JOURNAL OF ENVIRONMENTAL SCIENCES XX (2017) XXX–XXX

Available online at www.sciencedirect.com

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JES JOURNAL OF ENVIRONMENTAL SCIENCES

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Emission characteristics of offshore fishing ships in the Yellow Bo Sea, China

Yingshuai Liu[1,2], *Yunshan Ge*[1,2], *Jianwei Tan*[1,2,*], *Mingliang Fu*[3,4,5,*], *Asad Naeem Shah*[6], *Luqiang Li*[1,2], *Zhe Ji*[4], *Yan Ding*[7]

1. *National Lab of Auto Performance and Emission Test, School of Mechanical and Vehicular Engineering, Beijing Institute of Technology, Beijing 100081, China*
2. *Collaborative Innovation Center of Electric Vehicles in Beijing, Beijing 100081, China*
3. *State Key Joint Laboratory of ESPC, School of Environment, Tsinghua University, Beijing 10084, China*
4. *State Environmental Protection Key Laboratory of Sources and Control of Air Pollution Complex, Beijing 100084, China*
5. *Collaborative Innovation Centre for Regional Environmental Quality, Beijing 100084, China*
6. *Department of Mechanical Engineering, University of Engineering and Technology, Lahore 54000, Pakistan*
7. *Vehicle Emission Control Center, Ministry of Environmental Protection, Beijing 100012, China*

ARTICLE INFO

Article history:
Received 30 July 2016
Revised 13 February 2017
Accepted 14 February 2017
Available online xxxx

Keywords:
Marine
Offshore fishing ship
Emission factor
PEMS
Operating modes

ABSTRACT

Maritime transport has been playing a decisive role in global trade. Its contribution to the air pollution of the sea and coastal areas has been widely recognized. The air pollutant emission inventories of several harbors in China have already been established. However, the emission factors of local ships have not been addressed comprehensively, and thus are lacking from the emission inventories. In this study, on-board emission tests of eight diesel-powered offshore fishing ships were conducted near the coastal region of the northern Yellow Bo Sea fishing ground of Dalian, China. Results show that large amounts of fine particles (<0.5 μm, 90%) were found in maneuvering mode, which were about five times higher than those during cruise mode. Emission rates as well as emission factors based on both distance and fuel were determined during the cruise and maneuvering modes (including departure and arrival). Average emission rates and distance-based emission factors of CO, HC and PM were much higher during the maneuvering mode as compared with the cruise mode. However, the average emission rate of NO_x was higher during the cruise mode as compared with the maneuvering modes. On the contrary, the average distance-based emission factors of NO_x were lower during the cruise mode relative to the maneuvering mode due to the low sailing speed of the latter.

Introduction

Maritime transport plays a central role in global trade. The impacts of the pollution caused by ships on the air quality of the sea, territorial waters and coastal areas have become more and more significant during the last few years. Consequently, shipping emissions have become a growing concern of the scientific community working on the environment. Thus, exhaust emissions from ships and their impact on the atmospheric environment have become a hot research field around the world, mainly taking two directions. One is based on real-world emission tests on certain types of ships (Winnes

* *Corresponding authors.* E-mails: tanjianwei@bit.edu.cn (Jianwei Tan), fumingliang160@163.com (Mingliang Fu).

http://dx.doi.org/10.1016/j.jes.2017.02.020

et al., 2015), while the other is focused on the development of emission inventories at the regional scale (Jena et al., 2015).

The acquisition of accurate emission factors from the tests is the essential element to developing shipping emission inventories. Sinha et al. (2003) selected two representative diesel-powered ships in the southern Atlantic Ocean off the coast of Namibia and measured the emissions of trace gases and particles. The characteristics of particulate matter (PM) and gaseous emissions from a large cargo vessel operating on diesel were measured by Moldanová et al. (2009). Furthermore, Winnes and Fridell (2010) conducted experiments on the main engines of a ferry and a tanker, and measured the emission levels of NO_x and particles in maneuvering mode. Their emission inventories helped to evaluate the risks to the local environment caused by pollutants from the ships. Ugur and Nurten (2001) have estimated that the total emissions of ships are 353,625 and 347,221 tons/year on the Bosphorus and the Canakkale Strait, respectively. It has also been reported that ocean-going ships, harbor tugs and commercial boats emit twice the amount of smog-forming emissions as emitted by all the power plants working in the area of Los Angeles (Mitchell, 2001). The NO_x emitted from ships made up a significant amount of the total NO_x levels in central Copenhagen (Saxea and Larsena, 2004). According to a research study, NO_x, SO_2, PM and GHGs (primarily CO_2) emitted from ships increased from 0.585 billion in 1990 to 1.096 billion tons in 2007 (Tzannatos and Kokotos, 2009).

