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USING INFORMATION FROM AIS SYSTEM IN THE MODELLING OF EXHAUSTS COMPONENTS FROM MARINE MAIN DIESEL ENGINES

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Abstract

Society's growing pro-ecological pressure has made atmosphere pollution by marine diesel engine exhausts one of the main problems of marine environment protection of recent years. In order to determine the share of vessels in atmospheric air pollution and to counteract the harmful effects of toxic compounds in marine engines exhausts, it is necessary to know the emission values of these compounds from particular vessels, which is possible if one knows the vessel movement parameters, concentration values of particular compounds for these parameters and the atmospheric conditions in the area they are staying in.

The work presents conditions concerning the modelling of harmful compounds emission of engine exhausts based on the example of ships sailing in the Gulf of Gdańsk region, using information from AIS system.

Key words: *emission, exhausts, toxic compounds, modelling, narine engines, AIS*

1. Introduction

The problem of air pollution in ports and approaches to ports is important insomuch as ports are usually located close to or in the area of large cities, and their restricted space is the cause of large concentration of vessels in a small area. Widely conceived operational conditions are not without significance either. Among the latter there can be counted the way of operating the engines, frequency and character of steady and transient conditions, and external conditions affecting engine work. Exhausts toxicity is also affected by the kind of fuel and lubricating oil applied

Research conducted currently throughout the world concerning atmosphere pollution caused by emission of toxic compounds from ship engines, conceived both globally [1,2] and regionally [3,4], as also locally, e.g. in areas of large sea ports [5] is based on simplified input data [2,6,7]. The existing data bases of harmful compounds emission from exhausts of ships sailing in various regions of the world [7] cannot be used, however, for the estimation of emission in mezzo- and microscale, e.g. The Baltic Sea or the Gulf of Gdansk, as they lead to considerable underestimation of emission indexes, mainly due to too few details of vessel movement characteristics [8].

The factors determining global emission of substances contained in marine diesel engines exhausts have been classified and described in [4].

The process of modelling of toxic compounds (TC) emission in marine engines exhausts is very complex and requires information that can be divided into four basic groups:

- vessel parameters – length, breadth and draft of the vessel, technical condition of the propulsion system, kind of propulsion (including kind and number of engines), kind and number of propulsion screws etc.;
- vessel movement parameters – vessel's course and speed;
- external conditions – wind direction and force, air and water temperature, atmospheric pressure, air humidity, state of the sea;
- number of vessels with consideration of their categories.

Models of emission from inland transports created in Europe, like HBEFA, COPERT, DVG, DRIVE-MODEM attempt to take into account the largest possible number of parameters affecting emission, yet with such a large number of factors and complex description of phenomena determining the emission process, simplifying assumptions cannot be avoided. Besides, due to the difference in both hydrometeorological conditions and the specificity of vessel operation, they cannot be applied for the assessment of emission from ships.

The STEAM model (*Ship Traffic Emission Assessment Model*) of toxic compounds emission presented in [9] is based on data transmitted by the AIS system and calculations are made on their basis of toxic compounds emission indexes in the exhausts. Yet even in this model no simplifying assumptions have been avoided (for instance, when engine data were unavailable it was assumed that it was a medium-speed engine with self-ignition of rated rotation speed of n=500 rpm, which is likely to cause that the determined emission indexes will not reflect real emission values.

There exists thus the need to apply methods by means of which it will be possible to determine much more precisely the characteristic of vessel movement as also the emission values.

2. General characteristic of AIS system

The AIS (*Automatic Identification System*) is a radio system that enables automatic exchange of information of vessel identification, essential for vessel traffic safety in relation ship-to-ship, ship- to-plane and ship-to-shore.

According to MSC 74 (69) resolution of the Safety-at-Sea Committee of International Maritime Organisation [10] of newly-built vessels (of 300 BRT tonnage and larger in international shipping and 500 BRT and larger) were to be equipped systematically starting from 1 June 2002.

According to IMO recommendations, the AIS installed on the vessel should automatically transmit and receive the following data (using TDMA technique):

- **static:**
  - MMSI number (*Maritime Mobile Service Identity*),
  - ship's IMO number,
  - ship's calling signal and name,
  - vessel's length and breadth,
  - type of vessel,
  - antenna location of the ship's radio-navigational receiver connected to the AIS in relation to the ship's hull,
- **dynamic:**
  - geographical coordinates of position received from the ship's radio-navigational receiver connected to the AIS, with indication of its accuracy,

- UTC - Universal Time),
- course and speed over the ground (COG, VTG),
- true course (HDG),
- navigational status determined in accordance with the resolutions of international regulations on preventing collisions at sea (e.g. vessel hampered, at anchor etc.),
- rate of turning (angular speed) (ROT),
- optional: constant angle of heel and current values of longitudinal and athwart heels (if the ship has instruments for measuring them),

- **concerning the voyage:**
  - vessel's draft,
  - port of destination and ETA (*Estimated Time of Arrival*) – if the Master considers this information as required,
  - optional: route of transition (positions of successive turning points.

