Influence of Marine Exhaust Gases on Coastal Areas due to Sea Traffic in Osaka Bay*

Atsuyoshi TAKAYAMA, Osami NISHIDA, Hirotsugu FUJITA, Wataru HARANO**

Marine air pollutants, NO_x and SO_x, have an adverse influence on the environment. In the 26th MEPC (Marine Environmental Protection Committee) of IMO (International Maritime Organization) held in 1988, a proposal on the prevention of air pollution from ships titled “Exhaust Gas Emission from International Marine Transport” was made by Norway. As a result of deliberate discussions, emissions control (Phase I) of exhausted NO_x values came into force on May 2005. Stricter regulations (Phase II & III) will be implemented in the near future. These stricter regulations will increase the ECA (Emission Control Area). Therefore, the authors propose an estimate of marine exhaust gas dispersion on Osaka bay.

The simulation presented in this paper uses the Pasquill-Gifford model to simulate marine exhaust gas dispersion. The purpose of this simulation is to show the influence of marine exhaust gases at the coastal areas. The diffusion model at the sea surface adopts the OCD (Off-shore and Coastal Dispersion) model which utilizes the Monin-Obukhov atmospheric stability parameter. For this study, 40 vessels of over 500 gross tonnage were chosen using an AIS (Automatic Identification System). The degree of incidence in the coastal areas from marine exhaust gases was estimated to be about 50 % for NO_x and 30 % for SO_x.

1. Introduction

NO_x and SO_x in marine exhaust gases influence on the global environment, causing acidification and concerning for health effects. For marine exhaust gases regulation is decided below. In the 26th MEPC (Marine Environment Protection Committee) of IMO (International Maritime Organization) held in 1988^[1,2]. A proposal was made by Norway about prevention of air pollution from ships, titled “Exhaust Gas Emission from International Marine transport”. The 1st stage regulation for NO_x value is now being put into practice (from May 2005) by IMO. The 2nd & 3rd stage regular forms will come into force on coming 2011 & 2016.

The evaluation of marine diesel engines exhaust emissions from under the passage and transient operating conditions have been presented by the BCH (Sub-Committee on Bulk Chemicals) and BLG (Committee on Bulk Liquids and Gases). In Japan, those problems have been discussed by Ministry of Land, Infrastructure, Transport and Tourism, Ministry of the Environment and JIME (The Japan Institution of Marine Engineering).

*Received March 30 2010

**Kobe university

Concentration of marine air Pollutant having at the coastal zone by the vessels indicates Table 1.1^[3]. Kanto-area (One capital six prefectures) is 19% and Kansai-area (Hyogo, Osaka, Kyoto) is 46% about NO_x, Kanto-area is 6.7% and Kansai-area is 16% about SO_x.

Marine exhaust gas has discussed by some studies, but there are almost data of Tokyo bay. More strict regulation will make increase of ECA (Emission Control Area). Therefore, we proposed estimate of Marine Exhaust gases dispersion in Osaka bay, which will have to require. So we need to propose not only data of Tokyo bay but also data of Osaka bay. As a result, we will get more efficient data from this paper.

The discharge of the air pollutant brought from the ship to the land plays an important role in the area like the Osaka bay, the evaluation of the burst size is one of the important subjects. The existence of diffusion date on the land is with metrological phenomenon, but there exists no diffusion data on the sea surfaces nowadays. Because there are so many influencing parameters for diffusion model on the sea surfaces, it is not easy to determine quantitatively.

This paper is simulated by Off-shore and Coastal Dispersion Model of Godden^[5]. This input date for simulation is measured in Osaka bay by A.I.S (Automatic Identification System) of T.S (Teaching Ship) “FUKAEMARU”.

