Development of emission inventory of typical container port based on the real port investigation

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Abstract. Investigations on ships’ and cargo handling equipments’ (CHEs) activities were carried out in this study, including time of ships at at-berth and shift state, working hours of CHEs, and the engine power of ships and CHEs. Meanwhile, the emission inventory was developed based on the power emission estimation methodology and the emission contributions of ships, different types of CHEs, various port areas and operation processes were compared with. The results indicated that ships contributed most to the air pollution among all the pollutant sources and should be given higher priority for the improvement of the air quality. Shore power technology can be applied to the air pollutant mitigation in the future. Yard tractor and the process between port front to yard contributed a lot due to the usage of liquefied natural gas (LNG) on yard tractors. The application of LNG on CHEs should be given further consideration.

Keywords: container port, emission inventory, cargo handling equipments, emission contributions.

1. Introduction
With the rapid development of global economy environmental problems have become more and more prominent and more people began to pay attention to them. Air pollution, characterized by its regional transmission, complexity and uncertainty, has become a research focus by domestic and foreign scholars. According to the World Health Organization (WHO) statistics of ambient air pollution database in 2016, there were 84% of the people in the 103 countries investigated living in the environment that does not meet the WHO air quality standards ($PM_{10}$, 20 μg·m$^{-3}$; $PM_{2.5}$, 10μg·m$^{-3}$). What’s worse, more than 54% of the people lived in the environment where the $PM_{10}$ and $PM_{2.5}$ concentrations exceed 2.5 times the WHO air quality standards. Therefore, it’s necessary to take measures to control the air pollutants emission. The identification and emission contribution of pollutant sources are the primary tasks to be tackled for the government.

The development of emission inventory is an effective method and many efforts have been made on these. For example, Global and Asian emission inventories(Olivier et al., 2002[1]; Olivier et al., 2005[2]; Dentener et al., 2005[3]; Kurokawa et al., 2013[4]; Saikawa et al., 2017[5]), Multi-resolution Emission Inventory for China (http://meicmodel.org/), Chinese regional and urban agglomerations emission inventories (Zhou et al., 2014[6]; Sun et al., 2018[7]; Zhao et al., 2012[8]; Wangl et al., 2016...
[9]) were developed. Though most of these studies focused on the emission inventory excluding the port emission sources, some researches also carried out some investigations on port pollutant emission. For example, some researches has applied the AIS (Automatic Identification System) data to obtain the emission inventory of the ships pollutant emission (Aksoyoglu et al., 2016[10]; Merico et al., 2016 [11]; Chen et al., 2017[12]; Lang et al., 2017[13]), and some researchers has applied the fuel or engine power activities information of CHEs for the inventory of CHEs (Tan et al., 2013[14]; Jia et al., 2014[15]; Fan et al., 2017[16]; Peng et al., 2017[17]). However, there were many uncertainties and difficulties in AIS data application. In addition, the investigations for the emission inventory including ships and CHEs were rare. Therefore, the emission inventory of port including ships and the CHE were developed based on investigations on ships’ and cargo handling equipments’ (CHEs) activities. The emission contributions of ships, different types of CHEs, various port areas and operation processes were also investigated.

2. Methodology

2.1 Overview of the Study Area

One of typical container port in Shanghai Port was chosen for the study. It is situated at Gaoqiao Town, Pudong New Area, Shanghai and possessed more than five million container throughput per year after year 2006. Seven CHEs in port (i.e. rubber-tired gantry cranes (RTGs), rail mounted container gantry crane (RMGs), reach stacker(RS), top and side handlers(TSH), Forklifts(FL), Yard tractors(YT), and others(OS)) and one CHEs out of port (i.e. yard tractors out of port(YTOP)) were classified in this study, as showed in Table 1. Three operation processes and three areas were summarized in Fig. 1. Process ① stands for an activity that the cargo containers were carried by YT from the port front to port yard and the pollutant emission sources were mainly from YT. Process ② stands for an activity that the cargo containers were carried by RS from the yard to custom inspection and the pollutant emission sources were from RS. Process ③ stands for an activity that the cargo containers were carried by YT from the yard to cargo customers and the pollutant emission sources were mainly from YTOP. The mainly pollutant emission sources in yard area were TSH, FL and OS meanwhile the mainly pollutant emission sources in port front area and customs inspection area were ships and RS, respectively.