The ship's device should transmit autonomously in definite time intervals:

- static information – every 6 minutes and on demand,
- dynamic information, in time intervals from 2 to 12 seconds depending on movement velocity,
- voyage data, every 6 minutes, after each change of any of the data and on demand,
- brief information on safety, on demand.

Working in the way presented AIS must be able to exchange 2000 reports per minute.

AIS station can be composed of, among other things: satellite system receiver (GNSS) only for time determination, a monitor equipped with a keyboard for manual entry of data, processor controlling the work of the device and testing its proper functioning and enabling the control of correctness of the data transmitted and received, connection systems of external navigational devices, i.e. radio-navigational system receiver for position plotting, determining log and compass (of gyrocompass or electronic compass) and instruments for measuring rate of turn and optionally, angles of longitudinal and athwart heel), systems of connecting to the ECDIS/ECS, radar and ARPA.

For this reason the coastal AIS stations have become convenient instruments permitting constant monitoring of vessel traffic. Due to their connection to the pan-European network of data exchange it is possible to gather and transmit information concerning dangerous cargoes and passengers carried. Such data, transmitted in turn to VTS Centres, will permit *inter alia* [10]:

- identification in the VTS service centre of vessels present in the area of its functioning;
- presenting information on vessels' position and vectors of their movement with same accuracy as is available on these vessels, higher than available from shore radar devices equipped with tracking systems;
- presenting the above-mentioned information with minimum time delay, equalling less than 1 second;
- presenting information on manoeuvring vessels, inaccessible in the case of using radar devices, for instance current values of their gyrocompass courses and rate of turn;
- monitoring current hydrometeorological conditions in the VTS centre and on ships.

3. Theoretical bases of modelling the emission of exhausts components from ship engines

The emission of any pollution is express in mass *m*. This mass can be a function of time or way, that is *m(t)* lub *m(s)*. Way emission is defined as the derivative [11] of emission being the function of way m(s) covered by the vessel

$$b_s = \frac{dm_s(s)}{ds} \tag{1}$$

On the basis of equation (1) it can be written that emission on way *S* will equal

$$m_s(S) = \int_0^S b_s(s)ds \tag{2}$$

The intensity of emission as a function of time equals

$$E(t) = \frac{dm(t)}{dt} \tag{3}$$

Way emission as a function of time will assume the form

$$b_t(t) = b_s(s(t)) \tag{4}$$

Pollution emission in time T will thus equal

$$m_t(T) = \int_0^T b_t(t)v(t)dt \tag{5}$$

where $v(t)$ is the vessel's speed.

As the amount of harmful compounds emitted in marine engine exhausts depends on such values describing the engine's work state as torque M_o, rotational speed n, environmental conditions **G** (e.g. ambient temperature, pressure, air humidity) and sailing conditions **O** (wind direction and force, length and height of waves etc.) unit emission of n-th exhausts component:

$$e_n = f(M_o, n, \mathbf{G}, \mathbf{O}) \tag{6}$$

and the engine's effective power $P_e = 2\pi \cdot M_o \cdot n$, way emission can be modelled as the functional of a value describing the engine's work state, i.e. effective power and the vectors describing environmental and sailing conditions

$$b_t(t) = B_P\,[\,P_e(t), \mathbf{G}(t), \mathbf{O}(t)] \tag{7}$$

Way emission of a vessel in conditions of sea operation is the function of the vessel's instantaneous speed v, vector **A** , containing information on the ship's variable movement resistances bound with the sailing area (water depth, water area width like a channel's width etc.), vector **G**, describing environmental conditions and vector **O**, describing sailing conditions

$$b_t = f(v, A, G, O) \tag{8}$$

and it can can be presented as the operational dependence

$$b_t(t) = B_v\,[\,v(t), \mathbf{A}(t), \mathbf{G}(t), \mathbf{O}(t)] \tag{9}$$

In connection with dependences (3) and (7) vessel emission m_{okr} in time T equals

$$m_{okr} = \int_0^T B_v\,[v(t), \mathbf{A}(t), \mathbf{G}(t), \mathbf{O}(t)]\,v(t)dt \tag{10}$$

