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An Study on Estimating Cargo Handling Equipment Emission in the Port of Incheon

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Abstract

Currently, in-port emissions are a serious problem in port cities. However, emissions, especially non-greenhouse gases, from the operation of cargo handling equipment (CHE) have received significant attention from scientific circles. This study estimates the amount of emissions from on-land port diesel-powered CHE in the Port of Incheon. With real-time activity data provided by handling equipment operating companies, this research applies an activity-based approach to capture an up-to-date and reliable diesel-powered CHE emissions inventory during 2017. As a result, 105.6 tons of carbon monoxide (CO), 243.2 tons of nitrogen oxide (NOx), 0.005 tons of sulfur oxide (Sox), 22.8 tons of particulate matter (PM), 26.0 tons of volatile organic compounds (VOCs), and 0.2 tons of ammonia (NH3) were released from the landside CHE operation. CO and NOx emissions are the two primary air pollutants from the CHE operation in the Port of Incheon, contributing 87.71% of the total amount of emissions. Cranes, forklifts, tractors, and loaders are the four major sources of pollution in the Port of Incheon, contributing 84.79% of the total in-port CHE emissions. Backward diesel-powered machines equipped in these CHE are identified as a key cause of pollution. Therefore, this estimation emphasizes the significant contribution of diesel CHE to port air pollution and suggests the following green policies should be applied: (1) replacement of old diesel powered CHE by new liquefied natural gas and electric equipment; (2) the use of NOx reduction after-treatment technologies, such as selective catalytic reduction in local ports. In addition, a systematic official national emission inventory preparation method and consecutive annual in-port CHE emission inventories are recommended to compare and evaluate the effectiveness of green policies conducted in the future.

Key words: Diesel CHE emissions, Port emissions, Port of Incheon, Activity-based approach, NONROAD

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Ⅰ. Introduction

Although it is widely accepted that shipping is the greenest transport mode in term of emissions released per cargo weight transported (Corbett et al., 1997; Agrewal et al., 2008; Eyring et al., 2010; Song, 2014), however, due to the rapid growth of international sea traffic and supply chain, seaports, as a core component, have to expand quickly to adapt to emerging challenges. The improvement in the economic ability of ports, unfortunately, often comes with a serious environmental burden as a trade-off. These busy seaports are often located inside major coastal cities, where included dense population, therefore, they pose serious threats to local community health and environment in general and awareness of introduction and implementation of reducing emission solutions. As a result, local authorities and researchers have been paying increasing attention to the in-port emission, which contributed majorly to the picture of air pollution in the port-surrounding area.

A port area is a complicating operating area, which consists of a shipside area, container yard, and gate. A wide range of types of CHE is used to maintain the container handling process smoothly to and from vessels, railcars and drayage trucks in those areas due to the diversity of cargo (including containers, general cargo, and bulk cargo). Former CHE is often powered by fossil fuel like diesel, and it released a significant amount of pollutants: greenhouse gases (GHGs), carbon monoxide (CO), nitrogen oxides (NOx), sulfuroxides **(SO_x), gaseous ammonia (NH_3), particulate matter (PM), etc. (Zhang et al., 2017).** Besides, due to the global depletion of fossil energy and increasing energy costs, in recent years, they have been replaced gradually by the new ones, which use other renewable energy sources like LNG and electricity (Yang & Sam, 2009). While handling efficiency is improved by 20%, in contrast, electric CHE (e-CHE) offers 30% lower maintenance and repair costs, 70% fuel savings and 20% CO_2 emission reduction (Yang & Chang, 2013).

From the 2010s in Korea, the Korean government has motivated Green Growth Policy with national 5 years plans focusing on efficiency in energy consumption and low in gas emissions by applying new and renewable energy sources to enter the top 7 local greenest countries by 2020 (Green Growth Korea, 2013). In 2015, the government developed green port plans, then, offered conversion incentive to replace in-port old yard tractors, which use diesel as fuel, by new ones powered by LNG (Green Growth Korea, 2015). In March 2019, the National Assembly stated the need for the establishment of a special law on the improvement of air quality in the port area. They recommended designating “Port Air Quality Management Zone” to control strictly SO_x emission in the port area and set a new standard for CHE’s emission as well as limit the use of old equipment (Green Growth Korea, 2019).

The Port of Incheon is located in the west side of Incheon Metropolitan City, where is ranked the third in Korea in term of population. Port of Incheon is considered as one of the most important national hub-port in the north-west of Korea. According to a report from the American Association of Port Authorities (2016), it ranked the 27th in terms of revenue tons of handled cargo and the 50th in terms of the total number of TEUs transported through port. Until 2020, Port of Incheon has been expanded to 5 major component ports and 3 smaller specialized ports with a total of 128 berths and 29km of total berth length (Inchoen Port Authority, 2019a). To achieve the goal of becoming a green port, port administrators introduced a green plan named GEAR-20, including 4 targets: G-port (Green Port), E-port (Environmental management Port), A-port (Sustainable development Port), and R-port (Recyclable and eco-friendly Port) (Inchoen Port Authority, 2019b).

