Publisher: Taylor & Francis & A&WMA

Journal: *Journal of the Air & Waste Management Association*

DOI: 10.1080/10962247.2019.1629355

Title: Inhalation Exposure to Volatile Organic Compounds in the Printing Industry

Authors:

Abdullah Alabdulhadi, University of Newcastle, Callaghan, NSW, Australia; Public Authority of Applied Education and Training, Shuwaikh, Kuwait.

Ashraf Ramadan, Kuwait Institute of Scientific Research, Safat, Kuwait.

Peter Devey, University of Newcastle, Callaghan, NSW, Australia.

May Boggess, Arizona State University, Tempe, AZ, U.S.A.

Maya Guest, University of Newcastle, Callaghan, NSW, Australia.

INTRODUCTION

Concerted efforts have been made to reduce chemical exposure of printery workers in recent years (Wypych 2001, Section 14.23). These actions were motivated, in part, by the conclusion of the International Agency for Research on Cancer (IARC) in 1996 that chemicals used in the printing process produced adverse health outcomes and were possibly carcinogenic (IARC 1996, Section 5). In a 1999 initiative, the European Union (EU) Substitution of Organic Solvents in the Printing Industry Project verified that workers had lower exposure to volatile organic compounds (VOCs) when low volatile organic compound (VOC) products were used (Bartlett et al. 1999), echoing findings of an earlier study carried out by the United States (US) Environmental Protection Agency (EPA) (USEPA 1997). The results of these, and other studies, for example, that of the United Kingdom (UK) Health and Safety Executive (HSE) (UKHSE 2002), were widely used in the printing industry and served as an impetus to bring about change to the formulation of inks, fountain solutions and cleaners. The aim was to reduce exposures to VOCs, particularly benzene, toluene, ethylbenzene, xylenes (BTEX), by developing and encouraging the use of low VOC products, rather than petroleum-based products. Consequently, there is a continuing need to monitor VOC exposures in printeries to determine the effectiveness of these measures.

Advances in technology have also brought change to the printing industry. For example, computer-to-plate (CTP) has largely replaced the montage process (Rombult et al. 1999), and digital printers and photocopiers are now common in printeries. There is evidence of exposures to VOCs in photocopy centers and offices (Kagi et al. 2007, Sarkhosh et al. 2012, Kowalska et al. 2015, Senthong and Wittayasilp 2017), but no evaluation of exposures from these devices in printeries has been published. This highlights the need to monitor VOC exposures of all printery workers, not just those directly operating offset printing equipment.

The human auditory system is vulnerable to the toxic effects of some VOCs, even at concentrations below recommended occupational exposure limits (OELs) (Morata et al. 2002, Juárez-Pérez et al. 2014). One reason for this may be because ototoxicity is rarely cited in the determination of the American Conference of Governmental Industrial Hygienists (ACGIH) occupational exposure limit (OEL); currently this is so for only one VOC, ethylbenzene (ACGIH 2017). Additionally, authors of three major reviews on ototoxicity raised concerns about concurrent exposure to noise and ototoxic agents, suggesting a possible synergistic effect on the auditory system (Campo et al. 2009, Johnson and Morata 2010, Vyskocil et al. 2012). The printing industry is one industry in which the risk of exposure to noise and ototoxic VOCs has been particularly high (Morata et al. 1993, Morata 2007).

A feature of previous printery air quality studies is that the majority of target VOCs were found, particularly when only a handful of VOCs were targeted (Godoi et al. 2009, Ćurčić et al. 2013, Mansouri et al. 2015). However, even in studies where more VOCs were targeted, the majority were still found. For example, a study of Chinese printeries targeted 47 VOCs, of which only six were not detected (Zheng et al. 2013). This, together with the array of VOCs in products used in printeries (USEPA 1997, Section 1.4.3), suggests that a wider net needs to be cast to improve our knowledge of VOC exposures in printeries.

To detect a wide variety of VOCs, researchers (Leung et al. 2005, Zheng et al. 2013) have used USEPA methods TO-14A (USEPA 1999a) and TO-15 (USEPA 1999b), in which air samples are collected in large evacuated canisters and analysed using gas chromatography. LeBouf et al. (2012) confirmed that the evacuated canister method analysed by gas chromatography with mass spectrometry (GC-MS) met the validation criteria set by the US National Institute for Occupational Safety and Health (NIOSH) (Kennedy et al. 1996). Those authors pointed out that an advantage of the method was the ability to accurately detect VOCs at concentrations in the parts-per-billion (ppb). In fact, in a study of thermal desorption tubes, the evacuated canister method with GC-MS was used as the gold standard (Chang et al. 2015). We note that an earlier study of the evacuated canister method confirmed that two common methods of analysis, GC-MS and by gas chromatography with flame ionisation detection (GC-FID), have excellent agreement (Daughtrey et al. 2001).

The aim of this paper was to describe a wide variety of VOC exposures in three modern printeries in the state of Kuwait. The objectives were to 1) measure indoor air concentrations of 72 VOCs in both production and non-production areas using evacuated canisters with GC-FID, 2) compare these results to previously reported VOCs in printeries, and 3) determine whether ototoxic, carcinogenic or hazardous exposures exceeded relevant OELs.

METHODS

Printery descriptions

Table 1 lists work areas/sampling locations in each printery, together with type of air conditioning (AC), ventilation system, existence of openable windows or doors to outside air and type of equipment in each area. All the CTP work areas had local exhaust ventilation (LEV) systems, as did the two sheet-fed offset work areas. The web-fed offset work area had industrial exhaust fans (IEFs) to force indoor air to the outside. The review of available product labels revealed that all three printeries used petroleum based products. None of the study printeries were close to oil fields or oil refineries.

INSERT TABLE 1 HERE

Government Printery. The government printery was housed in two large reinforced concrete structures that were situated in a desert area, near some industrial facilities. The main entrance opened into the reception area. An open stairwell led to the second level which housed administration and design. The CTP room opened directly off the reception area, through a door that was usually open. Digital printing/photocopy also opened into the reception, which was the main thoroughfare to other areas of the printery. On the other side, digital printing/photocopy opened into the offset/commercial binding area. This area housed six manually cleaned sheet-fed offset machines (two four-color Heidelberg Speedmasters and four two-color Heidelberg Speedmasters, Germany). There was a large loading bay door for deliveries. The offset area was open, via a wide corridor, to other work areas, primarily maintenance/commercial binding. Upstairs, the decorative binding area had several binding machines as well as open wall-mounted storage racks for vinyl and plastic book coverings. This area was accessible to the maintenance/commercial binding area below via two wide open staircases. The main storage area, where fountain solutions inks, blanket washes, cleansers and lubricants were stored, was in a second building. In this area there was a desk for one store worker. There was also a separate, closed off, office for the store supervisor.

Scientific Printery. The scientific printery was a small research report printery near the ocean, downwind from a coastal power plant and desalination plant. It was housed in two small brick buildings. The entrance to the main building opened into a small lobby, which had doors to the four main works areas. The offset area housed two manually cleaned sheet-fed offset machines (two-color Heidelberg Speedmaster, Germany) in an area with a large door that could open to the outside for deliveries. The storage, administration/design area and binding area were accessed through a common lobby, via doors that were usually open. The CTP area was in a second building that also accommodated office workers not associated to printing activities.

Newspaper Printery. The newspaper printery was a medium-sized printery housed in a brick two story structure, with a lower ground level, located in an industrial area. It was not far from the scientific printery, so was also downwind of the power and desalination plant. The reception/administration area on level 1 did not have direct access to outside air; an elevator ride and a walk along a corridor was needed to enter the premises. The CTP area was on the same level as administration, separated by a glass partition and a door that was usually closed. The other levels of the premises were reachable by elevator and a stairwell with doors that were usually closed. The archive was housed upstairs on level 2. The offset printing area was on the lower ground level which had a large loading bay door for deliveries. It contained one high-speed, web-fed, coldset offset machine, with automatic cleaning (made in Germany). Safety data sheets (SDSs) were available for various products at this printery.

Sampling locations

Two criteria were used to identify appropriate sampling locations: firstly, the work areas were regularly occupied or visited by workers; and secondly, the sampling would not interfere with work safety or performance. Ten sampling locations were used at the government printery, as it was the largest printery. There were five sampling locations at each of the other two printeries. Table 1 describes the sampling locations.

Field sampling

Sampling and analysis were carried out in accordance with the USEPA Method TO-14A (USEPA 1999b). Passivated stainless-steel evacuated 6 L canisters (Silonite™, Entech Instruments Inc., Simi Valley, CA) were used for sampling (Section 7.1.1.2, USEPA 1999b), had been subject to five cleaning cycles with optional heating (Section 11.1, USEPA 1999b) using an Entech 3100A Smart Lab Canister Cleaning System**.** In all sampling locations, three evacuated canisters were placed close together at the height of breathing zone (i.e. 150 cm for a standing worker and 90 cm for a sitting worker). Due to a shortage of canisters, no field blanks were used. Time-integrated samples were collected (without pump) in the triplicate canisters, using an Entech CS1200E flow controller set to 8 hours (Section 9.1.1, USEPA 1999b).

Analysis and data quality

A literature review was performed to identify VOCs previously mentioned as used or detected in offset printing facilities. The Kuwait Institute for Scientific Research made available an analysis that targeted 72 VOCs, including 43 of those VOCs (see Supplement Table 1). The 72 VOCs targeted consisted of compounds commonly found in industrial facilities and were identified by their Chemical Abstracts Service (CAS) Registry Number and International Union of Pure and Applied Chemistry (IUPAC) name (CAS 2017, IUPAC 2017). Analysis was performed with an Agilent-7890A GC-FID (Agilent Technologies, Santa Clara, CA), with an Entech 7100A cryogen preconcentrator, utilizing a DB-624 fused silica capillary column (Section 10.1.3, USEPA 1999b). The compounds were qualitatively identified by Agilent ChemStation® software (Agilent Technologies, Santa Clara, CA) and quantitatively assessed by calibrating the system with a 50 ppb external standard calibration mixture of 72 components (Apel-Riemer Environmental Inc., Broomfield, CO). The calibration factors for target compounds were calculated individually, using four-point calibration from 5-50 ppb (Section 10.3.3, USEPA 1999b), which were within the bounds specified by the standard and gave all R-squared values in excess of 99%. The method detection limit (MDL) was calculated for each compound according to USEPA TO-15 (Section 11.2, USEPA 1999b) and were between 0.25-1.95 ppb (median 1.45 ppb). Ramadan (2017) and Al-Awadi (2018) also used this system; Ramadan had more detail on the methods and Al-Awadi reported retention times and a chromatogram.

Monitoring for possible contamination was accomplished through the use of laboratory method blanks. This was an unused certified canister that had not left the laboratory and was pressurized with humidified ultra-pure zero air or nitrogen. It was analysed after calibration standard check and immediately before analysing the samples. We verified that the blank did not contain any target analyte at a concentration greater than its MDL. These blanks were analysed at least once in a 24 hour analytical sequence.

A number of substances were co-eluting; these were pairs of VOCs that could not be individually identified. The results were reported as the total concentration of the constituent compounds**. T**he 66 individual VOCs and six coeluting pairs are listed with their MDLs in Table 2A and B.

INSERT TABLE 2A & B HERE

Exposure limits

Four types of exposure limits were utilized in this study (see Table 2A and B)**:**

1) The Kuwait Environment Public Authority of (KEPA), Decision No. 210/2001 lists OEL for various substances including VOCs (Appendix No.3(1), KEPA 2001, pg. 180-214).
2) US Occupational Safety and Health Administration (OSHA): General industry permissible exposure limits (PEL) are regulatory limits listed in the Annotated Z-tables and were available online (OSHA 2017). If no general industry limit was available, the construction

industry limit was used.

3) NIOSH: The NIOSH Pocket Guide to Chemical Hazards lists recommended exposure limits (REL) that are meant to reduce or eliminate adverse health effects (NIOSH 2007). Up-to-date information is available through an online search engine (NIOSH 2017).
4) ACGIH: Threshold limit values (TLVs) were used. Where a TLV value had not yet been established, the TLV short-term exposure limit (STEL) or ceiling value (C) was used (ACGIH 2017). The ACGIH state that their TLVs are only guidelines to assist in the control of potential workplace health hazards and are not fine lines between safe and dangerous concentrations (ACGIH 2017). These values were available online at the OSHA Chemical Sampling Information site (OSHA 2017). For two substances, no ACGIH TLV was available, and an American Industrial Hygiene Association (AIHA) Workplace Environmental Exposure Level (WEEL) value was available which was used instead (AIHA 2011).

The OEL used in this study was the lowest of Kuwaiti, OSHA, NIOSH and ACGIH limits. For the purpose of this analysis the limit for co-eluting compounds was the highest limit of the two constituents**.**

Exposure relative to the OEL

Because of the varying health effects for different substances, total VOCs (the sum of the individual concentrations) is not a good measure of the potential for adverse health effects from exposure to a mixture of substances. In this situation, the observed concentration of each constituent part is divided by its OEL. These quotients can then be added, as each one is the proportion of the OEL observed (ACGIH 2017, Appendix E, Application of the Additive Mixture Formula). If the sum is greater than one, then it indicates that there is a potential for adverse health effects from exposure to the mixture. Note that this method assumes that the effects of the constituents are additive, and so does not account for synergistic effects. For the nine VOCs without an OEL, the largest OEL of VOCs in this study was used (1,000 ppm).

Classifications of health and environmental risks

The following six classifications were utilized in this study (see Table 2A and B)**:**

1) European Agency for Safety and Health at Work (EASHW): In 2009, they carried out a study of the combined exposure to noise and ototoxic substances (Campo et al. 2009). EASHW formed three categories depending on the weight of evidence. Of the VOCs in this study six were categorized by EASHW and were category 1, confirmed ototoxic.
2) Nordic Expert Group (NEG): In 2010, the NEG studied the occupational exposure to chemicals and hearing impairment (Johnson and Morata 2010) and formed three categories. Category 1 meant that human data indicate auditory effects under or near existing OELs, as well as robust animal data supporting an effect on hearing from exposure, and category 2 meant human data are lacking whereas animal data indicate and auditory effect under or near existing OELs. Of the VOCs in this study categorized by the NEG, two were category 1 and three were category 2.
3) The Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail (IRSST): In 2012, the IRSST in Montreal developed a toxicological database of possible ototoxic substances found in workplaces (Vyskocil et al. 2012). They listed three of the solvents in this study as ototoxic (category 1) and three as possibly ototoxic (category 2).
4) IARC provides a classification of cancer risk to humans for numerous substances: Group 1: carcinogenic; group 2A: probably carcinogenic and group 2B: possibly carcinogenic. Five of the solvents in this study were in group 1 and three in group 2A.
5) The USEPA maintains a hazardous air pollutants (HAP) list containing 187 substances, which have been determined to cause serious health effects (USEPA 2017). Forty three of the VOCs in this study were on this list.
6) Montreal Protocol on Ozone Depleting Substances (ODS): Kuwait is an Article 5 party (developing country) to the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer (KEPA 2015). Eight VOCs in this study were controlled substances covered by the protocol (United Nations 1989). The phase down schedule specifies zero production and consumption as follows: Annex A group I (chlorofluorocarbon **(**CFC)) and Annex B group II (carbon tetrachloride) by 2010, Annex B group III (methyl chloroform) and Annex E group I (methyl bromide) by 2015 and Annex C group I (hydroCFC **(**HCFC)) by 2040.

VOC concentrations from previous studies

A literature review was conducted to identify studies performed since 2000 concerning outdoor air in Kuwait, indoor air in Kuwait, and offset printery air quality. Six studies of VOCs in outdoor air in Kuwait, in which individual concentrations were reported, were identified (Al-Salem and Bouhamrah 2006, Al-Hayi and Pillai 2012, Alhumoud et al. 2012, Al-Mudhaf et al. 2013, Al-Khulaifi et al. 2014, Yassin and Pillai 2018). Of the VOCs in this study, 43 had been reported in at least one previous study, yielding 186 observations for comparison.

Four studies of VOCs of indoor air in Kuwait, in which individual concentrations were reported, were identified: one of homes (Alhumoud et al. 2012), two of office buildings (Al-Mudhaf et al. 2013, Al-Khulaifi et al. 2014) and one of schools (Yassin and Pillai 2018). Of the VOCs in this study, 41 had been reported in at least one previous study, yielding 270 observations for comparison.

Seventeen studies of offset printeries, in which individual VOC concentrations were reported, were identified (Svendsen and Rognes 2000, Batterman et al. 2002, Gioda and de Aquino Neto 2002, Yu et al. 2004, Leung et al. 2005, Hautamäki et al. 2006, Thanacharoenchanaphas, Changsuphan, Thongsri, et al. 2007, Thanacharoenchanaphas, Changsuphan, Nimnual, et al. 2007, Rodriguez and Gibbins 2007, Caselli et al. 2009, Godoi et al. 2009, Lee et al. 2009, El-Said 2009, Gegic and Savic 2013, Ćurčić et al. 2013, Sancini et al. 2014, Mansouri et al. 2015). Just one used evacuated canister sampling methodology (Leung et al. 2005). Twelve of these studies measured four or less VOCs, usually BTEX. Nearly all studies were of production areas only. Of the VOCs in this study, 36 had been reported in at least one previous study, yielding 138 observations for comparison. Of these, 26 VOCs had concentrations greater than zero reported.

Supplement Table 2 lists the minimum and maximum VOC concentrations from these previous studies. We note that for quite a few VOCs even the maximum concentration reported was less than 5ppb. To help identify which VOCs observed in this study were likely to have been used inside the printery, and which may have been sourced from outside only, these VOCs were summarised as follows: “printery” if the maximum concentration from printery studies was relatively high, say exceeded 50 ppb; “outdoor” if the maximum concentration from outdoor studies exceeded say 15 ppb; and “indoor” if the maximum concentration indoor air studies exceeded say 15 ppb. As a result of this analysis, the following VOCs were expected to partly source from outdoors: n-pentane, methylene chloride, carbon tetrachloride, bromoform, CFC-114, CFC-11, propene, vinyl chloride, benzene, toluene, ethyl, methyl and n-propyl alcohol. The following VOCs were expected to be found inside the study printeries: n-hexane, methylene chloride, methyl chloroform, benzene/1,2-dichloroethane (1,2-DCEa), ethylbenzene, m/p-xylene, o-xylene/styrene, 1,3,5-TMB, 1,2,4-TMB, toluene, isopropyl alcohol and acetone.

Statistical analysis

In the event the measured concentration of a single VOC for a canister was below the MDL, the MDL value was used instead. The coefficient of variation **(**CV) and standard deviation (SD) within each sampling location (n = 3) was calculated. The VOC concentrations reported here are the mean of th**e** field triplicate canisters at that sampling location, for those locations where the within location CV was not greater than 20%. The total VOCs for a location is the sum of the VOC concentrations at that location, including those at the MDL. Correlation between VOC concentrations at different locations was estimated by applying a simple linear regression model to standardized log-transformed concentrations. The statistical analysis software Stata version 14.2 was used for data manipulation and analysis (StataCorp, College Station, Texas, USA).

To help identify which VOCs were likely utilized in printery operations the maximum concentrations and the across location CV in each printery was used. The expectation was that a VOC utilized in printery operations would have a relativity high maximum concentration and a relatively high CV. On the other hand, VOCs that were sourced from outside the printery would have low maximum concentration and CV, since the VOC would be found in most locations with similar concentrations. For each printery, a VOC cutoff was determined, such that those greater than it indicated a high concentration for that printery. Similarly, an across location CV cutoff was determined for each printery, such that those greater than it indicated a high CV for that printery.

RESULTS

Sampling was carried out during summer of 2015. At all three printeries, no windows were open on the sampling days due to the heat and dust outside. While indoor smoking was strictly prohibited in the government and newspaper printeries, that policy was not as thoroughly enforced in the scientific printery.

A total of 4,320 measurements were made: triplicates of 72 VOCs in 20 locations. Of these, 53.2% were at the MDL. The CV and SD of the triplicates are in the supplementary material (see Supplement Tables 3, 4 and 5). After taking the mean of the field triplicates, 1,440 observations were obtained. Of these, 95.1% (1,370) of observations had CV<20%; the remainder were discarded. Five of the 72 targeted VOCs were measured at the MDL or CV≥20% in all 20 locations: methyl iodide, methyl bromide and methyl vinyl ketone (MVK), 1,2,4-trichlorobenzene (TMB) and ethyl propyl ketone (EPK). Removing these left 1,277 observations, of which 49.6% were above the MDL. This left 634 observations of 67 VOCs.

Unusually high concentrations (relative to other locations) of CFC-114, vinyl chloride and propene were measured in the office of the store supervisor in the government printery (4.2, 2.3, and 0.5 ppm, respectively). The office was not used for the storage of chemicals. The supervisor later reported using an insecticide aerosol on the sampling day, so the results from this sampling location were discarded. Butadiene was only observed above the MDL in this location. This left 619 observations of 66 VOCs above the MDL with CV<20%.

