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Ecotoxicity Estimation of Hazardous Air Pollutants Emitted from Semiconductor Manufacturing Processes Utilizing QSAR

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This study aims to assess the ecological risk of the hazardous air pollutants (HAPs) emitted in the semiconductor manufacturing processes in Korea by using Quantitative Structure Activity Relationship (QSAR, EPA, US, EPI Suite^{TM} 4.1). Owing to the absence of environmental standards of hazardous air pollutants in the semiconductor manufacturing processes in Korea, 18 HAPs in the semiconductor field included in both the US EPA NESHAPs and the hazardous air pollutant list of Ministry of Environment in Korea were selected. As a results 8 chemicals (44.4%) of the selected 18 HAPs were VOCs. Cyanides (cyanides) and ethylene oxides (epoxy resins), and tetrachloro-ethylene (aliphatic compounds, halides) showed long half-lives. Cyanide HAPs especially had the highest half-life with the estimated value of 356.533 days. Nickel compounds (heavy metal compounds) possessed the highest water solubility followed by acetaldehyde (aldehyde compounds), ethylene oxides, and 1,4-dioxanes. The halides, including tetrachloro-ethylenes, carbon tetra-chlorides, benzene (aromatic compounds), and lead (heavy metals), are estimated to take the longest time for biodegradation. Tetrachloro-ethylene, with the acute toxicity end point of 3.685-7.033 mg/L, was assessed to be the most highly toxic substance among the 18 HAPs. However, considering the absence of the HAPs in the common category of log $K_{ow} \geq 4$ and BCF $\geq$ 500, which indicates the standard of bioconcentration potentials, potentials of the bioconcentration are considered to be low.

Key Words : Semiconductor, Hazardous air pollutant emissions, QSAR, EPI Suite^{TM} 4.1, Toxicity prediction

Introduction

The semiconductor industry in Korea has grown into a 50 billion dollar business in the global export trade based on 2011 data. Of the industry subsectors, memory and D-RAM have captured over 50% of the global market and have great impact on the semiconductor market.[1,2]

In recent years, however, there have been issues regarding occupational diseases due to the carcinogen exposure and occupational safety accidents owing to hydrofluoric acid leakages affecting the employees who work in semiconductor manufacturing so that more attention has been given to hazardous chemicals including hazardous factors.[3] The Korea Occupational Safety and Health Agency (KOSHA) performed epidemiological studies with regards to cancer occurrences and mortality by sex of the semiconductor workers.[4,5] Numerous studies have reported the potential health risks of toxic substances utilized in the semiconductor industry. In Taiwan, known to be a strong country for semiconductors, epidemiological studies were conducted to investigate the effects on delivery and health risks for the female workers of the semiconductor industry in the past.[6,7] Researchers also studied *in vivo* accumulation in local Taiwanese squirrels (*C. erythraeus*) of the trace elements such as GaAs (gallium arsenide), Cd, In, and Ti released from the semiconductor industry.[8]

By providing data on the potential hazardous factors for all stages of semiconductor manufacturing including wafer manufacturing, processing, and chip assembly, the results of the epidemiological study of the workers in response to the characteristics of their exposure to hazardous factors occurring in semiconductor processes have been reported.[9-11] Substances found include VOC toxic substances such as aromatic hydrocarbons like Isopropyl alcohol (IPA), hexane, benzene, toluene, and Propylene Glycol Monomethyl Ether (PGME) produced in semiconductor photolithography processes, as well as Particulate Matter (PM) toxic substances such as As(III), which can induce DNA damages owing to nervous system, Reactive Oxygen Species (ROS), and respiratory diseases.[12,13]

Particularly, when confirming chemicals in the semiconductor industry in Korea, direct epidemiological investigation or data collection regarding the amount of chemicals used and records of Material Safety Data Sheets (MSDS) are restricted on account of the protective measures put in place by the business secrets protection policy. It is therefore difficult to create a standard for levels of atmospheric hazardous chemicals in the semiconductor business.[3]

Recently however, in accordance with a global movement reinforcing the management and regulation of hazardous substances and new chemicals through policies such as EU REACH (Registration, Evaluation and Authorization and restriction of Chemicals) and RoHS (Restriction of the use of certain hazardous substances in electrical and electronic equipment), the Korean government has established policies regarding chemical registration and assessments by 2015 so that the legislation regarding such chemicals now tends to be reinforced.[14,15]

