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-alternatives, 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 (MSDSs); 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-procedure 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*

(Exposure to-noise: noise-levels, in printing-shops, may-exceed 100 Db; Exposure to UV-radiation, used for curing; Exposure to whole-body-vibration, from printing-presses); (3) *Chemical-hazards* (Exposure to-printing-inks may-cause dermatitis; acrylates, present in inks, are potential skin and respiratory-sensitizers. Ethylene-glycol-ethers are only mildly-irritating to the-skin, but their-vapor may-cause conjunctivitis and upper-respiratory-tract-irritation. Acute-exposure to ethylene glycol-ethers results in narcosis, pulmonary-edema, and severe-kidney and liver-damage; Phosgene, a-lethal-poisonous-gas, may-be-formed, if chlorinated-solvents, such-as trichloroethylene are decomposed, in-contact-with a-flame or hot-surface, or if a-worker smokes, in the-presence of their-vapors); (4) *Biological-hazards* (Printing-machines/shops, located in-cellars or old-buildings, may-be-infested with rodents, insects, etc., exposure to-which, may-cause transfer of diseases to-the-exposed-workers; Some printing-media support bacterial-growth and, thus, may-present a-hazard of bacterial-exposure; and (5) *Ergonomic, psychosocial and organizational-factors* (Fatigue, Musculo-skeletal-injuries(MSIs), back-pain or hernia, due to-lifting and transport of heavy-loads, or exertions, during manual-tasks; Eye-strain, in-particular, during quality-proofing-work; and Stresses and family-problems, caused by tight-work schedules, shift- and night-work).

Recent-studies by Starovoytova (2017a; 2017b; 2017c; 2017d; 2017e; 2017f) identified several-such-hazards, at the-subject-department.

This-study, however, was focused on *chemical*-hazards (*not* covered, in the-previous-studies, at the-department). Chemical-hazards are a-sub-type of occupational-hazards, which involve dangerous/hazardous-chemicals. There are many-classifications of hazardous-chemicals, including: neurotoxins, immune-agents, dermatologic-agents, carcinogens, reproductive-toxins, systemic-toxins, asthmagens, pneumoconiotic-agents, and sensitizers, among-others (CERI, 1996).

1.2. Impacts of chemicals, used in textile-industry

Textile-industry is one of the-most water-, chemicals-, and energy-consuming-industries. Over 10,000 types, of dyes and pigments, are used, for dyeing, or printing, on-textiles (Akarslana & Demiralayb, 2015). In-addition, many-different-groups of chemical-substances are also-used, in the-textiles-sector, including: solvents, optical-brighteners, crease-resistance agents, flame-retardants, heavy-metals, pesticides, and antibacterial-biocides (e.g., anti-mold, anti-bacterial, or anti-odor) (Gurel & Tunay, 2000), among-other substances. Many of these-compounds are metabolized, at the-intestinal-wall and in-the-liver, producing free-aromatic-amines, which are potentially-carcinogenic and mutagenic (Akarslana & Demiralayb, 2015).

Harmful-chemicals can-be absorbed by the-skin, inhaled, or digested. Certain reactive-dyes are recognized as-respiratory-sensitizers. Inhaling such-dyes can cause occupational-asthma. Once a-person is sensitized, re-exposure, to-even very-small-amounts of the-same-dye, may-result in allergic-symptoms, such-as: wheezing, chest-tightness and breathlessness. Certain-reactive, vat, and disperse-dyes, are recognized as skin-sensitizers (Chemical-Safety, in the-Workplace, 2001). Moreover, according-to E-Facts (2008), textile-industry has-been-identified as a-manufacturing-sector with an-increased carcinogenic-risk.

This-study was cantered on textile-manufacturing-industry.

1.3. Printing, specifics of rotary-screen-printing-process, and chemicals used

According to Webster's Dictionary, textile-printing can-be roughly-defined as the-act of impressing a-pattern, or design, on a-pliable-material, made, usually, by weaving, felting, or knitting fibers/filaments. *Printing*, like dyeing, is a-process for applying color, to a-substrate. However, instead of coloring the whole-substrate (yarn, fabric, garment, or carpet), as in-dyeing, printing-color is applied *only* to defined-areas, to-obtain the-desired-pattern; it-is essentially a-localized-application of colorants on substrates. Several-printing-techniques, such-as: direct, discharge, and resist-printing are used. Printing is done *via* roller, flat-screen, or rotary-screen-printing-machines. From a-commercial-viewpoint, textile-printing is one of the-largest-printing-markets in the-world.