For the purposes of visualization, observations of VOCs with maximum concentration above 5 ppb are displayed in Figure 1. Methyl and ethyl alcohol join isopropyl alcohol as the VOCs with the greatest observed concentrations. Next largest are aromatics, CFCs and aldehydes. Some VOCs had greatest concentrations in offset locations, such as 1,3,5-TMB, bromoform and acetone, and other VOCs had greatest concentrations elsewhere, such as isopropyl alcohol, CFC-114 and vinyl chloride.

INSERT FIGURE 1 HERE

Government printery

In the government printery, CTP, design, offset/commercial binding and maintenance/ commercial binding were sampled on one day and all other locations were sampled on a second day (because only 5 triplicate canister sets were available). The loading bay door in the maintenance/commercial binding area was partially open for two hours around noon on the sampling day, but the LEV system was not used at all that day. The loading bay door in offset/commercial binding was closed all day. The UV laminating machine was also not used that day, and had not been used for some time due to maintenance issues. The LEV system in the CTP area was also not used that day. On enquiry, it was found that the LEVs were rarely used as they were too noisy.

A total of 42 VOCs were observed above the MDL (n = 206) in at least one location in this printery (see Table 3). Two unusual observations were made: the concentration of CFC-12/HCFC-22 in CTP was 77 ppb, five times higher than that at other locations in this printery, and the concentration of CFC-114 was 195 ppb in CTP and 120 ppb in digital/photocopy, three times greater than in other locations.

INSERT TABLE 3 HERE

The VOC class with the highest concentrations were alcohols, mostly isopropyl, methyl and less ethyl, in offset/commercial binding, maintenance/commercial binding and decorative binding. The highest concentration of isopropyl alcohol was in maintenance/commercial binding at 2,260 ppb. The open stairwells to the decorative binding area above may be partly responsible for the isopropyl alcohol concentration of 1,200 ppb measured there. Indeed, the VOC concentrations in maintenance/commercial binding had 97% correlation with those in decorative binding area above.

The second most common class was aromatics (all three isomers of TMB, o-DCB, m/p-xylene and toluene) again in offset/commercial binding, maintenance/commercial binding and decorative binding. Concentrations were highest in offset/commercial binding, somewhat lower in the adjacent maintenance/commercial binding area and then lower again in the space above, decorative binding. This suggests that offset was the primary source of the aromatics in these areas.

The locations with lowest concentration and fewest numbers of VOCs were storage and administration, with the main contributors in both locations being alcohols, vinyl chloride and CFCs. Storage was in a separate building from printing activities. Administration was upstairs relatively removed from printing activities and likely saw little foot traffic.

Scientific printery

In the scientific printery, all locations were sampled on the same day. The loading bay door in offset was closed all day and the LEV system was not used. It wasn't typically used, again, due to noise. The doors between most work areas were usually left open.

A total of 63 VOCs were measured at concentrations at or above the MDL (n = 213) in at least one location in this printery (see Table 4). Acrolein was measured at an unusually high concentration, compared to other locations, in storage (16 ppb). CFC-12/HCFC-22 in CTP was more than ten times higher than that at other locations in this printery, 950 ppb.

INSERT TABLE 4 HERE

The VOC class with the highest concentrations were alcohols, mostly methyl and ethyl, in offset, binding/photocopy and administration/design, although at levels much lower than those seen in the government printery. Concentrations in these three locations were similar, perhaps because the entrance into these areas was through a common lobby that carried a lot of foot traffic.

The second most common class were aromatics, (all three isomers of TMB and DCB, toluene, ethylbenzene, m/p-xylene, benzyl chloride), again in offset, binding/photocopy and administration/design. The concentrations of these aromatics were three times higher in offset than the other two locations, suggesting that offset was the source of these VOCs. The toluene concentration of 100 ppb in offset was by far the highest toluene concentration observed in this study.

The location with lowest VOC concentrations was CTP, apart from the one unusually high CFC-12/HCFC-22 measurement, probably because it was housed in a building separate from the main printing activities.

Newspaper printery

At the newspaper printery all locations were sampled on the same evening. The loading bay door in the offset area was open for one hour at the end of the shift for outgoing deliveries. The IEF system in the offset area and the LEV in the CTP were in use for the entire shift.

A total of 53 VOCs were measured at concentrations at or above the MDL (n = 209) in at least one location in this printery (see Table 5). The only unusual observation was of high CFC-114 in CTP (83 ppb), double that in other locations.

INSERT TABLE 5 HERE

The class with the highest concentrations was again alcohols, mostly methyl and ethyl and less isopropyl. In all locations other than archive, high concentrations of methyl alcohol were seen (approximately 2 ppm), and in administration and CTP, ethyl alcohol concentrations were also high (approximately 1 ppm).

The second most common class was again aromatics. Nearly all targeted aromatics were observed in all locations. The concentrations of ethylbenzene in this printery were considerably higher than at the other two printeries, and offset had concentrations of m/p-xylene and styrene/o-xylene, ten times that seen at the other printeries. 1,2,3-TMB, chlorobenzene and benzyl chloride were at their highest concentrations in the CTP and administration area.

Nearly all VOCs were measured at concentrations above the MDL at all locations, suggesting that, despite the barrier the stairwell doors and elevator provided, the lack of access to outdoor air may have contributed to the relative homogeneity across locations. Indeed, there was a 98% correlation between VOC concentrations in administration and CTP, both situated on level 1 separated by a glass partition. The location with lowest VOC concentrations was archive, unsurprisingly, since it was on the second level of the building further separated from offset and sharing less foot traffic with other work areas.

Probable sources of VOCs

Table 6 contains the maximum concentrations and across location CV for each VOC and printery. It also contains the possible source summary from previous literature for each VOC from Supplement Table 2.

For the government printery, the max VOC cutoff of 15 ppb was selected and the across location CV cutoff of 50% was selected. From this we concluded that TMBs, methyl, ethyl and isopropyl alcohol, toluene, m/p-xylene, benzyl chloride, o-DCB, acetone, MEK, CFC-114, CFC-12/HCFC-22, vinyl chloride, bromoform, heptanal and octanal (18 VOCs) all had relatively high concentrations and across location CV, indicating a high likelihood of use inside the printery. Of these, 1,3,5 and 1,2,4-TMB, toluene, m/p-xylene, isopropyl alcohol and acetone were expected, by comparison to previous printery studies (see Supplement Table 1). By comparing this to previous Kuwait outdoor air quality studies (see Supplement Table 2), of these only bromoform, CFC-114, vinyl chloride, methyl and ethyl alcohol may have been partly sourced from outdoor sources. By comparing VOC concentrations from previous printery studies to those of the government printery (see Supplement Figure 1), we found that 1,3,5 and 1,2,4-TMB concentrations were around the same level, but that of 1,2,3-TMB and MEK were greater. All three isomers of DCB also had greater concentrations than previously. More positively, acetone and methylene chloride concentrations were less than previously reported.

INSERT TABLE 6 HERE

For the scientific printery, the max VOC cutoff of 15 ppb was selected and the CV cutoff of 40% was selected. The lower CV cutoff was needed because the four locations in the main building were fairly homogeneous, in comparison to the government printery. We found that at the scientific printery more VOCs appeared to be in use than at the government printery: cyclohexane, methylene chloride, chloroform, bromoform, CFC-114, CFC-11, CFC-12/HCFC-22, vinyl chloride, ethylbenzene, m/p-xylene, TMBs, toluene, benzyl chloride, o-DCB, methyl and ethyl alcohol, tert-butyl methyl ether (MTBE), acetone, hexanal, heptanal and octanal (23 VOCs). Of these, methylene chloride, 1,3,5 and 1,2,4-TMB, toluene, m/p-xylene, isopropyl alcohol and acetone were expected (see Supplement Table 1). By comparing this to previous Kuwait outdoor air quality studies (see Supplement Table 2), of these only methylene chloride, bromoform, CFC-114, CFC-11, vinyl chloride, methyl and ethyl alcohol may have been partly sourced from outdoor sources. By comparing VOC concentrations from previous printery studies to those of the scientific printery (see Supplement Figure 2), we found that 1,3,5 and 1,2,4-TMB concentrations were around the same level, but that of CFC-12/HCFC-22, cyclohexane, vinyl chloride, CFC-11, 1,2,3-TMB and o-DCB were greater. More positively, acetone and methylene chloride concentrations were less than previously.

It is notable that the across location CVs of VOC concentrations in the newspaper printery were generally lower than those of the other two printeries, an indication of the relatively homogeneous atmosphere in this printery. So for this printery, the max VOC cutoff of 30 ppb was selected and the CV cutoff of 30% was selected. Cyclohexane, bromoform, CFC-114, vinyl chloride, trans-1,3-DCPe, ethylbenzene, o-xylene/styrene, m/p-xylene, 1,3,5-TMB, 1,2,3-TMB, toluene, chlorobenzene, benzyl chloride, DCBs, methyl and ethyl alcohol, acetone, MEK, ethanal, hexanal, heptanal, octanal and nonanal (25 VOCs) had high across location CV and high concentrations, indicating probable use in this printery. Of these, ethylbenzene, o-xylene/styrene, m/p-xylene, 1,3,5-TMB, toluene, isopropyl alcohol and acetone were expected (see Supplement Table 1). Bromoform, CFC-114, vinyl chloride, toluene, methyl and ethyl alcohol and acetone may have been partly sourced from outdoor sources. By comparing VOC concentrations from previous printery studies to those of the newspaper printery (see Supplement Figure 3), we found that 1,3,5 and 1,2,4-TMB concentrations were around the same level, but that of cyclohexane, vinyl chloride, 1,2,3-TMB, all three DCB isomers and MEK were greater. More positively, acetone concentrations were less than previously reported.

Exposure to ototoxic VOCs relative to OELs

Six VOCs classified as ototoxic by EASHW were measured above the MDL in this study: toluene, p-xylene, styrene, ethylbenzene, n-hexane, and trichloroethene (TCEe). Figure 2 depicts the exposure, as a percentage of the OEL, totalled over these substances only. The highest percentages were seen in the newspaper printery (1-3% of OEL); their locations (other than archive and storage) had percentages greater than all locations at the other printeries. The largest contributor was ethylbenzene, followed by m/p-xylene, toluene and styrene/o-xylene. All of these VOCs were expected to be found in the study printeries, and we deemed all likely to be in use in at least one study printery. Of these only toluene may have been partly sourced from outdoors.

INSERT FIGURE 2 HERE

Exposure to carcinogenic or probably carcinogenic VOCs, relative to OELs

Four VOCs classified by IARC as carcinogenic were measured above the MDL in this study, vinyl chloride, propylene dichloride, benzene and TCEe, and three were classified as probably carcinogenic were measured above the MDL, benzyl chloride, ethylene chloride and ethylene dibromide. Figure 3 depicts the exposure as a percentage of the OEL totalled over these substances only. Four locations spreading throughout all three printeries were at 15-20% of OEL. Vinyl chloride almost entirely accounted for the exposure total relative to OEL, with very little contribution by the other group 1 VOCs. In the government printery, CTP and digital/photocopy, had vinyl chloride exposure close to 15% of OEL alone. Of the group 2A VOCs, benzyl chloride was the largest contributor, meeting nearly 5% of its OEL in several newspaper locations. Both vinyl chloride and benzyl chloride were deemed to likely be in use in all three study printeries. Only vinyl chloride may have been partly sourced from outdoors.

INSERT FIGURE 3 HERE

Exposure to hazardous VOCs relative to OELs

Thirty six VOCs measured above the MDL this study were classified as hazardous materials by the USEPA. Figure 4 depicts the exposure as a percentage of the OEL totalled over these substances only. Nine of hazardous VOCs were detected at over 1% of the OEL in at least one sampling location: bromoform, acrolein, vinyl chloride, ethylene dibromide, benzyl chloride, trans-1,3-DCPe, chloroform, ethylbenzene, methyl alcohol. The offset areas of the scientific and newspaper printeries had the highest hazardous exposure relative to OEL, 46% and 34%, respectively, in which the largest contributors were bromoform and vinyl chloride. Four more locations had exposure over 23% of OEL. The largest contributors in scientific printery storage were ethylene dibromide, vinyl chloride and acrolein. In the newspaper printery, CTP, administration and storage contributors were bromoform, vinyl chloride and benzyl chloride. Most of these VOCS were deemed likely to be in use. Bromoform, vinyl chloride and methyl alcohol may have been sourced partly from outdoors.

INSERT FIGURE 4 HERE

DISCUSSION

VOCs likely used in all study printeries

The following 14 VOCs were likely used in all three printeries: 1,3,5-TMB, 1,2,3-TMB, m/p-xylene, toluene, o-DCB, benzyl chloride, acetone, heptanal and octanal, methyl and ethyl alcohol, bromoform, vinyl chloride and CFC-114 (ordered from highest concentration to lowest). Of these, the last five may have been sourced in part from the outdoors. The newspaper printery had the highest concentration of 1,3,5-TMB found in this study: 225 ppb in offset. They also had 1,2,3-TMB at 50 ppb in CTP and 1,2,4-TMB at 15 ppb in CTP and offset. The scientific printery had lowest total aromatics, but considerable concentrations of TMBs: 170 ppb of 1,3,5-TMB, 50 ppb of 1,2,4-TMB and 35 ppb 1,2,3-TMB in the offset area. In the government printery, the most prevalent aromatics were 1,3,5-TMB and 1,2,4-TMB, both 130 ppb, in offset and 1,2,3-TMB at 50 ppb also in offset. Three printery air quality studies in the US between 1995 and 2007 found considerable amounts of 1,3,5-TMB and 1,2,4-TMB (Wadden et al. 1995, Batterman et al. 2002, Rodriguez and Gibbins 2007). In fact, the study of Batterman et al. (2002) found that one of the solvents used had 1,2,4-TMB as a major ingredient, and that it accounted for 66% of the total VOCs in that printery; 1,3,5-TMB accounted for 15% of total VOCs. In a review of stated ingredients in printery products, Sutton et al. (2009) found that 1,2,4-TMB was commonly used in blanket wash. On the other hand, documented use of 1,2,3-TMB was sparse. In comparison to previous reports then, the study printeries were using more 1,2,3-TMB than expected. There is reason to take note of increased TMB usage in printeries since animal studies have demonstrated neurotoxic effects all three TMB isomers (Korsak and Rydzynski 1996, Wiaderna et al. 2002, Gardner 2012).

The newspaper printery had the highest concentrations of m/p-xylene (640 ppb); markedly less in the other two printeries (scientific 30 ppb, government 26 ppb). Finding xylene was not a surprise, since its use has been extensively studied in printeries (see Supplement Table 1). Again, concern about xylene use, typically mixed isomers, is warranted since exposure can lead to neurotoxic (Nylén and Hagman 1994, Kandyala et al. 2010) and hepatic effects (Sancini et al. 2014). Furthermore, p-xylene has been classed as ototoxic for some time (Campo et al. 2009).

The highest concentration of toluene observed in this study was 100 ppb at the scientific printery. At the newspaper printery, with the web-fed offset machine, the toluene concentration was 60 ppb, government printery 30 ppb. These levels were, on average, somewhat lower than those reported in previous printery studies. This is good news since toluene has been shown to detrimentally effect reproduction (Taskinen et al. 1989), liver function in printery workers (Sancini et al. 2014) and, in rats, it has been shown to cause lipid peroxidation in the hippocampus (Mattia et al. 1993). Another study of printery workers suggested that chronic exposure to toluene may be implicated in genetic damage (Aksoy et al. 2006). Furthermore, it was been classified as ototoxic by the three major reviews of ototoxic substances (Campo et al. 2009, Johnson and Morata 2010, Vyskocil et al. 2012).

Concentrations of o-DCB were similar across the three printeries: 50 ppb at the newspaper printery, 44 ppb at the government printery and 34 ppb at the scientific printery. This was unexpected, since reports of DCB use in printeries is sparse. o-DCB was only reported once, by Wadden (2001) as a small percentage of total VOCs. In 2005, Leung only found small amount of p-DCB and no m- or o-DCB (2005). Increased usage of DCBs in printeries would be a cause for concern since severe hepatotoxic effects of o-DCB exposure have been observed in rats (den Besten et al. 1991, Elovaara 1998).

Benzyl chloride concentrations were 52 ppb at the newspaper printery, 30 ppb at the scientific printery and 15 ppb government printery. This finding was unexpected since benzyl chloride was not mentioned in any printery studied uncovered by our extensive literature review. It is classified by IARC as probably carcinogenic, and in rats exposure has been shown to cause leucopenia (Brondeau et al. 1990).

Acetone was present in all printeries at concentrations between 50 and 100 ppb. This finding was expected since its use in printeries has been previously documented (Kiurski et al. 2012, Zheng et al. 2013). This is another VOCs worth continued attention since acetone is neurotoxic, and these effects have been reported in occupational settings (Mitran et al. 1997). On a positive note, the acetone concentrations seen in this study were in general less than those reported in previous studies.

Heptanal and octanal were found mostly in the offset areas: heptanal was 50 ppb in government, 250 ppb in scientific and 30 ppb in newspaper; octanal was 25 ppb government, 60 ppb in scientific and 100 ppb in newspaper. This finding was unexpected since the use of any aldehydes in offset printing has only been documented twice: ethanal (Gioda and de Aquino Neto 2002), and nonanal (Vilcekova and Meciarova 2016). Tuomi et al. (2000) found several aldehydes, including heptanal and octanal, but that was in a study of laser printers only. The literature on the health effects of these aldehydes is sparse, other than octanal which was shown to cause lung disease in vitro (Song et al. 2014). Aldehydes are not rated as hazardous materials by the USEPA, nor carcinogenic by IARC. No ACGIH TLV, NIOSH REL nor OSHA PEL has been set for hexanal, heptanal, octanal or nonanal. This may indicate a lack of knowledge about these increasingly used VOCs.

Alcohols were the most prevalent class of VOCs; isopropyl alcohol was expected. The government printery had high concentrations of the three main alcohols: methyl (2,000 ppb), ethyl (1,000 ppb) and isopropyl alcohol (2,200 ppb). The newspaper printery had high concentrations of methyl (2,800 ppb) and ethyl alcohol (1,000 ppb). In the scientific printery, alcohol concentrations were considerably lower (≤150 ppb) and consisted of mainly methyl and ethyl alcohol. Some of these alcohols probably arose from non-printing specific activities: Al-Mudhaf et al. (2013) showed that ethyl alcohol was abundant in Kuwaiti office buildings, which can emit from hand sanitizers (MacLean et al. 2017) and dry erase markers (Castorina et al. 2016). Some may have come from outdoors, although the highest concentration of outdoor alcohol was only 25 ppb. On the other hand, isopropyl alcohol has been a key ingredient in fountain solutions for some time (Wypych 2001), which explains why it would be found in offset areas. The UKHSE has advised printery workers to keep isopropyl use low (2017), advice the newspaper and scientific printeries appear to have heeded. SDSs in the newspaper printery indicated that they used a low isopropyl alcohol fountain solution. The consequence of this isopropyl alcohol reduction may be the increased use of methyl alcohol, which no recent printery study has sought to measure, despite it being cleared for regulated emission from US printeries some years ago (Wypych 2001). The only mention we found of recent methyl alcohol use in a printery was of it being found in waste water (Prica et al. 2016). It is advisable to include methyl alcohol in future printery studies since long term methyl alcohol exposure can result in headaches and blurred vision (Kavet and Nauss 1990) and there is some evidence of adverse effects in the liver and kidney of rats (Aarstad et al. 1984).

Only one previous study in our literature review mentioned bromoform: a Kuwaiti outdoor air study (Al-Salem and Bouhamrah 2006). The government printery had bromoform measured at low levels (<15 ppb) at most locations. The scientific printery and the newspaper printer had some locations with low bromoform (CTP in scientific printery and archive in newspaper printery), but much higher bromoform in their offset locations (85-105 ppb). Desalination plants and coastal power plants release considerable amounts of bromoform directly into the atmosphere (Quack and Wallace 2003). A study of Kuwaiti desalination plants confirmed bromoform was released into the atmosphere (Ali and Riley 1989). The scientific printery and, to a lesser extent, the newspaper printery are near the ocean and downwind from a power and desalination plant. Therefore, some bromoform in the printeries probably came from outside. Bromoform has also been found in Kuwaiti tap water (Saeed et al. 1999, Al-Mudhaf and Abu-Shady 2008). Now, air quality studies on indoor swimming pools have shown good correlation between bromoform concentrations in the water and in the air (Tardif et al. 2016). In residential settings, bromoform enters indoor air when tap water is used, for example during dish washing and bathing (Nuckols et al. 2005). So the higher concentrations of bromoform in some printery locations may be due to water use during washing, or from its use as an ingredient in the fountain solution (Rossitza 2015). There is good reason for concern about this surprising finding: bromoform is a USEPA HAP and has been shown to be harmful to the liver and kidney in a drinking water study (Condie et al. 1983).