The goal of this paper is summarized as follows: (1) to generate the up-to-date and reliable diesel CHE emission inventory for 7 target pollutants of CAPSS: CO, NO_x, SO_x, PM (including PM10 and PM2.5), volatile organic compounds (VOC), and NH3 according geographical areas and CHE types based on activity-based approach and real-time activity hour to emphasize the contribution of diesel engines to port pollution; (2) to contribute to the literature of non-GHG diesel CHE emissions estimation; (3) to suggest appropriate green port policies for CHE in Korea seaports, especially application of green alternative fuel. Therefore, LNG and diesel-electric (hybrid) engines are not taken into consideration. This paper consists of five parts: The first part introduces the motivations, targets, and structure of the study. The second part contains a summary of the literature concerning non-road emission estimation and in-port CHE emission. The third part explains a methodology that is applied in this study. The fourth part shows the estimated diesel CHE emission inventory in Port of Incheon focusing on non-GHG emissions. The fifth part suggests CHE emission reducing solutions for port operators and local authorities, and presents further research directions.

II. Literature Review

1. Air pollution mobile sources classification

Mobile sources of air pollution could be classified generally into two main sectors: the on-road sector and the non-road sector. The on-road sector covers vehicles, which primarily includes light-duty vehicles (passenger cars, light trucks, motorcycles…) and heavy-duty vehicles (heavy trucks, buses…), certificated for highway use, for passengers and cargo transportation. Especially, refuse trucks and emergency response truck also be added into this group. All remaining mobile vehicles and engines are categorized as non-road sectors. This sector consists of various kinds of sources used in a wide range of end-use applications, and the main applications include railways, aviation, commercial navigation, and constructive and agricultural equipment (Dallmann & Menon, 2016). However, because of the complex and diverse in engine sizes and applications, the categorization between non-road vehicles and equipment is not consistent, even within the same country. These differences may cause an insignificant disparity in emission estimation, however, they could have a serious effect on collecting relevant data and evaluating policies (Shao, 2016).

2. National non-road emission estimation models

Developed countries including the United States (US) and European Union (EU) countries have introduced and updated their official non-road emission inventory models for practical application. There are the 3 most popular models, which were accepted and applied by the academic cycle: The EMEP/EEA air pollutant emission inventory guidebook (the EEA Guidebook), NONROAD model and OFFROAD model (Shao, 2016).

The California Air Resources Board (CARB) adopted the "In-Use Off-Road Diesel Vehicle Regulation" (off-road regulation) to cut down emissions, especially NO_x and PM emissions, emitted from diesel-powered non-road mobile sources in July 2007 (CARB, 2007). CARB's OFFROAD model was proposed and used as the basis for off-road regulation's adoption in California. By performing thousands of individual calculations inside, this proposed model could estimate an annual emission inventory for each species of equipment, that subject to the regulation (Lyons et al., 2010). Then, the fleet owners can collect and report exactly to the CARB an emission inventory of each piece of equipment in their fleet, as the requirement of off-road regulation.

For all states exclude California, the NONROAD model, proposed by Environmental Protection Agent (EPA) firstly in 1998, generates emission inventories at the national, state and county level for all US non-road equipment, except locomotives, commercial marine, and aircraft. The exhausted amounts are assessed as the products of emission factors and activity levels for all non-road mobile sources. The model covers more than 80 basic and 260 specific types of non-road equipment (EPA, 2008).

For EU case, the EEA Guidebook, formerly called the EMEP/CORINAIR emission inventory guidebook, published the first time in 1996, is the European Emission Agency (EEA)'s official technical concise guidance on how to prepare national emission inventories. Then, it has been revised and updated frequently. The latest 2019 update and former publication included a recognized set of estimating methods used for air pollution studies with default emission factors at various levels of sophistication in the EU geographical area (EEA, 2019). It provides default emission factors This Guidebook may be used for general reference or, fulfill the report in environmental conventions or meetings at the EU or international level (Monforti & Pederzoli, 2005; Trozzi, 2010; Droge et al., 2010; Pouliot et al., 2012). Comparison of 3 mentioned models are shown in ⟨Table 1⟩.

