

Introduction

Indoor air pollution is a global issue in today's modernized world. With probably less fresh air and more time spent indoors, people are prone to more pollutants. Worldwide, 7 million air related deaths is estimated that is one in eight of total global deaths as a result of air pollution exposure. These findings confirm that air pollution is now the world's largest single environmental health risk (WHO, 2014).

Indoor air pollutants take any forms, ranging from smoke emitted from solid fuel combustion, especially in households, to complex mixtures of volatile and semi-volatile organic compounds present in modern buildings.

Office equipments are major source of indoor air pollutants. Their emission occurs as a result of both equipment operation and off-gassing of residual components or episodic releases of organics related to catastrophic failure of a unit as per the United States Environmental Protection Agency Report (USEPA, 1995).

Office equipment used throughout the day in various amounts and duration, may emit variable pollutant concentrations during working hours and thereby may produce variable exposure level for the office occupants. The pollutants, during poor ventilation, may further build up to significant levels even when office equipment is not in use (Durga and Gokhale, 2015).

Photocopier / xerographic machines are inevitable office equipment in recent days of automation. It is a source of income to many people in developing countries. As per the transparency market research report (www.transparencymarketresearch.com/photocopiers-market.html), on photocopier market forecast 2012 - 2018, the future of photocopier industry lies in India. Both as manufacturing base and service provider of photocopier machines, India

has a huge demand for the photocopier machines among the service sector, banks and multinational companies.

Photocopiers are referred to as xerographic machines based on the process of dry ink marking process, xerography (electrophotography). In the seven decades, since its invention by Chester Carlson, xerography has revolutionized the printing industry and in-turn the office setup. Fifty trillion pages are produced worldwide today using production print technology; among which the digitally-printed pages are projected to grow at a 7% compound annual growth rate from 2012 to 2016. Digital printing trends dictate that the share of the total print market will grow from 9.8% in 2008 to 20.6% in 2018, with both xerography and inkjet process. The revenue market of digital print industry will reach \$ 187.7 billion in 2018 at a compound annual growth rate of 7.4% (Smithers-Pira, 2013).

According to Utell and Samet (2009), photocopier machines are an important source of indoor air pollutants in the form of aerosol. Researchers have conducted several studies to identify and characterize these aerosolized pollutants. The machine emits a range of pollutants from respirable micron size to sub micron and further precisely nano-size particulate emissions in addition to various organic gaseous co-pollutants namely ozone, volatile (VOC'S) and semi volatile organic compounds (SVOC's) (Bello *et al.*, 2013) with the inclusion of carbon monoxide, carbon dioxide, nitrogen dioxide, ammonia, perchloroethylene, and non-methane hydrocarbons and inorganic elements (Kiurski *et al.*, 2015).

The inorganic elements identified in nano-particulate emission include iron, titanium, silicon, manganese, aluminium, zinc, sulphur, copper, chromium, nickel, molybdenum, vanadium, cobalt, arsenic, cadmium and lead. These emissions originate either from toner particulate emissions or exhaust filter dust of photocopiers (Bello *et al.*, 2013). Photocopier machines also produce ultraviolet (UV) radiations (Singh *et al.*, 2014).

The principal component in photocopier emissions is toner (Elango *et al.*, 2013). The advent of high-tech toner formulation for good quality printing is a double edged sword at the expense of indoor air quality. Evaluating consumer risk of nanoparticle exposure from the use of nano-enabled toners during printing has become a necessity, since the market for this office technology has increased substantially (Pirela *et al.*, 2015).

Dry toner is an electrostatic ink powder used in xerographic process for printing characters and images (Gosman *et al.*, 2015). It usually contains resin which is a copolymer of styrene and acrylates (up to 55 %), iron oxides as pigment (up to 50 %) and up to 3 % of amorphous silica - a supplementary anti-caking agent. The resin, when subjected to heat, adheres the pigment particles to the paper (Kowalska *et al.*, 2015).

Xerographic machines emit higher concentration of atomic oxygen, which is associated with diatomic oxygen to form ozone (O₃) (Durga and Gokhale, 2015). It is a by-product of the electrophotographic process and is generated by the corona wires which place electrical charges onto photoconductive materials (Lee *et al.*, 2001).

About 80% VOCs emitted were from toners in the indoor air photocopy shop. One toner cartridge was estimated to emit nearly 1~8 mg VOCs in comparison to plain paper that emits 3~10 ng VOCs in photocopy shops at fuser temperature of 180 – 200⁰C in photocopier machine (Wu, 2006). Later, it was found that photocopiers also emanate semivolatile organic compounds (SVOCs) as a consequence of either homogenous nucleation reaction or secondary particle formation involving ozone (Moraswka *et al.*, 2009).

Extensive studies have been carried out to study the health effect of toners and their emissions both in *in-vitro* and *in-vivo* models. *In vitro* studies in cultured human epithelial A549 lung cells showed DNA damage on exposure to three selected black toner powders and their dimethyl sulfoxide extracts (Gminski *et al.*, 2011). There was significant increase in frequency of micronucleus in buccal epithelial cells and peripheral blood lymphocytes (Goud *et*

al., 2004). Photocopier emissions also exhibited genotoxicity in the plant clone hybrids of BNL 4430 *Tradescantia* hybrid (Filipini *et al.*, 2009).