The Quantitative Structure Activity Relationship (QSAR) program analyzes its own structures and physical properties of the substances that users desire to evaluate, and this provides both models and information capable of estimating toxic substances. Moreover, the program provides varied information that enables determination of the toxicity and bioconcentration of experimental animals so that it provides screening information useful in utilization of environmental risk assessments. OECD develops and provides the QSAR Toolbox (http://www.qsartoolbox.org/) in order for the government to utilize the hazardous chemical ecotoxicity data. Despite the fact that such issues are urgent matters, however, there are only a few that investigate basic data utilization of the semiconductor industry and risk assessment techniques based on this data.

Considering such problems, this study aims to perform environmental risk assessments with regards to hazardous air pollutants (HAPs; Hazardous Air Pollutants) emitted from the semiconductor industry utilizing QSAR. The EPI Suite^{TM} v4.11 program developed by US EPA was employed in this study (US EPA EPI Suite, 2012, http://www.epa.gov/opptintr/exposure/pubs/episuitedl.htm). A total 18 HAPs that were included in both US EPA NESHAPs and the hazardous air pollutant list of the Ministry of Environment in Korea were selected. Based upon the EPI (Estimation Programs Interface) Suite program by US EPA, environmental toxicity was estimated and this information would further be utilized as a screening tool of HAPs in the semiconductor manufacturing field. Target physicochemical properties of the substance according to the biological permeability, persistence and organism's predicted end point obtained by the QSAR program. In the next step, we compare with the survey data of the national chemical information system (NCIS) of Korea and the predicted ecotoxicity, and report the results.

Experimental

HAPs selection in the semiconductor field. In this study, the HAPs in the semiconductor field were selected within a common category of the hazardous substances proposed by both the Korean Clean Air Conservation Act and the Clean Air Act of US EPA (CAA; Clean Air Act). As shown in Figure 1, 18 total overlapping HAPs were selected for QSAR analyses. Among 61 air pollutants based on the Clean Air Conservation Act in Korea, 35 specific air pollutants including gaseous or particulate substances were primarily determined (Ministry of Environment, 2008).[16] Due to the absence of a HAPs standard in the semiconductor field in Korea, 32 major specific air pollutants that were suggested by the semiconductor field in the US EPA NESHAPs (National Emission Standards for Hazardous Air Pollutants) were selected first (US EPA NESHAPs, 2001),[17] and then 18 common substances were selected and subjected to the analyses.

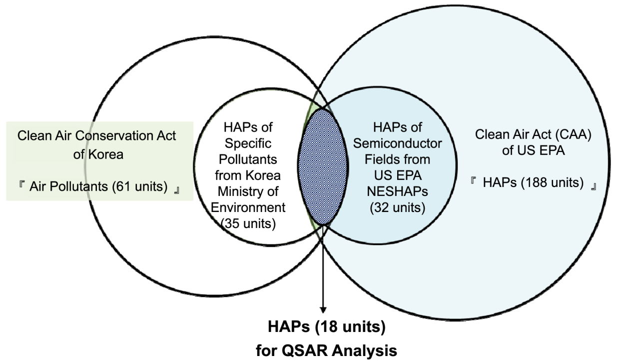


Figure 1. The HAPs selection from semiconductor fields for QSAR analysis.

Data Analysis Items of EPI Suite^{TM} v4.11 Program. We used the applicability domain of a QSAR model as in Table 1. Based on various models provided by the EPI Suite^{TM} v4.11 program, our investigation included aspects such as physicochemical properties, biodegradation, bioconcentration, water solubility, and toxicity estimation of the HAPs. This study utilized melting point, boiling point, Henry's law constant, atmospheric oxidation, water solubility, octanol-water partition coefficient (K_{ow}), soil organic carbon-water partition coefficient (K_{oc}), biodegradation, bio-concentration factor (BCF), and end point that were provided by the QSAR program. We compare with the survey data (National Institute of Environmental Research- Globally Harmonized System of Classification and Labeling of Chemicals; NIER-GHS or OECD Screening Information Data Set; OECD SIDS) of the national chemical information system (NCIS) of Korea and the predicted ecotoxicity of QSAR.