and the mean way emission from vessel can be described

$$b_{\acute{s}r} = \frac{1}{S}\int_0^T b_t(t)v(t)dt \tag{11}$$

Unit emission ***e*** is defined as the relation of emission *m* from the engine in definite time *T* to the work performed by the engine ***L***

$$e = \frac{m}{L} \tag{12}$$

As the work performed by the engine can be expressed as the product of the mean effective power and work time

$$L = P_{e_{śr}} \cdot T \tag{13}$$

and mean emission intensity $= m/T$, mean unit emission can be expressed as

$$e_{śr} = \frac{E_{śr}}{P_{e_{śr}}} \tag{14}$$

In work [12] the trajectory of vessel movement has been considered as the realisation of a two-dimensional stochastic process $\{S(t)=(X(t),Y(t)): \quad t \geq 0\}$, with the assumption that the process is one with multidimensional distribution of continuous type and continuous realisations. The realisation of such a process is a two-dimensional trajectory dependent on time $\{s(t)=(x(t),y(t)): \quad t \in T\}$.

The equation describing the mass of emitted exhausts can be presented as:

$$M = \int_{\alpha}^{\beta} f(s(t))|\bar{v}(t)|dt \tag{15}$$

where: (t) – length of vessel's velocity vector.

The mass of exhausts emitted in definite area Ω in time interval $[t_{i-1}, t_i]$ is the sum of masses emitted by all vessels present in this time interval in the area. If $W^{(k)}, \quad k = 1,\dots,K$ denotes the mass of exhausts emitted by the k-th vessel, then the total mass of exhausts emitted in area Ω in time interval $[t_{i-1}, t_i]$ is a random variable

$$\mathbf{W}_K = \sum_{k=1}^{K} W^{(k)} \tag{16}$$

Random variable $\mathbf{W}_K$ as the sum of independent random variables with normal distribution has a normal distribution of expected value

$$E(\mathbf{W}_K) = \sum_{k=1}^{K} W^{(k)} = \sum_{k=1}^{K} [E(\Delta M^{(k)}) + M^{(k)}] = \sum_{k=1}^{K} [M^{(k)} + \varepsilon^{(k)} \sum_{i=1}^{N} \gamma_i^{(k)} \Delta s_i^{(k)}] \tag{17}$$

Standard deviation of this random variables equals

$$\sigma(\mathbf{W}_K) = \sqrt{\sum_{k=1}^{K} V[\Delta M^{(k)}]} = \sqrt{\sum_{k=1}^{K} \rho^{(k)} \sum_{i=1}^{N} [\gamma_i^{(k)} \Delta s_i^{(k)}]^2} \tag{18}$$

4. Results of modelling toxic compounds emission in exhausts based on information obtained from the system

In the construction and research of the stochastic model of movement and exhausts emission from vessels [13,14,15] in the region of the Gulf of Gdańsk it is indispensable to know the number of vessels sailing in the region analysed, their distribution with respect to kind of vessels, their size, speed, power and kind of main propulsion engines etc.

For the statistical working out of marine vessel movement streams there were assumed the routes of approach fairways to the ports of Gdynia and Gdańsk, the fairway separating into both these water lanes and the traffic routes in the port of Gdynia.

In the research archival data were used, registered with the coastal AIS device by SAAB firm of R$ type, tracking vessel traffic in the Gulf of Gdańsk [16].

Fig. 1 presents parts of movement trajectory of the Stena Baltica ferry, taking consideration of movement parameters and atmospheric conditions. These pieces of information permit the tracking of changes in the vessel's course and speed, and eventually the working out of the vessel's movement's dynamic parameters.

On the basis of acquired statistical data concerning vessel traffic, there have been worked out typical characteristics of changes in the vessel's speed as the function of time for regular shipping vessels. An example of such characteristic is the averaged characteristic of changes in speed of Stena ferries during entering the port of Gdynia, presented in Fig. 2.

Fig. 3 presents calculation results of emission intensity of toxic compounds in exhausts for an engine with rated power $P_{e(n)} = 9$ MW mounted on vessel ($L = 129\ m,\ B = 22\ m,\ T \neq T_n = 6.1m$) with nominal velocity $v_n = 15$ knots, sailing at speed established from data from AIS system $v_{śr} = v_E = 13.6$ knots [15].

The example concerns the determination of total emission of toxic compounds of a vessel sailing in the Gulf of Gdańsk at nominal loading state $D = D_n$ $(T = T_n)$ and state of the sea $SM < 3^oB$ and the true depth of the sailing water area. The particular four stages of the way covered reflect the operational conditions and emission of toxic compounds during the voyage of each vessel sailing in the direction of the Gulf ports and its putting to sea.