Table 1.1 Influence of each emission source

Emission source (%)	Kansai area			Kanto area		
	NOx	SOx	PM	NOx	SOx	PM
Vessel	46	16	16	19	6.7	20
Air plane	3.0	3.0	16	9.0	5.3	20
Cargo-handling machine	3.0	0.0	8.0	16	0.0	11
Car	40	11	38	42	8.0	44
Factory	8.0	70	22	14	80	5.0
Total	100	100	100	100	100	100

2. Diffusion Model

2.1 Diffusion Model

Here is general diffusion equation of the consistency in the position (x, y, z) by G.I.Taylor^[6].

$$\frac{dC}{dt} = \frac{\partial}{\partial x} \left(K_x \frac{\partial C}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_y \frac{\partial C}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_z \frac{\partial C}{\partial z} \right) \quad (1)$$

The paper adopted a normal distribution plume model. It is calculated according to the following equation (2)-(3)^[6]. The effective stack height (H_e) is calculated according to the following equation (4)-(7)^[6].

$$C(x, y, z) = \frac{Q_p}{2\pi \cdot \sigma_y \cdot \sigma_z \cdot u} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \cdot F \quad (2)$$

$$F = \exp\left\{-\frac{(H_e - z)^2}{2\sigma_z^2}\right\} + \exp\left\{-\frac{(H_e + z)^2}{2\sigma_z^2}\right\} \quad (3)$$

$$H_e = H_0 + dH \quad (4)$$

$$H_0 = 2.59 \times T^{0.23} \quad (5)$$

$$dH = 0.175 \cdot Q_h^{0.5} \cdot u^{-0.75} \quad (6)$$

$$Q_h = 310.32 \cdot Q \cdot dt \quad (7)$$

2.2 Diffusion Parameter

(1) Diffusion parameter at sea surface

As stated previously, the paper signified simulation about dispersion of marine exhaust gases had two parameters, sea surface and land area. Purpose of this simulation is showing influence of marine exhaust gases at coastal zone. The diffusion model at sea surface is theoretically signified by

the atmospheric stability of Monin-obukhov, adopt an OCD model. Atmospheric stability is indicated by Stability length (L) (equation (8)). Those are calculated according to the following equation (9)^[7].

$$L = \frac{C_{un} \times 300 \times u^2}{0.4 \times 9.8 \times C_{fn}^2 \times (\theta_{vs} - \theta)} \quad (8)$$

(2) Diffusion parameter at land area

Diffusion parameter at land area is using Pasquill-Gifford model. This model is σ_y and σ_z . Fig.2.1 and Fig.2.2 show horizontal (σ_y) and vertical (σ_z) diffusion parameters^[7]. This study is determined by a combination of value of solar radiation (kW/m^2), amount of cloud and wind speed of land area. Additionally, atmospheric stability is dependent principally on air temperature (air temperature: 0.0098K/m).

$$\sigma_y, \sigma_z = f(x, u, z, L_v, \sigma_\theta) \quad (9)$$

Fig.2.1 Horizontal diffusion parameter (σ_y)^[7] Fig.2.2 Vertical diffusion parameter (σ_z)^[7]

2.3 Estimation model of marine exhaust gas

Fig.2.3 is made a correlation between tonnage and power, Fig.2.4 is made a correlation between power and fuel consumption^[6]. The intensity of point source of smoke of marine exhaust gas is calculated according to the following equation (10)-(13) by real dater of Fig.2.3 and Fig.2.4. Main engine is 2stroke and sub engine is 4stroke. Sub engine assumed that have dynamo engine of 2 sets. The intensity of point source of smoke of marine exhaust gas is calculated according to the following equation (14) and about NOx equation (15) about SOx^[8].