Results and Discussion

Atmospheric Emission and Volatile Organic Compounds. The most important physico-chemical property in the atmospheric emission of the 18 HAPs is volatility. Henry's law constant, vapor pressure, and K_{oa} (octanol-air partition coefficient) are the major criteria for volatility assessments. Of the 18 HAPs, 8 HAPs (acetaldehyde, acrylonitrile, benzene, 1,3-butadiene, carbon tetrachloride, ethylbenzene, formaldehyde, and tetrachloro-ethylene) were volatile organic compounds (VOCs; Volatile Organic Compounds) with high Henry's law constant (atm-m^3/mol). The remaining 8 HAPs, on the other hand, were mainly heavy metals that were incomplete non-volatile substances.Therefore Henry's law constant and actual values (values in parentheses) were not shown in the results of the QSAR analysis in Table 2. Because the chemical domains that are used in developing current EPI Suite^{TM} QSARs do not provide adequate coverage of nanoparticles, inorganic compounds, organo-metallic and certain other classes of chemicals, application of EPI Suite^{TM} for these classes of compounds within the PMN and pollution prevention (P2) programs is inappropriate.[19] Generally, VOCs are high in vapor pressure (mm Hg) along with Henry's law constant. However, as described in Table 2, there were some

Table 1. Classification for toxicity estimate using EPI Suite^{TM} models

EPI Suite^{TM} Models	Profiling	Database	Endpoint	Category grouping	Data gap filling
Physical/chemical property	Boiling, melting point, vapor pressure estimations by MPBPVP v1.43	- Chemical structure - Molecule weight - Boiling point - Melting point - Vapor pressure	Physical/chemical property	Physico-chemical property by MPBPVP v1.43	QSAR
Atmospheric emission and half-life	Henrys law constant by HENRYWIN v3.20 Atmospheric oxidation by AopWin v1.92	- Group method of henrys law constant and experimental database - Overall OH rate constant by hydroxyl radicals reaction	Henrys law constant Atmospheric half-life	Atmospheric emission by HENRYWIN v3.20 Atmospheric half-life by AopWin v1.92	QSAR
Water solubility	Water solubility estimate by WSKOW v1.42	- Water solubility from Log Kow	Water solubility	Water solubility by WSKOW v1.42	QSAR
Bio-degradation	Probability of rapid biodegradation by BIOWIN v4.10	- Ultimate survey model (Biowin3)	Bio-degradation	Bio-degradation by BIOWIN v4.10	QSAR
Bio-concentration	Bioaccumulation estimate by BCFBAF v3.01	- Log BCF from regression-based method	Bio-concentration	Bio-concentration by BCFBAF v3.01	QSAR
Eco-toxicity	Eco-toxicity estimate by ECOSAR v1.11	- Acute (short-term) toxicity from organism	Eco-toxicity	Eco-toxicity estimate by ECOSAR v1.11	QSAR

differences in the vapor pressure of the 18 HAPs except for differences with the vapor pressure of heavy metals, which was low. Chlorine (halides) manifested the highest vapor pressure followed by formaldehyde (aliphatic compounds, aldehydes) and 1,3-butadiene (aliphatic compounds). Given the expected values above, 44.4% of the selected 18 HAPs were VOCs, indicating that controls and management of the atmospheric pollutants emitted during the semiconductor processes seem to be necessary. Moreover, most of emission amount on NCIS data (2011 year) was shown air emission type. Particularly, Ethylbenzene is 2,273,385 kg/year that emission was the highest amount (Table 4).

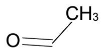
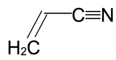
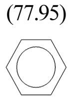
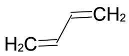
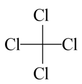
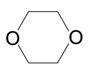
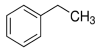
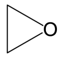
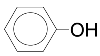
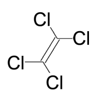
Atmospheric Half-life. Atmospheric Overall OH Rate Constant (cm^3/molecule-sec) shown in the Table 2 is the average concentration of OH radicals (Hydroxyl Radical) regarding atmospheric HAPs, which allows estimating atmospheric half-life (Half-life). Cyanide (cyanides), ethylene oxides (epoxy resins), and tetrachloro-ethylene (aliphatic compounds, halides) possess long half-lives. Of them, cyanide HAPs had the longest estimated half-life, totaling 356.533 days. According to the studies of cyanides performed by ATSDR (Agency for Toxic Substances & Disease Registry, http://www.atsdr.cdc.gov), most of the atmospheric cyanides were reported to be hydrogen cyanides (hydrocyanic acids) possessing a half-life of 1-3 years. Cyanides were reported to be non-degradable and strongly toxic substance that occurred in lead frame manufacturing processes, the plating process in the semiconductor field.[18] Owing to formations of secondary pollutants in the presence of long-term exposures to cyanides, it is considered to affect the human body and environment.