Vinyl chloride concentrations inside the printeries were similar to those previously reported in outside air in Kuwait. In fact, Al-Hayi and Pillai (2012) took air samples near an oil refinery and noted that vinyl chloride was the most abundant halogenated VOC found in their study. In Yassin and Pillai's study of Kuwait schools (2018), vinyl chloride was found in high concentrations in both indoor and outdoor air. However, markedly high concentrations were found in particular locations in all three printeries. For example, the government printery had two locations with higher concentrations (digital/photocopy and CTP 130-140 ppb) than others (50 ppb), indicating indoor use. In 1994 the USEPA listed vinyl chloride as being used in printeries (Exhibit 6, USEPA 1994). Back in 1975, vinyl chloride was determined to have caused angiosarcoma of the liver in printery workers (Herbert 1975) and is now an IARC class 1 carcinogen. It was observed more recently in just one printery study, but at less than 2 ppb (Leung et al. 2005). Vinyl chloride can be present in tap water (Walter et al. 2011), so it is possible that its presence in the printeries is from washing/rinsing with water. Consequently, it would be of interest to include vinyl chloride in future printery studies. Interestingly, concentrations of vinyl chloride and CFC-114 were very similar in all three printeries.

High concentrations of CFC-114, CFC-12/HCFC-22 and CFC-11 were found in the study printeries, mostly in the CTP areas. The most prevalent was CFC-114. Concentrations of 40-50 ppb were found in many sampling locations, not markedly different to that reported previously in Kuwaiti outdoor air (Al-Hayi and Pillai 2012). However, the highest concentrations were found in CTP (190 ppb) and digital/photocopy (120 ppb) in the government printery, and the CTP (85 ppb) in the newspaper printery. Globally, the primary use of CFC-114 was as a specialized refrigerant that accounted for only a small percentage of atmospheric chlorine in the 1980's (Prather and Watson 1990), so it seems unlikely to be sourced from leaking AC. So, it is possible that a new use for it has been found in printing activities. We note that increasing emissions of CFC-114 have recently been detected from the Chinese mainland from as yet unknown sources (Vollmer et al. 2018).

CFC-12 was one of the most commonly used CFC for AC in the 1980's (Prather and Watson 1990) and CFC-12 and HCFC-22 are among the most abundant CFC's in the atmosphere (Zhang et al. 2017). In the scientific and government printeries CFC-12/HCFC-22 was found in the CTP areas, at 950 ppb and 80 ppb, respectively. It seems likely that leaking AC units were the source of at least some of the CFC12/HCFC-22, as a study of office air quality in Kuwait did reveal evidence of HCFC-22 leaking from AC systems (Al-Mudhaf et al. 2013).

In the scientific printery CFC-11 was found at concentrations of 40-50 ppb in the main printing building, but less than 10 ppb in CTP. Global production was reduced to near zero due to the impact of the Montreal Protocol. Previously it was widely used as a blowing agent in rigid polyurethane building and appliance insulation and some CFC-11 is still being emitted from these foams as they age (McCulloch et al. 2001). So it is possible that aging insulation is the source of at least some of the CFC-11. Recently however, increasing CFC-11 emissions have been reported in South-East Asia, suggesting new production not in line with the Montreal Protocol (Montzka et al. 2018). As with CFC-12/HCFC-22, the localized high concentrations suggest another source, such as ingredients in a cleaning solution, as CFC-113 once was (it too has had increasing emission in South-East Asia in recent years (Adcock et al. 2018)). CFCs 11, 12 and 113 have been reported twice in a printery, but both were all at concentrations less than 2 ppb (Leung et al. 2005, Caselli et al. 2009).

VOCs likely used in some study printeries

Each printery had some VOCs likely in use not found in use in the others. Additional VOCs in the government printery were 1,2,4-TMB, isopropyl alcohol, MEK and CFC-12/HCFC-22 (18 in total). Additional in the scientific printery were 1,2,4-TMB, ethylbenzene, MTBE, cyclohexane, methylene chloride, chloroform, hexanal and CFC-11, CFC-12/HCFC-22 (23 in total). Additional in the newspaper printery were ethylbenzene, o-xylene/styrene, chlorobenzene, m and p-DCB, cyclohexane, trans-1,3-DCPe, MEK, ethanal, hexanal, nonanal (25 in total).

Ethylbenzene was found in the newspaper printery offset area at 320 ppb, the CTP area at 220 ppb and in administration at 100 ppb. Its use in printeries has been extensively documented. Ethylbenzene has endocrine disrupting properties (Bolden et al. 2015 and can cause hearing loss {Liu, 2013 #102). It was judged to be ototoxic or probably ototoxic by EASHW, NEG and IRSST.

o-Xylene/styrene was found in the newspaper printery at 210 ppb in the offset area and 110 ppb in CTP and 70 ppb in administration. The use of xylenes in printeries has been extensively documented, but styrene, less so. Styrene has neurotoxic effects (Cherry and Gautrin 1990). It was judged to be ototoxic by EASHW, NEG and IRSST and possibly carcinogenic by IARC. o-Xylene has been shown to cause kidney damage in rats (Morel et al. 1998).

Cyclohexane was found in the scientific printery offset area at 180 ppb. It is a solvent and has been measured in a few previous printery studies, but found at low concentrations (Caselli et al. 2009). It has been measured in both indoor and outdoor air in Kuwait but at less than 15 ppb (Yassin and Pillai 2018). It has beem considered a safer alternative to benzene and toluene, but adverse health effects are still a concern (Campos-Ordonez and Gonzalez-Perez 2016).

Hexanal was found at 50 ppb in the scientific printery and 70 ppb in the newspaper printery. Nonanal was found at 20 ppb in the scientific printery and 30 ppb in the newspaper printery. Nonanal was reported in only one previous printery study (Vilcekova and Meciarova 2016); we found no reference to hexanal in previous printery studies. Hexanal can cause irritation to the eyes and nose in humans (Ernstgård et al. 2006). Both hexanal and nonanal can cause pulmonary toxicity in rats (Choi et al. 2013, Cho et al. 2017).

Methylene chloride was found in the scientific printery at 70 ppb in storage and 50 ppb in offset. It is a solvent and was found in numerous previous printery studies (Crouch and Gressel 1999, Lee et al. 2009). Indeed, the carcinogenic effect of methylene chloride has been reported among printery workers, where it was used to remove ink from rollers (Kumagai et al. 2013). Methylene chloride is also used in paint strippers and has even been lethal in occupational settings (Fechner et al. 2001). It has been associated with multiple myeloma (Liu et al. 2013) and was classified as probably carcinogenic by IARC. It has been found in several Kuwaiti outdoor air studies previously, so some methylene chloride may have come from outdoors.

MEK was found at 45 ppb in the government printery offset area. It is a commonly used industrial solvent and has been measured in some recent printery air studies (Zheng et al. 2013). MEK has been listed as an ingredient in press cleaning solutions (Crouch and Gressel 1999) and printing inks (Batterman et al. 2002). According to the Agency for Toxic Substances and Disease Registry (ATSDR), it is irritating to the respiratory tract (ATSDR 1992).

Chloroform was found in the scientific printery offset area at 40 ppb. Chloroform has been measured in one recent printery air study (Leung et al. 2005). It is a by-product of tap water disinfection (Jo et al. 1990), so it is possible that its source is from washing, as we posited for bromoform. Chloroform has been associated by renal and hepatic tumours in mice (Meek et al. 2002) and is classified as possibly carcinogenic by IARC, so further research into its possible use in printeries is warranted.

MTBE was found at 30 ppb in the scientific printery offset area, which is within the range of a detectable unpleasant odour (Davis and Farland 2001). The only report of its use in a printery was a study of VOCS in the emission stack (Vega et al. 2000). It has been used as a gasoline additive for some time, and while it is present in auto emissions (Chang et al. 2003), no outdoor air study in Kuwait has reported measuring MTBE. Its health effects have been extensively studied: headaches and nausea can result from acute inhalation exposure, where chronic exposure has led to kidney effects in rats (ATSDR 1996).

Chlorobenzene was found at 20 ppb in the newspaper printery in the CTP and administration areas. Its main use has been as an industrial solvent, although we found no reference for its use in printing specifically. At low concentration levels chlorobenzene has been shown to increase risk of bronchitis (Diez et al. 2000).

trans-1,3-DCPe was found at around 20 ppb in scientific and newspaper printeries. It is a soil pesticide that is carcinogenic in rats (Yang et al. 1986) and has adverse health effects in an occupational setting (Brouwer et al. 1991). No previous report of use in printing industry was found. In fact, it was tested for by Leung but not found (2005). It has been found in well water near where pesticides were in use (Maddy et al. 1982), but this seems an unlikely route in this study.

Expected VOCs not found in the study printeries

The low concentrations of benzene (maximum 8 ppb) provides evidence that efforts to reduce its use have been effective (Novick et al. 2013). This is good news since benzene exposure has been linked to leukaemia (Snyder 2002) and in printery workers, it has been shown that benzene exposure may cause cytogenetic damage (Yadav and Chhillar 2002).

n-Hexane concentrations were also very low (< 2 ppb), apart from the offset area in the scientific printery, where it was 16 ppb. This is good news since n-hexane has been demonstrated to cause polyneuropathy in rats (Krasavage et al. 1980) and neuropathy in printery workers (Chang 1987). More recently, evidence has been surfacing concerning its possible ototoxicity (Vyskocil, Leroux, Truchon, Gendron, et al. 2008).

Ototoxic VOCs

Ototoxic VOCs were present in all printeries, consisting mostly of ethylbenzene, and to a lesser extent m/p-xylene, toluene and styrene/o-xylene. The highest concentrations were in the newspaper printery, totalling between 1-3% of the OELs. Ethylbenzene is the only VOC where its ototoxicity was cited in the setting of its TVL (ACGIH 2017). The ototoxicity of ethylbenzene has been confirmed in animal models (Cappaert et al. 2000, Fechter et al. 2007), and a recent study showed more hearing loss in workers exposed to ethylbenzene than to noise alone (Liu et al. 2013). p-Xylene has been confirmed to be harmful to the cochlea in rats (Maguin et al. 2006) and to also cause outer hair cell loss (Gagnaire et al. 2007).

The synergistic effects of some ototoxic substances with noise is of increasing concern, including ethylbenzene (Cappaert et al. 2000, Cappaert et al. 2001, Vyskocil, Leroux, Truchon, Lemay, et al. 2008), styrene (Morioka et al. 2000, Mäkitie et al. 2003, Lataye et al. 2005) and toluene (Lataye and Campo 1997, Brandt-Lassen et al. 2000, Lund and Kristiansen 2008). Recent studies in printeries have found evidence that concentrations of toluene and styrene below the OEL, when combined with noise below recommended limits, can have ototoxic effects (Chang et al. 2006, Juárez-Pérez et al. 2014). We note that noise exposures above the recommended 85 dB(A) were previously observed in the study printeries (Alabdulhadi et al. 2018), indicating that these workers may be at risk of hearing loss.

Carcinogenic or probably carcinogenic VOCs

Carcinogenic and probably carcinogenic VOCs were present in all three printeries and exposures were greater than 4% of the OEL in all sampled locations. Ten of the 20 locations were over 10% of OEL, with four of those exceeding 15% of OEL. These levels were primarily driven by concentrations of vinyl chloride and benzyl chloride. Vinyl chloride was present in all sampling locations, is an IARC class 1 carcinogen, and at some locations reaching almost 15% of OEL. The carcinogenicity of vinyl chloride has been well documented (Waxweiler et al. 1976, Kielhorn et al. 2000, Bolognesi et al. 2017) and its effects on the circulatory system have been also drawing recent attention (Lopez et al. 2013). Benzyl chloride is classified as probably carcinogenic by IARC, with some evidence of carcinogenic its effects in the workplace (Sakabe et al. 1976, Booth et al. 1983).

The finding of benzyl chloride was unexpected as it was not reported in any previous printery study. In this study it was found in all three study printeries. Some vinyl chloride was likely from outdoor sources, but in some sampling locations there was markedly higher concentrations than one would expect from diffusion from outside air alone. Also, vinyl chloride concentrations were surprisingly similar to that of CFC-114, which is not a CFC commonly used in AC systems. Given that vinyl chloride is carcinogenic, and CFCs are banned by the Montreal protocol, these VOCs warrant inclusion in future printery air quality studies.

Hazardous VOCs

Nine of hazardous VOCs were detected at over 1% of the OEL in at least one sampling location, of which the largest contributor was bromoform. Three of the 19 sampled locations, the scientific printery offset, and the newspaper offset and CTP, had bromoform concentrations between 10-20% of OEL. No studies on health effects of bromoform inhalation exposure in humans have been published (Section 3.2.1, Risher et al. 2005). This is concerning since the source in the printery may be from washing with desalinated water containing bromoform, and partly from outside air.

At one printery, a relatively high concentration of acrolein was detected in the storage area, ten times higher than concentrations elsewhere, most of which were only just above the MDL. Smoking is a significant source of acrolein in indoor air (Gilbert et al. 2005), and at that printery, the indoor smoking ban was not strictly enforced. We note that no workers were permanently stationed in the storage area where the acrolein was found and that smoking where highly flammable materials are stored is extremely dangerous.

Recommendations for management

Remove non-essential sources of VOCs, for example, strictly enforce a ban on smoking and the use of aerosols, air fresheners and hand sanitizers. Open exterior windows and doors whenever possible.

Keep up-to-date SDSs in places easily viewed by workers, such as the break room, and where VOC containing products are stored and used. Highlight important features such as the avenue of exposure and the risks to human health. Commence a hazards communication program (UKHSE 2002, OSHA 2018) to improve worker awareness: a 2005 study in printeries showed that less than half of the workers had good knowledge about the harmful effects of VOCs, and, furthermore, that adherence to key safe practices was positively associated with being provided chemical information and informed about safety precautions by supervisors (Yu, Lee, and Wong 2005).

Utilize already existing barriers, that is, keep doors between work areas closed at all times. Renew weather-stripping around doors to ensure good seal. Install automatic door closers.

Ensure AC systems for production and non-production areas are completely separate, to minimize the number of workers unknowingly at risk.

Utilise existing LEV and IEF systems. Multiple studies have confirmed the utility of LEVs in reducing VOC exposures in printeries (Crouch and Gressel 1999, Gegic and Savic 2013), so these systems need to be used consistently. Have a planned regular maintenance schedule for the AC, LEV and IEF systems, including the detection of CFC leaks so as not to unwittingly add to overall VOC load. Record these activities in a maintenance log. Find the causes of noise in the LEV systems and apply engineering controls to reduce it.

Create positive pressure in non-production areas by having a greater air supply than exhaust, so that air does not flow into those spaces when doors are opened. Similarly, create negative pressure in production areas to prevent the flow of airborne contaminants out of the source area. A 2017 study showed that negative pressure created by exhaust fans in attached residential garages reduced VOC concentrations inside the home by 50% (Mallach et al. 2017). A push-pull ventilation could be added to LEV systems to improve efficiency (Leung et al. 2005). Consider adding the capability to use the AC system to completely purge all work areas with outdoor air overnight, particularly when temperatures are moderate (Smith and Smith 2009).

Switch to low VOC products, such as vegetable-oil or water based products. Fountain solutions typically contained up to 10% isopropyl alcohol, but recently solutions have been developed that are alcohol free (Rossitza 2015). Offset printing inks that use vegetable oil rather than mineral oils have been developed (Roy et al. 2007, Park et al. 2013). The use of ultraviolet-cured inks have been shown to significantly reduce VOC exposure (Holme 2005, Robert 2015). A 2009 study showed significant reduction in VOC concentrations when using this type of ink compared to conventional ink (Godoi et al. 2009). Safer alternatives to clean-up solvents are also available (Sutton et al. 2009, Kikuchi et al. 2011).

Recommendations for Kuwaiti regulators

KEPA sets environmental regulations, which have not been updated since 2001 (Appendix 3(2) & 3(3), KEPA 2015). We provide the following suggestions for a future update. Currently AC is required in printeries. We suggest the regulations specify that all work areas, including production, be air conditioned with a specific percentage of outdoor air, require that it be operational during working hours and that there be a written maintenance and inspection program. We further suggest that AC systems for production areas be completely separate from those of non-production areas to help isolate contaminant sources. Currently, for newspaper printeries, LEV systems are required to have charcoal filters. We suggest that this be extended to any offset printery LEV and exhaust stack. Currently, LEV required is in production areas. We suggest that it be required to be operational during working hours, and additional use post-shift be recommended. In addition, there be a written maintenance and inspection program for LEVs.

Current regulations require appropriate information be available for storage of hazardous waste (Article 30, Items 6 & 7, KEPA 2001). We suggest similar regulations for pre-consumption storage of substances with hazardous ingredients. This can be achieved by requiring the display of up-to-date SDSs of all products where they are stored, used and discarded.

KEPA regulations currently recommend replacing cleaning fluids with white spirit. White spirit is a complex hydrocarbon solvent, still being studied to evaluate health risks from occupational exposure (Ernstgård et al. 2009), and no studies of possible carcinogenic risks have been carried out (McKee et al. 2018). We recommend that low VOC printery products be required in Kuwait, to be achieved within a specified timeframe.

We suggest the appropriate authority start a printery management education program. In this study managers reported having limited knowledge of alternative low VOC products, something that has likely inhibited their uptake. Similarly, lack of information may be behind incomplete compliance with the Montreal Protocol.

Trade secrecy is a motivation for producers to keep the ingredients of printing products unknown. But hazardous, especially ototoxic and carcinogenic, substances should be required to be disclosed to the end user so that workers are not unknowingly exposed. Recent research has shown that not all hazardous ingredients are always listed on SDSs (Tsai et al. 2015). We suggest KEPA establish a program to test printing products in use, and inform managers and workers of the actual hazardous ingredients.

Study strengths and limitations

This study is one of the first to measure airborne concentrations of VOCs in non-production areas of printeries, particularly areas utilizing new technology, such as digital printers and CTP. Furthermore, we targeted 72 VOCs commonly found in industrial settings, the largest number assessed in a printery study, and all but four were found at concentrations above the MDL. Another strength of this study was the use of the evacuated canister sampling method, USEPA TO-14A and TO-15. This methodology allows for simultaneous testing of multiple VOCs and good recovery of very VOCs, with a very low MDL. One possible reason this method is not used more frequently is the high cost of the equipment and analysis (Chang et al. 2015).

One weakness was that outdoor air samples were not collected due to budgetary constraints. Another is that more VOCs previously reported as being used in the printing industry were not targeted. For example, formaldehyde has been reported in several previous printery studies (Thanacharoenchanaphas, Changsuphan, Nimnual, et al. 2007, Kiurski et al. 2012). Formaldehyde, as well as low weight aldehydes, have also been reported to be emitted from photocopiers and laser writers (Tuomi et al. 2000), which would add to the VOC load of administrators and digital printer operators. Higher weight alkanes, such as nonane, decane, undecane, have been reported to account for over 10% of an offset printery's emissions each (Yuan et al. 2010), meaning that these VOCs alone account for over 30% of emissions. Lower weight alkanes were also found in this study, such as pentane and heptane. Yuan et al. (2010) also found p-diethylbenzene at 4% of emissions, and the isomers of ethyltoluene summed up to close to 3% of emissions. Smaller amounts of propylbenzene were reported by Yuan et al., a VOC that had been reported by Wadden et al. (1995). That study also reported all three isomers of ethyltoluene, n-propylbenzene and isopropylbenzene. Caselli et al. reported ethyltoluene, d-limonene, cyclohexanol, isobutylacetate and n-butylacetate (Caselli et al. 2009). So there is a range of VOCs that could additionally be targeted.

Future printery studies could look at washing activities involving water to determine whether or not desalination or disinfection by-products are adding to the total VOC in printeries. If so, LEVs could be recommended to mitigate this risk. Given the quantity of CFCs found in this study, a study to determine the sources of these VOCs in printeries, particularly those controlled by the **Montreal Protocol**. If they are coming from leaking AC systems, then regulations and/or inspections are needed to reduce this unnecessary risk to workers. If the CFCs are in products used inside the printery, then this strengthens the call for industrial product testing. The reduction of BTEX use raises the question as to whether or not OELs are sufficiently backed up by research for the ingredients that appear to have replaced them, such as low molecular weight aldehydes.

CONCLUSION

This study reports on occupational inhalation exposure to VOCs of workers in the Kuwaiti printing industry. We found that the efforts over recent years to reduce these exposures has been successful, as concentrations of key ototoxic and carcinogenic VOCs were substantially lower than reported in previous studies. However, there is still more to be done, as toluene, ethylbenzene and xylenes were found in this study.