Rotary-screen-printing is the-dominant-printing-method; producing 60-70% of overall-printed fabric-production (Horrocks & Anand, 2000). It belongs to *roll-to-roll* (R2R) family of manufacturing techniques, involving 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 (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 (Yacooub & 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; processingsequence; 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); *Breast-cancer* (Li *et al.,* 2015; 2013; Ray *et al.,* 2007); *Ovarian-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 & Meenaxi, 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, can*not* 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. Materials and Methods.

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-thorough-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.

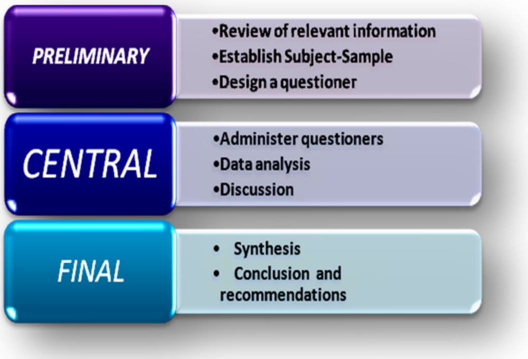

Figure1: Sequential-parts of the-study (Starovoytova & Namango, 2016).

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*' has-been defined, in this-study, as a-state of complete physical, mental, and social-wellbeing. '*Label*', on-the-other-hand, means the-written, printed, or graphical-information-elements, concerning a-hazardous-chemical, that is affixed to, printed-on, or attached-to the-container of a-hazardous-chemical (Safe-Work Australia, 2015).

In-relation to-chemicals, a-hazard is a-set of inherent-properties of the-substance, mixture, article, or process, which may cause adverse-effects to-organisms, or the-environment. There are two-broad-types of hazards, associated with hazardous-chemicals, which may-present an-immediate, or long-term-injury, or illness, to-humans. These are: (1) *Health hazards* – These are properties of a-chemical, which have the-potential-to-cause adverse-health-effects (can be acute (short-term) or chronic (long-term). Typical-acute-health-effects include headaches, nausea, or vomiting, and skin-corrosion, while chronic-health-effects include asthma, dermatitis, nerve-damage, or cancer; (2) *Physicochemical hazards* – These are physical or chemical-properties, of the-substance, mixture, or article, that pose risks, to-workers, other than health-risks, as they do *not* occur as a-consequence of the-biological-interaction of the-chemical with-people. They arise through inappropriate-handling, or use, and can, often-result in injury, to-people, and/or damage to-property, as a-result of the-intrinsic-physical-hazard. Examples of physicochemical hazards include flammable, corrosive, explosive, chemically-reactive, and oxidizing chemicals (Safe-Work Australia, 2012). Many-chemicals have-both; health and physicochemical-hazards.

Definitions and important-differences, between 'hazard' and 'risk' (in the-context of OSH), pointed-out, by Starovoytova (2017b), were applied, in-this-study. In-addition, it-is important to-clarify the-concepts of risk, with relation to chemical-exposure.

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. Results.

3.1. Validation of the-Questionnaire

Initially, the-EASHW-check-list /questionnaire was modified, to-suit the-specifics of the-study. Upon-validation, 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 perceptions and self-reports, and established relatively-high inter-item-consistency (Cronbach's $a > 0.8$).

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.

Table1: Demographic-information of the-respondents (Starovoytova, 2017 b).

	Mean	**S D**	**Range**
Age (years)	25.375	10.23	24 - 43
Duration of Employment (years)	2. 75	2.18	1 - 8
Height (cm)	169.07	11.84	146 - 182
Weight (kg)	65.375	9.80	54 - 85

3. 2.2. Actual-responses to the-questionnaire

The-following were the-responses, 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, goggles, 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, gloves, 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 3; serious-eye damage/eye-irritation - Category 2B; aspiration-hazard-Category 2; flammable-gas - Category 2; acute hazard to the-aquatic-environment - Category 1, 2 or 3; chronic-hazard to the aquatic-environment - Category 1, 2, 3 or 4; or hazardous to the-ozone-layer. This-definition is rather-complex and comprehensive, and it also-based on the-premise, that audience is familiar with GHS, which might *not* be the-case.