Water Solubility. Of the HAPs, nickel compounds (heavy metal compounds) revealed the highest estimated water solubility (mg/L) followed by ethylene oxides and 1,4-dioxanes. High water solubility indicates high solubility of the substance that penetrates into organisms. Although they have not been established as specific atmospheric pollutants in Korea, ethylene glycols proposed by US EPA NESHAPs of the semiconductor field have gained attention. Ethylene glycols are utilized as polyethylene glycols (PEG) in the semiconductor field. Occupational Safety and Health Research Institute (OSHRI) reported that ethylene glycols were employed in the solder ball mounted on circuit boards, the chip assembly in semiconductor manufacturing.[20] Many derivatives are produced depending upon the composition of the ethylene glycols. Based upon the MSDS data from the Korea Occupational Safety and Health Agency, even though composition of polyethylene glycols 8000 and 400 declare to have 100% ethylene glycols content, trivial amounts of other substances, up to 0.1%, such as acetaldehydes, ethylene oxide, and 1,4-dioxanes are also contained (KOSHA, 2003).[21] The above HAPs having high water solubility were contained in PEG.

In addition, studies reported that ethylene glycol ethers occurring in the semiconductor manufacturing had influences on pregnancy delay due to toxicity in female reproductive systems. Along with a previous study reporting that 1,4-dioxanes had the potential risk of causing cancer development, recent studies have proven the cancer risk of 1,4-dioxanes via a long-term animal study exposing the animals (Rats, Mice) to 1,4-dioxanes for 2 years.[22-24] This indicates that long-term exposures of HAPs are able to affect the human body and aquatic organisms in the environment depending on the concentration of the exposure.

Biodegradation. In this study, we estimated the results of biodegradation, which was in aerobic conditions, of the QSAR program. In this study, we assessed the biodegradation with The Biodegradation Probability Program, BIOWIN3 (Ultimate survey model, USM). BIOWIN3 is the high re-

Table 2. The physical and chemical properties from the HAPs estimations by QSAR analysis