Table 1. Comparison of national non–road emission estimation models

Model	Platform	Approach	Tool
NONROAD	A graphical user interface is written in Visual Basic, the core model is written in Fortran and a reporting utility written in MS Access	Activity-based	NONROAD 2008, MOVES 2014
OFFROAD	MS Access 2003 with Visual Basic Editor	Activity-based	OFFROAD 2007
Guidebook 2019	-	Fuel/ Activity-based	-

3. Individual non-road emission studies

Since the 1990s, non-road mobile-source emissions have gained attention from individual researchers. In the 1990s, Samaras and Zierock(1995) applied emission factors, engine power, activity levels, fuel types, and engine type to estimate EU non-road mobile source emissions, then compared to released amounts of air pollutants from on-road mobile vehicles to prove that non-road emissions were a significant contributor to atmospheric pollution. In the US, NOx and PM emissions from non-road diesel-powered mobile sources of 1996 were assessed based on fuel consumption records (Kean et al., 2000). Lingren and Hansson(2004) researched the effects of transient load conditions on the formation of non-road mobile machinery emissions. In Asia, Kurokawa et al. purposed the Regional emission inventory in Asia, that covered emissions from agriculture, power plant, road transport and other sources (Kurokawa, 2013). In China, Li et al.(2012) followed the basic concept of the NONROAD model to develop fuel consumption and emission estimation model for excavator and loader based on the actual fuel consumption rate. Zhang et al.(2010) proposed the emission estimation model using emission factors based on fuel consumption for five types of non-road mobile sources in the Pearl River Delta. A non-road mobile-source emission inventory for the Beijing – Tianjin - Hebei region was generated based on the fuel consumption method (Kui, 2013). In Korea, the first official national non-road emission inventory was mentioned in the 2007 Air Pollutant Emissions Report for CO, NO_x, SO_x, PM10 and VOC (Lee et al., 2011).

Also, the accuracy and reliability of national models were tested by researchers. Comparison between modeled data, estimated by the NONROAD model, and field data, recorded directly from the actual vehicles performing construction activities by using an onboard portable emissions monitoring system (PEMS), showed the difference between two sources (Lewis et al., 2009). The main reason is that the NONROAD model used average emission factor and standardized engine dynamometer test conditions to predict average emission for the entire fleet of vehicles, whereas PEMS collected data from individual vehicles, with real-time duty cycles and ambient conditions. Millstein and Harley also stated that the results of NO_x and PM emission for 2005 obtained from the OFFROAD model were 4.5 and 3.1 times higher than data derived from diesel fuel sales (Millstein & Harley, 2009).

4. Annual CHE emission inventory

According to the above classification, the amount of CHE emissions can be calculated based on the concept of non-road mobile-source emission. CHE emission inventory is often combined in port emission inventories. Each year, the Port of Long Beach and the Port of Los Angeles publish the OFFROAD model-based annual port-related emission inventories, including CHE source to track and evaluate port's green actions in their ports by comparing to 2005 baseline (Port of Long Beach, 2018; Port of Los Angeles, 2018). In Shanghai, the localized emission estimation was suggested based on the analysis of literature to establish the CHE emission inventory and propose green actions in Shanghai Port in 2010 (Tan et al., 2013). A fuel-based approach and activity-based approach (NONROAD model) was applied respectively to generate emission inventories from CHE in Nanjing Longtan Container Port in 2013 and 2014 (Jia et al., 2014; Zhang et al., 2017). In Korea, a NONROAD-based study about Port of Incheon's emission inventory in 2010 stated that CHE emission is the second most polluted sources in Port of Incheon (Han et al., 2011).

Ⅲ. Methodology

1. CHE emission estimation equation

The bottom-up approach with detailed activity time data of all CHE was applied to capture CHE emission inventory in this study. The estimation is followed NONROAD model of EPA (EPA, 2008; EPA, 2010a; EPA, 2010b). The equation was set up, consisting of four main parameters – engine power, emission factor, activity time and load factor, as below:

$$E_{k,i} = \sum_{n} T_e \times P_{e,j} \times LF_e \times EF_{e,i,j}$$

where,

E is the amount of a pollutant emitted by a given equipment type (g),

P is the rated power of an engine of a given equipment type (hp),

T is the annual activity of a given engine (hr/year),

LF is the load factor of a given equipment type (dimensionless), and

EF is the emission factor of a given engine (g/hp-hr).

The subscripts are defined as:

k denotes kind of equipment,

I denotes pollutant,

n denotes number of equipment,

e denotes engine, and

j denotes emission tier.

