Comparative Analysis of Ship Board Emission Based on Automatic Identification System (AIS) Data

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Abstract- Automatic Identification System (AIS) is a transponder system designed for the exchange of information related to ships. This automatic tracking system is used for collision avoidance and vessel traffic services.AIS provides static, dynamic and voyage information of ships from which the emissions could be estimated over a period. In this paper, emissions are calculated by taking AIS data of Oceanographic Research Vessel (ORV) Sagar Nidhi when it started its voyage from New Mangalore Port to Central Indian Ocean Basin (CIOB) and returned to Chennai Port. In this voyage, she has covered approximately 3000 nm (5556 Km) and encountered about three hundred ships. The author has calculated the emissions by considering the Gross Tonnage (GT), speed and other essential parameters of ship into account. A model is developed based on GT which is used for calculating fuel consumption and emissions. The calculated emissions are validated with emissions of ORV Sagar Nidhi which are measured using Testo Flue gas analyser. Based on ship type and fuel consumed, this simplified analysis can be used for emission calculation.

Keywords-Emissions; Ship Traffic; Automatic Identification System; Fuel Consumption.

I. INTRODUCTION

Global emission data estimates that shipping industry emits annual totals of 20.9 million and 11.3 million tonnes of NOx and SOx respectively, IMO (2014). Fuel consumption by shipping industry ranged between approximately 247 million and 325 million over a period of 2007-12, IMO (2014). International Maritime Organisation (IMO) focuses majorly on air pollution from ships exhaust and through MARPOL conventions IMO is framing policies to contain it. Exhaust emissions from marine engines viz., NOx, SOx, Particulate Matter (PM), CO_2 and CO pollute the environment and subsequently leading to global warming. Considering all these facts it is very important to estimate the emissions and measurements have to be taken to control the emissions. Reduction in emissions can be achieved through retrofit technology or stringent laws should be passed to make sure that polluter pays.

India is surrounded by two major seas and one ocean- Bay of Bengal (BoB), Arabian Sea and the Indian Ocean, there lies a huge potential for coastal transshipment. The coastal mode has several advantages over the other modes such as road and rail. It is energy-efficient, environment-friendly and has potential to reduce congestion on rail and road networks and can cater to movement of large volumes of bulk traffic at relatively cheaper cost. Coastal mode of transport scores over the other two in respect of fuel consumption, T Behra (2015). Major sea ports on the west coast are Kandla, Mumbai, Nhava Sheva, Marmagao, New Mangalore, and Kochi and those on the east coast are Calcutta-Haldia, Paradip, Vishakhapatnam, Chennai, and Tuticorin. Crude oil originating ports are from Mumbai, Rawa and Cuddalore and the discharge ports are to Vizag, Cochin, Chennai and Kandla. Iron ore originating ports are Vizag, Mormugao and the discharge ports are Magdalla, Dhramtar and Revdanda. By looking at the coastal transshipment it is understandable that there is a frequent movement of Bulk carriers, crude oil containers and iron ore containers from Eastern Coast to Western Coast and vice versa. Estimation of emissions in these coastal areas plays a vital role in the air quality assessment and its impacts on the environment, Tirka Pitana et al (2010).

Ocean Research Vessel 'Sagar Nidhi' is India's pride and a state of art ice-class research vessel of the sub-continent. It is built with Dynamic Positioning System [DP-II] of 5m accuracy, with an overall length of 103.6m and draft of 4.2m. She can accommodate 30 scientists with an endurance of 45 days. Sagar Nidhi is the 'first Indian flagged research ship that reached the 66°S latitude, facing 11 storms and 73 nm/hr wind speed, witnessing nature's harshest conditions. In this paper the author has considered one of its scientific expeditions which started from New Mangalore port, reached to Central Indian Ocean Basin (CIOB) for scientific experiments and concluded at Chennai Port. In this journey it has covered approximately 3000 nm and encountered different types of ships. Fig.1 shows the Voyage of the ship.

