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Air Pollutant Emission Factors from Composite Wood Products Manufacturing in Korea

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Abstract

In Korea, there is a general lack of information available on air emissions from industry. The reasons for this include the lack of regulatory requirements for emission monitoring, limited information on specific industries, and difficulties in monitoring certain sources. This paper presents the first detailed air pollutant emission factors from composite wood product manufacturing in Korea. This study introduced emission factors for wood-based panels such as plywood, particle board (PB), and medium density fiberboard (MDF). The emission factors of particulate matters (PM) and hazardous air pollutants (HAPs) from MDF were higher than that from other wood products. The concentration of total volatile organic compounds (TVOCs) for hot press from wood-based panels was higher than drying or gluing processes. Emissions data from NPIP were compared to the data from the suggested emission factors in this study and the US EPA's. The data from our emission factors were closer to the observed results than the data using the US EPA's emission factor.

Key words : Emission factors, Wood products manufacturing, PB, MDF, Plywood, HAPs

1. INTRODUCTION

In recent years, emission inventories and emission data have received a great deal of attention. With the help of emission inventories, it is possible to design and implement policy response options. Accurate emission inventories are tools used in management decisions, air modeling and risk assessment techniques. Emission factors are appropriate for use in developing emission estimates for emission inventories.

A number of countries have developed, or are in the process of developing, pollutant release and transfer registers (PRTR) to provide information on releases to air of a range of pollutant species. The objectives of PRTR include informing government policy on pollution issues and providing for community right-to-know initiatives.

However, the reality for Korea establishing a PRTR is that there is a severe lack of information regarding emissions to air. The resources available to Korea to develop and implement PRTRs are limited and, as a consequence, our emission inventory and factor data books rely heavily on default emission factors from the United States Environmental Protection Agency (USEPA, 2003) as a basis for characterizing emissions (Sullivan and Woods, 2000).

While there have been concerns expressed regard-

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ing the applicability of data from US industry to industrial examples in Korea, there has been limited systematic evaluation of the suitability of US emission factors in our PRTRs. Furthermore, there has been limited evaluation of the suitability of applying emission factors developed in one country for use in another country.

Over the last few decades, since the introduction of plywood, the construction industry has developed new and innovative methods to manufacture composite wood materials using glues and resins in order to bond wood fibers together into a panel. Composite wood products such as PB, plywood and MDF are widely used in all aspects of house construction, and are utilized in applications ranging from furniture to cabinets to shelving.

In Korea, the composite wood production in 2002 amounted to 2.79 million cubic meters of plywood, PB, and MDF (KPI, 2002). There is an increasing tendency to use increasing amounts of pressed wood products in new house constructions, and a trend towards the increasing use of pressed wood products in home renovations and new construction.

For stationary sources, several investigations have been undertaken concerning VOCs emission from wood products (Colak and Colakoglu, 2004; Guo *et al.*, 2002), but there are few studies for the emission from the stacks of manufacturing plants. In order to improve the air quality, the Korean Ministry of Environment has declared a policy to minimize the emissions from major sources. However fundamental data to back up any research and assessment of the effectiveness of certain policies are severely lacking. A more accurate emission inventory is necessary for successful implementation of the policies. Simply transposing emission factors from one country to another may lead to a very misleading characterization of actual emissions, not only for individual facilities but also for the industrial sector as a whole (Sullivan *et al.*, 1998). In addition, no specific emission factors data for the wood products industry are currently available in Korea.

The aim of this study is to present, for the first time, emission factors for air pollutants derived from wood product manufacturing in Korea. In addition, the approach adopted for the evaluation of the comparison of our emission factors and US emission factors in the wood products industry is covered.

2. MATERIALS AND METHODS

2.1 Selection of wood products manufacturing plant

The national point source inventory program (NPIP) produced by the National Institute of Environmental Research (NIER) is a database of estimated emissions from point sources in Korea. Its main aim is to provide information on the types and amounts of pollutants emitted into the atmosphere. The first NPIP database listing estimating emissions of target compounds was publicly released in early 2000. The consolidated emissions database includes approximately 2,500 emission test runs and is the largest single source of emission data for any industry, including the wood products industry.