Chemical Name (CAS #)	Chemical Structure (Mol. Wt.)	Boiling Point (°C)	Melting Point (°C)	Henry's Law Constant at 25 °C (atm-m^3/mol)	Vapor Pressure at 25 °C (mmHg)	Atmospheric Overall OH Rate Constant (cm^3/ molecule-sec) and Half-life (days)	Water Solubility at 25 °C (mg/L)	Biodegradation Ultimate Survey Model (USM)	Log K_{ow} (octanol/ water) partition coefficient	K_{oc} (L/kg)	BCF (L/kg wet-wt)
										Log K_{oc} at K_{ow} method	Biotransformation Half-life (days)
Acetaldehyde (000075-07-0)	 (44.05)	33.83 $(20.1)^a$	-106.38 $(-123)^a$	6.00×10^{-5} $(6.67\times10^{-5})^a$	910 $(902)^a$	16.98×10^{-12} (0.630)	2.57×10^5 $(1\times10^6)^a$	3.1241 (weeks)	-0.17 $(-0.34)^a$	3.219 (0.508)	3.162 (0.05458)
Acrylonitrile (2-Propenenitrile) (000107-13-1)	 (53.06)	94.65 $(77.3)^a$	-72.38 $(-83.5)^a$	1.38×10^{-4} $(1.38\times10^{-4})^a$	97.5 $(109)^a$	4.21×10^{-12} (2.542)	4.53×10^4 $(7.45\times10^4)^a$	2.9995 (weeks)	0.21 $(0.25)^a$	28.55 (1.456)	3.162 (0.07152)
Arsenic (007440-38-2)	As (77.95)	473.40 $(817)^a$	188.28 $(613)^a$	Incomplete (None)	1.14×10^4 (None)	0.00×10^{-12} (None)	3.471×10^4 (None)	3.0269 (weeks)	0.68 (None)	3.888 (0.590)	3.162 (0.02963)
Benzene (000071-43-2)	 (78.11)	102.24 $(80.0)^a$	-77.92 $(5.5)^a$	5.35×10^{-3} $(5.55\times10^{-3})^a$	87.2 $(94.8)^a$	1.95×10^{-12} (5.486)	2.00×10^3 $(1.79\times10^3)^a$	2.4406 (weeks-months)	1.99 $(2.13)^a$	70.51 (1.848)	11.81 (1.542)
Beryllium (007440-41-7)	Be (9.01)	482.98 $(2471)^a$	188.60 $(1287)^a$	Incomplete (None)	2.59×10^{-20} $(2.19\times10^{-7})^a$	0.00×10^{-12} (None)	1.49×10^5 (None)	3.1793 (weeks)	-0.57 (None)	0.3198 (-0.495)	3.162 (0.01838)
1,3-Butadiene (000106-99-0)	 (54.09)	15.55 $(-4.4)^a$	-123.21 $(-108.9)^a$	7.05×10^{-2} $(7.36\times10^{-2})^a$	2.05×10^3 $(2.11\times10^3)^a$	66.60×10^{-12} (0.161)	7.92×10^2 $(7.35\times10^2)^a$	3.0796 (weeks)	2.03 $(1.99)^a$	53.3 (1.727)	9.55 (0.338)
Cadmium (007440-43-9)	Cd (112.41)	485.37 $(765)^a$	184.54 $(321)^a$	Incomplete (None)	8.98×10^{-18} $(1.95\times10^{-14})^a$	0.00×10^{-12} (None)	1.23×10^5 (None)	2.9508 (weeks)	-0.07 (None)	0.8687 (-0.061)	3.162 (0.01422)
Carbon tetrachloride (000056-23-5)	 (153.82)	80.36 $(76.8)^a$	-58.38 $(-23)^a$	3.00×10^{-2} $(2.76\times10^{-2})^a$	99.5 $(115)^a$	0.00×10^{-12} (None)	279.5 $(793)^a$	1.9544 (months)	2.44 $(2.83)^a$	285.6 (2.456)	34.22 (1.21)
Chlorine (007782-50-5)	Cl—Cl (70.91)	472.51 $(-34.05)^a$	169.34 $(-101)^a$	2.45×10^{-2} (None)	4.99×10^3 $(5.85\times10^3)^a$	0.00×10^{-12} (None)	2.54×10^4 $(6.30\times10^3)^a$	3.0425 (weeks)	0.85 (None)	5.462 (0.737)	3.162 (0.03485)
Cyanide (000057-12-5)	HC≡N (27.03)	48.73 $(25.6)^a$	-87.99 $(-13.4)^a$	2.45×10^{-2} $(1.33\times10^{-4})^a$	743 $(742)^a$	0.03×10^{-12} (356.533)	9.54×10^4 $(1\times10^6)^a$	3.1394 (weeks)	-0.69 $(-0.25)^a$	15.1 (1.179)	3.162 (0.02074)
1,4-dioxane (000123-91-1)	 (88.11)	102.77 $(101.5)^a$	-63.61 $(11.8)^a$	1.12×10^{-7} $(4.80\times10^{-6})^a$	40.6 $(38.1)^a$	28.03×10^{-12} (0.382)	2.14×10^5 (None)	2.9871 (weeks)	-0.32 $(-0.27)^a$	3.931 (0.595)	3.162 (0.03108)
Ethylbenzene (000100-41-4)	 (106.17)	148.30 $(136.1)^a$	-46.94 $(-94.9)^a$	8.88×10^{-3} $(7.88\times10^{-3})^a$	7.59 $(9.60)^a$	5.95×10^{-12} (1.799)	228.6 $(169)^a$	2.9117 (weeks)	3.03 $(3.15)^a$	541.4 (2.733)	55.64 (0.3519)
Ethylene Oxide (Oxirane) (000075-21-8)	 (44.05)	12.29 $(10.6)^a$	-109.30 $(-111.70)^a$	5.23×10^{-5} $(1.48\times10^{-4})^a$	1.25×10^3 $(1.31\times10^3)^a$	0.28×10^{-12} (38.157)	2.37×10^5 $(1.00\times10^6)^a$	3.0931 (weeks)	-0.05 $(-0.30)^a$	4.662 (0.669)	3.162 (0.02673)
Formaldehyde (000050-00-0)	$O=CH_2$ (30.03)	9.50 $(-19.1)^a$	-110.94 $(-92)^a$	6.14×10^{-5} $(3.37\times10^{-7})^a$	3.49×10^3 $(3.89\times10^3)^a$	8.13×10^{-12} (1.316)	5.70×10^4 $(4.00\times10^5)^a$	3.1551 (weeks)	0.35 $(0.35)^a$	7.752 (0.889)	3.162 (0.05495)
Lead (007439-92-1)	Pb (207.20)	485.37 $(1749)^a$	196.28 $(327.5)^a$	Incomplete (None)	7.28×10^{-11} $(1.92\times10^{-7})^a$	0.00×10^{-12} (None)	9581 (None)	2.7413 (weeks-months)	0.73 (None)	4.297 (0.633)	3.162 (0.01431)
Nickel (007440-02-0)	Ni (58.69)	482.98 $(2732)^a$	188.60 $(1455)^a$	Incomplete (None)	4.24×10^{-9} $(2.19\times10^{-7})^a$	0.00×10^{-12} (None)	4.22×10^5 (None)	3.0695 (weeks)	-0.57 (None)	0.3198 (-0.495)	3.162 (0.01371)
Phenol (000108-95-2)	 (94.11)	170.04 $(181.8)^a$	-2.27 $(40.9)^a$	6.58×10^{-7} $(3.33\times10^{-7})^a$	3.23×10^{-1} $(3.50\times10^{-1})^a$	33.47×10^{-12} (0.320)	2.62×10^4 $(8.28\times10^4)^a$	3.0696 (weeks)	1.51 $(1.46)^a$	79.34 (1.900)	4.269 (0.03152)
Tetrachloro -ethylene (000127-18-4)	 (165.83)	114.28 $(121.3)^a$	-60.56 $(-22.3)^a$	1.77×10^{-2} $(1.77\times10^{-2})^a$	17.8 $(18.5)^a$	0.214×10^{-12} (49.998)	80.32 $(206)^a$	2.1400 (months)	2.97 $(3.40)^a$	892.2 (2.950)	81.34 (3.355)