Fig. 1: ORV Sagar Nidhi voyage from Western Coast to Eastern Coast of India.

The types of ships ranging from Bulk Carriers, Container Ships, Vehicle Carriers and General Cargo Ships. The ship particulars like seven digit IMO number, nine digits Maritime Mobile Service Identity (MMSI) number, gross tonnage, dead weight, the size of the ship and its speed etc are obtained from AIS receiver system installed on board ORV Sagar Nidhi. Fig.2 shows the types of ships encountered during voyage.

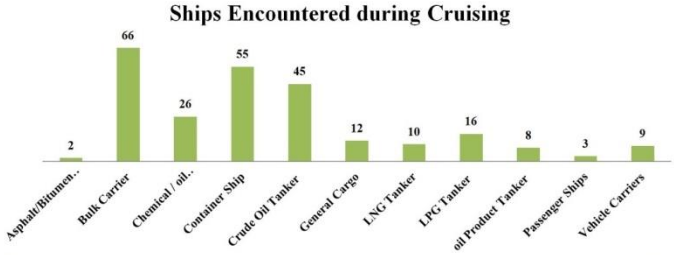

Fig. 2: Types of ships encountered by ORV Sagar Nidhi during its voyage.

II. SHIP TO SHIP & SHIP TO SHORE (4S) – AN OVERVIEW OF AIS

The AIS is a shipboard broadcast system that acts like a transponder, operating in the VHF maritime band that is capable of handling well over approximately 4,500 reports per minute and updates as often as every two seconds to ten seconds depending on the type of AIS installed onboard. It uses Self-Organizing Time Division Multiple Access (SOTDMA) technology to meet this high broadcast rate and ensure reliable ship-to-ship operation.

It is a VHF communication system that provides 3 types of different information transmitted by ship. First and primary information of ship called as static information, the second one is dynamic information and the third one is about voyage related information.

In 2000 IMO adopted a new requirement-Regulation 19 of Safety of Life At Sea (SOLAS) Chapter V, made mandatory for all ships to carry automatic identification system (AIS) capable of providing information about the ship to other ships and to coastal authorities automatically. The regulation requires AIS to be fitted aboard all ships of 300 gross tonnages and upwards engaged on international voyages, cargo ships of 500 gross tonnages and upwards not engaged on international voyages and all passenger ships irrespective of size.

A. AIS Installation:

In the vicinity of the ORV Sagar Nidhi approximately 96nm, the details about other vessels are obtained from AIS dual channel receiver/GPS receiver installed on board. A computer has been installed to log and display the real-time AIS data. The data transmitted from ships within range can be displayed on the screen, giving the navigator a visual interpretation of the traffic within VHF range. Fig.3 represents the installation on AIS instrument onboard.