The wood products manufacturing plants were selected according to the emissions of pollutants, the total output of the product, and the amounts of fuel used. There were 7 plants that submitted emission test reports together with their responses to our survey of the wood product industries (13 plants). These reports include measurements of particulate matter (PM), CO, CO_2, NO_x, and SO_x. The reports also include measurements of controlled emissions from sources equipped with several types of wet scrubbers, electrified filter beds (EFBs), multicyclones, and bag filters (fabric filter). There were 2 plants producing plywood, PB and MDF, and 3 plants producing just PB and MDF. The remainder of the plants only produced a single product.

2.2 Development of emission factors

The procedures for preparing emission factor documents by the US EPA to develop emission factors are referenced (US EPA, 1997) in this study.

Emission factors are usually expressed as the weight of pollutant divided by the unit weight, volume, distance, or duration of the activity that emits the pollutant. Emission factors rely on the correlation of emissions with one or more underlying performance parameters, where these performance parameters are generally easily measured. Typical performance parameters include production rate and fuel or other raw materials consumption data. In very general terms, the utility of emission factors depends on factors such as the sources of data, the number of samples taken to characterize releases, the degree of correlation between emissions and the specified performance parameters and the rig-out of the sampling and analytical techniques.

Other parameters that could significantly impact emissions also were used to group the data where appropriate. Once grouped, the test data were used to calculate average emission factors for a year (2002). The emission data that were evaluated for weekly or bi-monthly data collection at each plant source were grouped by pollutant, wood product, general source type and control device.

The data from NPIP that are currently available are of limited use for the purposes of emissions estimation. The reason is that these data have been reported in the form of pollutant information exiting a stack. To develop emission factors specifically for a certain industry requires that a typical or average facility or process in a given industry be monitored and evaluated. As a consequence, source-specific data were obtained from industries, cities and local agencies for the year 2002. In addition, companies were contacted to obtain copies of test reports and process information. Test reports contained sufficient detail to evaluate both the testing procedures (e.g., sampling methodologies and test methods used) and the source's operating conditions. The data were averaged for a year and used to calculate the emissions. Figure 1 provides an overview of the process and the steps required to develop the emission factor document.

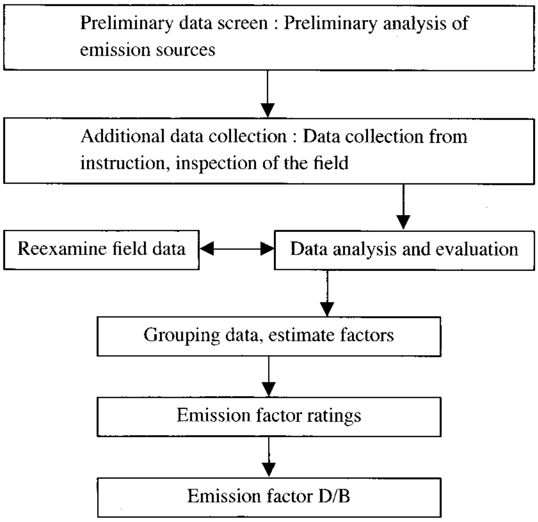

Fig. 1. Flowchart showing the methodology used in present study for development of emission factor.

2.2.1 Test methods

Source tests have been the basis for the development of emission factors. NIER has published reference methods for measuring emissions of PM, SO_x, NO_x, CO, VOCs, etc. The sampling method for the pollutants was the Korean standard air pollution testing method (NIER, 1999) which is similar to 40 CFR Part 60 (US EPA, 1995). In Korea, VOCs, with the exception of formaldehyde, are not estimated in the wood products industries so that the emissions of VOCs are directly evaluated for the sources such as hot press, dryer, etc of wood products mills by the Korean standard method for air pollution, which is similar to the US EPA method 18 (US EPA, 2000).

We screened the emission factors of VOCs using a bag sampling method followed by gas chromatography with flame ionization detector (GC/FID) analysis. GC/FID (Younglin M600D, Korea) was equipped with a thermal desorption cold trap injector (ATD 400, Perkin-Elmer). The samples were thermodesorbed into the GC/FID instrument for VOCs quantification. A film capillary (Supelco SPB -624, 60 m × 0.25 mmID × 1.4 μm) was employed for the separation of VOCs. The adsorbed sample was cryotrapped at −30°C and injected in the GC. TO-14 (Spectra gas, USA) is used for standard VOC mixture gas. The GC temperature program was 40°C for 7 min → 6°C/min → 150°C for 3 min → 10°C/min → 210°C for 3 min. The injection temperature was 220°C and the temperature of the detector was 270 °C. The concentration of TVOCs was calculated from the total area of the FID chromatogram using a toluene response factor. Consequently, the total area of the chromatogram was converted into an equivalence of toluene. Replicate analysis of samples and standards were regularly conducted.