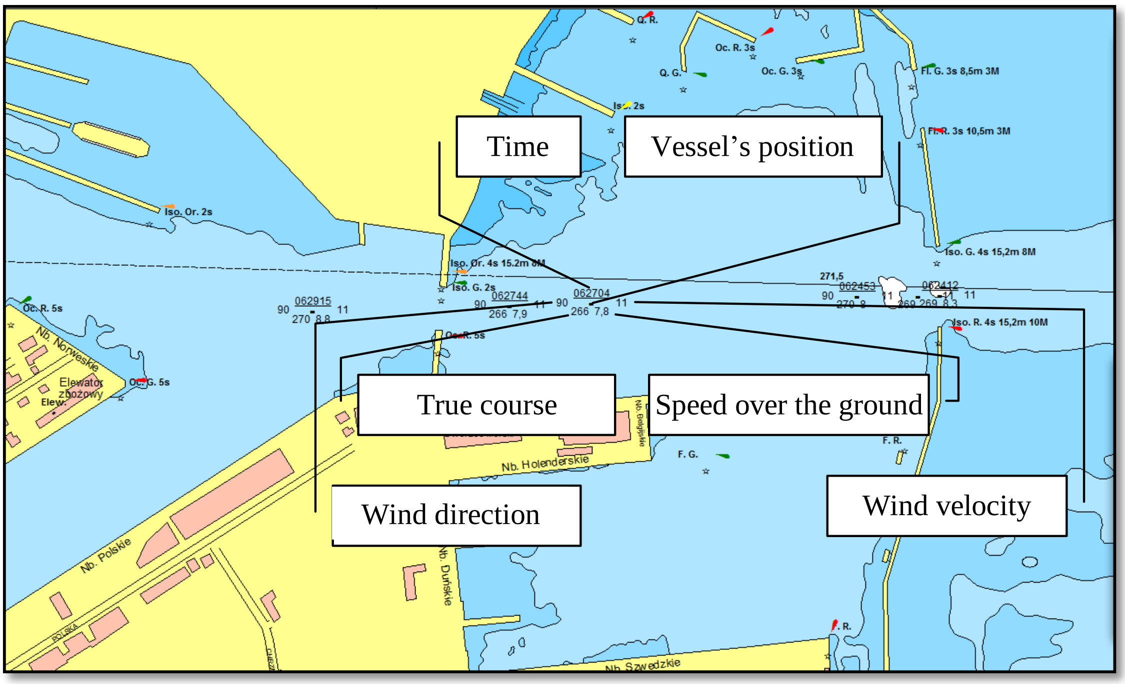

Fig. 1. Part of movement trajectory of Stena Baltica ferry taking consideration of vessel parameters and atmospheric conditions

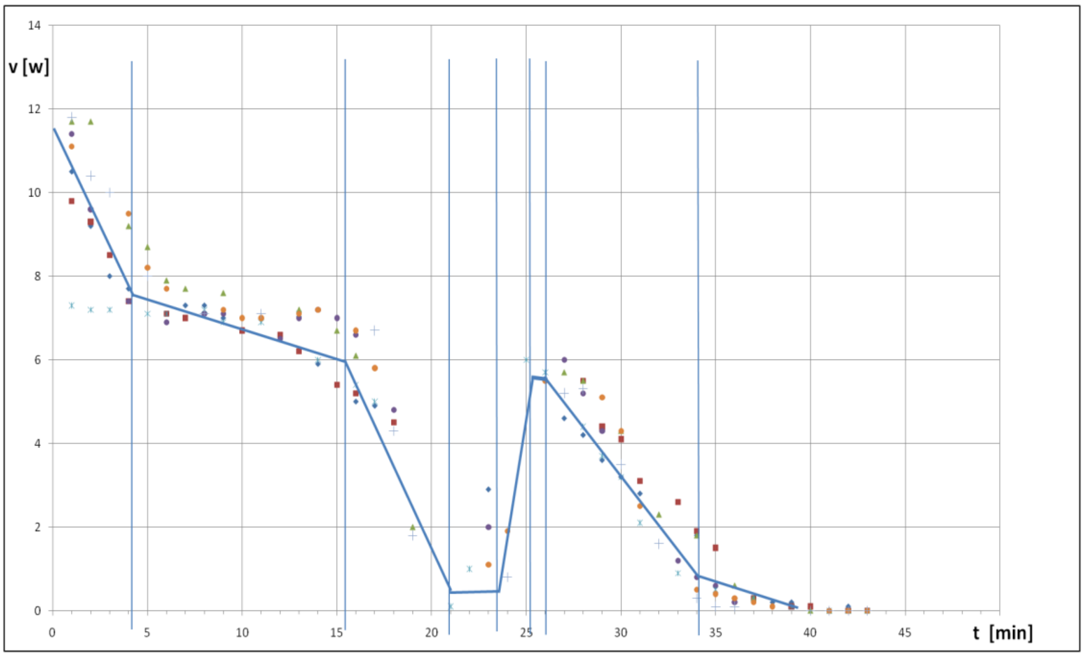

Fig. 2. Time course of ferry speed (active braking) entering the port of Gdynia, obtained from AIS system