A strength of this study was the large number of VOCs we were able to detect, many more than previous studies. Unfortunately, we found nearly all target VOCs, revealing the large number of VOCs used in printery activities, possibly in part a result of the recent changes in formulations with the removal of more dangerous VOCs. Nearly all VOCs expected to be found, based on a review of the literature, were found in the study printeries.

Non-production areas were sampled along with the offset printing areas, another strength of this study. This revealed exposures to ototoxic, carcinogenic and hazardous VOCs among administrative workers, digital printer operators, and CTP operators. This highlights the need to increase education of printery management and workers of the ventilation principles key in the prevention of unknowing exposure of non-production workers.

Exposure to ototoxic VOCs up to 3% of the OEL were observed in this study, consisting mostly of ethylbenzene, which was likely in use in two of the study printeries. Ototoxic exposures, even those below the OEL, are particularly worrying for workers concurrently exposed to noise over 80 dB(A) since previous research has shown that this combination can result in hearing loss.

Exposure to carcinogenic or probably carcinogenic VOCs was 15-20% of the OEL at four locations across the three printeries, consisting mostly of vinyl chloride and benzyl chloride. Vinyl chloride was partially sourced from outdoors, but was also likely used inside the study printeries. Interestingly, concentrations of vinyl chloride were similar in most sampling locations to that of CFC-114, a CFC banned by the Montreal Protocol and not commonly used as a refrigerant. This unexpected finding suggests further study is warranted to identify the use of these VOCs in printeries.

Exposure to hazardous VOCs up to nearly 50% of the OEL, consisting largely of bromoform and vinyl chloride. Bromoform was found in all the study printeries, sources partially from outdoor air. The higher concentrations inside the printeries may have resulted from the use of the desalinated water for washing. This raises the issue of hazardous VOCs being emitted from sources other than blanket washes, and inks, etc.

ACKNOWLEDGEMENTS

We wish to thank all printeries managers and their workers for their valuable time, effort, and contribution to this study, without whose support this study would not have been possible**.** The research was generously funded by the Government of Kuwait.

REFERENCES

Aarstad, K, K Zahlsen, and O Nilsen. 1984. "Induction of microsomal enzymes after inhalation of methanol." In *Disease, Metabolism and Reproduction in the Toxic Response to Drugs and Other Chemicals*, edited by P Chambers, P Preziosi and C Chambers, 295-297.

ACGIH. 2017. "TLV®/BEI® Guidelines." Accessed Sept 2017. http://www.acgih.org/tlv-bei-guidelines/tlv-chemical-substances-introduction.

Adcock, K, C Reeves, L Gooch, E Leedham Elvidge, M Ashfold, C Brenninkmeijer, C Chou, P Fraser, R Langenfelds, and N Mohd Hanif. 2018. "Continued increase of CFC-113a (CCl3 CF3) mixing ratios in the global atmosphere: Emissions, occurrence and potential sources." *Atmos. Chem. Phys.* 18 (7):4737-4751.

AIHA. 2011. "WEEL® Values." Accessed Sept 2017. https://www.aiha.org/get-involved/AIHAGuidelineFoundation/WEELs/Documents/2011WEELValues.pdf.

Aksoy, H, S Yõlmaz, M Çelik, D Yüzbaşıoğlu, and F Ünal. 2006. "Genotoxicity study in lymphocytes of offset printing workers." *J. Appl. Toxicol.* 26 (1):10-15.

Al-Awadi, L. 2018. "Assessment of indoor levels of volatile organic compounds and carbon dioxide in schools in Kuwait." *J. Air Waste Manag. Assoc.* 68 (1):54-72.

Al-Hayi, M, and A Pillai. 2012. Characterization and identification of volatile organic compounds around a petroleum refinery in Kuwait. Safat, Kuwait: Kuwait Institute for Scientific Research.

Al-Khulaifi, N, H Al-Mudhaf, R Alenezi, A Abu-Shady, and M Selim. 2014. "Seasonal and temporal variations in volatile organic compounds in indoor and outdoor air in Al-Jahra City, Kuwait." *J. Environ. Prot.* 5 (4):310-326.

Al-Mudhaf, H, and A Abu-Shady. 2008. "Trihalomethane levels and their seasonal variation in drinking water produced from thermal desalination in Kuwait." *Open Environ. Sci.* 2:88-100.

Al-Mudhaf, H., A. Abu-Shady, and N. Al-Khulaifi. 2013. "Indoor and Ooutdoor volatile organic compounds at office buildings in Kuwait." *Air, Soil Water Res.* 6:53-72.

Al-Salem, S, and W Bouhamrah. 2006. "Ambient concentrations of benzene and other VOCs at typical industrial sites in Kuwait and their cancer risk assessment." *Res. J. Chem. Environ.* 10 (3):42-46.

Alabdulhadi, A, P Davey, M Boggess, and M Guest. 2018. "Personal noise exposure assessment of Kuwaiti printing industry workers." *Submitted, Int. J. Occup. Saf. Ergon.*

Alhumoud, J, F Al-Ruwaih, S Ali, and M Redhaee. 2012. "Traffic contribution of volatile organic compounds to the air-shed of Kuwait." *Man. Envir. Qual.* 23 (2):204-221.

Ali, M, and J Riley. 1989. "The production of brominated methanes in desalination plants in Kuwait." *Water Res.* 23 (9):1099-1106.

ATSDR. 1992. "Toxilogical profile for 2-butanone." Accessed Sept 2017. https://www.atsdr.cdc.gov/toxprofiles/tp29.pdf.

ATSDR. 1996. "Toxilogical profile for methyl tert-butyl ether." Accessed Sept 2017. https://www.atsdr.cdc.gov/toxprofiles/tp91.pdf.

Bartlett, I, A Dalton, A McGuinness, and H Palmer. 1999. "Substitution of organic solvent cleaning agents in the lithographic printing industry." *Ann. Occup. Hyg.* 43 (2):83-90.

Batterman, S, T Metts, P Kalliokoski, and E Barnett. 2002. "Low-flow active and passive sampling of VOCs using thermal desorption tubes: Theory and ppplication at an offset printing facility." *J. Environ. Mon.* 4 (3):361-370.

Bolden, A, C Kwiatkowski, and T Colborn. 2015. "New look at BTEX: Are ambient levels a problem?" *Environ. Sci. Technol.* 49 (9):5261-5276.

Bolognesi, C, M Bruzzone, M Ceppi, and M Kirsch-Volders. 2017. "The lymphocyte cytokinesis block micronucleus test in human populations occupationally exposed to vinyl chloride: A systematic review and meta-analysis." *Rev. Mut. Res.* 774:1-11.

Booth, S, A Mould, A Shaw, and RC Garner. 1983. "The biological activity of 4-chloromethylbiphenyl, benzyl chloride and 4-hydroxymethylbiphenyl in 4 short-term tests for carcinogenicity: A report of an individual study in the UKEMS genotoxity trial 1981." *Mutat. Res. Lett.* 119 (2):121-133.

Brandt-Lassen, R, S Lund, and G Jepsen. 2000. "Rats exposed to toluene and noise may develop loss of auditory sensitivity due to synergistic interaction." *Noise Health* 3 (9):33-44.

Brondeau, M, P Bonnet, J Guenier, P Simon, and J De Ceaurriz. 1990. "Adrenal-dependent leucopenia after short-term exposure to various airborne irritants in rats." *J. Appl. Toxicol.* 10 (2):83-86.

Brouwer, E, C Evelo, A Verplanke, R Van Welie, and F De Wolff. 1991. "Biological effect monitoring of occupational exposure to 1, 3-dichloropropene: Effects on liver and renal function and on glutathione conjugation." *Occup. Environ. Med.* 48 (3):167-172.

Campo, P, K Maguin, S Gabriel, A Möller, E Nies, M Gomez, and E Toppila. 2009. Combined exposure to noise and ototoxic substances. Luxembourg: European Agency for Safety and Health at Work.

Campos-Ordonez, T, and O Gonzalez-Perez. 2016. "Cyclohexane, a potential drug of abuse with pernicious effects on the brain." *Front. Pharm.* 6:291-294.

Cappaert, N, S Klis, A Baretta, H Muijser, and G Smoorenburg. 2000. "Ethyl benzene-induced ototoxicity in rats: A dose-dependent mid-frequency hearing loss." *J. Assoc. Res. Otolaryngol.* 1 (4):292-299.
Cappaert, N, S Klis, H Muijser, B Kulig, and G Smoorenburg. 2001. "The damaging effects of noise and ethyl benzene on hearing." *Clin. Otolaryngol. Allied Sci.* 26 (4):344-344.
CAS. 2017. "Chemical abstracts service registry number " Accessed Sept 2017. https://www.cas.org/content/chemical-substances.
Caselli, M, G de Gennaro, M Saracino, and M Tutino. 2009. "Indoor contaminants from newspapers: VOCs emissions in newspaper stands." *Environ. Res.* 109 (2):149-157.
Castorina, R, M Tysman, A Bradman, S Hoover, S Iyer, M Russell, D Sultana, and R Maddalena. 2016. "Volatile organic compound emissions from markers used in preschools, schools, and homes." *Int. J. Environ. Anal. Chem.* 96 (13):1247-1263.
Chang, CC, SJ Lo, JG Lo, and JL Wang. 2003. "Analysis of methyl tert-butyl ether in the atmosphere and implications as an exclusive indicator of automobile exhaust." *Atmos. Environ.* 37 (34):4747-4755.
Chang, CP, TC Lin, YW Lin, YC Hua, WM Chu, TY Lin, YW Lin, and JD Wu. 2015. "Comparison between thermal desorption tubes and stainless steel canisters used for measuring volatile organic compounds in petrochemical factories." *Ann. Occup. Hyg.* 60 (3):348-360.
Chang, SJ, CJ Chen, CH Lien, and FC Sung. 2006. "Hearing loss in workers exposed to toluene and noise." *Environ. Health Persp.* 114 (8):1283-1286.
Chang, YC. 1987. "Neurotoxic effects of n-hexane on the human central nervous system: Evoked potential abnormalities in n-hexane polyneuropathy." *J. Neurol. Neurosurg. Psychiatry* 50 (3):269-274.
Cherry, N, and D Gautrin. 1990. "Neurotoxic effects of styrene: Further evidence." *Occup. Environ. Med.* 47 (1):29-37.
Cho, Y, JH Lim, MK Song, SC Jeong, KH Lee, YJ Heo, TS Kim, and JC Ryu. 2017. "Toxicogenomic analysis of the pulmonary toxic effects of hexanal in F344 rat." *Environ. Toxicol.* 32 (2):382-396.
Choi, HS, MK Song, and JC Ryu. 2013. "Integrated analysis of microRNA and mRNA expression profiles highlights alterations in modulation of the apoptosis-related pathway under nonanal exposure." *Molec. Cell. Toxicol.* 9 (4):351-364.
Condie, L, C Smallwood, and R Laurie. 1983. "Comparative renal and hepatotoxicity of halomethanes: Bromodichloromethane, bromoform, chloroform, dibromochloromethane and methylene chloride." *Drug Chem. Toxicol.* 6 (6):563-578.
Crouch, K, and M Gressel. 1999. "The control of press cleaning solvent vapors in a small lithographic printing establishment." *Appl. Occup. Environ. Hyg.* 14 (5):329-338.
Ćurčić, L, L Pezo, P Tanović, and M Pucarević. 2013. "Benzene, ethyl benzene and xylene in the air of offset priniting shop." *Monit. Exp. Safety Eng.* 3 (4):51-58.
Daughtrey, H, K Oliver, J Adams, K Kronmiller, W Lonneman, and W McClenny. 2001. "A comparison of sampling and analysis methods for low-ppbC levels of volatile organic compounds in ambient air." *J. Environ. Mon.* 3 (1):166-174.
Davis, J, and W Farland. 2001. "The paradoxes of MTBE." *Toxicol. Sci.* 61 (2):211-217.
den Besten, C, Jurgen J Vet, H Besselink, G Kiel, B van Berkel, R Beems, and P van Bladeren. 1991. "The liver, kidney, and thyroid toxicity of chlorinated benzenes." *Toxicol. Appl. Pharmacol.* 111 (1):69-81.

Deng, JF, JD Wang, TS Shih, and FL Lan. 1987. "Outbreak of carbon tetrachloride poisoning in a color printing factory related to the use of isopropyl alcohol and an air conditioning system in Taiwan." *Am. J. Ind. Med.* 12 (1):11-19.

Diez, U, T Kroeßner, M Rehwagen, M Richter, H Wetzig, R Schulz, M Borte, G Metzner, P Krumbiegel, and O Herbarth. 2000. "Effects of indoor painting and smoking on airway symptoms in atopy risk children in the first year of life results of the LARS-study1." *Int. J. Hyg. Environ. Health* 203 (1):23-28.

Djogo, M, J Kiurski, D Adamovic, M Miloradov, J Radonic, and M Turk-Sekulic. 2011. "Hazardous air pollutants (HAPs) in printing facility in Novi Sad." *Annals of the Faculty of Engineering Hunedoara* 9 (4):101-104.

Doherty, R. 2000. "A history of the production and use of carbon tetrachloride, tetrachloroethylene, trichloroethylene and 1, 1, 1-trichloroethane in the United States: Part 1--Historical background; Carbon tetrachloride and tetrachloroethylene." *Environmental forensics* 1 (2):69-81.

El-Said, K. 2009. "Evaluation of occupational combined exposure to organic solvents and noise in printing industry." *Bull. High. Inst. Public Health* 39 (1):71-79.

Elovaara, E. 1998. The Nordic expert group for criteria documentation of health risks from chemicals 122. Dichlorobenzenes. In *Arbete och Hälsa*. Solna, Sweden: National Institute for Working Life.

Ernstgård, L, A Iregren, S Juran, B Sjögren, C van Thriel, and G Johanson. 2009. "Acute effects of exposure to vapours of standard and dearomatized white spirits in humans. 2. Irritation and inflammation." *J. Appl. Toxicol.* 29:263–274.

Ernstgård, L, A Iregren, B Sjögren, U Svedberg, and G Johanson. 2006. "Acute effects of exposure to hexanal vapors in humans." *J. Occup. Environ. Med.* 48 (6):573-580.

Fechner, G, A Du Chesne, and H KöhIer. 2001. "Fatal intoxication due to sxcessive dichloromethane inhalation." *Forensic Sci. Int.* 122 (1):69-72.

Fechter, L, C Gearhart, S Fulton, J Campbell, J Fisher, K Na, D Cocker, A Nelson-Miller, Pa Moon, and B Pouyatos. 2007. "Promotion of noise-induced cochlear injury by toluene and ethylbenzene in the rat." *Toxicol. Sci.* 98 (2):542-551.

Gagnaire, F, C Langlais, S Grossmann, and P Wild. 2007. "Ototoxicity in rats exposed to ethylbenzene and to two technical xylene vapours for 13 weeks." *Arch. Toxicol.* 81 (2):127-143.

Gardner, D. 2012. Acute exposure guideline levels for selected airborne chemicals. Chapter 8: Trimethylbenzenes. Washington DC: Committee on Toxicology, National Research Council.

Gegic, A, and B Savic. 2013. "The perspective of solving the problem of emission of volatile compounds from printing industry into living." *J. Selcuk Uni. Nat. Appl. Sci.*:204-211.

Gilbert, N, M Guay, D Miller, S Judek, C Chan, and R Dales. 2005. "Levels and determinants of formaldehyde, acetaldehyde, and acrolein in residential indoor air in Prince Edward Island, Canada." *Environ. Res.* 99 (1):11-17.

Gioda, A, and F de Aquino Neto. 2002. "Exposure to high levels of volatile organic compounds and other pollutants in a printing facility in Rio de Janeiro, Brazil." *Indoor Built Environ.* 11 (5):302-311.

Godoi, A, E Sawada, M de Marchi, R Van Grieken, and R Godoi. 2009. "Determination of BTEX by GC-MS in air of offset printing plants: Comparison between conventional and ecological Inks." *Water Air Soil Poll.: Focus* 9:163-169.

Hautamäki, M, P Kalliokoski, M Hyttinen, P Pasanen, J Laitinen, J Kangas, R Luukkonen, and S Batterman. 2006. "Evaluation of the use of low flow passive sampling technique in offset printing plants." *Int. J. Occup. Med. Environ. Health* 19 (4):228-234.

Herbert, J. 1975. "Angiosarcoma of the liver among printers." Environmental aspects of chemical use in printing operations, King of Prussia, PA.

Holme, I. 2005. "Advances in the science and technology of paints, inks and related coatings." *Surf. Coat. Int. Part B: Coat. Trans.* 88 (4):285-299.

IARC. 1996. *Printing processes and printing inks, carbon black and some nitro compounds, IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, No. 65*. Lyon, France.

IUPAC. 2017. "International union of pure and applied chemistry nomenclature." Accessed Sept 2017. https://iupac.org/what-we-do/nomenclature/.

Jo, WK, C Weisel, and P Lioy. 1990. "Routes of chloroform exposure and body burden from showering with chlorinated tap water." *Risk Anal.* 10 (4):575-580.

Johnson, A, and T Morata. 2010. "The Nordic Expert Group: Criteria documentation of health risks from chemicals. 142. Occupational exposure to chemicals and hearing impairment." *Arbete och Hälsa* 44 (4):1-177.

Juárez-Pérez, C, A Torres-Valenzuela, L Haro-García, V Borja-Aburto, and G Aguilar-Madrid. 2014. "Ototoxicity effects of low exposure to solvent mixture among paint manufacturing workers." *Int. J. Aud.* 53 (6):370-376.

Kagi, N, S Fujii, Y Horiba, N Namiki, Y Ohtani, H Emi, H Tamura, and Y Kim. 2007. "Indoor air quality for chemical and ultrafine particle contaminants from printers." *Build. Environ.* 42 (5):1949-1954.

Kandyala, R, S Raghavendra, and S Rajasekharan. 2010. "Xylene: An overview of its health hazards and preventive measures." *J. Oral Maxillofac. Pathol.* 14 (1):1-5.

Kavet, R, and K Nauss. 1990. "The toxicity of inhaled methanol vapors." *Crit. Rev. Toxicol.* 21 (1):21-50.

Kennedy, E, T Fischbach, R Song, P Eller, and S Shulman. 1996. "Summary of the NIOSH guidelines for air sampling and analytical method development and evaluation." *Analyst* 121 (9):1163-1169.

KEPA. 2001. "Regulations implemented under Law no. 21 of 1995, as amended by law no. 16 of 1996, regarding environmental requirements and standards in the State of Kuwait." Accessed Sept 2017. https://www.epa.org.kw/article.php?id=15.

KEPA. 2015. "The Environment Protection Law No. (42) Year 2014, Amended Version No. (99)." Accessed Sept 2017. https://epa.org.kw/Portals/0/PDF/epa-law-2015pdf.pdf.

Kielhorn, J, C Melber, U Wahnschaffe, A Aitio, and I Mangelsdorf. 2000. "Vinyl chloride: Still a cause for concern." *Environ. Health Persp.* 108 (7):579-588.

Kikuchi, E, Y Kikuchi, and M Hirao. 2011. "Analysis of risk trade-off relationships between organic solvents and aqueous agents: Case study of metal cleaning processes." *J. Cleaner Prod.* 19 (5):414-423.

Kiurski, J, B Marić, D Adamović, A Mihailović, S Grujić, I Oros, and J Krstić. 2012. "Register of hazardous materials in printing industry as a tool for sustainable development management." *Renew. Sust. Energy Rev.* 16 (1):660-667.

Korsak, Z, and K Rydzynski. 1996. "Neurotoxic effects of accute and subchronic inhalation exposure to trimethylbenzene isomers (pseudocumene, mesitylene, hemimellitene) in rats." *Int. J. Occup. Med. Environ. Health* 9:341-350.

Kowalska, J, M Szewczyńska, and M Pośniak. 2015. "Measurements of chlorinated volatile organic compounds emitted from office printers and photocopiers." *Environ. Sci. Pollut. Res.* 22 (7):5241-5252.

Krasavage, W, J O'Donoghue, G DiVincenzo, and C Terhaar. 1980. "The relative neurotoxicity of methyl-n-butyl ketone, n-hexane and their metabolites." *Toxicol. Appl. Pharmacol.* 52 (3):433-441.

Kumagai, S, N Kurumatani, A Arimoto, and G Ichihara. 2013. "Cholangiocarcinoma among offset colour proof-printing workers exposed to 1, 2-dichloropropane and/or dichloromethane." *Occup. Environ. Med.* 70:508-510.

Laire, G, M Viaene, H Veulemans, R Masschelein, and B Nemery. 1997. "Nocturnal oxygen desaturation, as assessed by home oximetry, in long-term solvent-exposed workers." *Am. J. Ind. Med.* 32 (6):656-664.

Lataye, R, and P Campo. 1997. "Combined effects of a simultaneous exposure to noise and toluene on hearing function." *Neurotoxicol. Teratol.* 19 (5):373-382.