Fig. 3: AIS installation onboard Orv Sagar Nidhi

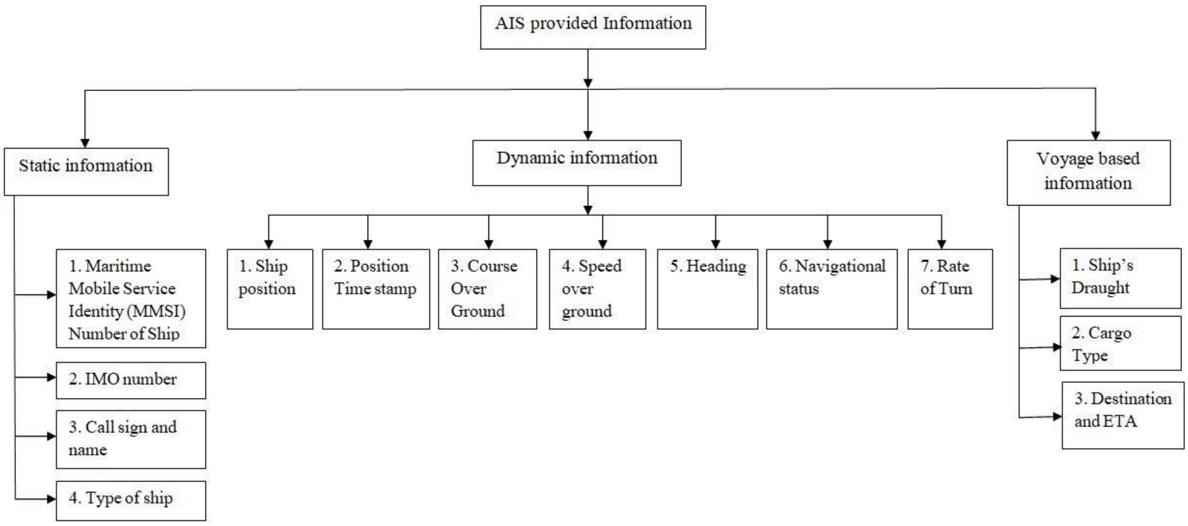

Fig. 4: AIS information overview

III. LITERATIRE REVIEW

There are various works of literature available on methods of calculating emissions from ship particulars, maritime navigation and ship traffic. Carlo Trozzi (2010) reported about the estimation of emissions from navigation. The methodology uses both installed capacity and fuel consumption as an alternative for the emissions estimates and take into account both the main and auxiliary engines. Carlo Trozzi et al (1999) mentioned emission factors for NOx, SOx, Non-Methane Volatile Organic Compounds (NMVOC), and PM for different engine types/fuel combinations. Spatial analysis of emission estimation is done by Perez et al (2009). The Combination of AIS and GIS data is used for spatial analysis. AIS data will not provide the main and auxiliary engine power, type of fuel used by vessel. AIS only provides the traffic and ship particulars. Trika Pitana et al (2010) highlighted the importance of AIS data and how it plays a decision-making role when it comes to the estimation of emissions.

Stain (2016) has calculated emissions from AIS data through empirical methods. Taking ship particulars into account, estimated resistance needed to propel the ship from the Holtrop-Mennen method, Holtrop-Mennen et al (1982). From resistance calculation, fuel consumption has derived. Lloyd's Register is a classification society and certification award company which maintains the database of ships. Ship data base information, AIS data and GIS data will give vital information about types of ships, engine details, type of fuel and its consumption rate, ship traffic and spatial presence etc. This subsequently leads to the estimation of the emissions and provides a detailed picture of air pollution levels.

IV. AIS DATA ANALYSIS

In this paper, the data obtained from AIS is arranged in user specified format. i.e., based on MMSI number-ship type, gross tonnage, speed and draft are arranged in a tabular format (Table I) for emission calculation. After categorization of data, fuel consumption is calculated for each category of ship. For a simplified analysis, in this paper author has considered only those ships which met ORV Sagar Nidhi when it is in cruising mode. When the ship is in maneuvering or hotelling mode there are always chances of maximizing the error of reportage in emissions due to proximity to land or port area activities.

A. *Emission Calculation From AIS Data*

Emission calculation from AIS data is based on the fuel consumption. Depending on the speed of the ship, Gross Tonnage and type of the fuel used, the required propulsion power is calculated. Main ship characteristics are used for calculating required propulsion power from approximation methods and standard empirical methods. From AIS data main ship characteristics like dead weight, gross tonnage, speed and size of the ship etc., could be derived. Remaining characteristics were found by general ship approximation methods which are available from literature surveys. Fig.5 shows the Fuel consumption. Fig.6-11 shows the fuel consumption for each type of vessels.