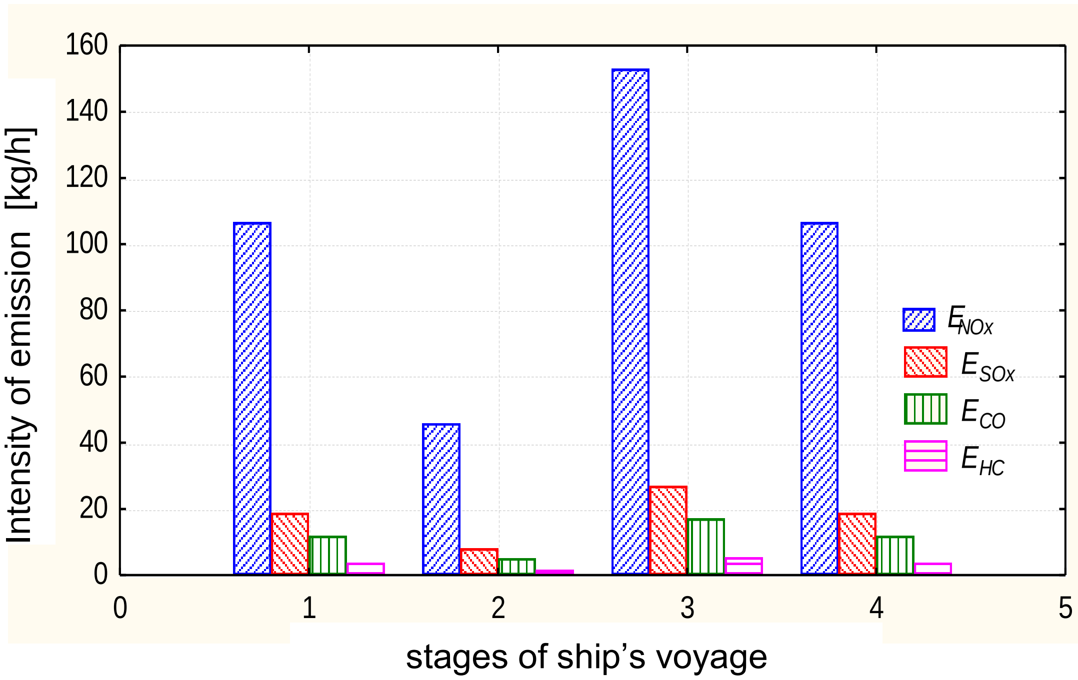

Fig. 3. Distribution of pollution emission intensity on distinguished stages of a typical ship voyage in the waters of the Gulf of Zatoki Gdańsk
Stage 1 – free sailing at speed v_E = idem; Stage 2 – vessel's braking down to v = 0;
Stage 3 – starting and accelerating up to v_E = 13,6 k; Stage 4 – free sailing at speed v_E = idem

Recapitulation

The modelling of emission of harmful compounds is a very important and at the same time a very complex subject. Many attempts are undertaken in the world aimed at estimating models of harmful compounds emission in vessel exhausts. Unfortunately, due to the model structure being dependent not only on its intended use, but also largely on the amount and quality of input data, many studies being based on an insufficient amount and quality of input data, frequently acquired from numerous various sources, and it being necessary to apply simplifications, all this significantly affects the model's reliability.

The possibility of obtaining data from AIS, such as name of vessel, length and breadth, type of vessel, universal time bound with the vessel passing through the "gate", course and speed over the ground (COG, VTG) and the vessel's draft permits the creation of innovative models describing the vessels' movement in the area examined and the emission of harmful compounds in exhausts both for a single vessel and the whole area examined.

Apart from problems that motorization specialists cope with when modelling toxic compounds emission, in the case of sailing vessels among parameters disturbing the accurate emission determination of particular compounds (due to lack of information or its changeability) there can be additionally counted the technical condition of the engine, fuel apparatus in particular, and atmospheric conditions (particularly wind direction and force).

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