Fig.2.3 Correlation between gross tonnage and power^[6]

Fig.2.4 Correlation between gross tonnage and fuel consumption^[6]

$$PS_{(Main\ Engine)} = LR \times 93.142 T^{0.472} \tag{10}$$

$$q_{(Main\ Engine)} = 0.180 \times (PS)^{0.9605} \text{ (kg/h)} \tag{11}$$

$$PS_{(Sub\ Engine)} = LR \times 68.72 T^{0.4962} \times 2 \tag{12}$$

$$q_{(Sub\ Engine)} = 0.206 \times (PS)^{0.9402} \text{ (kg/h)} \tag{13}$$

$$Q_p)_{NOx} = 1.49 \times (PS)^{1.14} \times 10^{-3} \text{ (m}^3/h) \tag{14}$$

$$Q_p)_{SOx} = q \times S \times \frac{1}{100} \times \frac{22.4}{32} \text{ (m}^3/h) \tag{15}$$

2.4 Decide to fuel and calculated marine exhaust gas

As stated previously equation (10)-(15), calculated value of NOx and SOx indicates Table 2.1. Load ratio is main engine: 50% (heavy diesel oil) and sub engine: 100% (light diesel oil) about influence of momentary emission. Max load ratio of each gross tonnage indicates Table 2.2^[9,10]. It calculated according to the following equation Table 2.2 about the simulation moving vessels.

Table 2.1 Calculated Value of NOx and SOx

	Gross Tonnage (t)	NOx			SOx		
		500	5000	30000	500	5000	30000
Main engine	Power (PS)	1750	5190	12100	1750	5190	12100
	PS×LR (50%)	875	2595	6050	875	2595	6050
	Fuel Consumption q (kg/h)	121	343	772	121	343	772
	Exhaust Gas QM (m³/s)	0.33	0.95	2.14	0.33	0.95	2.14
	Amount of Emission (m³/h)	3.24	11.5	30.6	2.15	6.11	13.8
Sub engine	Power (PS)	1500	4700	11400	1500	4700	11400
	PS×LR (50%)×2(sets)	1500	4700	11400	1500	4700	11400
	Fuel Consumption q (kg/h)	199	585	1345	199	585	1345
	Exhaust Gas QM (m³/s)	0.55	1.63	3.74	0.55	1.63	3.74
	Amount of Emission (m³/h)	6.20	22.9	63.0	0.88	2.58	5.95
Total Exhaust Gas QT (m³/s)		0.88	2.58	5.88	0.88	2.58	5.88
Total Amount of Emission (m³/h)		9.44	34.4	93.6	3.03	8.69	19.8
Total First Concentration (PPM)		2980	3710	4420	956	936	935

Table 2.2 Load ratio for main engine

Gross Tonnage (t)	Max LR (%)	Max Velocity (knot)	LR (%) v (knot)
500	70	15~20	$LR=1.58 \times 10^{-4} \times v^3 + 0.171$
5000	50	15~20	$LR=1.23 \times 10^{-4} \times v^3 + 0.085$
30000	30	15~20	$LR=8.71 \times 10^{-4} \times v^3 + 0.076$

3. Experiment Description

3.1 Experimental Method and outline of simulation

We choose about 40 vessels over 500 gross tonnages which are chosen for the subject of the study using A.I.S. 500 gross tonnage is less or equal 100m length, 5000 gross tonnage is from 100m to 200m length, and 3000 gross tonnage is over 200m length^[11]. So under a given weather condition, it is wind of Southwesterly and velocity of 8 m/s.

Simulation of the paper has Microsoft office excel. This simulation assumes that 50km×50km area in Osaka bay, which each mesh is 200m×200m, arrange mesh in 250×250 lines. To input weather condition (air and sea temperature, wind velocity) and other marine information by AIS (degrees of latitude, degree of longitude, tonnage) can be decided the atmospheric stability. Diffusion parameter can be decided at each position by the atmospheric stability.

Vessel's data can be required by using A.I.S on T.S “FUKAEMARU”. It is appurtenances auto discriminating the vessels took the VHF radio. Over 500 gross tonnage vessels have a requirement taking AIS. AIS data is degrees of latitude, degree of longitude, tonnage and vessel velocity. Each vessel is kind of two, navigation and anchorage. AIS information at Osaka bay is simulated on the Microsoft office excel on real time. About an hour later, the marine exhaust gas on the sea determined by AIS attains to coastal areas.