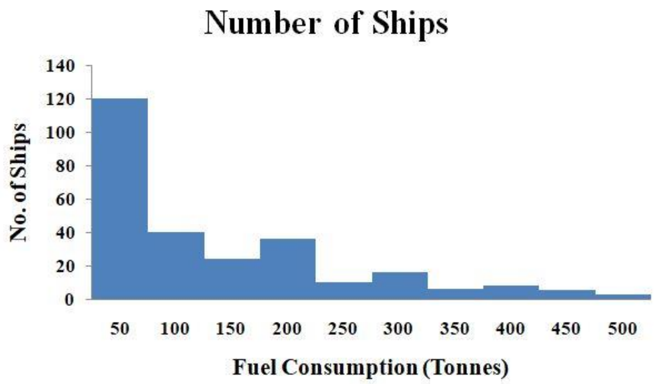

Fig. 5: Fuel consumption of ships

Considering standard methods, empirical data sets and own records of ORV Sagar Nidhi, the author came to a conclusion that calculating fuel consumption based on gross tonnage yields fruitful results. Approximately ORV Sagar Nidhi has encountered three hundred ships in cruising phase.

Table I: Categorised AIS Data Sample:

S.No	MMSI Number	IMO Number	Ship Type	Size (m)	GT (Tonne)	Speed (Kn)
1	370195000	8864189	Asphalt/Bitumen Tanker	104.1 x 15	3800	9
2	419000806	9124691	Asphalt/Bitumen Tanker	69.81 x 11.5	999	8.4
3	351360000	9401867	Bulk Carrier	182.98 x 32.26	32987	12.1
4	373531000	9604770	Bulk Carrier	169.37 x 27.2	32962	11.9
5	565677000	9416032	Chemical/Oil Product Tanker	146.6 x 23.7	11770	14.8
6	351214000	9343998	Chemical/Oil Product Tanker	182.03 x 28.2	25184	11.4
7	256985000	9327803	Container Ship	366. 07 x 51.23	66199	17.9
8	477274400	9467299	Container Ship	150.9 x 18.5	150853	18.5
9	538002321	9172856	Crude oil Tanker	330 x 60.04	15976	11.2
10	355961000	9357365	Crude oil Tanker	274.18 x 50	85462	14
11	419683000	9384485	ORV Sagar Nidhi	103.6 x 18	5050	14