2. Load factor

The load factor is described as the ratio of average load used at normal operations divided by the rated maximum engine's horsepower over a specified duration of time. In theory, every engine can be operated at full capacity when working under-designed speed and load. However, in practice, it is difficult to run the engine at designed conditions, and engines are often operated typically with various usage patterns with different speed and load values. Thus, a load factor is estimated to present an average value of rated power used to reflect and cover all practical working conditions that happened, including idle status, sectional load conditions, and transient operation in estimation. All 3 above models suggested their estimated values; however, EPA's method was recommended to apply for estimation (Shao, 2016). CHE is classified into different groups with their specific Source Classification Codes and the specific given average value of load factor for each code (EPA, 2010a). In this study, these load factor values were applied, followed above recommendation, and were shown in ⟨Table 2⟩ below:

Table 2. Load factor values

Source Classification Codes	Equipment	LF value
2270002045	Crane	0.43
2270002060	Rubber Tire Loader	0.59
2270002072	Skid Steer Loaders	0.21
2270003010	Manlift	0.21
2270003020	Forklift	0.59
2270003030	Sweeper	0.43
2270003040	Top handler	0.43
2270003050	Car loader, empty cont. loader, Reach Stacker, Side handler	0.21
2270003070	Yard Tractor	0.59

Source: The United States Environmental Protection Agency

3. Emission factor

The emission factor represents the emission rates of a pollutant emitted in the practice from engine combustion, not emission limits. The emission factors are estimated differently by considering the forming process and affected factors.

1) HC, CO, NOx emission factors

Although HC is not a target pollutant of this study, however, HC emission is an important factor in the estimation of SO_2 **and VOC emission factors. The HC, CO, NOx** emission factors of a given engine in a given model year/engine age are estimated as follows:

$$EF_{adj,e,(HC,CO,NO_x)} = EF_{0,i} \times TAF_{k,e,i} \times DF_{e,j,i}$$

where,

$EF_{adj,e}$ is adjusted emission factor for a given engine, after adjustments to account for transient operation and deterioration for a given engine (g/hp-hr),

EF_0 is zero-hour emission factor (g/hp-hr),

TAF is transient adjustment factor (unitless), and

DF is deterioration factor (unitless).

The adjusted emission factor used in the model is a function of EF_0, TAF and DF. EF_0, the emission factor of new equipment (used for 0 hour), are mainly a function of emission tier and engine horsepower category. CHE is assigned an emission tier value based on the model year of the engine. The emission rate will increase with daily operation through the application of the DF. EFs also are adjusted by the TAF, the ratio between transient emission factor and zero-hour emission factor of given equipment type, to be more representative of real-world operation. The ways to identify EF_0, DF and TAF are provided details in EPA guidelines for NONROAD model (EPA, 2010a; EPA, 2010b).

2) PM emission factor

In NONROAD model, PM emission is assumed to be equal to PM10 emissions and the amount of PM2.5 is assumed as 92% of PM10 (EPA. 2010b). Since sulfate is considered as the main component of diesel engine' s PM emissions, the sulfur content of the used fuel makes a big positive impact on the amount of PM emissions, a PM adjustment ($S_{adj,e,PM}$) **for a given engine is recommended to consider variations of sulfur content of the used fuel (Shao, 2016). It adjusts PM emissions by correcting the default value of fuel sulfur level when calculating EF_0 for PM emissions to the current level in the fuel used. The sulfur content for diesel fuel in Korea is 10ppm. The adjusted PM emission factor (**$EF_{adj,e,PM}$) for a given engine in g/hp-hr is calculated using the following equation:

$$EF_{adj,e,PM} = EF_{0,PM} \times TAF_{k,e} \times DF_{e,j,PM} - S_{adj,e,PM}$$

The EPA compared PM emission from nine engines operated in reality with different levels of sulfur content in fuel, then, suggested an equation to capture this adjustment, as follows:

$$S_{adj,e,PM} = BSFC_{0,e} \times TAF_{k,e} \times 453.6 \times 7 \times soxcnv \times 0.01 \times (soxbas - soxdsl)$$

where,

$BSFC_0$ is the zero-hour BSFC, provided in (EPA, 2010b),

453.6 is the conversion factor from pounds to grams,

soxcnv is the fraction of fuel sulfur converted to direct PM,

0.01 is the conversion factor from weight percent to weight fraction,

soxbas is default certification fuel sulfur weight percent, and

soxdsl is the episodic weight percent of sulfur.

3) SO_x emissions factor

The calculation of SO_x emission factor for a given engine is different from above pollutants while NONROAD model of EPA computed SO_x emission factor directly (not using EF_0) based on brake-specific fuel consumption and adjusted HC emission factor. However, the effect of HC emission factor is minor [16]. Similar to PM emission factor, the calculation also requires adjustment based on the current level of sulfur in fuel used. The equation is shown below:

$$EF_{e,SO_2} = [BSFC_{0,e} \times TAF_{k,e} \times 453.6 \times (1 - soxcnv) - EF_{adj,e,HC}] \times 0.01 \times soxdsl \times 2$$

where,

$EF_{e,SOx}$ is SO_x emission factor for a given engine, and

2 is the grams of SOx formed from a gram of sulfur.

