually-innovative and relatively-new development (‘Air-Dyeing-Technology’), as one of the-solutions to heavily-polluted-effluent; (b) high-water-pressure-system to-clean the-screens; and (c) to-steam the-raw-cotton, to-reduce cotton-dust;

(5) **On-site recovery/reuse** (e.g. (a) to-recover solvent, from shop-towels/rags, for reuse or recycling, by using gravity-draining, through false-bottom-containers, or hand-wringing; (b) to-reduce waste and to-recover printing-paste, from supply-system, via ‘ball’-technique; and (c) Another-possibility, which has also already-been-implemented, in-some-companies, is to-recover and re-use, paste-residues, for making-up new-recipes;

(6) **Production of a-useful by-product** (making isolation-panels-building-materials); and

(7) **Good-housekeeping** (to-avoid, or reduce, fugitive-air-emissions, from chemical spills, the-study recommended improved-work-practices, via good-housekeeping-practices. The-goal of good-housekeeping is to-contain and remove hazards, and requires the-following: Proper-storage and handling; Proper clean-up-procedures; and Prompt-removal and correct-disposal of chemical-wastes).

Moreover, to-address, the-complains of the-respondents, further-studies on the-exposure to cotton-dust, at the-mill, was recommended.

6. **Final-annotation.**

This-unfunded-study-series, largely, has done its-part, by: (1) publishing its-results, in 6 scientific-papers (covering different-risks and hazards, at rotary-screen-printing); and (2) offering various-recommendations, putting particular-emphasis on affordable and underdemanding-solutions. Implementation, however, will remain the-responsibility of the-mill’s management. In-this-regard, the-author hopes, that their-actions will-be considerate, prudent, and timely.

7. **Acknowledgment.**

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