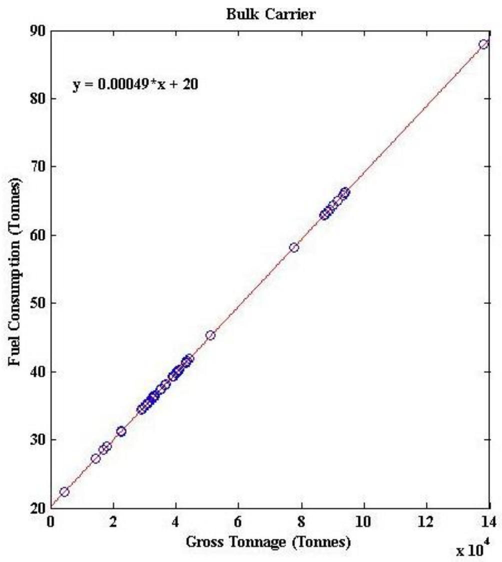

Fig. 6: Bulk Carrier

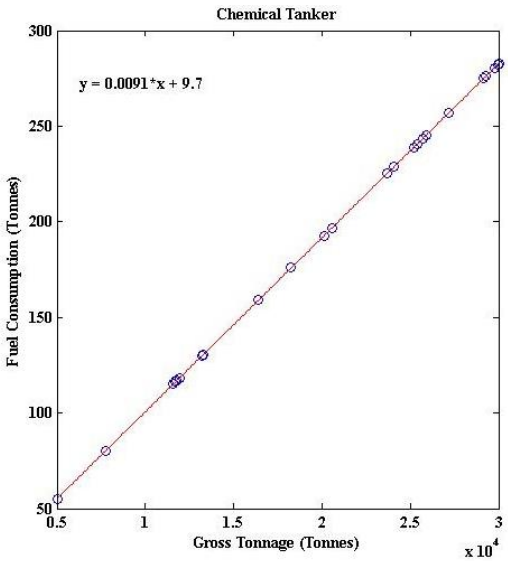

Fig. 7: Chemical Tanker

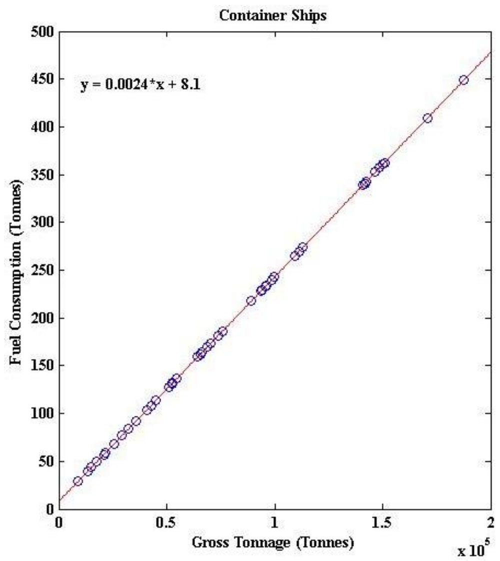

Fig. 8: Container Ships

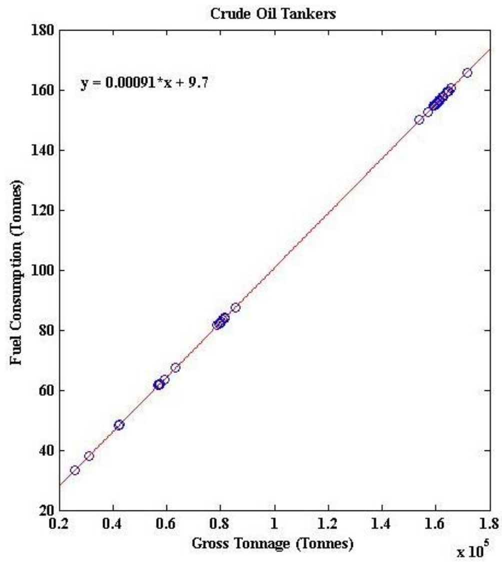

Fig. 9: Crude Oil Tankers

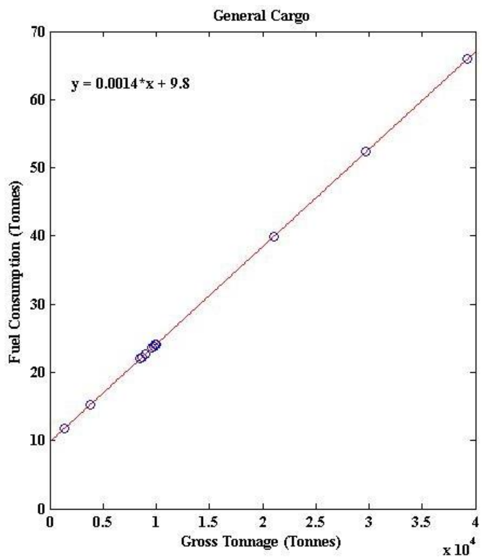

Fig. 10: General Cargo

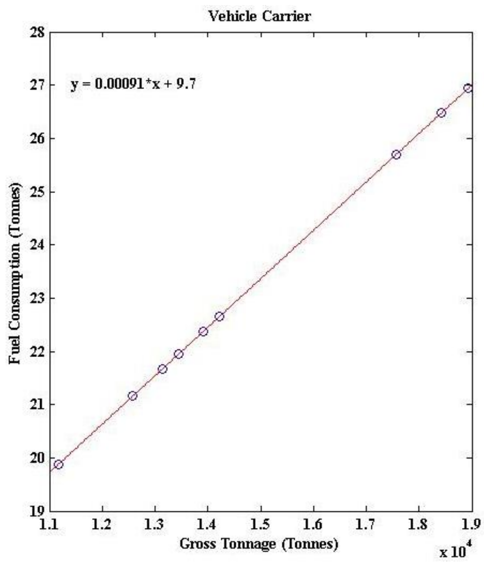

Fig. 11: Vehicle Carrier

Depending on the type of ship, fuel consumption is observed in Tonnes/day.