2. 2. 2 Data analysis

An emission factor is an estimate of the amount of a pollutant emitted due to some activity divided by some measure of the level of that activity. The emission factors of various pollutants were assessed with the exhaust concentration, the volume of the exhaust, and the total product unit. The equations are listed as follows:

$$E=M \times V \times 10^{-6}, \quad EF=E/A$$

where E is the exhaust average amount of the pollutant (kg) in the specific source for a year, M is the concentration of the pollutant (mg/Nm^3), V is the normalized value of the exhaust gas volume given after temperature and pressure correction (Nm^3), and A is the activity given as product amount of wood composites or the amount of the given material resins used.

2. 2. 3 Assignment of emission factor ratings

The method of the assignment for emission factor ratings is referenced from the AP-42 emission factor rating system (US EPA, 1997). The data quality ratings are an appraisal of the reliability of the emissions data that will be used later to develop the emission factor. Emission factor rating determinations are presented in Table 1.

The emission factor rating is an overall assessment of how well a factor represents the emission source. Higher ratings are for emission factors based on many unbiased observations, or on widely accepted test procedures. For example, 20 or more source tests on randomly selected plants would likely be assigned an "A" rating if all tests are conducted using a single valid reference measurement method

Table 1. Assignment of data quality ratings.

Data quality ratings	Standards
A	Tests are performed by using NIER reference test method, or when not applicable, an EPA reference test method. The data for evaluation of quality are obtained from 20 or more source tests.
B	Tests are performed by using NIER reference test method, or when not applicable, an EPA reference test method. The data for evaluation of quality are obtained from 10 or more source tests.
C	Tests are performed by using NIER reference test method, or when not applicable, an EPA reference test method. The data for evaluation of quality are obtained from less than 10 source tests.
D	Tests are based on unproven or new methodology, or are lacking significant amount of background information. The data for evaluation of quality are obtained from 1 source test.

Table 2. Assignment of emission factor ratings.

Emission factor ratings	Standards
A (Excellent)	Emission factor is developed primarily from A- and B-rated source test data taken from more than 70% of the chosen facilities in the industry population. The source category population is sufficiently specific to minimize variability. Although the data was taken from only 50～70% of the chosen facilities in the industry population, the facilities tested are representative of the industry.
B (Above average)	Emission factor is developed primarily from A- and B-rated source test data taken from more than 50% of the chosen facilities in the industry population. Although the data was taken from only 30～50% of the chosen facilities in the industry population, the facilities tested are representative of the industry.
C (Average)	Emission factor is developed primarily from A- B-, and C-rated source test data taken from more than 30% of the chosen facilities in the industry population. Although the data was taken from only 10～30% of the chosen facilities in the industry population, the facilities tested are representative of the industry.
D (Below average)	Emission factor is developed primarily from A- B-, and C-rated source test data taken from more than 10% of the chosen facilities in the industry population. There also may be evidence of variability within the source population.
E (Poor)	Emission factor is developed primarily from A- B-, and C-rated source test data taken from less than 10% of the chosen facilities in the industry population.
F (Unrated)	Emission factor is developed from D-rated source test data.

(Table 2).

2.3 Evaluation of emission factors

There are limited data presently available to allow direct comparisons between measured Korea pollutant emissions and those predicted by the emission factors in our report.

Uncertainties currently exist when applying emission factors developed in other countries to the Korean situation.

Emission factors obtained in our report are evaluated by comparing them with emissions calculated using the US EPA emission factor and that calculated in this study.

3. RESULTS AND DISCUSSION

3.1 Emission factor

The primary emissions from the manufacture of wood-based panels include particulate matter from log debarking, bucking, cutting and sanding, and organic compounds from gluing and hot pressing.

Measurement of VOC and particulate matter emission rates are highly dependent on stack gas and sampling train filter temperatures. In Korea, most emission sources have control devices to eliminate the air pollutants and to recover the material for reuse. However, small amounts of particulate matter may be released from the grinding and sanding processes.