– $( )^a$: The numbers in parentheses are experimental values of the suggested EPI Suite^{TM} v4.11 or MSDS.

Table 3. The organism's endpoint of predicted ECOSAR programs and experimental data of NCIS from HAPs

Chemical Name (CAS #)	ECOSAR Organism's Predicted End Point (mg/L)				NCIS DB (NIER GHS or OECD SIDS) Organism End Point (mg/L)		
	Fish LC 50 96-hr	Daphnia LC 50 48-hr	Algae EC 50 96-hr	Earthworm LC 50 14-day	Fish LC 50 96-hr	Daphnia EC 50 48-hr	Algae EC 50 72-hr
Acetaldehyde (000075-07-0)	34.280	162.879	152.215	None	None	None	None
Acrylonitrile (000107-13-1)	26.805	1.715	2.505	None	9.3(*Lepomis macrochirus*)[a] 25(*Brachydanio rerio*)[a]	7.38(*Daphnia magna*)[a]	3.1(*Scenedesmus subspicatus*)[a]
Arsenic (007440-38-2)	983.517	494.322	222.376	185.772	9.9(*Pimephales promelas*)[a]	1.9(*Daphnia pulex*)[a,g] 3.8(*Daphnia magna*)[a,g]	None
Benzene (000071-43-2)	65.106	36.944	27.446	136.037	5(Minnow)[a,c]	20.6(*Daphnia magna*)[a]	None
1,3-Butadiene (000106-99-0)	41.505	23.639	17.832	93.307	None	None	None
Carbon tetrachloride (000056-23-5)	50.649	29.957	26.418	240.644	27(*Lepomis macrochirus*)[a] 150(Menidia beryllina)[a] 20.8(*Pimephales promelas*)[a] 7.6(*Oryzias latipes*)[a]	8.1(*Daphnia magna*)[a]	0.46(*Selenastrum capricornutum*)[a]
Chlorine (007782-50-5)	628.980	321.142	154.180	None	None	None	None
Cyanide (000057-12-5)	5818.115	2576.326	686.491	89.376	None	None	None
1,4-dioxane (000123-91-1)	8770.489	4019.757	1235.028	266.548	None	None	None
Ethylbenzene (000100-41-4)	10.335	6.454	7.128	144.292	12.1(*Pimphales promelas*)[b] 4.2(*Oncorhynchus mykiss*)[b]	1.81(*Daphnia magna*)[b,g] 3.2(*Ceriodaphnia dubia*)[b,g]	3.6(*Selanastrum capricornatum*)[b] 7.7(*Skeletonema costatum*)[b]
Ethylene Oxide (000075-21-8)	57.672	277.857	501.535	None	84(*Pimephales promelas*)[a]	137-300(*Daphnia magna*)[a,g]	None
Formaldehyde (000050-00-0)	12.544	46.086	48.403	None	25.5(*Ictalurus punctatus*)[a] 24.1(*Pimephales promelas*)[a] 118(Rainbow trout)[a] 0.138(*Oncorhynchus mykiss*)[a]	5.8(*Daphnia pulex*)[a] 2(*Daphnia magna*)[a]	14.7(*Scenedesmus subspicatus*)[b]
Phenol (000108-95-2)	38.351	9.295	44.824	138.315	13.5(Bluegill)[a] 9.4(Rainbow trout)[a,e] 60–200(Gold fish)[a,d] 15(Carp)[a,f]	None	None
Tetrachloro -ethylene (000127-18-4)	4.268	3.685	7.033	180.839	13.4(*Pimephales promelas*)[a] 4.68(*Oncorhynchus mykiss*)[a] 5(*Salmo gairgneri*)[a] 13(*Lepomis macrochirus*)[a] 9.3(*Danio rerio*)[a]	1.3(*Daphnia magna*)[a]	27(*Selenastrum capricornutum*)[a]