In-this-regard, some-elaboration is in-order. Surprisingly, a-substance may-be considered flammable, or toxic (based, for-example, on Acute-oral-toxicity (LD_{50})), by one-agency or country, but *not* by another. To-address, this-problem, here comes the-United-Nations Globally-*Harmonized*-System of Classification and Labeling of Chemicals (GHS), which is *not* a-regulation or a-standard; it establishes agreed-hazard-classification and communication-provisions, with explanatory-information on how to-apply the-system. GHS is a-logical and comprehensive-approach to: (1) Defining health, physical, and environmental-hazards of chemicals; (2) Creating classification-processes, that use available-data, on chemicals, for comparison-with the-defined-hazard criteria; and (3) Communicating hazard-information, as-well-as protective-measures, on-labels and Safety Data Sheets (SDSs).

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 hazards, 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; Serous-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).

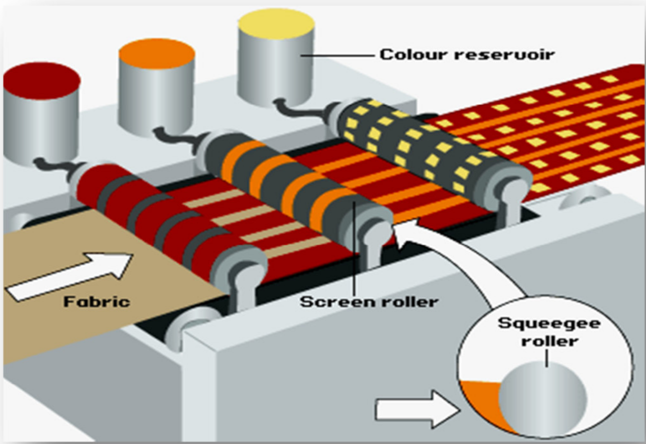

Figure 2: Rotary-screen-printing-machine (BBC, GCSE).

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^{o}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* (cresotinic-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 sarcosine, 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-Butanoi; n-Butyl-acetate; Ethyl-acetate, Hydrocrbon-solvent (white-spirit), 1-Propanoltlram; 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 10mm 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 identifies 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 320^0 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%; Thickener -4%; Catalyst- solution -3%, and Emulsifier -1%. Pastes, which are entirely water-based, are obtained by replacing the-white-spirit, with water; and (2) *Plastisol* printing-pastes: based, on a-vinyl-resin, dispersed in-plasticizer; characterized by virtually 100% *non*-volatility (*no* solvent is present); used frequently for printing on-dark-colored-fabrics. Components of plastisol-printing-pastes consist of: (a) PVC-homo-polymer (i.e., a vinyl-resin), dispersed in phthalate-plasticizer; (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-wells-as related-hazards. For-example, solvent-based-inks (e.g., inks, containing ethanol, isopropanol, ethylene-glycol, xylene, toluene, cyclo hexanone 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-acrylic-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-butoxyethyl-acetate), among-others. Large rotor-gravure 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-acetate-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-adhesives and varnishes can-create solvent-vapor-hazards. If epoxy-adhesive is used, to-secure rotary-screens, to-their-end-rings, there is a-risk of skin-contact, until the-adhesive 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, methylnaphthalene, 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).