Lataye, R, P Campo, G Loquet, and G Morel. 2005. "Combined effects of noise and styrene on hearing: comparison between active and sedentary rats." *Noise Health* 7 (27):49-64.

LeBouf, R, A Stefaniak, and M Virji. 2012. "Validation of evacuated canisters for sampling volatile organic compounds in healthcare settings." *J. Environ. Mon.* 14 (3):977-983.

Lee, EG, M Harper, R Bowen, and J Slaven. 2009. "Evaluation of COSHH essentials: Methylene chloride, isopropanol, and acetone exposures in a small printing plant." *Ann. Occup. Hyg.* 53 (5):463-474.

Leung, M, C.H. Liu, and A Chan. 2005. "Occupational exposure to volatile organic compounds and mitigation by push-pull local exhaust ventilation in printing plants." *J. Occup. Health* 47 (6):540-547.

Liu, T, QE Xu, CH Zhang, and P Zhang. 2013. "Occupational exposure to methylene chloride and risk of cancer: a meta-analysis." *Cancer Causes Control* 24 (12):2037-2049.

Lopez, V, A Chamoux, M Tempier, H Thiel, S Ughetto, M Trousselard, G Naughton, and F Dutheil. 2013. "The long-term effects of occupational exposure to vinyl chloride monomer on microcirculation: A cross-sectional study 15 years after retirement." *BMJ Open* 3 (6):e002785.

Lund, S, and G Kristiansen. 2008. "Hazards to hearing from combined exposure to toluene and noise in rats." *Int. J. Occup. Med. Environ. Health* 21 (1):47-57.

MacLean, R, G Valentine, P Jatlow, and M Sofuoglu. 2017. "Inhalation of alcohol vapor: Measurement and implications." *Alcohol. Clin. Exp. Res.* 41 (2):238-250.

Maddy, K, HR Fong, J Lowe, D Conrad, and A Fredrickson. 1982. "A study of well water in selected California communities for residues of 1, 3-dichloropropene, chloroallyl alcohol and 49 organophosphate or chlorinated hydrocarbon pesticides." *Bull. Environ. Contam. Tox.* 29 (3):354-359.

Maguin, K, R Lataye, P Campo, B Cossec, M Burgart, and D Waniusiow. 2006. "Ototoxicity of the three xylene isomers in the rat." *Neurotoxicol. Teratol.* 28 (6):648-656.

Mäkitie, A, U Pirvola, I Pyykkö, H Sakakibara, V Riihimäki, and J Ylikoski. 2003. "The ototoxic interaction of styrene and noise." *Hear. Res.* 179 (1-2):9-20.

Mallach, G, M St.Jean, M MacNeill, D Aubin, L Wallace, T Shin, K Van Ryswyk, R Kulka, H You, and D Fugler. 2017. "Exhaust ventilation in attached garages improves residential indoor air quality." *Indoor Air* 27 (2):487-499.

Mansouri, N, A Eynipour, Z Behrami, and M Mahbobi. 2015. "Evaluation of exposure measure to BTEX in Offset printing, Silk and UV workplaces in Tehran." *Tech. J. Eng. Appl. Sci.* 5 (3):123-126.

Mattia, C, S Ali, and S Bondy. 1993. "Toluene-induced oxidative stress in several brain regions and other organs." *Mol. Chem. Neuropathol.* 18 (3):313-328.

McCulloch, A, P Ashford, and P Midgley. 2001. "Historic Emissions of fluorotrichloromethane (CFC-11) based on a Market Survey." *Atmos. Environ.* 35 (26):4387-4397.

McKee, R, R Tibaldi, M Adenuga, J.C. Carrillo, and A Margary. 2018. "Assessment of the potential human health risks from exposure to complex substances in accordance with REACH requirements.White spirit as a case study." *Regul. Toxicol. Pharmacol.* 92:439-457.

Meek, M, R Beauchamp, G Long, D Moir, L Turner, and M Walker. 2002. "Chloroform: exposure estimation, hazard characterization, and exposure-response analysis." *J. Tox. Environ. Health Part B* 5 (3):283-334.

Mitran, E, T Callender, B Orha, P Dragnea, and G Botezatu. 1997. "Neurotoxicity associated with occupational exposure to acetone, methyl ethyl ketone, and cyclohexanone." *Environ. Res.* 73 (1-2):181-188.

Montzka, S, G Dutton, P Yu, E Ray, R Portmann, J Daniel, L Kuijpers, B Hall, D Mondeel, and C Siso. 2018. "An unexpected and persistent increase in global emissions of ozone-depleting CFC-11." *Nature* 557 (7705):413-429.

Morata, T. 2007. "Promoting hearing health and the combined risk of noise-induced hearing loss and ototoxicity." *Aud. Med.* 5 (1):33-40.

Morata, T, D Dunn, L Kretschmer, G Lemasters, and R Keith. 1993. "Effects of occupational exposure to organic solvents and noise on hearing." *Scand. J. Work Environ. Health* 19 (4):245-254.

Morata, T, AC Johnson, P Nylen, E Svensson, J Cheng, E Krieg, AC Lindblad, L Ernstgård, and J Franks. 2002. "Audiometric findings in workers exposed to low levels of styrene and noise." *J. Occup. Environ. Med.* 44 (9):806-814.

Morel, G, P Bonnet, B Cossec, S Morel, C Cour, A Lambert, M Roure, and M Brondeau. 1998. "The role of glutathione and cysteine conjugates in the nephrotoxicity of o-xylene in rats." *Arch. Toxicol.* 72 (9):553-558.

Morioka, I, N Miyai, H Yamamoto, and K Miyashita. 2000. "Evaluation of combined effect of organic solvents and noise by the upper limit of hearing." *Ind. Health* 38 (2):252-257.

NIOSH. 2007. NIOSH pocket guide to chemical hazards. edited by M. Barsan. Pittsburgh, PA.

NIOSH. 2017. "NIOSH pocket guide to chemical hazards." Accessed Sept 2017. https://www.cdc.gov/niosh/npg/default.html.

Novick, R, J Keenan, S Gross, and D Paustenbach. 2013. "An analysis of historical exposures of pressmen to airborne benzene (1938–2006)." *Ann. Occup. Hyg.* 57 (6):705-716.

Nuckols, J, D Ashley, C Lyu, S Gordon, A Hinckley, and P Singer. 2005. "Influence of tap water quality and household water use activities on indoor air and internal dose levels of trihalomethanes." *Environ. Health Persp.* 113 (7):863-870.

Nylén, P, and M Hagman. 1994. "Function of the auditory and visual systems, and of peripheral nerve, in rats after long-term combined exposure to n-hexane and methylated benzene derivatives. II. Xylene." *Pharmacol. Toxicol.* 74 (2):124-129.

OSHA. 2017. "Chemical sampling information." Accessed Sept 2017. https://www.osha.gov/dts/chemicalsampling/toc/toc_chemsamp.html.

OSHA. 2018. "Hazard communication." Accessed Sept 2017. https://www.osha.gov/dsg/hazcom/.
Park, JM, YH Kim, and SB Kim. 2013. "Development of solvent-free offset ink using vegetable oil esters and high molecular-weight resin." *J. Oleo Sci.* 62 (6):345-352.
Prather, M, and R Watson. 1990. "Stratospheric ozone depletion and future levels of atmospheric chlorine and bromine." *Nature* 344 (6268):729-734.
Prica, M, V Kecić, S Adamović, J Radonić, and M Sekulić. 2016. "Occupational exposure to hazardous substances in printing industry." Proceedings of 8th International Engineering Symposium at Bánki.
Quack, B, and D Wallace. 2003. "Air-sea flux of bromoform: Controls, rates, and implications." *Glob. Biogeochem. Cyc.* 17 (1):1-27.
Ramadan, A. 2017. "Assessment of spatial variation of ambient volatile organic compound levels at a power station in Kuwait." *J. Air Waste Manag. Assoc.* 67 (11):1170-1179.
Risher, J, D Jones, and M Lumpkin. 2005. "Toxicological profile for bromoform and dibromochloromethane." ATSDR, Division of Toxicology Accessed Sept 2017. https://www.atsdr.cdc.gov/toxprofiles/tp130.pdf.
Robert, T. 2015. "Green ink in all colors - Printing ink from renewable resources." *Prog. Org. Coat.* 78:287-292.
Rodriguez, M, and J Gibbins. 2007. Nuisance odors from a neighboring printing facility - Air quality evaluation at a label distributing company. Southfield, MI: NIOSH.
Rombult, P, L Krupica, D Larsen, and P Beildeck. 1999. Method and apparatus for making lithographic printing plates in an automated computer to plate imaging system. US Patent No. 5,992,324. US Patent and Trademark Office.
Rossitza, S. 2015. "Offset printing without isopropyl alcohol in damping solution." *Energy Procedia* 74:690-698.
Roy, A, M Bhattacharjee, R Mondal, and S Ghosh. 2007. "Development of mineral oil free offset printing ink using vegetable oil esters." *J. Oleo Sci.* 56 (12):623-628.
Saeed, T, H Khordagui, and A Al-Bloushi. 1999. "Distribution of volatile liquid hydrocarbons in the vicinity of power/desalination plants in Kuwait." *Wat. Sci. Tech.* 40 (7):99-107.
Sakabe, H, H Matsushita, and S Koshi. 1976. "Cancer among benzoyl chloride manufacturing workers." *Ann. N. Y. Acad. Sci.* 271 (1):67-70.
Sancini, A, T Caciari, A Chighine, P Gioffrè, G Andreozzi, L Sacchi, R Giubilati, G Tomei, A Suppi, and C Sacco. 2014. "Workers of the printing industry and hepatic damage." *Ann. Ig.* 26:321-329.
Sarkhosh, M, A Mahvi, M Zare, Y Fakhri, and H Shamsolahi. 2012. "Indoor contaminants from hardcopy devices: Characteristics of VOCs in photocopy centers." *Atmos. Environ.* 63:307-312.
Senthong, P, and S Wittayasilp. 2017. "Measurements and health impacts of carbon black and BTEXs in photocopy centers." *Arch. Environ. Occup. Health* 73 (3):169-175.
Smith, T, and S Smith. 2009. "Specification of airflow rates in laboratories." *J. Chem. Health Saf.* 16 (5):27-35.
Snyder, R. 2002. "Benzene and leukemia." *Crit. Rev. Toxicol.* 32 (3):155-210.
Song, MK, HS Lee, HS Choi, CY Shin, YJ Kim, YK Park, and JC Ryu. 2014. "Octanal-induced inflammatory responses in cells relevant for lung toxicity: Expression and release of cytokines in A549 human alveolar cells." *Hum. Exp. Toxicol.* 33 (7):710-721.

Sutton, P, K Wolf, and J Quint. 2009. "Implementing safer alternatives to lithographic cleanup solvents to protect the health of workers and the environment." *J. Occup. Environ. Hyg.* 6 (3):174-187.

Svendsen, K, and K Rognes. 2000. "Exposure to organic solvents in the offset printing industry in Norway." *Ann. Occup. Hyg.* 44 (2):119-124.

Tardif, R, C Catto, S Haddad, S Simard, and M Rodriguez. 2016. "Assessment of air and water contamination by disinfection by-products at 41 indoor swimming pools." *Environ. Res.* 148:411-420.

Taskinen, H, A Anttila, ML Lindbohm, M Sallmén, and K Hemminki. 1989. "Spontaneous abortions and congenital malformations among the wives of men occupationally exposed to organic solvents." *Scand. J. Work Environ. Health* 15 (5):345-352.

Thanacharoenchanaphas, K, A Changsuphan, R Nimnual, T Thongsri, S Phetkasem, and C Lertkanawanitchakul. 2007. "Investigation of BTEX and ozone concentrations in a printing facility in Bangkok, Thailand." *Int. J. Appl. Environ. Sci.* 2 (1):41-49.

Thanacharoenchanaphas, K, A Changsuphan, T Thongsri, S Phetkasem, and C Lertkanawanitchakul. 2007. Formaldehyde and isopropyl alcohol emissions from sheetfed offset lithographic printing operations in printing house in Thailand. Naresuan University, Thailand.

Tsai, CJ, IF Mao, JY Ting, CH Young, JS Lin, and WL Li. 2015. "Quality of chemical safety information in printing industry." *Ann. Occup. Hyg.* 60 (3):361-370.

Tuomi, T, B Engström, R Niemelä, J Svinhufvud, and K Reijula. 2000. "Emission of ozone and organic volatiles from a selection of laser printers and photocopiers." *Appl. Occup. Environ. Hyg.* 15 (8):629-634.

UKHSE. 2002. "Control of substances hazardous to health regulations 2002. Approved codes of practice." Accessed Sept 2017. http://www.hse.gov.uk/pUbns/priced/l5.pdf.

United Nations. 1989. "Montreal protocol on substances that deplete the ozone layer (with annex)." Accessed Sept 2017. https://treaties.un.org/doc/Publication/UNTS/Volume%201522/volume-1522-I-26369-English.pdf.

USEPA. 1994. Federal environmental regulations potentially affecting the commercial printing industry, EPA 744B-94-001. Washington, DC.

USEPA. 1997. Cleaner technologies substitutes assessment: Lithographic blanket washes. Washington, DC.

USEPA. 1999a. Compendium method TO-14A: Determination of volatile organic compounds (VOCs) in ambient air using specially prepared canisters with subsequent analysis by gas chromatography. Cincinnati, OH.

USEPA. 1999b. Compendium method TO-15: Determination of volatile organic compounds (VOCs) in air collected an specially-prepared canisters and analyzed by gas chromatography/mass spectrometry (GC/MS). Cincinnati, OH.

USEPA. 2017. "Initial list of hazardous air pollutants with modifications." Accessed Sept 2017. https://www.epa.gov/haps/initial-list-hazardous-air-pollutants-modifications.

Vega, E, V Mugica, R Carmona, and E Valencia. 2000. "Hydrocarbon source apportionment in Mexico City using the chemical mass balance receptor model." *Atmos. Environ.* 34 (24):4121-4129.

Vilcekova, S, and L Meciarova. 2016. "Monitoring of indoor environmental quality in a printing company – Case study." People, Buildings and Environment 2016, Luhacovice, Czech Republic.

Vollmer, M, D Young, C Trudinger, J Mühle, S Henne, M Rigby, S Park, S Li, M Guillevic, and B Mitrevski. 2018. "Atmospheric histories and emissions of chlorofluorocarbons CFC-13 (CClF3), ΣCFC-114 (C2 Cl2 F4), and CFC-115 (C2 ClF5)." *Atmos. Chem. Phys.* 18 (2):979-1002.

Vyskocil, A, T Leroux, G Truchon, M Gendron, N El Majidi, and C Viau. 2008. "Occupational ototoxicity of n-hexane." *Hum. Exp. Toxicol.* 27 (6):471-476.

Vyskocil, A, T Leroux, G Truchon, F Lemay, F Gagnon, M Gendron, and C Viau. 2008. "Ototoxicity of trichloroethylene in concentrations relevant for the working environment." *Hum. Exp. Toxicol.* 27 (3):195-200.

Vyskocil, A, G Truchon, T Leroux, F Lemay, M Gendron, F Gagnon, N Majidi, A Boudjerida, S Lim, C Emond, and C Viau. 2012. "A weight of evidence approach for the assessment of the ototoxic potential of industrial chemicals." *Toxicol. Ind. Health* 28 (9):796-819.

Wadden, R, P Scheff, C Keil, J Franks, and L Conroy. 1995. "Determination of VOC emission rates and compositions for offset printing." *J. Air Waste Manag. Assoc.* 45 (7):547-555.

Walter, R, PH Lin, M Edwards, and R Richardson. 2011. "Investigation of factors affecting the accumulation of vinyl chloride in polyvinyl chloride piping used in drinking water distribution systems." *Water Res.* 45 (8):2607-2615.

Waxweiler, R, W Stringer, J Wagoner, J Jones, H Falk, and C Carter. 1976. "Neoplastic risk among workers exposed to vinyl chloride." *Ann. N. Y. Acad. Sci.* 271 (1):40-48.

Wiaderna, D, S Gralewicz, and T Tomas. 2002. "Assessment of long-term neurotoxic effects of exposure to mesitylene (1, 3, 5-trimethylbenzene) based on the analysis of selected behavioral responses." *Int. J. Occup. Med. Environ. Health* 15 (4):385-391.

Wypych, G. 2001. *Handbook of solvents*. Toronto, Canada: ChemTec Publishing.

Yadav, J, and A Chhillar. 2002. "Cytogenetic damage in offset printing press workers occasionally exposed to benzene." *J. Human Ecol.* 13 (3):217-224.

Yang, R, J Huff, G Boorman, J Haseman, M Kornreich, and J Stookey. 1986. "Chronic toxicology and carcinogenesis studies of Telone II by gavage in Fischer-344 Rats and B6C3F1 mice." *J. Tox. Environ. Health Part A* 18 (3):377-392.

Yassin, M, and A Pillai. 2018. "Monitoring of volatile organic compounds in different schools: A determinant of the indoor air quality." *Int. J. Mod. Sci. Technol.* :1-12.

Yu, I, NL Lee, XH Zhang, WQ Chen, YT Lam, and TW Wong. 2004. "Occupational exposure to mixtures of organic solvents increases the risk of neurological symptoms among printing workers in Hong Kong." *J. Occup. Environ. Med.* 46 (4):323-330.

Yuan, B, M Shao, SH Lu, and B Wang. 2010. "Source profiles of volatile organic compounds associated with solvent use in Beijing, China." *Atmos. Environ.* 44 (15):1919-1926.

Zhang, Y, W Yang, Z Huang, D Liu, I Simpson, D Blake, C George, and X Wang. 2017. "Leakage rates of refrigerants CFC-12, HCFC-22, and HFC-134a from operating mobile air conditioning systems in Guangzhou, China: Tests inside a busy urban tunnel under hot and humid weather conditions." *Environ. Sci. Technol.* 4 (11):481-486.

Zheng, J, Y Yu, Z Mo, Z Zhang, X Wang, S Yin, K Peng, Y Yang, X Feng, and H Cai. 2013. "Industrial sector-based volatile organic compound (VOC) source profiles measured in manufacturing facilities in the Pearl River Delta, China." *Sci. Total Environ.* 456:127-136.

Author Bios

Mr. Abdullah Alabdulhadi is a PhD student in the program of Environmental and Occupational Health in the University of Newcastle, Australia, funded by the Public Authority of Applied Education and Training**, Shuwaikh, Kuwait.**

Dr. Ashraf Ramadan is a research scientist at the Kuwait Institute for Scientific Research and the supervisor of Kuwait National Meteorological Network.

Mr. Peter Devey is a certified occupational hygienist and a conjoint lecturer in the Discipline of Environmental & Occupational Health at the University of Newcastle, Australia.

May Boggess is an associate professor in the School of Mathematical and Statistical Sciences at Arizona State University, Tempe, AZ, U.S.A.

Maya Guest recently retired from her position of lecturer in the Faculty of Health and Medicine, at University of Newcastle, Callaghan, NSW, Australia**.**

Implications Statement -100 words

Results from this study indicate that efforts to reduce worker exposure to VOCs particularly dangerous to human health in recent years have been successful, but there is still much to be done to protect workers. Exposures to ototoxic and carcinogenic VOCs were identified, among both production and non-production workers. Unexpected findings included the apparent use in printing activities of the carcinogen vinyl chloride and CFC-114, banned under the Montreal Protocol. Observed lapses in safety procedures included failure to utilize ventilation systems and closing doors between work areas, indicating management and worker education should remain a priority.

Figure 1. Observations of VOCs above the MDL with CV<20% and maximum concentration above 5 ppb (49 VOCs, 565 observations).

Figure 2. Exposure to Ototoxic VOCs, relative to OELs, by sampling location.

Figure 3. Exposure to Carcinogenic and probably Carcinogenic VOCs, relative to OELS, by sampling location.

Figure 4. Exposure to Hazardous VOCs, relative to OELS, by sampling location.