The velocity of deposition rate both NO_x and SO_x is 0.50 (m/s), especially no problem because the subsidence fall is 18m even by one hour. The day when the weather was steady at the time of cleared up was chosen among the navigations of five days, and AIS was measured five times.

3.2 Experimental Result and Discussion

It indicates Fig.3.1, Fig.3.2 about simulation of influence on the land area of marine exhaust gas in Osaka bay. This simulation calculated temporal integration using diffusive concentration for instantaneous smoke of marine exhaust gas. Ground-based observatory is A: Rokko island, B: Nada, C: Hyogo Nanbu, D: Suma or Tarumi, E: Nanko Center Park and F: Takaishi.

Influence area is more ship on the berth area and many vessels exist upwind. At the same time, the inland doesn't show an influence. In this way, marine exhaust gas has an important consequence for coastal area.

It indicates Fig.3.3 about value of influence at measure point by Measurement of five times. The degree of incidence to coastal zone from marine exhaust gas is

estimated about 30-50 % in NO_x and 15-30 % in SO_x. A, B and E were shout about abnormality. But C, D and F were big about abnormality. Because C, D and F were ran through more vessels. There was little influence on the inland.

Fig.3.1 Influence on the Land of Marine NO_x

Fig.3.2 Influence on the Land of Marine SO_x

Fig.3.3 Influence at coastal zone of Marine exhaust gas

4. Simulation of wind and moving vessel parameter

4.1 Estimation method of wind series

Estimation of wind series is calculated to interpolate lattice position by some area, observed some wind data. Most common tool is a method which average inverse of square of distance from arbitrary point to measurement point. Because it's limited a method of observation, this method can't calculate the perpendicular value. there is no problem because high point is only 10 meters. Wind series is calculated according to the following equation (15), (16) [12].

$$U_{i,j} = \sum_k W_{i,j,k} U_k / \sum_k W_{i,j,k} \quad (15)$$

$$W_{i,j,k} = 1/r_{i,j,k} \quad (16)$$

As identified above, this method doesn't have time series, so it averaged three hours about measurement value.

Wind simulation indicates fig 4.1. Actual data on the sea is "latitude of 34.35 degrees north, longitude of 135.03 degrees east, wind direction is SW, wind velocity is 8m/s". This is had same result against this simulation result.. By the way, the simulation of wind series is had better result having better point. But four points is enough.

Fig 4.1 Simulation of wind series

4.2 Simulation of moving vessel

This simulation thought moving vessel. The information got A.I.S. data could calculate each distance moving vessels. Vessel velocity decided to the distance moving vessel and the time, so load factor decided in answer vessel velocity. Wind direction is Fig 4.1. Object substance is NOx.

4.3 Experimental Result and Discussion

The simulation of wind and moving vessel parameter is Fig4.2. Marine exhaust gas became diffuse over a wide range in Osaka bay, 1~10ppb. Pollutant group formed moving vessel and wind series had some objects. Of particular interest was moving toward east-northeast. Marine air pollutant had gathered at a certain place. So marine air pollutant had a very large effect coming from direction moving vessels at coastal area, this result was an important for discussing measures to be taken in the future.

Fig.4.3 is influence of marine pollutant. A-F point is same Fig. 3.4. The effect of Marine air pollutant is NOx about 50% and SOx about 30% at the coastal area. This simulation is nothing at the land, estimating the impact of marine air pollutant on the land is 0.05~1ppb in a wide sphere. According to Fig1.1, Marine NOx is 46% and Marine SOx is 16%. Marine NOx is similar in value, but is SOx large value. It cause not only to break down NOx and SOx but also calculated by displacement and fuel consumption for 1 year.