Studies have also been performed in China to measure the emission factors and estimate the amounts of emissions contributed by ships in several large ports. Yang et al. (2007) developed an air pollutant emission inventory and estimated that the exhaust emissions such as NO_x, SO_2, CO, PM and volatile organic compounds (VOC) emitted from ships at Shanghai Port in 2003 were 44,270, 39,560, 34,220, 6290 and 17,570 tons, respectively. Emissions from the transport ships in Tianjin harbor were reported to be 5360 tons in 2006 (Jin et al., 2009). The maritime transport emission inventory of Qingdao established by J. Liu et al. (2011), Z. Liu et al. (2011) indicated that ports and shipping lines contribute about 8.0% of the total discharges of SO_2 and about 12.9% of NO_x on an urban scale. Yau et al. (2012) also developed a detailed maritime emission inventory for ocean-going vehicles (OGVs) in Hong Kong. They showed that the total ship emissions from OGVs in 2007 were 17,097, 8190, and 1035 tons, accounting for 17%, 11%, and 16% of the total emissions of NO_x, SO_2, and PM_{10}, respectively. Fu et al. (2013) measured seven inland ships using different power engines, and thus calculated the emission factors of the ships.

The establishment of a coastal emission inventory has been included as one of the objectives of the Chinese government. However, the emission factors used in the ship emission inventory of the Chinese harbors are mostly based on the previously established European and US ship emission databases, which are not expected to reflect the real conditions of the local regions. Therefore, it is of great importance to determine the local emission characteristics of ships in China for an accurate shipping emission inventory.

According to the statistics of the China Fisheries Association, there were a total of about 452.5 thousand offshore fishing ships in China in the year 2012. In fact, nearly 70% of ship emissions occur within 400 km of land, leading to the potential of these emissions to affect the air quality of the coastal areas (Endresen et al., 2003; Eyring et al., 2005). Moreover, the use of residual oil characterized by high density, high viscosity, and high concentrations of impurities aggravates the emission conditions of the ships (Corbett et al., 1999; Mudway et al., 2004; Moldanová et al., 2009). This leads to the fact that the pollutants from the offshore fishing ships adversely affect the local atmospheric environment. However, the literature related to emissions of low tonnage offshore fishing ships is sparse, and thus there is a need to study these ships separately.

The objective of this study is to enhance the understanding of emission levels of offshore fishing ships in China and provide references for stricter regulations on marine pollution. The emissions from offshore fishing ships, such as CO, HC, NO_x, and PM, were measured by using a portable emission measurement system (PEMS). These measurements were used to obtain emission factors of offshore fishing ships in the northern Yellow Bo Sea fishing ground off the coast of Dalian China. In addition to this, a comparison of the obtained fuel-based emission factors with those of previous studies is presented.

1. Experimental section

1.1. *Instruments for measurements*

In this study, we employed a portable emission measurement system (PEMS) to test the offshore fishing ships. The use of such systems on ocean ships has rarely been reported in the literature. This system, however, has been employed to measure the emissions from inland ships by Fu et al. (2013). In the current study, the use of PEMS was extended to investigate the pollutants emitted from the offshore fishing ships under real driving conditions.

This system consists of a SEMTECH-DS (DS, Sensor Inc., US), electrical low pressure impactor (ELPI) and some other useful accessories. The SEMTECH-DS is able to measure the instantaneous emissions of gaseous pollutants, such as CO_2, CO, HC, and NO_x, applying corresponding measurement modules (Dearth et al., 2005; Durbin et al., 2007). Environmental humidity, temperature, pressure, instantaneous location, speed of the ship, and some other parameters were measured and transmitted to a computer through a data line. Moreover, the SEMTECH-DS was zeroed and calibrated with pure nitrogen and standard gases respectively prior to each test to guarantee the accuracy of the measurements (Huo et al., 2012a, 2012b). The ELPI was used for the real-time monitoring of aerosol particle size distributions and providing second-by-second PM emission data with a minimum response time of less than 5 sec (Marjämaäki et al., 2000). This instrument can measure airborne particle size distributions in the size range of 7 nm to 10 μm. The instrument should also be zeroed before starting a test. Table 1 shows the truncation diameter and median diameter level of the ELPI.

Two ejector dilutors (dilutors, Dekati, Finland) were installed between the ELPI and the sampling probe. The exhaust gas was diluted by compressed air passing through the dilutors in

Please cite this article as: Liu, Y., et al., Emission characteristics of offshore fishing ships in the Yellow Bo Sea, China, J. Environ. Sci. (2017), http://dx.doi.org/10.1016/j.jes.2017.02.020