In vivo animal studies have shown that intratracheal exposure to toner particles in mice inhibited their normal growth and were found to lead to significant inflammatory responses and lesion in lung tissues that prolonged for many weeks (Bai *et al.*, 2010). Further, instillation of mice with nano particulate matter leads to rise in lung injury and inflammatory markers in bronchoalveolar lavage (BAL fluid) (Pirela *et al.*, 2013). Chronic inhalation of non carbon based magnetite photocopying toner showed dark discoloration of the lungs, associated lymph nodes and increased incidence of inflammatory cells infiltration, inflammation and few instances of alveolar ciliated metaplasia but showed no increase in the incidence of pulmonary tumors (Slesinski and Turnbull, 2008).

Human study reports are available that have shown a constant exposure to high levels of photocopier emissions in the office environment resulted in various health effects among the workers that commence in mild respiratory irritation to chronic respiratory disease and possibly cancer. Photocopiers usage is positively associated with sick building syndrome symptoms (Abdel-Hamid *et al.*, 2013). The non-specific mucosal, skin and general symptoms that are temporally related to working or living in a sick building comprise the 'sick building syndrome' (SBS) (Burge, 2004). Adetunji *et al.* (2009), pointed out that high level of nanoparticles emitted during photocopier usage pose potential occupational health risk. Submesothelial deposition of carbon nano particles in the peritoneum has been observed in female office workers with dust toner exposure (Theegarten *et al.*, 2010). Nanoparticle emissions from photocopiers have shown to induce oxidative stress and upper respiratory tract infection in healthy volunteers (Khatri *et al.*, 2013).

In contrast to the above health impact reports available due to photocopier emissions, there were few studies that showed no health impact

among workers handling toners. A retrospective epidemiological mortality study among employees indicated no evidence that toner exposure increases the risk of all-cause mortality or cause specific mortality over a follow-up time period (Abraham *et al.*, 2010). Another cross sectional cohort study by Kitamura *et al.* (2009), observed no difference in pulmonary function indices between the toner-exposed workers. However, the prevalence of subjective respiratory symptoms was higher in the exposed workers. It was also found that there were prevalent of respiratory health deterioration among workers handling toner (Nakadate *et al.*, 2006). Similar observation was also noted among photocopier workers in Taiwan (Yang and Haung, 2008).

Xerographic service professionals are regularly exposed to toner materials on long term basis due to their work nature of involvement in routine machine maintenance, revamp of refurbished photocopier machines and in toner refilling process irrespective of their occasional exposure to toner emissions at customer's photocopy shop.

In photocopier industry, machine maintenance is a routine and labour intensive process performed by service professionals. The customers who choose to use reconditioned machines do so to cut start up costs, requirements and safe work environment. Commercial focus on high-tech sophisticated fine quality copier machines neglect real health impact on these workers.

Photocopier centres in India are generally small and serve as both businesses and residences affecting both the employees and the residents leading to adverse health effects among both the community (Massey and Taneja, 2011). Despite their economic benefits, indoor emissions and toner residuals from photocopiers have become an alarming health concern (Elango *et al.*, 2013)

Occupational exposure to the xerographic equipments among service professionals imposes the need to monitor the release of any harmful pollutants into the indoor air through real time field experiments. In addition to this, all the

above mentioned extensive studies showed a range of minimal to nonexistent health impacts due to toner handling and photocopier emissions. This lay emphasize on the need for an epidemiological study to identify an ideal biomarker in bio fluids especially blood and urine that could reflect the health impact among substantial population who service the xerographic machine.

Metabolomics appears to be an important tool to gain qualitative and quantitative information on low-molecular weight metabolites present in cells, tissues and fluids (Sofia *et al.*, 2011). Non invasive samples like urine could be easily collected, analysed and correlated to metabolic profiles from animal studies in order to identify the critical effects in humans subjected to incidental environmental / occupational exposure (Vulimiri *et al.*, 2012)

Hence, the present study was undertaken in two phases with the following two main objectives under each phase:

Phase I : Air quality analysis

- To elucidate the physical characteristics of both the selected xerographic units and machines.
- To analyse the ambient air quality of the selected xerographic centers.
- To determine physico-chemical characteristics of four selected brands of toner by Scanning Electron Microscopy Energy dispersive X ray Spectra (SEM EDX) elemental composition and head space Gas Chromotography Mass Spectrometry (GC-MS)

Phase II: Health surveillance of photocopier service personnel in xerographic units

- To assess lung function by spirometry
- To assess the status of biochemical, oxidative, inflammatory, selenium, cadmium and selenoprotiens (invasive systemic biomarkers levels) in occupational settings amongst the study population.

- To assess genotoxicity exposure among study population
- To determine metabolomic differences in excretory urinary biomarkers by non invasive approach

1.1 Scope of the Study

This study may highlight the important rationale for framing indoor air emission guidelines in India which is not in existence and will also insist upon regulation criterion for approval of xerographic devices. Air quality and health surveillance study is essential to establish clean technologies to reduce health hazards.

1.2 Novelty of the Study

Millions of people who operate photocopiers across world for livelihoods may be exposed to photocopier emissions in indoor environments such as commercial photo copier units or offices. Apart from the operators, thousands of people are also involved in the maintenance of photocopiers. In India, majority of the photocopier units are dependent on second hand reconditioned machines to cut start-up costs. Consequently, service personnel are required to recondition these second hand machines and thus are a costly labour intensive process. Xerographic service personnel are maximally exposed to toner powder rather than pollutant emitted during the photocopying process. However, health surveillance studies among photocopier maintenance personnel have not been studied till date in India.