The emission factors for particulate matter are listed in Table 3. These emission factors were based on the whole amount of each wood product. Significant quantities of sawdust and other small wood particles were generated by cutting and sanding operations. The emission factors of particulate matter for the sources of cutting and sanding were in the range of 5.90E−03 ~ 4.40E−02 kg/m^3. Among these

Table 3. Emission factors for particulate matter.

Source	Emission control device	Emission factor (kg/m^3 plywood products)	Emission factor ratings	Emission factor (kg/m^3 PB products)	Emission factor ratings	Emission factor (kg/m^3 MDF products)	Emission factor ratings
Cutting	Bag filter	9.68E−03 ± 2.80E−03*	A	2.07E−02 ± 3.36E−03*	C	3.45−02 ± 1.55E−02*	B
	Multicyclone	1.53E−02	C				
	Multicyclone /Bag filter	5.90E−03	C				
Grinding	Bag filter	8.44E−03 ± 5.68−03*	C	1.0E−02 ± 8.38E−03*	C	5.00E−02	A
	Multicyclone	8.75E−03 ± 5.23E−03*	B				
	Multicyclone /Bag filter			7.92E−03 ± 7.40E−03*	C	2.68E−02	C
Log bucking	Bag filter	8.44E−03 ± 5.68E−03*	C				
	Multicyclone	5.23E−03 ± 8.75E−03*	C				
Sanding	Multicyclone /Bag filter	1.26E−02	A				
	Bag filter	9.13E−03 ± 4.66E−03*	B	1.90E−02 ± 9.97E−03*	C	4.40E−02 ± 1.20E−02*	B
Debarking	Bag filter	1.25E−02	C	1.00E−02 ± 8.38E−03*	C		
	Multicyclone /Bag filter			7.92E−03 ± 7.40E−03*	C		
Gluing	Cyclone	6.22E−03	C		C		
Hot pressing	Multicyclone	6.54E−03	C				
	Bag filter			2.28E−03	C		
	Scrubber					1.14E−01	C
Drying	Bag filter			5.40E−01	C		
	Multicyclone					7.34E−02 ± 7.49E−03*	C
Screening	Bag filter			7.28E−03	C	9.06E−03	C

*GEOMEAN ± S.D.

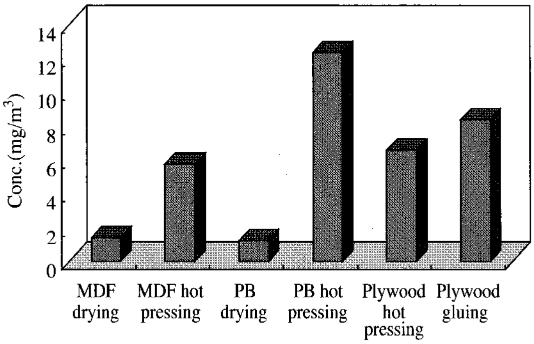

Fig. 2. The TVOC concentration of various industrial stacks.

types of wood products, the particulate matter emission factors were in this order: plywood < PB < MDF. Although the air pollution control devices for these products are all bag filters, their particulate emission factors differ significantly from source to source.

The following figures represent the concentration of TVOCs from pressed wood products. The TVOCs concentration from hot pressing of the PB product passes through a maximum value as shown in Figure 2. The maximum TVOCs concentration was 12.33 mg/m^3. The TVOCs concentrations from MDF dryer and PB dryer were 1.40 and 1.27 mg/m^3, respectively as shown in Table 4. The emissions from wood-based boards vary considerably depending on the glue system used. The results indicate that the TVOCs concentrations from hot pressing were higher than that from drying.

Emissions from hot presses are dependent on the type and amount of resin used to bind the wood fibers together, as well as wood species, wood moisture content, wax and catalyst application rates, and press conditions. When the press opens, vapors that include resin ingredients such as formaldehyde and other VOCs are released. VOC control technologies commonly used in the wood products industry for controlling both press and dryer exhaust gases are typically wet scrubber and adsorption systems.

The TVOCs emission factors for hot pressing were 3.76E−03±7.41E−04, 2.37E−02±7.79E−03, 3.02E−02±1.15E−03, and 4.64E−05±2.81E−06 kg/m^3 for the plywood and MDF with adsorption system, and PB and MDF with scrubber, respectively (Table 4). The emission factors of TVOCs were 3.91E−04±2.31E−05 and 8.02E−05±1.96E−05 kg/m^3 for drying of the PB and MDF. The differences in emission factors observed may be due to differences in VOCs capture. The results are difficult to compare with the emission factors of the US EPA because those are based on propane for the uncontrolled state but our results were based on toluene and have control systems.