4) VOC and NH_3 emission factors

The broad category of VOC makes a challenge to capture VOC emissions. The VOC emission factor for a given engine is assumed to be equal to 1.053 times the calculated adjusted HC emission factor (EPA, 2009). EPA' s NONROAD model does not cover NH_3 emissions, therefore, our model refers EF provided in the EEA guidebook (EEA, 2019), which is 0.002g/kWh. Applying conversation rate **1g/hp-hr = 0.7457g/kWh (Shao, 2016), the common NH_3 emission factor applied in our model is approximately 0.0015g/hp-hr.**

Ⅳ. Empirical Analysis

1. Geographical scope and data

This study will cover all CHE activities in 5 key component ports of Port of Incheon, including North Port, Inner Port, Coastal Port, South Port, and New Port, with 3 other specialized ports named Geocheom-do Port, Song-do Port, and Yeongheung-do Port. 17 berths in North Port are specialized for handling industrial raw materials (timber, steel…) with the handling maximum capacity of 50,000DWT. Inner Port with a lock-gate, that help keeps a calm water level, is available for loading and unloading semiconductor equipment, automobiles, and precision machine parts. Cereal, fruit, and general cargo also are key products here. Inner Port can receive concurrently 48 vessels, that not exceed 50,000DWT. The South Port is available for handling small and medium container vessels, that up to 4,000DWT; while New Port is on-going constructed for handling the maximum 12,000TEU container vessels. In the case of three small ports, Song-do Port is specialized in serving tankers; Geocheom-do Port is available for handling sand, and Yeongheung-do Port is used to support the **operation of Yeong-heung Thermal Power Plants (Incheon Port Authority). The geographical locations of ports are shown in ⟨Figure 1⟩.**

There is a total of 390 in-port CHE operated in Port of Incheon during 2017. The real-time operating activity data of CHE was collected

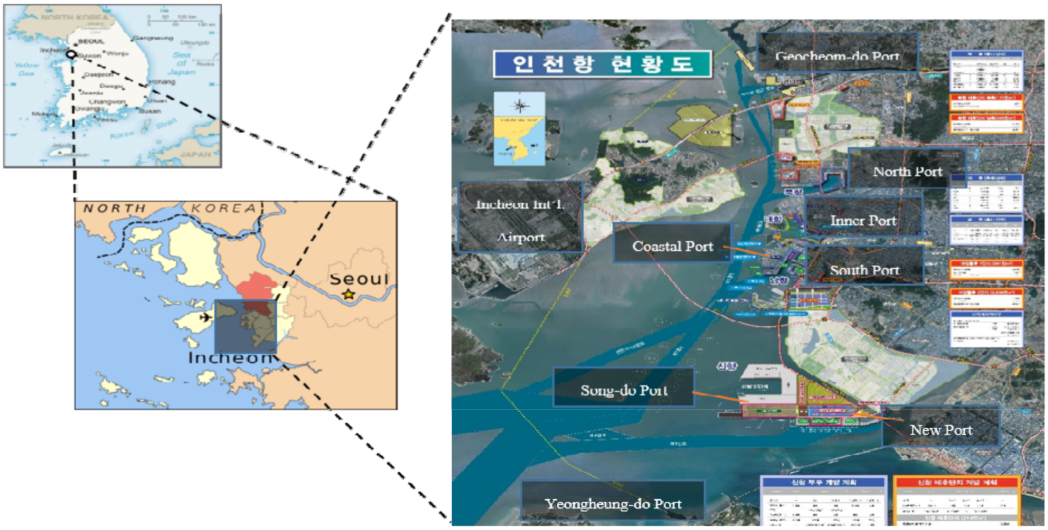

Figure 1 Geographical location of Port of Incheon

from all port handling companies. In this study, CHE is classified into 8 groups with different characteristics and functions in port operation: Crane, Container Handling Equipment (CtHE), Yard Tractor, Forklift, Loader, Excavator, and Sweeper. The collected data were summarized and shown in 〈Table 3〉.

2. Emission factor calculation

For specific equipment, with specific equipment type, engine horsepower, manufacture

Table 3. CHE data summary

No	Group of CHE	Population	Average engine manufacture year	% of CHE population manufactured after 2011	Average engine's horsepower (hp)	Annual cumulative activity (hours)	% of activity done by CHE manufactured after 2011
1	Crane	77	2003	1.3	389	103,806	1.1
2	CtHE	35	2008	37.1	302	106,485	43.8
3	Yard Tractor	120	2011	56.7	202	369,440	70.1
4	Forklift	71	2007	18.3	127	279,364	4.9
5	Loader	43	2001	9.3	309	73,404	12.0
6	Excavator	32	2008	21.9	169	104,611	18.4
7	Sweeper	12	2009	7.0	361	21,427	8.0

Table 4. Average estimated EFs by group of equipment

(Unit: g/hp-hr)

