VOCs Emissions and Reduction Possibility in Solvent Utilization – A Case Study

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ABSTRACT

The Korean government established the "Framework for Special Act on Seoul Metropolitan Air Quality Improvement" as part of the "Special Measures for Metropolitan Air Quality Improvement" in 2005. General reduction measures of VOCs were included in the "Framework" for air quality improvement. For successful reductions of VOCs emissions, VOCs emission estimating methods for specific sources and source-specific reduction programs must be developed. In this study, emission factors for dry cleaning, metal degreasing and printing facilities, were developed and their VOCs emissions estimated. VOCs emissions were estimated to be 27,482 tons from these sources in Seoul Metropolitan Area in 2001. And 12,851 ~ 15,451 tons of VOCs are estimated to be reduced in SMA by 2014.

INTRODUCTION

The air quality in the Seoul Metropolitan Area (SMA ; includes Seoul, Incheon and Gyeonggi-do) has persistently gotten worse and at one time was the worst level among OECD countries. The O_3, PM_{10}, and NO_x concentrations are serious. O_3 is especially serious. In 2004, 48% of short-term O_3 air quality standard (8h) exceedances and 64% of ozone alarms in all of Korea was occurred in SMA.

Therefore, the Korean government established the “Special Act for Seoul Metropolitan Air Quality Improvement” and the “Framework for Special Act on Seoul Metropolitan Air Quality Improvement” as part of the “Special Measures for Metropolitan Air Quality Improvement” in 2005. General reduction measures and reduction rates of VOCs were included in the “Framework” for air quality improvement. However, fundamental data to back up any research and assessment of the effectiveness of the “Framework” is heavily lacking. One of the biggest obstacles in estimating the impact of the “Framework” is the quality of the emission inventories of air pollutant compounds. The problem gets much worse for VOCs due to the abundance of sources, the number of compounds involved, and the scattered nature of its sources, mostly area sources.

For successful reductions of VOCs emissions and for the success of the “Special Act” VOCs emission estimating methods for specific sources and source-specific reduction programs must be developed. And air pollutant emission inventory has already been developed by the Clean Air Policy Support System (CAPSS) in Korea. However, the reliability of its VOC emissions is very poor, mostly because they relied on emission factors from U.S EPA AP–42 rather than developing independent domestic factors.

So, this study attempts to develop VOCs emission factors and estimating VOCs emissions at certain sources in the solvent utilization category (dry cleaning, metal degreasing and printing facilities which are widely spread in SMA). And we also attempt research of source-specific reduction programs and estimation reduction potential of VOCs emissions with regard to these source-specific reduction programs.

METHOD

Development of Emission Factors and Estimation of Emissions

In this study, we attempted to develop VOCs emission factors and VOCs emission estimations from dry cleaning, metal degreasing and printing facilities which are wide spread in SMA. In order to calculate the VOCs emission from these sources, we adopted the mass balance method where we assume that the entire amount of solvent utilized within these sources makes its way to the atmosphere. So VOCs emissions from these sources are calculated using the equations below. Equation 1 refers to dry cleaning and metal degreasing, and 2 are that for printing facilities.

Equation (1) $E = [(1/n)\Sigma S] \times A$

where E = VOCs emission from dry cleaning and metal degreasing facilities (kg VOCs/yr)

S = annual net solvent usage (annual solvent usage of facility – annual solvent waste disposed; kg solvent/yr/facility or worker)

n = number of data (number of facilities in dry cleaning, number of workers in metal degreasing)

A = activity data (total number of facilities in dry cleaning and total number of workers in metal degreasing)

Equation (2) $E_i = (I_iC_i + V_{i,}D) \times A_i$

where E = VOCs emission from printing facilities (kg VOCs/yr)

I = annual ink usage per facility or worker (kg/yr/facility or worker)

C = solvent content of ink (%)

V = annual solvent usage per facility or worker (L/yr/facility or worker)

D = density of solvent (kg/L)

A= activity data (total number of facility or worker)

i = printing method

Therefore, the goal here is to obtain the net annual solvent usage per facility or worker, annual ink and solvent usage per facility or worker, solvent content of ink, and density of solvent. Annual solvent and ink usage, number of workers in a facility and amount of disposed solvent from metal degreasing facilities were obtained via questionnaire surveys. The solvent content of ink and density of solvent were obtained through experiment and literature. And we attempted both questionnaire survey and laboratory evaporation simulation experiment for estimating the amount of annual disposed solvent from dry cleaning facilities.