Emission factors of formaldehyde are 3.16E−03 and 2.06E−02 kg/m^3 for hot pressing of plywood and MDF. The emissions from wood-based boards vary considerably depending on the glue system used. For plywood and hardboards, phenolic resins were used. For the PB, urea-formaldehyde (UF) resin was used as an adhesive. These wood products are bonded or finished with UF-resins, which are responsible for free formaldehyde liberation into the atmosphere.

The results indicate that the formaldehyde emission factors of MDF were higher than those of plywood. These results are similar to the report of Guo *et al.* (2002) which observed that the formaldehyde emission rates into indoor air of MDF were higher than PB and plywood. They also compare favorably to the TVOCs results obtained from MDF, PB, and plywood.

Although the air pollution control devices are all adsorption-based systems, their VOCs and formaldehyde emission factors differ significantly from source to source. As has been mentioned, emission factors are affected by fuel, manufacturing processes and air-pollution control devices.

3.2 Evaluation of emission factor

In Korea, the emission factors were derived from CORINAIR (CIEPA, 1992) and the US EPA source emission factor catalogues (US EPA, 2003). As national conditions for each emission sector were found to differ to a greater or lesser extent from working conditions and the United States (from which the emission factors were derived) more Korea emission factors should have been used in this work. However, as these were not available, European emission fac-

Table 4. Emission factors for hazardous air pollutants (HAPs).

Source	HAPs	Emission control device	Emission factor (kg/m³ plywood products)	Emission factor ratings	Emission factor (kg/m³ PB products)	Emission factor ratings	Emission factor (kg/m³ MDF products)	Emission factor ratings
Hot Pressing	Formaldehyde	Adsorption system	3.16E-03	A			2.06E-02	B
	TVOC as toluene		3.76E-03±7.41E-04*	C			2.37E-02±7.79E-03*	C
	Acetone		4.98E-04±3.28E-04*	C			4.43E-03	C
	Methyl ethyl ketone		1.56E-04±1.47E-04*				1.14E-03	C
	Methyl isobutyl ketone		3.84E-04	C			2.47E-04	C
	Benzene		1.43E-04±9.16E-05*	C			7.92E-04	C
	Toluene		1.80E-04±6.88E-06*	C			8.53E-04	C
	Ethylbenzene		1.94E-04±9.38E-06*	C			4.31E-04	C
	Chlorobenzene		2.42E-04	C			4.86E-04	C
	Methanol		3.03E-04	C			–	–
	Tetrachloroethylene		7.16E-04	C			2.56E-03	C
	Ethyl acetate		8.00E-04	C			2.91E-03	C
	TVOC as toluene	Scrubber			3.02E-02±1.15E-03*	C	4.64E-05±2.81E-06	C
	Methanol				4.30E-03	C	–	–
	Acetone				4.17E-02	C	–	–
	Benzene				6.01E-04	C	3.70E-06	C
	Toluene				9.53E-04	C	5.91E-05	C
	Ethylbenzene				7.90E-04	C	2.22E-05	C
	Styrene				3.91E-04	C	–	–
	Tetrachloroethylene				1.99E-03	C	1.48E-05	F
Gluing	TVOC as toluene	Adsorption system	8.08E-03±9.27E-04*					
	Acetone		3.05E-04	C				
	Methyl ethyl ketone		6.97E-05	C				
	Benzene		2.51E-05	C				
	Toluene		2.13E-04	C				
	Chlorobenzene		6.89E-05	C				
	Ethylbenzene		1.34E-04	C				
	Xylene		2.87E-05	C				
	Styrene		2.59E-05	C				
Drying	TVOC as toluene	Adsorption system			3.91E-04±2.31E-05*	C	8.02E-05±1.96E-05	C
	Isopropyl alcohol				9.25E-06	C	2.22E-05	C
	Benzene				2.31E-06	C	3.70E-06	C
	Methyl ethyl ketone				4.63E-06	C	7.39E-06	C
	Tetrachloroethylene				1.39E-05	C	1.48E-05	C
	Toluene				2.08E-05	C	5.91E-05	C
	Ethylbenzene				1.62E-05	C	2.22E-05	C
	Chlorobenzene				4.63E-06	C		

*GEOMEAN±S.D.

tors had to be adopted and used. Whenever European emission factors were insufficient to quantity the industrial subcategories then the US EPA industrial categories were utilized as they had a sufficient degree of similarity to Korean emission factors.