Table 1. Description of Field Sampling Locations

Sampling locations	Placement	Equipment	Ventilation	Access to Outside Air
Government Printery				
Reception	**Level 1**		**RCAC**	**Exterior door, openable window**
Administration	**Level 2**	**2 PCs, 2 laser printers**	**RCAC**	**Openable window**
Design	**Level 2**	**6 PCs, 1 laser printer**	**RCAC**	**None**
CTP	**Level 1**	**1 Fuji Films CTP machine**	**RCAC, LEV**	**Openable window**
Digital printing/ photocopy	**Level 1**	**3 blue print machines, 1 digital printer, 5 photocopiers, 1 hole punch and spiral binder**	**Portable RCAC**	**None**
Sheet-fed Offset/ Commercial binding	**Level 1**	**6 sheet-fed offset, 1 folder, 1 thermal gluing binder, 2 cutters, 1 UV laminating**	**Portable RCAC, LEV**	**Loading bay door**
Maintenance/ Commercial binding	**Level 1**	**1 carbon copy binder, 2 cutters, 1 thread binder, 1 sorter, 3 folders, 1 embosser, air compressor**	**RCAC**	**Loading bay door**
Decorative binding	**Level 2**	**5 binding machines**	**CSRAC**	**None**
Storage	**Building 2**		**RCAC**	**None**
Store supervisor	**Building 2**		**RCAC**	**Openable window**
Scientific Printery				
Admin/Design	**Building 1**	**2 PCs, 2 laser printers**	**RCAC**	**Openable window**
Binding/Photocopy	**Building 1**	**6 photocopiers, 3 binders, 2 cutters**	**CSR**	**None**
Storage	**Building 1**		**RCAC**	**None**
Sheet-fed Offset	**Building 1**	**2 sheet-fed offset, 1 folder, 1 laminator**	**CSRAC, LEV**	**Loading bay door, openable window**
CTP	**Building 2**	**1 Fuji Films CTP machine**	**CSRAC, LEV**	**Openable window**
Newspaper Printery				
Administration	**Level 1**	**2 PCs, 2 laser printers**	**CSRAC**	**Openable window**
CTP	**Level 1**	**2 Fuji Films CTP machines**	**CSRAC; LEV**	**Openable window**
Archive	**Level 2**	**2 PCs**	**CSRAC**	**None**
Storage	**Ground**		**CSRAC**	**None**

Offset	**Web-fed**	**round**	**G folder,**	**1 web-fed offset, 1 cutter & 1 UV laminating**	**AC; IEF**	**CSR**	**door**	**Loading bay**

Notes: RC= reverse cycle, no external air; AC=air conditioning; PC=personal desk-top computer; CTP=computer-to-plate; LEV= **local exhaust ventilation;** CSR = ceiling supply and return, 10% exterior, 90% recirculated, 5 to 12 air changes per hour; IEF= **industrial exhaust fans.**

Table 2A. Target VOCs: Health Risk Classifications and Exposure Levels

s	Clas	IUPAC Name	m/ tion	Synony Abbrevia	AS umber	(I	ASHW NEG- RSST	ARC	S PA AP	P DS	EPA ppm)	SHA EL ppm)	CGIH LV ppm)	IOSH EL ppm)	DL ppb)
ne	Alka	n-Pentane			09-66-0							00	00	20	.700
		n-Hexane			10-54-3		-3-2		es		0	00	0	0	.341
		Cyclopentane			87-92-3								00	00	.808
		Cyclohexane			10-82-7						00	00	00	00	.326
roalkane	Chlo	Chloromethane	Chloride	Methyl	4-87-3				es			00	0		.619
		Dichloromethane	e Chloride	Methylen	5-09-2			A	es		5	5	0		.018
		Trichloromethane	m	Chlorofor	7-66-3			B	es			0[c]	0		.335
		Tetrachlorometha ne	Tetrachloride	Carbon	6-23-5			B	es	,gr II		0			.646
		Chloroethane	Chloride	Ethyl	5-00-3				es			,000	00		.731
		1,1- Dichloroethane			5-34-3				es			00	00	00	.255
		1,1,1- Trichloroethane	Chloroform	Methyl	1-55-6		- 3		es	,gr III	50	50	50	50	.350
		1,1,2- Trichloroethane	TCEa	1,1,2-	9-00-5				es			0	0	0	.607
		1,1,2,2- Tetrachloroethane	TCEa	1,1,2,2-	9-34-5			B	es						.584
		1,2- Dichloropropane	e Dichloride	Propylen	8-87-5				es			5	5		.618
alkane	Iodo	Iodomethane	Iodide	Methyl	4-88-4				es						.851
moalkane	Bro	Bromomethane	Bromide	Methyl	4-83-9				es	,gr I		0[c]			.796
		1,2- Dibromoethane	Dibromide	Ethylene	06-93-4			A	es		.045	0		.045	.461
		Tribromomethane	m	Bromofor	5-25-2				es			.5	.5	.5	.451
robromo	Chlo	Bromodichlorome thane			5-27-4			B							.509
	Chlo	1,2-		CFC-114											

rofluoro	Dichlorotetrafluoroethane			6-14-2				,gr l		,000	,000	,000	.283
	Trichlorofluoromethane		CFC-11	5-69-4				,gr l		,000	,000^{C}	,000^{C}	.908
Alke ne	Propene			15-07-1									.406
	Buta-1,3-diene		Butadiene	06-99-0			es						.642
	2-Methylprop-1-ene		Isobutylene	15-11-7							50		.707
	2-Methylbuta-1,3-diene		Isoprene	8-79-5		B					^{W}		.854
Chlo roalkene	Chloroethene		Vinyl Chloride	5-01-4			es						.267
	cis-1,2-Dichloroethene	DCEe	cis-1,2-	56-59-2						00	00	00	.333
	cis-1,3-Dichloropropene	DCPe	cis-1,3-	0061-01-5			es						.469
	trans-1,3-Dichloropropene	DCPe	trans-1,3-	0061-02-6			es						.466
Aro matic	Ethylbenzene			00-41-4	-2-2	B	es			00	0	00	.593
	1,3,5-Trimethylbenzene	TMB	1,3,5-	08-67-8						5^{T}	5	5	.752
	1,2,3-Trimethylbenzene	TMB	1,2,3-	26-73-8						5^{T}	5	5	.756
	1,2,4-Trimethylbenzene	TMB	1,2,4-	5-63-6						5^{T}	5	5	.756
	Toluene			08-88-3	-1-1		es		00	00	0	00	.536
Chlo roaromatic	Chlorobenzene			08-90-7	3-		es		5	5	0		.466
	Chloromethylbenzene	Chloride	Benzyl	00-44-7		A	es					^{C}	.732
	1,2-Dichlorobenzene		o-DCB	5-50-1						0	5	0	.604
	1,3-Dichlorobenzene		m-DCB	41-73-1									.411
	1,4-Dichlorobenzene		p-DCB	06-46-7		B	es		5	5	0		.438
	1,2,4-Trichlorobenzene	TCB	1,2,4-	20-82-1			es				^{C}	^{C}	.815
Alco hol	Methanol	Alcohol	Methyl	7-56-1			es		00	00	00	00	.575
	Ethanol	Alcohol	Ethyl	4-17-5	-3				,000	,000	,000^{S}	,000	.466
	Propan-1-ol		n-Propyl										

		Alcohol	1-23-8				00	00	00	.365
	Propan-2-ol	Isopropyl Alcohol	7-63-0			00	00	00	00	.289
Ester	Ethenyl ethanoate	Vinyl Acetate	08-05-4	B	es			0	C	.792
Ether	1,4-Dioxacyclohexane	1,4-Dioxane	23-91-1	B	es	5	00	0	C	.709
	2-Methoxy-2-methylpropane	MTBE	634-04-4		es			0		.722
Ketone	Propan-2-one	Acetone	7-64-1			50	,000	50	50	.388
	Butan-2-one	MEK	8-93-3		es		00	00	00	.871
	But-3-en-2-one	MVK	8-94-4					.2[C]		.815
	Pentan-2-one	MPK	07-87-9				00	00	50	.790
	Pentan-3-one	DEK	6-22-0					00	00	.856
	Hexan-2-one	MBK	91-78-6				00			.673
	Hexan-3-one	EPK	89-38-8							.627
	4-Methyl-pentan-2-one	MIBK	08-10-1	B	es	0	00	0	0	.792
Aldehyde	Ethanal		5-07-0	B	es	00	00	5[C]		.956
	Propanal		23-38-6		es			0		.231
	Butanal		23-72-8					5[W]		.624
	Pentanal		10-62-3					0	0	.896
	Hexanal		6-25-1							.831
	Heptanal		11-71-7							.679
	Octanal		24-13-0							.835
	Nonanal		24-19-6							.940
	Prop-2-enal	Acrolein	07-02-8		es	.1	.1	.1[C]	.1	.373
	2-Methylprop-2-enal	Methacrolein	8-85-3							.468
Nitri	Ethanenitrile	Acetonitri								

le	le	5-05-8	es	0	0	0	0	.527

Table 2B. Target Coeluting VOCs: Health Risk Classifications and Exposure Levels

Cl ass	Name	IUPAC	onym/ reviation	Syn Abb	AS umber	ASHW NEG- RSST	ARC	S PA AP	P DS	EPA ppm)	SHA EL ppm)	CGIH LV ppm)	IOSH EL ppm)	DL ppb)
C hlorofluoro	omethane	Dichlorodifluor	-12	CFC	5-71-8				,gr I		,000	,000	,000	.299
	methane	Chlorodifluoro	C-22	HCF	5-45-6				,gr I			,000	,000	
C hloroalkene	Dichloroethene	1,1-	DCEe	1,1-	5-35-4			es						.958
C hlorofluoro	Trichloro-1,2,2- trifluoroethane	1,1,2-	-113	CFC	6-13-1				,gr I		,000	,000	,000	
C hloroalkene	e	Trichloroethen	Ee	TC	9-01-6	-3-1		es			00	0	5	.368
Al cohol		Butan-1-ol	Butyl Alcohol	n-	1-36-3	-3					00	0	0^{C}	
C hloroalkane	Dichloroethane	1,2-	DCEa	1,2-	07-06-2		B	es			0	0		.452
Ar omatic		Benzene			1-43-2			es		.1		.5	.1	
Ar omatic	ne	Ethenylbenze	ene	Styr	00-42-5	-1-1	B	es		0	00	0	0	.665
	Dimethylbenzene	1,2-	Xylene	o-	5-47-6			es			00	00	00	
Ar omatic	Dimethylbenzene	1,3-	Xylene	m-	08-38-3			es			00	00	00	.670
	Dimethylbenzene	1,4-	Xylene	p-	06-42-3	-2-2		es			00	00	00	

Table 2A & 2B footnotes

Notes: MP=Montreal Protocol; ODS=Ozone Depleting Substances, listed by Annex and group number; C=ceiling value; W=WEEL; T=Construction; S=STEL; MTBE=tert-Butyl Methyl Ether; MEK=Methyl Ethyl Ketone; MVK=Methyl Vinyl Ketone; MPK=Methyl Propyl Ketone; DEK= Diethyl Ketone; MBK=Methyl n-Butyl Ketone; EPK=Ethyl Propyl Ketone; MIBK=Methyl Isobutyl Ketone; CFC=chlorofluorocarbon; HCFC=hydrochlorofluorocarbon; ED=Ethylene Dichloride ; IARC: 1=carcinogenic, 2A=probably carcinogenic, 2B=possibly carcinogenic, 3=not classifiable; EASHW: 1=confirmed ototoxic; NEG:1= good evidence of ototoxicity, 2=fair evidence of ototoxicity, 3=poor evidence of ototoxicity; IRSST: 1=ototoxic, 2=possibly ototoxic, 3=no evidence of toxicity.

Table 3. **Government Printery: VOC Concentrations (ppb)**

	TP evel 1	cpt. evel 1	dmin. evel 2	esign evel 2	igital/ hoto. evel 1	ffset/ om. ind evel 1	aint/ om. ind evel 1	ec. ind evel 2	St orage Bu ilding 2
n-Pentane	.60			.29		.68	.66		
n-Hexane						.37			
Cyclohexane	.49					.09	.12		
Methyl Chloride	.16								
Methylene Chloride	.40			.13	.57		.20	.68	11. 7
1,1,2,2-TCEa	.17			.11		.59			
Bromoform	.17			.80	.77		4.8	1.3	
Bromodichlorometha ne						.49			
CFC-12/HCFC-22	6.7	4.7			.79	.43	6.6	.46	12. 1
CFC-114	92	0.4	3.4	3.4	21	1.2	6.4	2.3	6.9 2
CFC-113/1,1-DCEe						.38			
CFC-11						.46	.17		
Propene	0.9	.73	.89	.26	0.3	.65	.44	.46	0.8 1
Vinyl Chloride									

	31	1.2	8.3	5.1	42	8		3		
cis-1,2-DCEe						.11	.83			
TCEe/n-Butyl Alcohol						.38	.21			
Ethylbenzene						.47				
o-Xylene/Styrene						.67	.18	.84		
m-Xylene/p-Xylene					.82	6.8	1.0	0.4		
1,3,5-TMB	1.6	.48	.78	.74	9.7	29	7.8	5.0		
1,2,3-TMB	.27	.90		.12	.30	9.4	9.2	9.9		
1,2,4-TMB	2.8	.94	.95	.93	4.4	28	6.3	0.0	7	2.0
Toluene						0.3	.53	.68		
Benzyl Chloride	.88				.58	5.1	.28	.9		
o-DCB	.53	.71		.75	.32	4.1	1.8	6.3		
m-DCB	.56				.28	2.8	.80	.38		
p-DCB					.88	2.5	.07	.78		
Methyl Alcohol	65	7.2	3.8	14	20	,994	59	94	2	24.
Ethyl Alcohol	09	74	24	11	29	92	28	91	5	8.1
Isopropyl Alcohol	84	1.5	1.3	77	20	2.5	,258	,191	3	1.7
MTBE						.76	.44			
Acetone	1.7	.99	.21	.48	.04	6.6	6.5	.29	0	2.5

MEK						4.8	.21			
MPK						.48				
Ethanal	.68			.76	.95	.22	.27	.57	9	0.9
Propanal						.93	.11			
Hexanal						.94	.1			
Heptanal	.44	.14		.63	5.7	2.3	3.5	0.5		
Octanal	.33		.02	.51	.41	4.1	1	.83		
Nonanal	.13	.45	.29	.55	.74	3.7	.11	.23	2	2.9
Acrolein							.54			
Acetonitrile	.88			.97						
Total VOCs	,836	05	90	,073	,334	,923	,268	,322	0	16

Table 4. Scientific Printery: VOC Concentrations (ppb)

	Storage Building 1	Admin/Design Building 1	Binding/Photocopy Building 1	Sheet-fed Offset Building 1	CTP Building 2
n-Pentane	21.4	7.63	7.48	24.1	0.91
n-Hexane	9.57	4.11	3.69	16.3	
Cyclopentane	2.32			2.66	
Cyclohexane	36.5	41.9	33.7	183	2.48
Methyl Chloride		0.63	0.64	0.70	
Methylene Chloride	69.4	26.5	21.9	47.5	2.18
Chloroform	8.02	7.58	6.22	37.9	
Carbon Tetrachloride	6.46	2.82	2.69	8.27	
Ethyl Chloride	1.08			0.85	
1,1-Dichloroethane	2.95			3.42	
Methyl Chloroform	8.55	7.06	5.37	9.10	
1,1,2-TCEa					8.88
1,1,2,2-TCEa			1.65	5.47	
Propylene Dichloride				5.47	
Ethylene Dibromide	3.44			2.76	
Bromoform	2.14	23.5	25.1	106	5.59
Bromodichloromethane			1.96		
CFC-12/HCFC-22	71.1	82.1	76.7	72.8	949
CFC-114	38.2	45.1	48.1	47.0	7.62
CFC-113/1,1-DCEe	0.99			1.29	
CFC-11	47.6	13.5	12.6	49.7	1.71
Propene	6.83	13.4	14.5	11.0	2.77
Isoprene	1.17	2.58	2.36	2.04	1.19
Vinyl Chloride	55.6	65.5	79.9	65.2	9.37
cis-1,2-DCEe	1.63	3.75		4.25	
cis-1,3-DCPe			3.47		
trans-1,3-DCPe		3.16	2.55	17.0	
TCEe/n-Butyl Alcohol				2.14	
Benzene/1,2,-DCEa	1.51	6.25		8.21	1.63
Ethylbenzene	6.68	12.0	11.0	36.5	
o-Xylene/Styrene	3.87	4.58	4.05	15.1	
m-Xylene/p-Xylene	12.0	11	9.73	31	3.42
1,3,5-TMB	6.24	41.5	40.5	172	6.91
1,2,3-TMB	3.72	8	7.73	34.1	
1,2,4-TMB	12.4	14.1	17.1	46.5	
Toluene	86.8	50.1	41.9	100	3.06
Chlorobenzene				2.02	
Benzyl Chloride		6.97	6.74	30.3	
o-DCB	3.10	6.79	6.96	34.8	

m-DCB		3.68	3.95	13.5	
p-DCB		6.35	6.08	27.5	
Methyl Alcohol	67.3	122	100	103	22.6
Ethyl Alcohol	39.1	139	150	114	10.6
n-Propyl Alcohol			1.46	5.06	
Isopropyl Alcohol	5.05	24.8	16.4	17.4	11.8
Vinyl Acetate	2.95			3.93	
1,4-Dioxane		1.93			
MTBE	20.7	8.18	7.26	31.2	
Acetone	41.4	53.9	45.3	48.1	7.29
MEK	11.5			9.01	
DPK	4.76	7.77	7.16	28.6	
DEK	6.63		1.93		
MIBK	2.52	3.91	2.88		
Ethanal	5.40	4.08		3.92	2.02
Propanal	2.00	1.44		1.55	
Butanal	15.7	4.72		18.0	
Hexanal		8.37	8.63	48.0	3.05
Heptanal	3.02	64.5	72.5	248	12.3
Octanal	2.39	15.0	15.0	58.0	3.77
Nonanal	5.34		6.52	20.8	
Acrolein	15.8				
Methacrolein				1.66	
Acetonitrile	2.84	3.54			1.56
Total VOCs	821	1,022	966	2,052	1,150

Table 5. Newspaper Printery: VOC Concentrations (ppb)

	Archive	Administration	TP	Storage	Web-fed Offset
n-Pentane	8.14	8.60	.08	7.43	7.35
n-Hexane	1.35	1.51			1.47
Cyclohexane	9.56	13.9	7.5	13.5	25.6
Methyl Chloride		0.82		0.64	0.62
Methylene Chloride	6.64	9.72	0.5	10.3	11.9
Chloroform	1.91	3.18	.22	2.98	6.09
Ethyl Chloride			.76		
Methyl Chloroform		1.71	.56		3.66
1,1,2,2-TCEa		5.62	.55	6.10	5.32
Bromoform	9.29	30.8	6.0	38.3	84.5
Bromodichloromethane		1.96	.32		4.46
CFC-12/HCFC-22	7.51	8.55		9.46	
CFC-114	38.4	83.7	3.6	48.1	
CFC-11	7.87	9.27	.16	8.09	9.47
Propene	6.16	13.5	1.2	9.95	10.5
Isobutylene					0.73
Isoprene	1.47	3.06	.6	3	1.38
Vinyl Chloride	4	83.2		48	

	5.4		8.8	.7	
cis-1,2-DCEe	1.41	2.59	.56	1.94	
cis-1,3-DCPe					1.57
trans-1,3-DCPe	1.68	7.4	2.1	7.8	21.7
Benzene/1,2-DCEa			.51		
Ethylbenzene	18.0	94.2	22		316
o-Xylene/Styrene	13.8	65.8	14	75.2	214
m-Xylene/p-Xylene	38.9	188	26	213	641
1,3,5-TMB	29.5	93.0	48	113	225
1,2,3-TMB	12.1	35.0	9.3		
1,2,4-TMB	7.77	12.2	3.2	14.6	15.2
Toluene	9.27	25.9	6.9	21.3	56.2
Chlorobenzene		21.4	0.2		
Benzyl Chloride	14.4	48.6	2.4	47.5	35.6
o-DCB	10.6	52.2	3.2	61.8	111
m-DCB	4.22		3.3	37.3	
p-DCB	10.3	29.9	5.9	66.2	50.0
Methyl Alcohol	328	1,870	,782	1,634	2,191
Ethyl Alcohol	292	998	31	1,058	616
n-Propyl Alcohol		2.19		2.	3.78

			.66	22	
Isopropyl Alcohol	43.2	52.7	1.9	32.7	50.7
1,4-Dioxane				1.92	
MTBE	5.56	5.42	.85	4.16	4.67
Acetone	22.6	58.3	6.6	42.8	63.7
MEK	3.68	11.2	5.8	4.97	6.09
MPK	2.95		.16	3.47	4.89
MBK			.84		
Ethanal	6.86	14.9	0.0	16.2	26.6
Propanal	2.99	6.32	.34	8.25	11.5
Butanal	1.78	2.05	.70		1.95
Pentanal	2.13	5.49	.13	5.41	11.4
Hexanal	11.3	32.5	9.6	32.6	74.4
Heptanal	4.27		8.4	13.3	29.1
Octanal	12.5		6.5	58.6	99.7
Nonanal	15.6	32.9		21.1	
Acrolein		1.4			2.39
Total VOCs	1,112	4,074	,882	3,836	5,078