Table 1 The type and capacity of the CHEs

| Classification | CHEs in port | CHEs out of port |
|----------------|--------------|------------------|
|                | RMGs         | RTGs            | RS              | TSH | FL | YT  | OS | YTOP |
| Energy type    | Electricity  | Electricity     | diesel oil      | diesel oil | diesel oil | diesel oil | LNG | diesel oil |
| capacity       | 4            | 2               | 60              | 7    | 5  | 17  | 30 | 65   | 121 | 45 | -   |

Figure 1 Emission areas and emission process of air pollutants
2.2 Emission Estimation Methods
The emission estimation methodology for the air emission inventory of CHEs and ships were mainly referred to the power emission estimation methodology based on the power, load factor, emission factor and activities hours of the CHEs and ships [18-19]. The power and the activities hours of CHEs and ships in year 2017 were collected based on detail investigations. The load factors and emission factors were referred to data from port of Long Beach air emission inventory 2013 (https://www.polb.com/environment/air/emissions.asp).

3. Results and discussion

3.1 Emission contributions of CHEs and ships
CHEs with the energy type of electricity were not included for the air emission inventory in this study. The pollutants emission capacity were obtained based on the estimation methodology. The emission capacity of PM$_{10}$, PM$_{2.5}$, THC(Total Hydrocarbon), NOx, CO, SO$_2$ in year 2017 were 85.79 ton, 74.73 ton, 224.99 ton, 2755.52 ton, 440.30 ton and 642.91 ton. The emission contributions of CHEs in port, CHEs out of port and ships were showed in Fig. 2. It indicated that ships contributed most on all the pollutants except THC. The emission contribution for PM$_{10}$, PM$_{2.5}$, NOx, CO, SO$_2$ were 85.67%, 84.93%, 89.06%, 55.03% and 99.92%, respectively. However, the THC emission contributions of ships(34.28%) was less than those of CHEs (65.72%). This results were coordinated with the results of emission inventory of Tianjin Port in 2014 and emission inventory of Port of Long Beach in 2015. This might be attributed to the use of LNG in YT. Therefore, pollutant emission of ships should be given the priority for the improvement of the environmental quality in port. Shore power technology may be an effective way to make it owing to its cleaner emission.

![Figure 2 Emission contributions of two types of CHEs and ships](image-url)

3.2 Emission contributions of different areas and processes
The pollutants emission capacity of different types of CHEs in port were obtained based on the estimation methodology. The total pollutant emission capacity of RTGs, TSH, RS, FL, OS and YT were 110.9 ton, 37.1 ton, 17.7 ton, 3.6 ton, 12.3 ton and 349.5 ton. YT and RTGs was the biggest contributors among the CHEs in port, 65.8% and 20.9%, respectively, showed in Fig.3. Meanwhile, the YT with the energy type of LNG contributed 67% of the YT contribution, twice of the YT with the energy type of diesel oil. What’s more, the YT contributions of THC and NO$_x$ reached 88.39% and 64.56%, respectively. This also explained the results that the CHEs’ contributions to THC were more than the ships’. Therefore, pollutant emission of YT and RTGs should be given the higher priority and the LNG usage in CHEs should be given a further consideration for the improvement of the environmental quality in port.

3.3 Emission contributions of different areas and processes
Fig. 4 and Fig. 5 showed the total pollutant emission capacity and different pollutant emission contributions of the three areas and three processes. Port front and process ① were the biggest
contributors of the areas and the processes, respectively. Port front contributed most for the emission of PM$_{10}$, PM$_{2.5}$, NO$_x$, and SO$_2$, and process ① contributed most for the emission of THC. In addition, port front contributed about 99.5% of the total SO$_2$ emission. Therefore, port front was the area which should be strictly controlled when SO$_2$ mitigation was the priority for the improvement of environmental quality. Low sulfur oil usage and shore power technology may be the better alternative.

![Figure 3 Emission contributions of different types of CHEs in port](image)

![Figure 4 Total pollutant emission capacity of the three areas and three processes](image)

![Figure 5 Emission contributions of the three areas and three processes](image)

4. Conclusions
This study developed the emission inventory of typical container port based on detail investigation on the ships’ and CHEs’ engine power and activity hours. The results showed that ships contributed most for the pollutant emission of port and the yard tractor was the second contributor owing to the usage of the LNG. Coordinately, port front and the process from port front to yard were the biggest contributors of the areas and the processes, respectively. More technologies should be taken for the pollutant mitigation of port, especially for ships and yard tractor. Low sulfur oil usage and shore power
technology should be encouraged in pollutant mitigation in the future for the better air quality.

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