Table II: Fuel Consumption:

S.No	Type of Ship	Fuel Consumption (Tonnes)
1	Bulk Carrier	20 + 0.00049 x GT
2	Chemical Tanker	9.7 + 0.0091 x GT
3	Container Ship	8.1 + 0.0024 x GT
4	General Cargo Ship	9.8 + 0.0014 x GT
5	Crude oil Tanker	9.7 + 0.0091 x GT
6	Vehicle Carrier	9.7 + 0.0091 x GT

Based on the emission factors and fuel consumption, the emissions are calculated.

$$Emission = Emission\ Factor\ x\ Fuel\ Consumption \qquad (1)$$

Carlo Trozzi et al (2010) proposed emission factors depending on the type of fuel and speed of the ship.

Table III: Emission Factors:

S.No	Pollutant	Emission Factor (Kg/Tonne)
1	NOx	63.1
2	SOx	20 x % of Sin Fuel oil
3	CO	7.4
4	PM	1.5
5	CH_4	0.05
6	CO_2	3206
7	NMVOC	2.33

B. Approximate Power Prediction Method: Holtrop-Mennen Method

AIS data will not provide information about type of fuel used, specific fuel oil consumption, engine type and its rated power. Without knowing all these facts it is not possible to calculate the emissions of ships in empirical method. But AIS data provides ship particulars information. Based on ship particulars, a theoretical method can be developed to calculate the required power propulsion. There are several empirical methods mentioned in literature for power prediction calculations. Most of the empirical methods use hull resistance and total resistance to obtain the propulsion power of a ship. Holtrop-Mennen method is the widely used method in calculating the total resistance of the ship.

Holtrop-Mennen is a method for calculating propulsive power of ships. This is done by using basic hull dimensions. Total ship resistance is divided into component for regression analysis. This was done using an extensive number of models test and trial measures (Holtrop & Mennen, 1982). From Holtrop-Mennen effective power (P_E) and resistance R_T are estimated (Holtrop & Mennen, 1982).

The total resistance of a ship has been sub divided into

$$R_T = (1+K_1)R_F + R_W + R_B + R_{TR} + R_{App} + R_A \qquad (2)$$

Where, R_T is total resistance, $(1+K_1)$ is form factor of bare hull, R_F is friction resistance from the ITTC 1957 line, R_W is wave resistance of bare hull, R_B is wave resistance of the bulbous bow, R_{TR} is additional resistance from the immersed transom, R_{App} is appendage resistance, and R_A is correlation allowance.

Brake power (P_B) from engine is required to calculate fuel consumption.

$$P_B = (R_T x\ V) / (\eta_T\ x\ 0.85) \qquad (3)$$

Where, R_T is total resistance in Newton, V is the speed of the ship in m/s, η_T is the total efficiency and 0.85 is a sea margin. i.e., factor taking into account extra power required because of rough conditions at sea.

Fuel consumption varies depending on ship size and its cruising speed. Emissions are calculated from fuel consumption as mentioned in (1).

$$Fuel\ Consumption = SFC\ x\ T\ x\ P_B \qquad (4)$$

Where SFC is specific fuel consumption in g/kWh i.e., the amount of fuel consumed to produce 1 kWh of energy, T is the time span between AIS messages given by a ship in seconds and P_B is the break power from engine in kW.

SFOC depends upon on engine type, size, load, and year manufactured or years of running condition. Eyring et al (2005) proposed a common SFOC consumption pattern of MDO/HFO based ships depending on ship type.