Table 6. VOC Possible Source Summary

VOC	Possible Previously Reported Source	Government Max (ppb)	Government CV (%)	Scientific Max (ppb)	Scientific CV (%)	Newspaper Max (ppb)	Newspaper CV (%)
n-Pentane	Outdoor, Indoor	1.7	43	24	81	8.6	7
n-Hexane	Printery	1.4	1	16	86	1.5	6
Cyclohexane	Indoor	7.1	88	183	119	26	38
Methylene Chloride	Outdoor, Printery	12	76	69	77	12	20
Chloroform		MDL	0	38	120	6.1	43
Carbon Tetrachloride	Outdoor	MDL	0	8.3	65	MDL	0
Methyl Chloroform	Printery	MDL	0	9.1	50	3.7	47
1,1,2-TCEa		MDL	0	8.9	106	MDL	0
1,1,2,2-TCEa		2.2	15	5.5	73	8.5	46
Propylene Dichloride		MDL	0	5.5	72	MDL	0
Bromoform	Outdoor	15	104	106	131	84	65
CFC-12/HCFC-22	Indoor	77	144	949	156	9.5	11
CFC-114	Outdoor, Indoor	192	90	48	46	84	38
CFC-11	Outdoor	1.5	19	50	88	9.5	8
Propene	Outdoor, Indoor	11	67	14	50	14	26
Vinyl Chloride	Outdoor, Indoor	142	74	80	49	83	32
cis-1,2-DCEe		6.1	82	4.2	54	2.6	27
trans-1,3-DCPe		MDL	0	17	130	22	73

Benzene/1,2-DCEa	Outdoor, Print	MDL	0	8.2	76	4.5	0
Ethylbenzene	Printery	3.5	35	37	99	316	81
o-Xylene/Styrene	Printery	7.7	74	15	90	214	77
m-Xylene/p-Xylene	Printery	27	126	31	77	641	80
1,3,5-TMB	Printery	129	133	172	128	225	59
1,2,3-TMB		49	122	34	119	49	58
1,2,4-TMB	Printery	128	124	47	91	15	23
Toluene	Outdoor, Indoor, Print	30	176	100	68	56	59
Chlorobenzene		MDL	0	2	16	21	115
Benzyl Chloride		15	105	30	125	52	39
o-DCB		44	125	35	129	111	58
m-DCB		13	105	13	105	37	72
p-DCB		13	109	28	127	76	58
Methyl Alcohol	Outdoor, Indoor	1,994	152	122	47	2,782	52
Ethyl Alcohol	Outdoor, Indoor	992	74	150	69	1,058	55
n-Propyl Alcohol	Outdoor, Indoor	MDL	0	5.1	77	3.8	36
Isopropyl Alcohol	Indoor, Printery	2,258	150	25	48	53	18
MTBE		9.8	99	31	86	5.6	12
Acetone	Indoor, Printery	77	136	54	47	64	34
MEK		45	203	11	89	16	60
MPK		2	1	2	1	4	2

	.5	2	9	06	.9	2
DEK	M DL	0	6 .6	7 7	M DL	0
Ethanal	4 .2	5 8	5 .4	3 6	2 7	4 3
Propanal	5 .9	8 4	2	2 1	1 1	4 2
Butanal	M DL	0	1 8	8 0	2	8
Pentanal	M DL	0	M DL	0	1 1	5 3
Hexanal	2 .9	1 9	4 8	1 38	7 4	5 9
Heptanal	5 3	1 03	2 48	1 23	2 9	6 4
Octanal	2 4	1 12	5 8	1 21	1 00	6 0
Nonanal	1 4	6 5	2 1	7 9	3 3	3 8
Acrolein	1 .5	4	1 6	1 45	2 .4	3 1

Previous sources: Print=previous printery concentrations > 50 ppb; Outdoor=previous Kuwait outdoor concentration > 15 ppb; Indoor=previous Kuwait indoor concentration > 15 ppb.

Categories: white= maximum concentration at MDL; green max < 5 ppb; cream=max & CV < cutoffs; yellow=max > cutoff & CV < cutoff; orange=max < cutoff & CV > cutoff; red= max & CV > cutoffs.

Max cutoff: 15 ppb for government and newspaper, 30 ppb for scientific.

CV cutoff: 50% for government, 40% for scientific; 30% for newspaper.

Supplementary Figure Captions

Supplementary Figure 1. VOC Concentrations from Government Printery compared to recent Printery Air Quality Studies

Supplementary Figure 2. VOC Concentrations from Scientific Printery compared to recent Printery Air Quality Studies

Supplementary Figure 3. VOC Concentrations from Newspaper Printery compared to recent Printery Air Quality Studies

Supplement Table 1. **VOCs in Previous Printery Studies**

VOC	First Author and Year
n-Pentane	Laire1997, Vega2000, Yuan2010
n-Hexane	Chang1987, Wadden1995, Laire1997, Crouch1999, Vega2000, Wypych2001, Batterman2002, Yu2004, Sutton2009, Yuan2010
Cyclopentane	Vega2000, Yuan2010
Cyclohexane	Laire1997, Vega2000, Casselli2009, Yuan2010
Methyl Chloride	
Methylene Chloride	Laire1997, Crouch1999, Wypych2001, Leung2005, Lee2009, Sutton2009, Kumagagai2013, Zheng2013, Prica2016
Chloroform	Leung2005
Carbon Tetrachloride	Deng1987, Doherty2000, Prica2016
1,2-DCEa	Leung2005
Methyl Chloroform	Laire1997, Leung2005, Sancini2014
1,1,2-TCEa	Leung2005
TCEa	Crouch1999, Gioda2002, Prica2016
1,1,2,2-TCEa	Leung2005
Propylene Dichloride	Kumagagai2013
Bromoform	
HCFC-22	
CFC-12	Leung2005
CFC-114	
CFC-11	Leung2005
CFC-113	Leung2005, Casselli2009
Propene	Yuan2010
Vinyl Chloride	Herbert1975, USEPA1994, Leung2005
1,1-DCEe	
cis-1,2-	

DCEe		
-1,3-DCPe	cis/trans	
	TCEe	Wypych2001, Batterman2002, Leung2005
	Benzene	Wadden1995, Crouch1999, Vega2000, Batterman2002, Gioda2002, Yu2004, Leung2005, Casselli2009, elSiad2009, Godoi2009, Yuan2010, Kirurski2012, Curic2013, Mansouri2015
zene	Ethylben	Wadden1995, Crouch1999, Vega2000, Wypych2001, Gioda2002, Leung2005, Casselli2009, Godoi2009, Yuan2010, Djogo2011, Kirurski2012, Curic2013, Mansouri2015
	Styrene	Vega2000, Batterman2002, Leung2005, Casselli2009, Yuan2010, Zheng2013
Xylene	m-	Wadden1995, Gioda2002, Leung2005, Casselli2009, Sancini2014
	o-Xylene	Wadden1995, Laire1997, Gioda2002, Leung2005, Casselli2009, Godoi2009, Yuan2010, Vilcekova2016
	p-Xylene	Wadden1995, Gioda2002, Leung2005
Xylenes	m/p-	Laire1997, Vega2000, Godoi2009, Yuan2010
	Xylenes	Crouch1999, Wypych2001, Rodriguez2007, elSiad2009, Kirurski2012, Curic2013, Mansouri2015,
TMB	1,3,5-	Wadden1995, Laire1997, Batterman2002, Vega2002, Leung2005, Rodriguez2007, Casselli2009, Sutton2009, Yuan2010
TMB	1,2,3-	Wadden1995, Laire1997, Casselli2009, Yuan2010
TMB	1,2,4-	Wadden1995, Laire1997, Crouch1999, Wypych2001, Batterman2002, Gioda2002, Leung2005, Rodriguez2007, Casselli2009, Sutton2009, Yuan2010, Zheng2013
	Toluene	Wadden1995, Laire1997, Crouch1999, Svendson2000, Vega2000, Wypych2001, Batterman2002, Gioda2002, Yu2004, Leung2005, Rodriguez2007, Casselli2009, elSiad2009, Godoi2009, Yuan2010, Djogo2011, Kirurski2012, Sancini2014, Mansouri2015
enzene	Chlorob	Leung2005
Chloride	Benzyl	
	o-DCB	Wadden1995,
	m-DCB	Wadden1995,
	p-DCB	Wadden1995, Leung2005
Alcohol	Methyl	Crouch1999, Wypych2001, Prica2016
Alcohol	Ethyl	Crouch1999, Zheng2013, Prica2016
Alcohol	n-Propyl	Crouch1999
l Alcohol	Isopropy	Brugone1983, Wadden1995, Laire1997, Crouch1999, Svendson2000, Wypych2001, Yu2004, Casselli2009, Hautamaki2009, Kirurski2012, Zheng2013, Rossita2015
Alcohol	n-Butyl	Wypych2001, Casselli2009
Dioxane	1,4-	Wypych2001
	MTBE	Vega2000
	Acetone	Crouch1999, Kirurski2012, Zheng2013, Prica2016,

MEK	Crouch1999, Wypych2001, Batterman2002, Casselli2009, Zheng2013, Prica2016
MIBK	Crouch1999, Wypych2001, Zheng2013
Ethanal	Gioda2005
Propanal	
Butanal	
Pentanal	
Hexanal	
Heptanal	
Octanal	
Nonanal	Vilcekova2016

Supplement Table 2. **VOC concentrations (ppb) from recent Air Quality Studies**

VOC	Summary	Kuwait Outdoor Air		Kuwait Indoor Air		Printery Air	
		Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
n-Pentane	Outdoor, Indoor	1.3	17	1.1	37		
n-Hexane	Printery	1	5.7	0.7	9.8	20	14,800
Cyclopentane		1.1	1.4	0.8	1.8		
Cyclohexane	Indoor	0.5	5.3	0.5	22	0.3	1.7
Methyl Chloride		0.8	0.8	1	1.1	2.1	2.1
Methylene Chloride	Outdoor, Printery	0.9	209	0.7	8.4	192	6,900
Chloroform		11	11			12	12
Carbon Tetrachloride	Outdoor	9	24			0	0
Ethyl Chloride						0	0
1,1-Dichloroethane						0	0
Methyl Chloroform	Printery					0.5	6,287
1,1,2-TCEa						0	0
1,1,2,2-TCEa						15	15
Propylene Dichloride						0	0
Ethylene Dibromide						0	0
Bromoform	Outdoor	74			74		
Bromodichlorometh							

ane								
	CFC-12/HCFC-22	Indoor	0.2	6.7	0.2	18	2	2
	CFC-114	Outdoor, Indoor	11	119	9.6	231		
	CFC-113/1,1-DCEe						0.2	1.2
	CFC-11	Outdoor	0.5	43	0.5	0.8	1.5	1.5
	Propene	Outdoor, Indoor	3.2	94	3.5	177		
	Isobutylene		1.5	1.7	2	5.4		
	Isoprene		0.9	1.8	1.6	2		
	Vinyl Chloride	Outdoor, Indoor	13	138	12	171	1.4	1.4
	cis-1,2-DCEe						1.4	1.4
	cis-1,3-DCPe						0	0
	trans-1,3-DCPe						0	0
Alcohol	TCEe/n-Butyl		2	2	2.7	2.7	3.6	14
	Benzene/1,2-DCEa	Outdoor, Print	1.1	36	0.4	5	0.3	95,000
	Ethylbenzene	Printery	0.7	8.5	0.6	6.1	0.2	10,200
	o-Xylene/Styrene	Printery	1.1	8.2	0.8	7.9	0.4	71
	m-Xylene/p-Xylene	Printery	0.9	19	0.8	14	0.3	72,162
	1,3,5-TMB	Printery	0.3	0.3	0.2	4.6	1.4	1,585
	1,2,3-TMB		0.3	0.3	0.3	0.3	0.3	3.1
	1,2,4-TMB	Printery	0.6	0.6	0.8	1.4	0.1	7,176
	Toluene	Outdoor, Indoor, Printery	2.1	23	1.3	16	14	26,000
	Chlorobenzene						1.9	1.9
	Benzyl Chloride							
	o-DCB						0	0
	m-DCB				0.8	2.1	0	0
	p-DCB		2	2.	2	2.	3	3

		.3	3	.5	5	.4	.4
Methyl Alcohol	Outdoor, Indoor	4 .5	2 3	7 .5	4 2		
Ethyl Alcohol	Outdoor, Indoor	3 .3	1 7	9 .3	7 53		
n-Propyl Alcohol	Outdoor, Indoor	8 1	8 1	1 7	4 3		
Isopropyl Alcohol	Indoor, Printery	0 .9	6. 6	1 .8	5 7	2	2 67,000
Vinyl Acetate		0 .5	0. 5	0 .5	0. 5		
1,4-Dioxane							
MTBE		0 .5	0. 7	0 .6	0. 9		
Acetone	Indoor, Printery	2 .7	1 9	3 .4	1 9	1 2,100	1 2,100
MEK		1 .1	1. 1	1	2. 8	0 .8	1 2
MPK							
DEK							
MBK							
MIBK							
Ethanal		0 .5	4. 9	1 .1	7. 7		
Propanal		3 .7	4. 9	5 .7	6. 1		
Butanal		0 .6	1	1 .2	1. 4		
Pentanal		0 .4	0. 4	0 .5	0. 5		
Hexanal		0 .6	0. 7	0 .5	1 2		
Heptanal							
Octanal							
Nonanal		2 .1	3. 7	3 .1	8. 2		
Acrolein		0 .5	0. 7	1	1		
Methacrolein		1 .2	1. 2	0 .8	0. 8		
Acetonitrile		1 .9	3. 3	1 .9	4. 1		

Supplement Table 3. **Government Printery: Percentage coefficient of variation (CV (%)) (SD (ppb)) of VOC concentrations**

	C	R	A	D	D	O	M	D	S

		TP	cpt.	dmin.	esign	igital/Photo.	ffset/Com. Bind	aint/Com. Bind	ec. Bind	torage
	n-Pentane	1.1 (0.018)			3.5 (0.045)		1.6 (0.026)	3.3 (0.055)		
	n-Hexane						0.3 (0.004)			
	Cyclohexane	1.1 (0.016)					0.4 (0.031)	1.4 (0.043)		
	Methyl Chloride	2.4 (0.028)								
	Methylene Chloride	0.5 (0.034)			1.7 (0.087)	2.5 (0.088)		2.0 (0.1)	3.1 (0.2)	8.5 (1.0)
	1,1,2,2-TCEa	3.4 (0.073)			2.4 (0.051)	>20	0.2 (0.003)			
	Bromoform	5.4 (0.2)			2.3 (0.064)	4.4 (0.2)		1.2 (0.2)	3.0 (0.3)	
	Bromodichloromethane						3.3 (0.082)			
	CFC-12/HCFC-22	0.5 (0.4)	3.3 (0.5)		**>20%**	2.8 (0.2)	6.9 (0.4)	6.8 (1.1)	5.7 (0.3)	6.7 (0.8)
	CFC-114	1.2 (2.2)	2.3 (0.7)	6.2 (2.7)	3.8 (2.8)	5.0 (6.1)	1.8 (1.1)	17.7 (8.2)	6.5 (0.8)	18.8 (1.3)
	CFC-113/1,1-DCEe						2.5 (0.060)			
	CFC-11						2.9 (0.043)	19.4 (0.2)		
	Propene	2.2 (0.2)	2.7 (0.074)	7.1 (0.2)	1.1 (0.1)	5.0 (0.5)	1.7 (0.1)	8.8 (0.7)	7.0 (0.1)	16.3 (0.1)
	Vinyl Chloride	1.9 (2.6)	2.4 (0.7)	5.6 (2.7)	5.6 (3.1)	5.1 (7.3)	2.5 (1.2)	**>20%**	9.6 (1.2)	**>20%**
	cis-1,2-DCEe						4.3 (0.3)	5.5 (0.1)		
	TCEe/n-Butyl Alcohol						8.3 (0.3)	8.8 (0.3)		
	Ethylbenzene						2.2 (0.078)			
	o-Xylene/Styrene						1.9 (0.1)	1.9 (0.080)	3.7 (0.1)	

m-Xylene/p-Xylene					3.2 (0.1)	1.7 (0.4)	1.4 (0.2)	3.2 (0.3)	
1,3,5-TMB	4.7 (0.5)	2.0 (0.089)	2.3 (0.041)	7.0 (0.6)	2.7 (0.5)	0.7 (0.8)	2.0 (1.4)	3.3 (1.5)	
1,2,3-TMB	0.6 (0.030)	2.0 (0.038)		6.0 (0.2)	3.3 (0.3)	1.1 (0.5)	2.1 (0.6)	3.7 (0.7)	
1,2,4-TMB	0.3 (0.042)	5.7 (0.3)	10.9 (0.2)	2.1 (0.2)	3.1 (0.8)	1.2 (1.5)	2.4 (2.3)	3.8 (2.3)	10.6 (0.2)
Toluene						0.7 (0.2)	1.3 (0.1)	3.3 (0.056)	
Benzyl Chloride	2.4 (0.046)				3.6 (0.1)	1.3 (0.2)	1.7 (0.1)	3.0 (0.1)	
o-DCB	0.3 (0.015)	10.8 (0.2)		2.4 (0.067)	3.3 (0.3)	1.1 (0.5)	2.5 (0.5)	3.9 (0.6)	
m-DCB	2.1 (0.032)				4.0 (0.1)	0.6 (0.078)	1.7 (0.1)	3.5 (0.2)	
p-DCB					4.2 (0.079)	1.0 (0.1)	1.5 (0.077)	3.0 (0.1)	
Methyl Alcohol	0.8 (1.3)	2.3 (1.3)	4.1 (1.4)	2.7 (3.1)	1.8 (4.0)	1.2 (24.8)	2.3 (17.2)	3.1 (12.3)	6.6 (1.6)
Ethyl Alcohol	1.2 (9.6)	1.7 (4.7)	4.8 (6.0)	1.8 (9.2)	1.4 (3.2)	17.4 (173.1)	2.7 (19.8)	2.7 (10.6)	7.2 (0.6)
Isopropyl Alcohol	1.6 (4.4)	1.8 (1.7)	5.0 (2.1)	1.4 (2.5)	1.2 (4.8)	0.4 (0.3)	2.5 (55.8)	2.9 (34.1)	11.8 (0.2)
MTBE						0.7 (0.066)	1.4 (0.033)		
Acetone	1.5 (0.3)	6.3 (0.2)	7.7 (0.2)	4.9 (0.4)	2.3 (0.2)	1.0 (0.8)	3.8 (1.0)	3.2 (0.2)	4.4 (0.1)
MEK						0.3 (0.1)	4.3 (0.2)		
MPK						2.4 (0.059)			
Ethanal	1.5 (0.056)			6.0 (0.1)	3.5 (0.068)	3.8 (0.2)	0.5 (0.016)	3.0 (0.047)	2.7 (0.027)
Propanal						3.7 (0.2)	1.3 (0.027)		
Hexanal						0.8 (0.023)	6.9 (0.1)		
Heptanal	0.9 (0.089)	3.4 (0.1)		1.7 (0.1)	2.5 (0.4)	0.7 (0.2)	1.4 (0.8)	3.4 (1.4)	
Octanal	1		1	4	7	1.	1	2	

	2.0 (0.4)		5.9 (0.3)	.4 (0.1)	.0 (0.3)	2 (0.3)	.8 (0.2)	.9 (0.2)	
Nonanal	4.1 (0.2)	2.8 (0.068)	13.7 (0.4)	2.8 (0.1)	12.2 (0.6)	2.0 (0.3)	0.6 (0.036)	10.3 (0.5)	8.9 (0.3)
Acrolein							18.9 (0.3)		
Acetonitrile	1.8 (0.053)			19.5 (0.4)					

Supplement Table 4. **Scientific Printery: Percentage coefficient of variation (CV (%)) (SD (ppb)) of VOC concentrations**

	Storage	Admin/ Design	Binding/ Photocopy	Sheet-fed Offset	CTP
n-Pentane	0.2 (0.041)	4.7 (0.4)	1.9 (0.1)	0.9 (0.2)	7.7 (0.071)
n-Hexane	0.2 (0.023)	6.7 (0.3)	2.2 (0.082)	0.7 (0.1)	
Cyclopentane	0.6 (0.014)			0.8 (0.022)	
Cyclohexane	0.1 (0.047)	6.9 (2.9)	2.4 (0.8)	0.7 (1.2)	1.6 (0.041)
Methyl Chloride		2.4 (0.015)	1.3 (0.008)	1.1 (0.008)	
Methylene Chloride	3.5 (2.4)	6.3 (1.7)	2.2 (0.5)	0.5 (0.2)	7.4 (0.2)
Chloroform	0.5 (0.044)	6.3 (0.5)	3.4 (0.2)	0.6 (0.2)	
Carbon Tetrachloride	0.0 (0.002)	6.1 (0.2)	2.6 (0.069)	0.4 (0.035)	
Ethyl Chloride	0.1 (0.001)			5.6 (0.047)	
1,1-Dichloroethane	0.1 (0.003)			0.8 (0.027)	
Methyl Chloroform	0.2 (0.019)	5.6 (0.4)	2.5 (0.1)	0.6 (0.057)	
1,1,2-TCEa					0.3 (0.031)
1,1,2,2-TCEa			3.8 (0.063)	17.1 (0.9)	
Propylene Dichloride				0.8 (0.045)	
Ethylene Dibromide	0.5 (0.018)			3.8 (0.1)	
Bromoform	3.2 (0.069)	6.1 (1.4)	1.7 (0.4)	6.2 (6.6)	2.9 (0.2)
Bromodichloromethane			18.9 (0.4)		
CFC-12/HCFC-22	0.4 (0.3)	2.8 (2.3)	1.1 (0.9)	0.2 (0.1)	0.5 (4.8)
CFC-114	0.4 (0.1)	11.8 (5.3)	3.1 (1.5)	0.3 (0.1)	12.2 (0.9)
CFC-113/1,1-DDEe	0.1			0.9	