The NCIS DB is [a]GHS (*Globally Harmonized System of Classification and Labelling of Chemicals*) of NIER (*National Institute of Environmental Research*) and [b]OECD SIDS (*Screening Information Data Set*). Fish LC50 was is [c]mg/L/6 h, [d]mg/L/24 h, [e]mg/L/48 h, [f]mg/L/168 h and [g]Daphnia LC50 was is mg/L/48 h.

liability ($r^2 = 0.77$) among six different models in BIOWIN suggested by the EPI Suite™ v4.11 were chosen.[25]

As shown in the Table 2, the values proposed by USM models score in the range of 1-5 for biodegradation assessments, which indicates 1 = long-term (longer than several months), 2 = months, 3 = weeks, 4 = days, and 5 = hour.[26]

The halides including tetrachloro-ethylenes, carbon tetrachlorides, benzene (aromatic compounds), and lead (heavy metals) are anticipated to take the longest time for biodegradation. Much of the literature mentioned that long-term biodegradation of such HAPs would have serious impacts on bioconcentration and toxicity of cells and organs in aquatic ecosystem.[27-30]

Bioconcentration. In the present study, we analyzed the results estimated by bioconcentration factor (BCF) and octanol-water partition coefficient (K_{ow}), the important bioconcentration indicators. Bioconcentration of the US EPA KOAWIN (KOWWIN™ use) QSAR was in a range of

Table 4. The emission and movement amount from HAPs of NCIS DB by 2011

Chemical Name (CAS #)	NCIS DB (2011 year) Emission amount (kg/year)				NCIS DB (2011 year) Movement amount (kg/year)		
	Air Emission	Water Emission	Soil Emission	Total Emission	Waste Water Movement Amount	Waste Movement Amount	Total Movement Amount
Acetaldehyde[a] (000075-07-0)	563	0	0	563	4,427	0	4,427
Acrylonitrile[a] (000107-13-1)	98,987	2	0	98,989	13,705	98,001	111,706
Benzene[a] (000071-43-2)	168,603	2	0	168,605	600	967,127	967,727
1,3-Butadiene (000106-99-0)	49,565	1	0	49,566	65	304,187	304,252
Carbon tetrachloride[a] (000056-23-5)	8,959	0	0	8,959	0	160	160
Chlorine (007782-50-5)	86,681	36	0	86,717	15,924	18,364	34,288
1,4-dioxane (000123-91-1)	10,092	0	0	10,092	14,597	390,267	404,864
Ethylbenzene[a] (000100-41-4)	2,273,385	2	0	2,273,387	14,711	1,564,770	1,579,481
Ethylene Oxide (000075-21-8)	14,816	11	0	14,827	3,885	145	4,030
Formaldehyde[a] (000050-00-0)	68,306	32	0	68,338	75,903	96,172	172,075
Phenol (000108-95-2)	76,295	79	0	76,374	22,213	183,311	205,524
Tetrachloro-ethylene[a] (000127-18-4)	130,695	0	0	130,695	44,500	70,502	115,002