No	Group of CHE	Average EF						The ratio between NOx and CO avg. EF
		CO	NO_x	SO_x	PM10	VOC	NH_3	
1	Crane	1.30	4.70	3.3E-05	0.24	0.35	0.0015	3.62
2	CtHE	1.56	2.98	3.7E-05	0.23	0.41	0.0015	1.91
3	Yard Tractor	0.64	1.66	3.3E-05	0.13	0.22	0.0015	2.59
4	Forklift	1.76	3.00	3.4E-05	0.32	0.27	0.0015	1.70
5	Loader	2.81	5.39	3.3E-05	0.47	0.66	0.0015	1.92
6	Excavator	2.05	2.85	3.9E-05	0.37	0.51	0.0015	1.39
7	Sweeper	0.66	2.10	3.3E-05	0.12	0.17	0.0015	3.18

year, engine technology and annual activity, specific EFs of all pollutants for that given equipment were estimated promptly. Estimated EFs reflect more accuracy in the real-world operation and exhausted amount of emissions. 〈Table 4〉 represents the average estimated values of EFs for each group of CHE.

3. Results

The 2017 CHE emission inventory in Port of Incheon was estimated according to the foregoing method. The results show that during 2017, CHE operation in Port of Incheon released 105.6 tons of CO, 243.2 tons of NO_x, 0.005 tons of SO_x, 22.8 tons of PM10 (including 22.1 tons of PM2.5), 26.0 tons of VOC and 0.2 tons of NH_3, among which NOx was accounted for the highest percentage (61.15%). CO ranked second with 26.56% of the total amount of emissions. In contrast, exhausted SO_x and NH_3 emissions from CHE were minor, only 0.001% and 0.04% respectively of the total amount of emissions. The

Table 5. The 2017 CHE emission inventory by geographical area at Port of Incheon

(unit: ton)

Port	CO	NO_x	SO_x	PM10	PM2.5	VOC	NH_3
Inner Port	38.58	78.48	0.001	9.12	8.85	6.84	0.032
South Port	30.40	74.51	0.001	6.95	6.75	6.98	0.041
North Port	24.32	59.22	0.001	4.76	4.62	5.89	0.032
New Port	9.44	22.68	0.001	1.40	1.36	5.74	0.047
Coastal Port	1.51	2.91	0.000	0.34	0.33	0.24	0.001
Others	1.36	5.37	0.000	0.20	0.19	0.27	0.002
Total	105.6	243.2	0.004	22.8	22.1	26.0	0.2

proportions of PM10 and VOC were respectively 5.73% and 6.53%.

〈Table 5〉 illustrates the CHE emission inventory by geographical areas during 2017 in Port of Incheon. Inner Port was the most polluted port, accounted for 36.53% of CO, 32.27% of NO_x, 20.80% of SO_x, 40.06% of PM10, 26.34% of VOC and 20.81% of NH_3. Emissions emitted from Inner Port contributed to 33.46% of the total amount of emissions. South Port and North Port ranked second and third with a ratio of 29.89% and 23.69% of the total amount of emissions respectively. The top 3 most polluted ports shared 87.05% of the total amount of emissions. Coastal ports shared the smallest proportion with almost 1.81% of the total amount of emission. Detailed emission inventories of two most polluted ports were shown in 〈Table A〉 and 〈Table B〉 in the Appendix.

〈Figure 2〉 represents the contribution by equipment types in the 2017 CHE emission inventory of Port of Incheon. Cranes and forklift are the top 2 most emitted sources, which contributed over 50% of the total amount of emissions. Cranes contributed 18.31% of CO, 31.01% of NO_x, 16.33% of SO_x, 16.37% of PM10, 18.13% of VOC and 16.68% of NH_3, whereas corresponding percentages of forklift group were 29.94%, 22.80%, 20.00%, 39.16%, 17.79% and 20.25%. Yard tractor and loader also accounted for a significant amount of emissions. The top 4 contributed 84.79% of total in-port CHE emission.

V. Discussion and conclusion

In this study, with the application of the bottom-up approach and real-time activity, the 2017 diesel CHE emission inventory in Port of Incheon was estimated. The estimation results show that 105.6 tons of CO, 243.2 tons of NO_x, 0.005 tons