	(0.001)			(0.011)	
CFC-11	0.2 (0.074)	5.4 (0.7)	2.2 (0.3)	0.9 (0.5)	2.1 (0.036)
Propene	0.7 (0.045)	1.0 (0.1)	0.3 (0.037)	0.7 (0.080)	5.9 (0.2)
Isoprene	0.4 (0.004)	5.0 (0.1)	2.1 (0.051)	0.2 (0.004)	0.5 (0.006)
Vinyl Chloride	0.4 (0.2)	1.8 (1.2)	0.3 (0.2)	0.3 (0.2)	9.6 (0.9)
cis-1,2-DCEe	0.9 (0.015)	1.7 (0.065)	**>20%**	6.5 (0.3)	
cis-1,3-DCPe		**>20%**	1.8 (0.062)		
trans-1,3-DCPe		5.3 (0.2)	2.2 (0.057)	1.0 (0.2)	
TCEe/n-Butyl Alcohol				1.3 (0.028)	
Benzene/1,2-DCEa	3.3 (0.049)	2.3 (0.1)	**>20 %**	11.2 (0.9)	17.9 (0.3)
Ethylbenzene	1.5 (0.1)	6.4 (0.8)	2.6 (0.3)	1.0 (0.4)	
o-Xylene/Styrene	3.2 (0.1)	5.9 (0.3)	1.0 (0.039)	3.6 (0.5)	
m-Xylene/p-Xylene	0.2 (0.022)	6.8 (0.7)	2.9 (0.3)	1.9 (0.6)	3.1 (0.1)
1,3,5-TMB	1.0 (0.065)	6.0 (2.5)	2.3 (0.9)	1.9 (3.3)	3.8 (0.3)
1,2,3-TMB	0.7 (0.027)	5.6 (0.5)	9.9 (0.8)	2.8 (1.0)	
1,2,4-TMB	0.4 (0.054)	5.6 (0.8)	1.2 (0.2)	3.8 (1.7)	
Toluene	0.0 (0.029)	6.8 (3.4)	2.4 (1.0)	0.3 (0.3)	0.4 (0.013)
Chlorobenzene				8.0 (0.2)	
Benzyl Chloride		5.3 (0.4)	1.5 (0.1)	9.9 (3.0)	
o-DCB	3.7 (0.1)	6.6 (0.4)	2.7 (0.2)	7.5 (2.6)	
m-DCB		4.0 (0.1)	3.2 (0.1)	7.8 (1.1)	
p-DCB		4.9 (0.3)	2.1 (0.1)	5.7 (1.6)	
Methyl Alcohol	5.6 (3.8)	4.2 (5.1)	6.2 (6.2)	2.4 (2.5)	3.9 (0.9)
Ethyl Alcohol	3.4	1.4	10.0	2.3	7.0

	(1.3)	(2.0)	(15.0)	(2.7)	(0.7)
n-Propyl Alcohol			11.3 (0.2)	3.0 (0.2)	
Isopropyl Alcohol	3.6 (0.2)	6.5 (1.6)	4.8 (0.8)	4.0 (0.7)	5.4 (0.6)
Vinyl Acetate	0.1 (0.003)		**>20%**	2.7 (0.1)	
1,4-Dioxane		10.6 (0.2)	**>20%**	**>20%**	
MTBE	0.1 (0.024)	6.3 (0.5)	2.1 (0.2)	0.8 (0.2)	
Acetone	0.4 (0.2)	0.4 (0.2)	12.0 (5.5)	1.1 (0.5)	7.0 (0.5)
MEK	2.6 (0.3)			2.8 (0.2)	
DPK	0.3 (0.012)	5.4 (0.4)	8.8 (0.6)	2.7 (0.8)	
DEK	0.2 (0.010)		6.2 (0.1)	**>20%**	
MIBK	0.6 (0.014)	8.6 (0.3)	6.1 (0.2)	**>20%**	
Ethanal	0.7 (0.039)	3.3 (0.1)	**>20%**	3.6 (0.1)	6.0 (0.1)
Propanal	1.3 (0.027)	3.9 (0.056)	**>20%**	15.5 (0.2)	
Butanal	0.2 (0.028)	5.9 (0.3)	**>20%**	1.1 (0.2)	
Hexanal		5.2 (0.4)	4.7 (0.4)	9.6 (4.6)	3.2 (0.1)
Heptanal	3.7 (0.1)	5.6 (3.6)	1.7 (1.2)	1.3 (3.3)	4.4 (0.5)
Octanal	2.3 (0.055)	7.7 (1.2)	5.1 (0.8)	15.6 (9.1)	15.7 (0.6)
Nonanal	1.6 (0.085)	**>20%**	19.8 (1.3)	2.8 (0.6)	**>20%**
Acrolein	0.1 (0.008)		**>20%**		
Methacrolein				3.7 (0.061)	
Acetonitrile	2.5 (0.070)	15.6 (0.6)	**>20%**	**>20%**	3.9 (0.062)

Supplement Table 5. **Newspaper Printery: Percentage coefficient of variation (CV (%)) (SD (ppb)) of VOC concentrations**

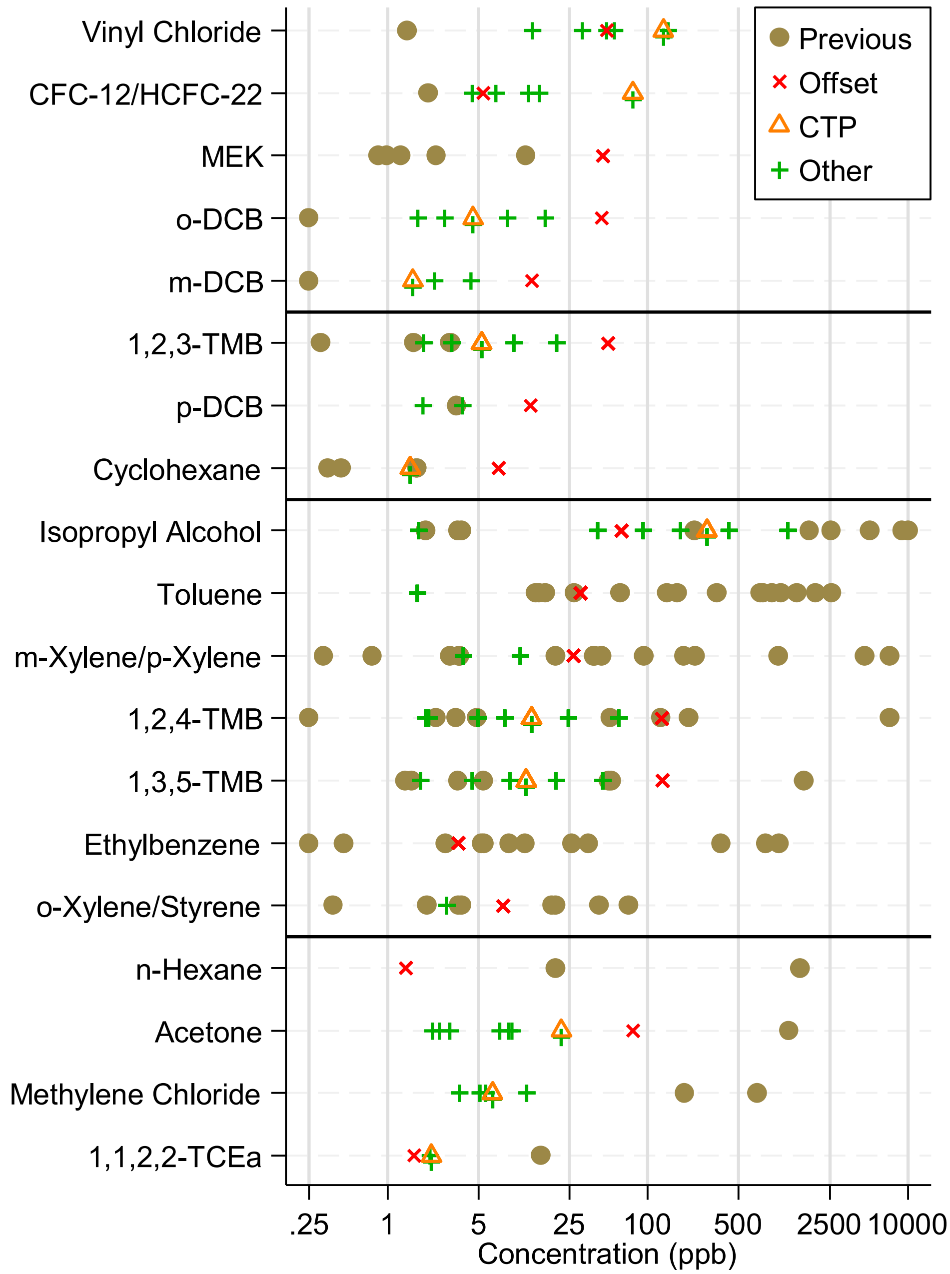
	Archive	Administration	CTP	Storage	Web-fed Offset

n-Pentane	0.7 (0.053)	0.7 (0.049)	0.8 (0.071)	15.6 (1.3)	7.9 (0.6)
n-Hexane	1.3 (0.017)		3.4 (0.051)	>20	10.1 (0.1)
Cyclohexane	0.4 (0.040)	0.8 (0.1)	0.2 (0.022)	8.7 (1.5)	11.3 (2.9)
Methyl Chloride		3.0 (0.019)	2.7 (0.022)	>20	0.8 (0.005)
Methylene Chloride	0.1 (0.009)	0.3 (0.031)	0.6 (0.063)	7.1 (0.7)	5.8 (0.7)
Chloroform	1.0 (0.019)	1.0 (0.031)	0.2 (0.007)	9.4 (0.4)	5.2 (0.3)
Ethyl Chloride				7.2 (0.055)	
Methyl Chloroform			1.2 (0.020)	6.2 (0.2)	3.9 (0.1)
1,1,2,2-TCEa		13.1 (0.8)	4.9 (0.3)	3.4 (0.3)	0.7 (0.038)
Bromoform	11.1 (1.0)	6.5 (2.5)	9.1 (2.8)	9.6 (5.4)	4.1 (3.5)
Bromodichloromethane		**>20%**	7.6 (0.1)	7.7 (0.2)	9.2 (0.4)
CFC-12/HCFC-22	4.3 (0.3)	2.5 (0.2)	16.3 (1.4)	**>20%**	**>20%**
CFC-114	5.8 (2.2)	5.0 (2.4)	3.1 (2.6)	2.2 (1.0)	**>20%**
CFC-11	1.2 (0.1)	0.4 (0.034)	0.4 (0.035)	5.7 (0.5)	5.4 (0.5)
Propene	5.1 (0.3)	1.7 (0.2)	0.5 (0.073)	10.9 (1.2)	8.3 (0.9)
Isobutylene					4.4 (0.032)
Isoprene	1.8 (0.026)	1.8 (0.053)	3.0 (0.1)	13.1 (0.2)	15.7 (0.2)
Vinyl Chloride	4.5 (2.0)	5.6 (2.7)	1.7 (1.4)	2.2 (1.1)	**>20%**
cis-1,2-DCEe	6.6	17.8	6.3	15.8	**>20%**

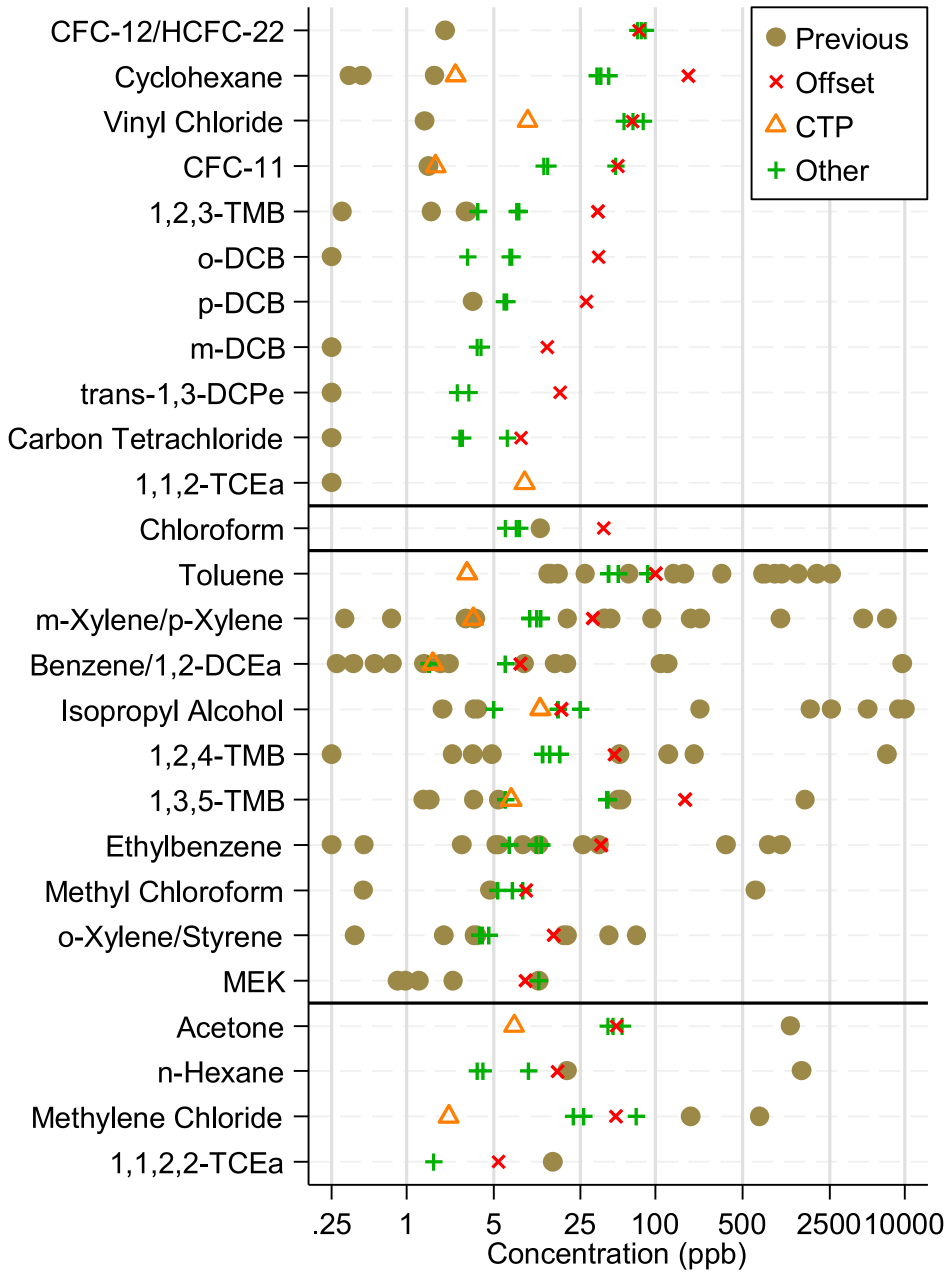
	(0.1)	(0.3)	(0.2)	(0.4)	
cis-1,3-DCPe					6.5 (0.1)
trans-1,3-DCPe	2.0 (0.033)	1.0 (0.077)	2.0 (0.1)	4.6 (0.6)	5.4 (1.2)
Benzene/1,2-DCEa	**>20%**	**>20%**	**>20%**	5.3 (0.2)	**>20%**
Ethylbenzene	1.7 (0.3)	**>20%**	6.4 (6.0)	1.4 (3.1)	1.9 (6.0)
o-Xylene/Styrene	1.1 (0.2)	1.7 (1.3)	1.1 (0.7)	5.6 (6.5)	4.1 (8.8)
m-Xylene/p-Xylene	1.3 (0.5)	1.8 (3.8)	2.0 (3.8)	4.8 (15.6)	2.6 (17.0)
1,3,5-TMB	2.2 (0.6)	1.1 (1.3)	2.2 (2.1)	3.8 (5.6)	2.6 (5.8)
1,2,3-TMB	2.8 (0.3)	**>20%**	5.1 (1.8)	14.7 (7.2)	**>20%**
1,2,4-TMB	2.3 (0.2)	4.6 (0.7)	14.0 (1.7)	6.3 (0.8)	3.4 (0.5)
Toluene	1.0 (0.1)	1.2 (0.3)	1.6 (0.4)	4.9 (1.8)	7.4 (4.2)
Chlorobenzene			2.3 (0.5)	6.7 (1.4)	
Benzyl Chloride	2.0 (0.3)	9.3 (4.4)	12.2 (5.9)	10.4 (5.5)	18.6 (6.6)
o-DCB	2.2 (0.2)	2.3 (1.4)	2.2 (1.1)	2.8 (2.3)	3.0 (3.3)
m-DCB	0.8 (0.036)	16.2 (6.0)	**>20%**	19.3 (6.4)	**>20%**
p-DCB	2.1 (0.2)	8.3 (5.5)	16.6 (5.0)	6.6 (5.0)	17.4 (8.7)
Methyl Alcohol	4.6 (15.1)	1.0 (17.0)	0.5 (9.9)	0.7 (18.2)	0.1 (1.6)
Ethyl Alcohol	4.0 (11.6)	0.5 (4.8)	0.9 (9.3)	4.6 (15.3)	2.0 (12.6)
n-Propyl Alcohol		7.2 (0.2)	3.9 (0.086)	8.3 (0.2)	8.3 (0.3)

Isopropyl Alcohol	2.6 (1.1)	0.4 (0.1)	3.1 (1.7)	4.9 (2.5)	3.5 (1.8)
1,4-Dioxane		18.8 (0.4)			**>20%**
MTBE	0.5 (0.026)	0.4 (0.017)	2.6 (0.1)	11.7 (0.6)	8.0 (0.4)
Acetone	2.3 (0.5)	3.2 (1.4)	1.0 (0.6)	11.9 (6.8)	12.4 (7.9)
MEK	1.7 (0.063)	1.2 (0.058)	2.1 (0.2)	6.7 (1.1)	6.9 (0.4)
MPK	2.7 (0.080)	7.9 (0.3)	**>20%**	5.8 (0.2)	5.9 (0.3)
MBK		**>20%**	**>20%**	6.7 (0.3)	**>20%**
Ethanal	1.6 (0.1)	1.6 (0.3)	1.6 (0.2)	8.5 (1.7)	6.7 (1.8)
Propanal	4.1 (0.1)	3.2 (0.3)	1.9 (0.1)	8.6 (0.7)	8.5 (1.0)
Butanal	12.9 (0.2)	>20	8.3 (0.2)	7.8 (0.1)	13.6 (0.3)
Pentanal	6.9 (0.1)	3.3 (0.2)	2.1 (0.1)	6.1 (0.4)	4.4 (0.5)
Hexanal	0.9 (0.1)	1.3 (0.4)	1.9 (0.6)	5.4 (2.7)	6.8 (5.1)
Heptanal	11.0 (0.5)	13.7 (1.8)	**>20%**	8.0 (1.5)	5.4 (1.6)
Octanal	4.6 (0.6)	4.8 (2.8)	**>20%**	2.9 (2.3)	2.1 (2.1)
Nonanal	12.8 (2.0)	9.6 (2.0)	11.9 (3.9)	**>20%**	**>20%**
Acrolein		**>20%**	3.0 (0.042)		10.3 (0.2)

Supplement Figure 1. VOC concentrations (ppb) from Government printery and that from post-2000 printery studies.


Vinyl Chloride
CFC-12/HCFC-22
MEK
o-DCB
m-DCB
1,2,3-TMB
p-DCB
Cyclohexane
Isopropyl Alcohol
Toluene
m-Xylene/p-Xylene
1,2,4-TMB
1,3,5-TMB
Ethylbenzene
o-Xylene/Styrene
n-Hexane
Acetone
Methylene Chloride
1,1,2,2-TCEa
Previous
Offset
CTP
Other
.25
1
5
25
100
500
2500
10000
Concentration (ppb)

Supplement Figure 2. VOC concentrations (ppb) from Scientific printery and that from post-2000 printery studies.



Supplement Figure 3. VOC concentrations (ppb) from Newspaper printery and that from post-2000 printery studies.