There is little data currently available on emissions of NPIP-listed substances from Korean wood product facilities. Historically, licensing conditions for wood product manufacturing plants have only required the monitoring of a limited number of pollutant species. In particular, there is a lack of VOCs data in the NPIP list because we have previously not needed to check the emissions of VOCs from wood product facilities in Korea. Only in certain industries, such as petrochemical complexes and petroleum refineries, have there been a requirement to

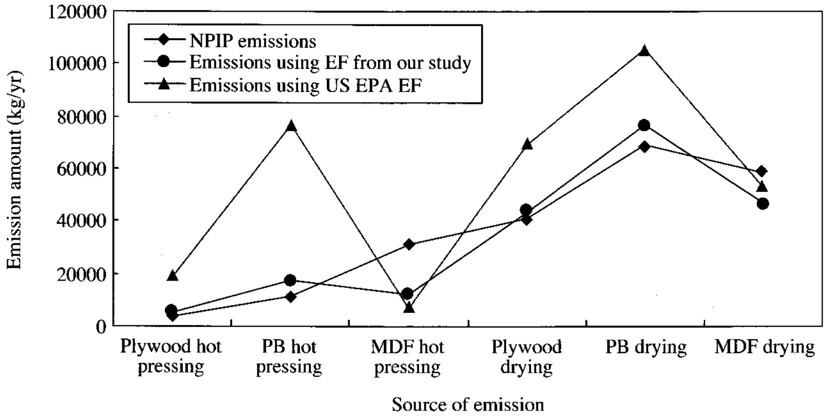

Fig. 3. Comparison of emissions calculated using EF from present study and US EPA's with actual NPIP emission.

check the VOCs emissions.

There are only limited data presently available to allow direct comparison between the emission factors measured in our studies and EPA's. This is partially due to the controls-based method of our study and the uncontrolled nature of the US EPA research. The data presented in Figure 3 highlights the sources characterizing emissions from wood products. First of all, the use of average emission factors could lead to a significant difference between the emissions from our emission factors and those from the US EPA's. The emissions used in our emission factors are similar to the NPIP emissions. It must be noted here that there are significant differences in regulatory requirements between Korea and other countries. As many facilities tend to aim for compliance with legislation rather than emissions minimization there is a likelihood that many of the quoted emissions factors actually reflect regulatory requirements (i.e. defined emission limits) rather than the intrinsic performance of processes and pollution controls. The obvious difficulty here is that the emission factors could not be rigorously validated by comparison with monitoring data. The approach presented in this paper reflects the situation where the validation was simply based on wood product characteristics.

The approach adopted here for validating emissions from the wood product industry is clearly a very simple qualitative approach. As discussed above, it is not imperative that facilities conduct monitoring to meet their reporting requirements under the NPIP. The consequence is that alternative approaches to validating emissions needed to be developed.

Actual emissions of PM and HAPs are dependent on a range of interrelated parameters, such as emitted PM and HAPs concentrations, type of process, wood species, wood moisture content, wax and catalyst application rates, and press conditions. In this context, it is pertinent to note that there are significant ongoing research efforts in Korea to develop more accurate emission factors.

4. CONCLUSIONS

Development of emission inventories and factors is an expensive and difficult task because of the wide diversity and large number of emission sources. Techniques to estimate emissions using readily available data and simplifications are a necessity.

This paper presented emission factors for composite wood product manufacturing. The emission factors of PM and HAPs from MDF were greater than those of other wood products. The concentration of TVOCs for hot press from wood-based panels was higher than for either drying or gluing.

The emissions for actual emissions from NPIP were compared to the emissions from our emission factors and the US EPA's. The emissions from our emission factors are closer than the US EPA's. That is, the characteristics of raw materials as well as site -specific issues such as system maintenance, the performance of air pollution controls and site management practices will determine the actual emissions from particular facilities or from an industry sector as a whole.

There is a need for comprehensive source testing programs to provide an adequate characterization of emissions from Korean Industry. A larger sample of data upon which emission factors are based would improve confidence that emission factors are representative of actual emission rates. Emission factors for point sources need to be updated periodically to insure that they are representative of current technologies and operating practices.

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