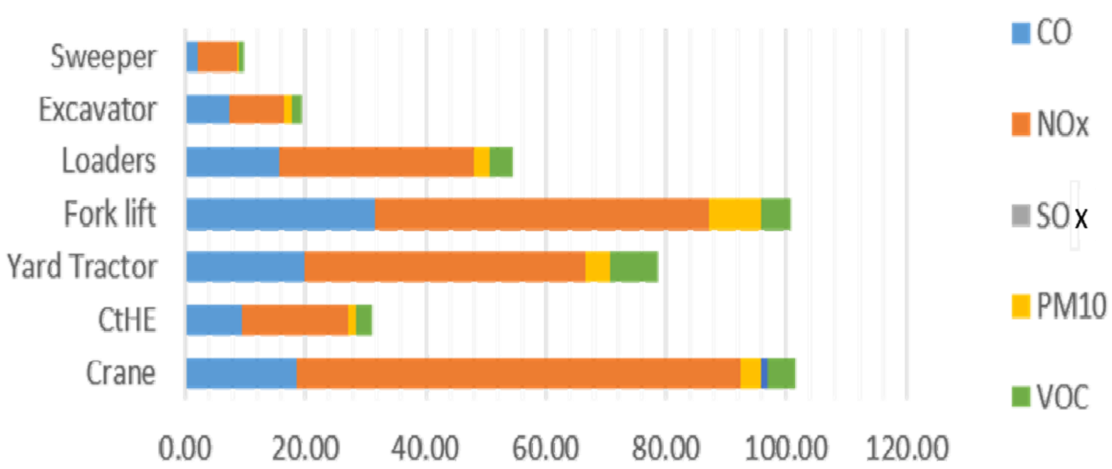

Figure 2. The 2017 CHE emission inventory by equipment type in Port of Incheon

of SO_x, **22.8 tons of PM10 (including 22.1 tons of PM2.5), 26.0 tons of VOC and 0.2 tons of NH_3 were generated by CHE operation in** Port of Incheon **during 2017. CO and NO_x** emissions are the two primary air pollutants from CHE operation, which contributed 87.71% of the total amount of emissions. This showed the consistency with the results of previous studies in literature. In contrast, due to the reduction of sulfur content in the fuel used, SO_x accounted for an extremely minor proportion of total emissions.

1. Suggested green policies

The emitted emission from CHE operation was significant, therefore, the green policies related to CHE is indispensable to combat with air pollution in Port of Incheon. In this section, available green CHE-related polices will be pointed out and discussed.

1) Diesel-powered engines replacement

Although the yard tractor group has the most annual cumulative activity, however, the volume of emissions exhausted from yard tractor just ranked third, after crane and forklift. The main reason here is that in 2011, there was a big improvement in engine manufacture, which reduced the emitted amount of NO_x over 9 times. There were 56.7% of yard tractor fleet equipped engine, manufactured from 2011 and operated in Port of Incheon during 2017. Their cumulative activity time was accounted for until 70.1% of the cumulative activity of the entire group. Also, the average of their engine power is low medium when comparing with the average values of other groups.

In the case of cranes, although the annual activity time is not huge, however, almost their engines are backward. There are 6 engines (7.9%) manufactured before 2003, and 69 pieces (90.8%) were manufactured between 2003 and 2010. With the largest average engine power compared to others, these backward engines released an extreme amount of emissions, especially NO_x emission. The high volume of NO_x emitted pushed crane to the nod among polluted air sources.

From the above analyses, it is undeniable that backward diesel machines are one of the vital sources of CHE emissions, especially in case of tractor and crane fleets. Therefore, old diesel-powered yard tractors and cranes should be overhauled and replaced by new ones that use greener alternative fuel such as LNG fuel or electricity. Actually, the greener alternative fuel usage is not a new concept with port operators. In 2008, 14 electric RTGC were launched, and they have been operated in Port of Incheon. However, this number still markedly small if compared to the current total number of in-port crane fleet. Of course, the transformation is a long-term run because it is impossible to change all vehicles immediately due to the burden of finance, re-planning, and technological operation. However, since after 2008, no improvement in port facilities has been noted. Therefore, port operators should pay more intention on the replacement of old diesel-powered engine with a long-term, clear and detailed plan.

2) Other NO_x reduction technologies

NO_x is proved as the dominant pollutant in CHE emissions. Besides the changing greener fuel-powered engine, other technologies also should be applied to reduce completely NO_x emissions. These technologies could be considered as short-term solutions, which are easy to apply, cheap and fact acting. Magnetization treatment for diesel fuel can help reduce exhausted emissions, especially NO_x emission, and fuel consumption [45]. In addition, the use of **NO_x** reduction after-treatment technologies like selective catalytic reduction equipped in engines also optimizes fuel consumption and reduces NO_x **and SO_x** emissions [46]. These solutions should be applied shortly, especially in the top 3 most polluted ports (Inner Port, North Port, and South Port).

3) Annual port emission inventory

Besides counter-measures, port operators also need to track and evaluate them frequently. A practice of annual port emission inventories in Port of Long Beach and Port of Los Angeles is considered as the effective tool to track and evaluate port' s green actions conducted (Port of Long Beach, 2018; Port of Los Angeles, 2018).