Estimation of Emissions Reduction Potential

Estimation of future emissions from these sources and site-specific reduction programs are needed for estimating future emission reduction potential. Site-specific program was obtained by literature. Future VOCs emissions were estimated for 2014 SMA, because

2014 is the target year of "Framework." Reduction potential was assessed by comparing between future VOCs emissions and future emissions for source-specific reduction program scenarios. Future emissions are estimated using the equation below;

Equation (3) $E_{future, s} = E_{base, s} \times G_s \times R_s$

where E_{future} = emissions in 2014 (ton/yr)
E_{base} = emissions in base year (base year is 2001; ton/yr)
G = growth factor
R = regulation factor
s = source

RESULTS

Emission Factors and Estimation of Emissions

Dry Cleaning Facilities

These on-site surveys were conducted for two cities, Seoul, the capital city, and Daejeon, a big city in central Korea. A total of 891 facilities were visited and, due to some lack of cooperation, the effective number of obtained results was 438, of which 342 was in Seoul and the balance in Daejeon. The questionnaire included the following items:

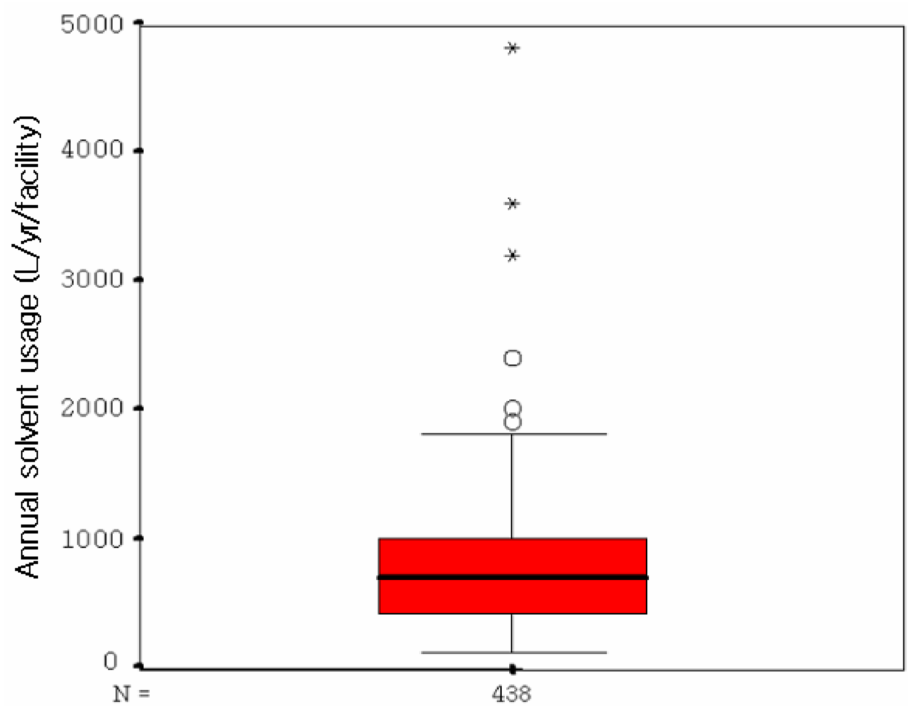
1) type of solvent used
2) estimated solvent usage per year
3) filter exchange cycle
4) number of days before used filter pick-up
5) etc.