[a]Volatile organic compounds (VOC) HAPs

$-4 \leq \log K_{ow} \leq 8$, and all HAPs were included in the log K_{ow} of KOAWIN. However, there were no HAPs in the common category of log $K_{ow} \geq 4$ and BCF ≥ 500, which were the criteria of chronic exposures and bioconcentration potentials when trivial HAPs were exposed for a long period of time, indicating that potentials of the bioconcentration are considered to be low.[31-33] We also analyzed the estimated soil organic carbon-water partition coefficient (K_{oc}) possessing quantitative relationships of K_{ow}.[34] Based upon this, the impact of mobility in response to levels of soil absorption was evaluated and estimated. Compared with the study performed by Jung H. J. *et al.* (2004),[35] considering the low estimated values of QSAR K_{oc}, there was large mobility in the soil matrix due to the low absorption levels of the HAPs emitted from the air and aquatic systems. Because of the short period of time of HAPs exposing to terrestrial animals, the effects on bioconcentration seem to be insignificant.

Ecotoxicity. Forecasting model of ecotoxicity in QSAR was ECOSAR v1.1 program. Utilizing data was until 2010, however cannot be updated automatically on ECOSAR to date. To assess ecotoxicity of the HAPs, this study used forecasting acute toxicity data of aquatic organisms including fish, daphnia, and algae, as well as terrestrial organisms including earthworms utilizing ECOSAR. Also, exposure time and end point (mg/L), depending upon species of the organisms, were shown in Table 2. While prioritizing HAPs toxicity is difficult due to different sensitivity by species, the acute toxicity end point of acrylonitrilie (1.715-26.805 mg/L), ethylbenzene (6.454-10.335 mg/L), and tetrachloroethylene (3.685-7.033 mg/L) are assessed to be the most toxic substances among the HAPs based on responses from aquatic organisms. We compared with foresting data on ECOSAR and experimental data on NCIS (National Chemical information System, http://ncis.nier.go.kr/) of Korea (Table 3).

In Acrylonitrile, the ECOSAR value was 26.805 (Fish LC50, 96 h) whereas the NICS value was 9.3 (*Lepomis macrochirus*) ~25 (*Brachydanio rerio*), there was also difference in formaldehyde with foresting data and experimental data. The reason was the average value of various species data on ECOSAR. We suggest that the big data system is needs in order to correct errors between foresting data of ECOSAR and experimental data. The MicroArray Quality Control (MAQC) project can be the good case. MAQC project is helping improve the microarray and next-generation sequencing technologies and foster their proper applications in discovery, development and review of FDA regulated products The resulting microarray datasets have been used for assessing the precision and cross-platform/laboratory comparability of microarrays. MAQC have been made readily accessible to the scientific community, allow individual laboratories to more easily identify and correct procedural failures.[36]

By analyzing the estimated values of the HAPs, various estimations were possible as indicators of ecotoxicity when HAPs are exposed to the environment. Based on this, we also confirmed feasibility as a screening tool for ecology risk assessments. Furthermore, the QSAR program is considered to be utilized in the selection of analysis ranges during ecological risk assessments using actual measurements through monitoring.

Conclusion

In the present study, ecology risk assessments of the hazardous air pollutants (HAPs) emitted from semiconductor manufacturing processes in Korea were carried out using Quantitative Structure Activity Relationship (QSAR, EPA, US, EPI Suite™ v4.1). A total of 18 HAPs in the semiconductor manufacturing field included on both the US EPA NESHAPs and the hazardous air pollutant list in Korea were selected. 44% of the selected 18 HAPs were VOCs. Cyanide HAPs showed the highest half-life with an estimated value of 356.533 day. Nickel compounds (heavy metals compounds) had the greatest solubility. Tetrachloro-ethylene, estimated to have longest biodegradation time, was assessed to pose the highest in ecological risk among the 18 HAPs due to its acute toxicity end point of 3.685-7.033 mg/L. However, in consideration of the absence of the HAPs in the common category of log $K_{ow} \geq 4$ and BCF ≥ 500, which indicates the standard of bioconcentration potentials, potentials of the bioconcentration are considered to be low.

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