Table IV: SOFC for different types of Vessels:

S.No	Ship Type	SFOC (g/kWh)
1	Tankers	191-229
2	Containers	194-222
3	General Cargo Vessels	200-230
4	Bulk Carriers	192-202

V. RESULTS

ORV Sagar Nidhi has started its journey from New Mangalore port, reached CIOB for a scientific expedition and returned to Chennai Port for disembarkation. It has encountered variety of ships ranging from container ships, cargo ships, oil tankers, bulk carriers and vehicle carrier (Ro-Ro) etc in the total journey of 3000nm. Algorithm based on GT for Fuel consumption has been tabulated (Table II). Subsequently emissions are calculated using (1). To validate our algorithm which is based on GT and emissions calculations, it has corroborated with the emission data of ORV Sagar Nidhi. Emission data of ORV Sagar Nidhi collected through Testo flue gas analyser.

Results obtained through Gross tonnage algorithm, subsequent emissions based on emission factor and fuel consumption are tabulated in Table V.

Table V : Emission Calculation Based on GT Algorithm:

S.No	ORV Sagar Nidhi	Tonnes/Day
1	Fuel Consumption	14.308

2	NOx	0.902
3	SOx	0.286
4	CO	0.105
5	PM	0.021
6	CO2	45.871
7	CH4	0.000715
8	NMVOC	0.0333

Testo flue gas analyser measures ambient and exhaust temperatures along with exhaust gases NO2, SO2, CO_2, CO, NO, SO, and PM etc. NMVOCs are measured by using other flue gas analyser. The results are tabulated in Table VI. These flue gas analyser values are used for validation of emission calculations deduced from GT algorithm. During the voyage of ORV Sagar Nidhi, the following emissions are observed from its exhaust.

Table VI: Emissions Measured by Testo Flue Gas Analyser:

S.No	ORV Sagar Nidhi	Tonnes/Day
1	NOx	0.878
2	SOx	0.278
3	CO	0.097
4	PM	0.019
5	CO2	41.275
6	CH4	0.000658
7	NMVOC	0.03

Table VII: Calculated Emission Values and Measured Values:

S. No	Emissions	Calculated	Measured	Deviation (%)
1	NOx	0.902	0.878	2.733
2	SOx	0.286	0.278	2.877
3	CO	0.105	0.097	8.24
4	PM	0.021	0.019	10.52
5	CO2	45.871	41.275	11.135
6	CH4	0.000715	0.000658	8.66
7	NMVOC	0.0333	0.03	10

The deviation from calculated and measured is tabulated in Table VII. By observing that deviation, it can be concluded that the derived algorithm based on GT for calculation of emission can be used to assess the emissions primarily. Ship type and its GT values are derived from AIS data and these values can be incorporated to calculate the emission. Hence this corroborated algorithm which validated using actual values from a flue gas analyser can be used to calculate the emissions.

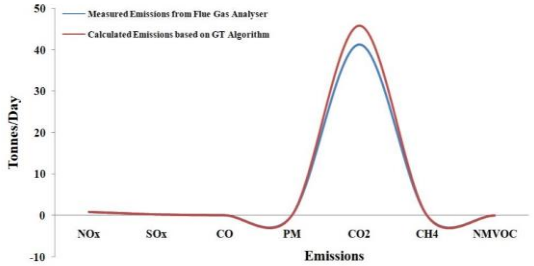

Fig. 12: Calculated emission values vs. Measured values

VI. CONCLUSION

This paper explained the importance of AIS data to estimate NOx, SOx, CO, PM, CO_2, CH_4 and NMVOC emissions from shipping activities. This exhaust estimation results could be used for evaluating the impact of marine traffic on air quality and global warming.

In this study author considered a particular voyage and estimated the emissions. Continuous availability of AIS data, port statistics and emission inventories have helped to give a robust mechanism to calculate the emissions over a region. These mechanisms are used to draw an emission map on a global level.

An in depth analysis, sophisticated calculations and accurate data availability are important in emission calculation. Emission calculation in the coastal region, the spatial distribution of these emissions from shipping gives the clear understandings of the contribution of GHG from shipping activities. A database of emissions from coastal, inland and international shipping should be maintained. This database can be used to develop the retrofit technology for age old ships and contemporary innovative engine designs for emission reduction from shipping in the future course.

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