Numbers 3) and 4) were needed to estimate the potential emissions from the used filters of the washing machines.

Following a statistical analysis of the on-site questionnaires, the average solvent usage per dry cleaning facilities was estimated to be 793 L/facility/yr. However, the standard deviation was calculated to be 575 L/yr/facility. The reasons for the large standard deviation are numerous but a big one is thought to be due to the location of the store, i.e., whether the store is located in a single residence community or a multi-household residential area, like the many apartment complexes that are so common in the cities of Korea.

Laboratory evaporation simulation experiments demonstrated that we could ignore the emissions from the used waste filters (amount of disposal solvent estimated to be 0.82 kg/yr/facility). Thus, the "net solvent usage of facility" becomes simply the "solvent usage of facility". Then applying the average density of 0.77 L/kg of the representative solvent to the above emission factor we obtained a mass based emission factor of 610.37 kg/yr/facility. Utilizing the number of dry cleaning facilities data from the Statistics Bureau for the year 2001 in SMA, we were able to estimate the total VOC emissions from the dry cleaning industry in SMA for that year to be 9,856 tons.

Figure 1. Results of on-site questionnaire survey: solvent usage per facility per year.



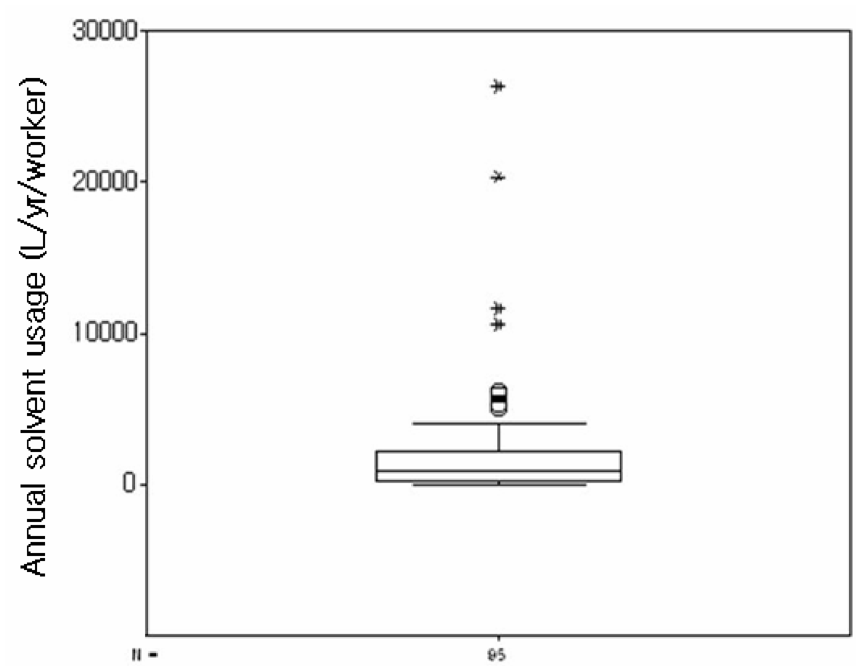
Metal Degreasing Facilities

The current CAPSS database uses the U.S. EPA AP-42 annual employee-based emission factor of 39.5 kg/yr/employee for calculating the VOCs emissions from the metal degreasing industry. Our study incorporated activity factors derived from the employee data of 5 production sub-categories including the metal casting industry and the metal assembling & production industry, etc.

In order to develop a new emission factor, the number of workers and solvent usage per company were investigated using site visitation and mail questionnaires. A total of 790 companies were targeted resulting in a usable data set of only 95 entries. The resulting box plot is given in Figure 2.

Through the above research a worker-based emission factor of 223.1 kg/yr/worker was developed. This emission factor is, remarkably, about 7 times greater than the value proposed by the CAPSS inventory. In addition, it was found that only the metal plating and the metal heat treatment industries have metal degreasing processes while the CAPSS inventory includes the entire 5 sub-categories. The estimated metal degreasing industry VOCs emissions for 2001 in SMA from these results is 2,344 ton/yr. This is only about 13% of the estimated emissions from the CAPSS inventory. Despite the much bigger emission factor the drastic decrease in the estimate of emissions is a result of a difference in the activity level parameter application.