In national level, CAPSS reported emissions from several CHE operations with the application of the national average **parame**ters in calculation. It may lead to inaccuracy and misunderstanding about the contribution of CHE emission to local air pollution. In regional level, emission calculations with Environment Ship Index were conducted and reported in Port of Busan and Port of Ulsan. However, there has not yet an official emission inventory preparation method for whole port-related mobile sources in general, and CHE, especially, for regional estimation. Therefore, the systematic and consecutive annual CHE emission inventories need to be conducted to compare and evaluate the effectiveness of green policies conducted in port. Besides, other port-related emissions sources (e.g. ships, drayage trucks) should be combined in an annual report to provide a comprehensive view and understand about port annual emission inventory.

2. Limitation and further studies

This study reviewed the literature to select the most appropriate model for CHE emission estimation, then calculate the corresponding emission factors. However, LF, EF**s**, and other parameters were constructed based on other foreign situation. The calculated EFs could not reflect exactly the domestic situation, then, reduce the confidence level of estimated results.

Thus, further research on localized EFs and LFs is promising and interesting realm to obtain reliable basis data for the emission preparation in the future. In terms of weight contribution, PM emissions were not considerable air pollutant, however, due to their size and weight, they would be a significant threat to

the environment and the local community' s health. Therefore, studies about PM concentration dispersion in port area should be conducted and combined into port emission inventories to provide a full view about effect of emitted PM emission to local health.

Appendix

Table A. Emission inventory of Inner Port

	CO	NO_x	SO_x	PM10	PM2.5	VOC	NH_3
RTGC	0.71	1.63	0.000006	0.19	0.18	0.19	0.0002
Crane	6.22	21.21	0.000179	1.33	1.29	1.63	0.0055
CtHE	3.04	5.41	0.000074	0.42	0.41	0.58	0.0019
Yard Tractor	0.19	0.89	0.000008	0.06	0.05	0.06	0.0003
Fork lift	19.21	34.21	0.000630	5.71	5.54	2.77	0.0192
Loaders	6.36	12.34	0.000122	0.88	0.86	1.23	0.0037
Excavator	2.78	2.60	0.000048	0.52	0.50	0.37	0.0012
Sweeper	0.06	0.19	0.000004	0.01	0.01	0.01	0.0001
Total	38.58	78.48	0.001071	9.12	8.85	6.84	0.03211

Table B. Emission inventory of South Port

	CO	NO_x	SO_x	PM10	PM2.5	VOC	NH_3
Crane	5.27	23.21	0.000291	0.96	0.93	1.07	0.00895
CtHE	2.53	4.03	0.000118	0.42	0.41	0.82	0.00309
Yard Tractor	13.35	29.15	0.000767	3.04	2.95	3.18	0.02337
Fork lift	4.22	6.85	0.000142	1.17	1.14	0.57	0.00426
Loaders	4.99	11.21	0.000039	1.36	1.32	1.33	0.00120
Excavator	0.04	0.05	0.000001	0.01	0.01	0.01	0.00003
Total	30.40	74.51	0.00	6.95	6.75	6.98	0.04

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인천항 하역기계로 인한 대기오염물질 배출량 산정 연구

조정정 · 범태황 · 이향숙

국문요약

최근들어 항만도시에서의 대기오염이 심각한 문제로 대두되고 있다. 그러나 항만의 하역기계에서 배출되는 온실가스는 선박, 트럭 등 타 수단에 비해 상대적으로 주목받지 못하였다. 본 연구에서는 인천항에서 디젤엔진으로 가동되는 하역기계로부터 배출되는 대기오염물질 배출량을 산정하였다. 이를 위해 각 항만하역사로부터 2017년 기준 하역장비의 대수, 제원, 가동시간 등 활동자료를 수집하였다. 분석결과, CO 105.6톤, NOX 243.2톤, SOX 0.005톤, PM 22.8톤, VOC 26.0톤, NH3 0.2톤이 발생한 것으로 나타났다. CO와 NOX의 배출은 하역기계 전체 배출량의 87.71%를 차지하였으며, 크레인, 지게차, 트랙터, 로더의 배출량이 하역기계 전체 배출량의 84.79%를 차지하였다. 또한 노후화된 디젤엔진을 장착한 하역기계가 주 배출원임을 규명하였다. 분석된 대기오염물질 배출량 수치는 하역기계에 의한 항만 대기오염의 심각성을 나타내며, 다음과 같은 친환경장비 도입이 시급함을 시사한다. 첫째, 오래된 디젤 장비의 LNG연료 또는 전기장비로의 교체가 필요하다. 둘째, NOX의 배출을 감소시킬 수 있는 선택적환원촉매(SCR)와 같은 후처리장비의 사용이 필요하다. 향후 체계적이고 공식적인 국가 대기오염배출 인벤토리 정립 방법을 설정하고, 매년 하역기계에서 배출되는 대기오염물질 배출량을 모니터링 및 평가하는 것이 필요하다.

주제어: 하역기계 대기오염물질, 항만 대기오염, 인천항, 활동기반접근법, 비도로