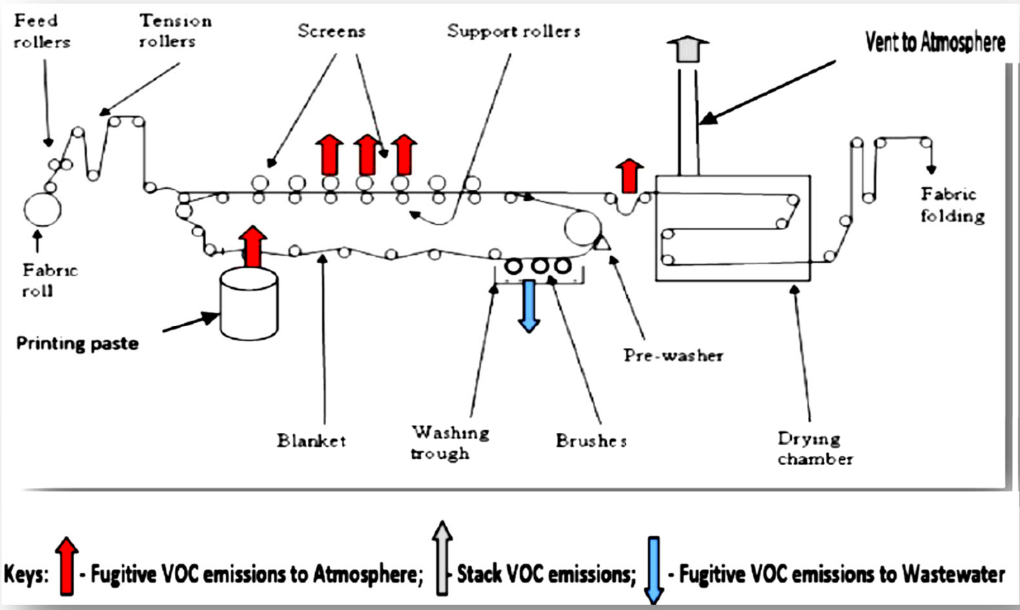

Figure 3: VOCs-emissions in printing

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-chemical-hazards.

Eliminating the-hazard is removing the-hazard, or hazardous-work-practice, from the-workplace. This-is the-most-effective control-measure, and *must* always-be-considered, before other-control-measures. For-example, *not* using a-hazardous-chemical, or eliminating-exposure, by: using-nails, instead of using chemical-based-adhesives; and eliminating a handling-activity and potential-worker-exposure, by purchasing pre-mixed or diluted-chemicals, instead of manually-mixing or diluting-chemicals, at the-workplace (Safe-Work Australia, 2012).

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 can*not* 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-absorbers; 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); Australian-Environment-Business-Network and Printing-Industries-Association (2003); and Enroth (2001), stated, that Occupational-health and safety-performance should-be-evaluated, against internationally-published-exposure-guidelines, including: the-Threshold-Limit-

Value (TLV®) occupational-exposure-guidelines, and Biological-Exposure-Indices (BEIs®) published by American-Conference of Governmental-Industrial-Hygienists (ACGIH), (available at http://www.acgih.org/TLV/); the-Pocket-Guide to Chemical-Hazards, published by the-United-States National-Institute for Occupational-Health and Safety (NIOSH) (available at http://www.cdc.gov/niosh/npg/); Permissible-Exposure-Limits (PELs), published by OSHA, (available at http://www.osha.gov/pls/oshaweb/owadisp.show/); and Indicative-Occupational-Exposure-Limit-Values, published by European-Union-member-states, or other-similar-sources.

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).

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

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 un-chlorinated-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 Müezzino, 1998). Textile-effluent is also a-cause of significant-amount 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 reuse rinsing-water-leftover, 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 of 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 my a-number of leading-textile-industries.

4.10. Hazardous-waste and its-minimization

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 'acutely-hazardous' and are regulated more-strictly, 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-Procedure.

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 careful-maintenance 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 can*not* 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 sending-them 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: Dedicate 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 *non*-hazardous 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 with 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-metaperiodate, 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 (dye-pipe with 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-trichloroethane; 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 Resitex (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 the-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)).

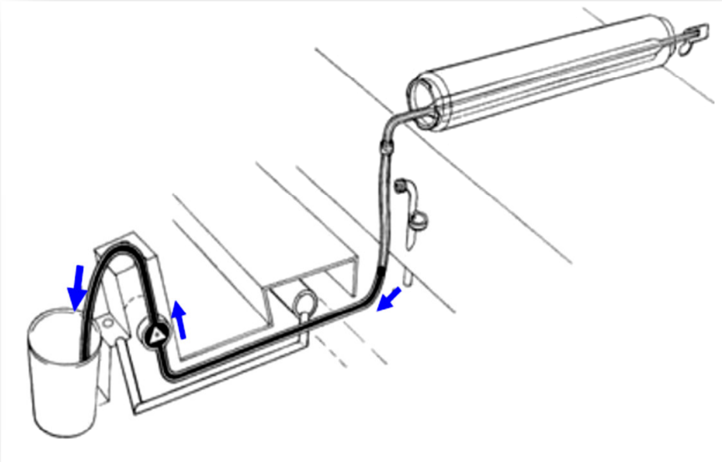

Figure 4: Paste-recovery-system

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) firealarm; (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.

4.14. Cotton-dust and its-control

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 & Meenaxi (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 Elwod *et al.* (1986); Salnaggio (1986); and Croften (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-arena 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, infact, 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-comprise 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-comprise 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 (Metgud *et al.,* 2008).

The-study recommended, that: (1) Appropriate-PPE should-be-chosen, 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 can*not* 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 MSDSs; (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 can*not* 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 MSDSs. 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 undemanding-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.

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