Figure 2. Annual solvent usage per worker at metal degreasing facilities.



Printing Facilities

To estimate VOCs emissions from the printing industry, CAPSS uses the per capita annual emission factor of 0.4 kg/yr/cap given in the U.S. EPA AP-42 and activity levels from employee statistics of the printing-related industries. However, during our reliability evaluation of the CAPSS data we discovered a critical error in the CAPSS calculation. Despite using a per capita emission factor, activity levels based on "number of employees" were paired in the calculation of emissions resulting in a gross underestimation of the VOCs emissions from the printing industry.

In order to develop a new emission factor, the number of workers, printing method and annual ink and solvent usage were investigated using site visitation and mail questionnaires. From literature analysis, the major printing method categories were found to be master printing, offset lithography, screen printing, and rotogravure in Korea.

Meanwhile, ink and organic solvent usage amounts were highly correlated with the "number of employees" for the offset lithography and rotogravure processes as described in Table 1. So we adopted "total number of workers" as activity data for these methods. However, the master printing and screen printing methods were found to be better correlated with the number of facilities, so "total number of facilities" adopted as activity data for these.

Table 1. Correlation between annual ink & solvent usage and number of workers w.r.t. printing method.

Printing Method		Annual ink usage	Annual solvent usage
Master Printing	r	0.179	0.18
	p	0.18	0.17
	N	59	59
Offset Lithography	r	0.788	0.713
	p	1.07E-11	4.47E-08
	N	44	44
Screen Printing	r	0.226	0.281
	p	0.38	0.28
	N	17	17
Rotogravure	r	0.854	0.889
	p	1.32E-05	1.80E-06
	N	17	17

r: correlation coefficient

p: significance value

N: number of data

Also, the major parameters in the emission factor calculation, solvent content of ink, annual ink usage, density of solvent and annual solvent usage were investigated through a questionnaire survey and are given in Table 2. The resulting VOCs emission factors from printing facilities, with respect to printing methodology, were developed using equation (2) and Table 2, and are given in Table 3.

The VOCs emissions for the capital region in 2001 using the emission factors in Table 3 was 15,282 ton/yr which is 340 times greater than that calculated by CAPSS. This is a result of the error in the activity level application in the CAPSS calculation.

Table 2. Typical parameters used in developing emission factors for printing facilities.

Printing method	Solvent content of ink (%)	Annual ink usage (kg/yr)	Density of Solvent (kg/L)	Annual solvent usage (L/yr)
Master Printing	37	287.9	0.879	130.6
Offset Lithography	24	259.4	0.879	211.6
Screen Printing	41	1,450.8	0.852	1,290.5
Rotogravure	63	3,266.7	0.867	2,751.8

Table 3. Emission factor with respect to printing method.

Printing method	Emission factors (This study)	Emission factor (CAPSS)
Master Printing	499.6 (kg/yr/facility)	0.4 (kg/cap)
Offset Lithography	248.3 (kg/yr/worker)	
Screen Printing	1,694.3 (kg/yr/facility)	
Rotogravure	4,443.8 (kg/yr/worker)	

Estimation of Emissions Reduction Potential

<u>Estimation of VOCs emissions for 2014</u>

To assess VOCs emissions reduction potential for these sources, this study estimated VOCs emissions for the "Special Measure" target year of 2014 in SMA. In case of dry cleaning facilities, VOCs emissions were estimated using predicted activity data through linear regression analysis of the number of dry cleaning facilities from 1995 to 2004. VOCs emissions from metal degreasing and printing facilities were estimated using equation (3).