Fig 4.2 Diffusion Simulation of Marine NOx

Fig 4.3 Influence at coastal zone of Marine exhaust gas

5. Conclusion

We got following result.

- (1) Marine air pollutant could consist of load ratio, marine tonnage and kind of the fuel (heavy diesel oil for main engine and light diesel for sub engine) etc.
- (2) The degree of incidence to coastal area from marine exhaust gas is estimated about 50 % in NO_x and 30 % in SO_x (max late in the cards of wind condition).
- (3) The simulation of moving vessel changed shape of air pollutant diffusion for moving and wind direction.
- (4) The consistency on the land area was demonstrate significant decrease in this simulation.
- (5) This paper could describe air pollutant diffusion by image simulation.

References

- [1] "Review and vision of condition of the maritime market", Japan Marine Equipment Association All rights reserved, Japan, No.237, pp.4-20, (2008).
- [2] "Correspondence of ocean-going shipping toward marine exhaust gas regulation", T.Kawashima, Journal of The Japan Institute of Marine Engineering, Japan, pp.37-42, (2008), Japanese.
- [3] "Research of marine air pollutant", Asahi newspaper, Environment agency, Japan, (2004.1.7).
- [4] "Atmospheric diffusion of air pollution from ship and environment impact assessment of coastal area", T.Ishida, Journal of The Japan Institute of Marine Engineering, Japan, Vol.42, No.1, pp.41-46, (2007).
- [5] "The overwater plume dispersion study", D.Godden, NTIS PB 87-222378, (1987).
- [6] "Influence on the Land of Marine Particulate Matter by the Maritime Transportations", O.Nishida, Review of Graduate School of Maritime Sciences, Kobe University of Mercantile Marine, Japan, Vol.47, pp.128, (1999).
- [7] "Measurement and total control technology of suspended particulates for air cleaning", N.Isahaya, R&D planning, Japan, pp.166-176, (1987).
- [8] "This or that marine air pollutant", O.Nishida, Aerosol research, Japan, No.1, Vol.3, pp.235-239, (1996).
- [9] "Total inquest report connected effect on the environment of marine exhaust gas and emission limitation", Ship and Ocean Foundation, Japan, pp.67, (2002).
- [10] "Effect on the earth's environment of marine exhaust gas and research of prevention technique", Ship and Ocean Foundation, Japan, pp.77, (1999).

[11] Correspondence by vessel travel (domestic vessel), N.Isaki, Journal of The Japan Institute of Marine Engineering, Japan, pp.29-38, (2008).

[12] "Simulation of air environment", N.Yokoyama, Hakua shobo, Japan, pp.112-131, (1992).

Nomenclature

K : Diffusion coefficient

t : Time (s)

u : Wind velocity (m/s)

T : Gross tonnage (t)

σ_y : Diffusion parameter

σ_z : Diffusion parameter

x,y,z : Position (m)

He : Effective stack height (m)

H_0 : Actual stack height (m)

dH : Ascent of exhaust gas (m)

dt : Difference between exhaust and ambient temperature

C : Consistency (g/m³)

Cun : Momentum resistance coefficient of middle stage

Ctn : Caloric resistance coefficient of middle stage

Q_h : Heat quantity of emission (cal/s)

Q : Amount of exhaust gas (m³/s)

Q_p : Intensity of point source of smoke (m³/h)

PS : Power (PS),

LR : Load ratio (%)

v : Vessel velocity (knot)

$U_{i,j}$: Point (i, j) value of wind information

U_k : Measurement point [k] value of wind information

$W_{i,j,k}$: Weighting function

$r_{i,j,k}$: Distance From point [i, j] to [k] (m)

L : Stability length

S : Sulfur content (A heavy oil: 0.63w%, C heavy oil: 2.55w%)

q : Fuel Consumption (kg/h)

θ : Sea temperature

θ_{vs} : Atmosphere temperature

σ_θ : Variation of wind direction