The rate of energy demand increase for the assembly metal industry for metal degreasing and for the manufacturing industry for printing facilities were used as growth factors. Future VOCs emissions from dry cleaning facilities were estimated to be 10,387 tons which is approximately the same level as present. Metal degreasing facilities emissions were estimated to be 3,757 ~ 4,098 tons VOCs which is 1.6 ~ 1.7 times more than that emitted in 2001. In case of printing facilities, VOCs emissions were estimated to be 19,439 ~ 21,187 tons for 2014 in SMA which is 4,157 ~ 5,905 tons more than the base year.

Table 4. Energy demand rate of increase.

	Annual average increasing rate (%)	
	\`02 ~ \`10	\`11 ~ \`20
Assembly metal industry	3.9 ~ 4.7	3.1 ~ 3.7
Manufacturing industry	2.1 ~ 2.8	1.1 ~ 1.7

Table 5. VOCs emissions in 2001 and estimated VOCs emissions for 2014.

	VOCs emissions in 2001	VOCs emissions for 2014
Dry cleaning	9,856	10,387
Metal degreasing	2,344	3,757 ~ 4,098
Printing	15,282	19,439 ~ 21,187

To assess VOCs emissions reduction potential, this study also investigated source-specific emission reduction programs through literature analysis. The most appropriate source-specific reduction programs and its effects are presented in Table 6. As a result, installation of solvent recycling system is deemed most appropriate for dry cleaning facilities and application of this program results in reduction in emissions for 2014 that are estimated at 748 ~ 2,347 tons. This is 7.2 ~ 22.6 % of emissions without applying this program. Switching to water-soluble solvents is deemed to be the most appropriate program for metal degreasing, and emissions were estimated to be 1,233 ~ 1,352 tons after application of this VOCs emissions reduction program for metal degreasing. And application of source-specific reduction programs for printing facilities, mostly the reduction of VOC content in printing inks, resulted in a reduction in emissions for the target year that were estimated to be 12,851 ~ 15,451 tons.

Table 6. Most appropriate source-specific emissions reduction program and its effect.

Source	Emissions reduction program	VOCs emissions for 2014 in SMA (tons)	
		Without program	With program
Dry cleaning	To Install solvent recycling system	10,387	748 ~ 2,347
Metal degreasing	Switching to water-soluble solvent	3,757 ~ 4,098	1,233 ~ 1,352
Printing	Reduction of VOC content in printing inks	19,439 ~ 21,187	12,851 ~ 15,451

SUMMARY AND CONCLUSIONS

This study attempted to develop VOCs emission factors and estimate VOCs emission at certain sources in the solvent utilization category (dry cleaning, metal degreasing and priting facilities). We also attempted research of source-specific reduction programs for these sources and studied the estimation reduction potential of VOCs emission with regard to source-specific reduction programs.

As a result, the estimated VOCs emission factors are 610.37 kg/yr/facility for dry cleaning facilities and 223.1 kg/yr/worker for metal degreasing facilities. For printing facilities, VOCs emission factors developed w.r.t printing method are 499.6 kg/yr/facility for master printing, 1,694.3 kg/yr/facility for screen printing, 248.3 kg/yr/worker for offset lithography and 4,443.8 kg/yr/worker for rotogravure, and emissions were estimated to be 9,856 tons, 2,344 tons and 15,282 tons, respectively, for the three source categories in SMA 2001.

VOCs emissions from these sources for the "Special Measure" target year of 2014 are estimated to be 33,583 ~ 35,672 tons. The most appropriate source-specific VOCs emissions reduction programs are deemed to be installation of solvent recycling system for dry cleaning facilities, switching to water-soluble solvent for metal degreasing facilities and reduction of VOCs content in printing ink for printing facilities. Application of source-specific reduction program for these sources resulted in a reduction in emissions for 2014 that are estimated to be 12,851 ~ 15,451 tons. So VOCs emissions reduction potential for these sources are estimated to be 16,522 ~ 18,751 tons.

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KEY WORDS

VOCs, Emission factors, Emissions, Emissions Reduction Potential