Greenhouse Gas Emission due to Fuel Consumption in Maritime Transportation

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Abstract
Container shipping is an important part of transportation. It also plays a vital role in global trade. The most important cost item for shipping liners consists of bunker consumption. In the study, we analysed bunker consumption of a 3000 TEU container ship. Ship's operation time in the ports were ignored. Also the ship's weight (containing its cargo) is neglected. The only weight is the weight of the fuel in the tank which is represented as ∇ and there was no breakdowns during its voyage. In addition, carbon dioxide emission, sulfur oxide emission and particulate matter (PM) emission, which directly affect human health, during the voyage of the ship were examined and this amount was calculated.

Keywords: Maritime Transportation, GHG Emission, Fuel Consumption

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1.Introduction

Experimental data show that fuel consumption varies geometrically with increasing speed. For example, at some speeds, when you increase your ship's speed by 30%, your consumption is twice as fast as the original speed. While the vessels are anchored in the port, roughly a quarter of the fuel consumption in the sea is produced by fuel fuels [1]

$$F(v) = \lambda . v^3 . \nabla^{\frac{2}{3}}$$

Where ∇ is the weight of the ship and λ is constant which all engines have. $\lambda = 1/120{,}000$ for diesel engine.

In this study, it will be accepted that the ship speed is constant at economic speed (V_{eco}) throughout the journey. However, port time of the ship will be neglected.
When the fuel consumption function in the article published by Barras in 2004 is examined, it is seen that the instant fuel consumption of the ship is neglected. Therefore, it can be said that the most convenient formula is;

$$\nabla(0) - \left(\sqrt[3]{\nabla(0)} - \frac{\lambda . v^3 . t}{3}\right)^3$$

Where $\nabla(0)$ is the weight of the ship at the start point and $\left(\sqrt[3]{\nabla(0)} - \frac{\lambda . v^3 . t}{3}\right)^3$ is the weight of the ship at any time ***t***. (Mersin et al. 2017)

Table 1. Distance between ports

Distance (mil)	Pire	İstanbul	Bingazi
Pire	0	352	400
İstanbul	352	0	711
Bingazi	400	711	0

The distance between ports is given in Table 1. Now fuel consumption and SO_X and PM emissions of a container ship traveling on the Istanbul-Piraeus-Benghazi route can be calculated.

Now, we can calculate the total fuel consumption and flue gaz emissions of the 3000 TEU container ship, which makes the Istanbul-Piraeus-Benghazi voyage at a speed of 20 kt and has a fuel of 15,000 tons.

Table 2. The Voyage Times Between Ports (Days)

Days	Pire	İstanbul	Bingazi
Pire	0	0,73	0,83
İstanbul	0,73	0	1,48
Bingazi	0,83	1,48	0

Container demands in ports are neglected for convenience. Thus the load weight of the ship is fixed. Therefore, weight of fuel is the only variable that represents the weight of the ship. If we calculate each leg of the ship's voyage seperately, we can find the total consumption..

Istanbul-Piraeus leg;

$$C(0{,}73) = \nabla(0) - \left[\sqrt[3]{\nabla(0)} - \frac{20^3 \times 0{,}73}{3 \times 120{,}000}\right]^3 = 29.58$$

Piraeus-Benghazi leg;

$$C(0{,}83) = 14{,}970.42 - \left[\sqrt[3]{14{,}970.42} - \frac{20^3 \times 0{,}83}{3 \times 120{,}000}\right]^3 = 33.59$$

Benghazi-Istanbul Leg:

$$C(1{,}48) = 14{,}934.83 - \left[\sqrt[3]{14{,}934.83} - \frac{20^3 \times 1{,}48}{3 \times 120{,}000}\right]^3 = 59.76$$

So, the total consumption of the ship is 59.76+33.59+29.58=122.93 tonnes.

In parallel with the total fuel consumption, GHG is also relased into the atmosphere. As it is known, as of January 1, 2020, the sulfur rate in fuels were reduced to 0.5%. Therefore, when calculating the SO_X emission value, we have to calculate according to this ratio. Calculation factors are given in table 3.

Table 3. Emission factors of pollutant gases

Pollutant	Emission Factor(kg/tonne)
PM	1.1
CO_2	3200
SO_X	20×S

Where 20×S means fuel emits 20 times SO_X of sulfur in its content. According to this table, PM, CO2 and SOX emissions can be calculated by multiplying emission factor of pollutant and fuel consumption. Results of these calculations are givenin table 4.

Table 4. Some GHG Emissions of the ship

Pollutant	Emission (kg)
PM	1.1×122.93=135.223 kg
CO_2	3200×122.93=393,376 kg
SO_X	20×0.005×122.93=12.293 kg

Clearly, CO_2 takes the biggest part of these emissions with 393 tonnes. Nevertheless, the total weight of the ship is 15,000 tonnes. So, $\frac{393}{15,000}$=0.0262 tonnes of CO_2 is emmited for transporting 1 tonne of cargo. This value is lower than lots of transportation modes.

2.GHG Gases and Effects

With the development of the industry, the amount of gases released into the atmosphere also increases. Particularly, fossil fuels directly affects the amount of CO_2 in the atmosphere. These fuels, which are the most common fuel type in the world, can be given as an example of CO_2 emissions originating from human. Especially, CO_2 and other gases emitted into the air by combustion of fuels used in transportation cause global warming and health problems such as respiratory diseases, cardiovascular disease and lung cancer (Natural Resources Defense Council-NRDC, 2004).

Among these emission impurities, nitrogen oxides (NO_X), sülfür oxides (SO_X) and particulate matter (PM) have environmental effect in coastal areas where people live, while carbon dioxide (CO_2) and carbon monoxide (CO) hava a harmful effect on the global environment. According to the projection made by the Organization for Economic Cooperation and Development in 2012, early deaths due to PM will increase more than twice by 2050 and reach 3,6 million per year. It is stated that the countries where these deaths will be the most common are China and India. It is estimated that more than 500,000 people die annually due to $PM_{2.5}$ (Nel, 2005; Wang et al, 2013).

3.Literature Review

Alderton (1981) published a formula for fuel consumption of a ship. In this formula, the weight of the ship was neglected. Then Ronen (1982) and Chrzanowski (1989) used this formula in their work. Barras (2004) published a formula for fuel consumption, which did not neglect the weight of the ship. Corbett et al (2010) has developed the profit maximization function to calculate the economically effective speed by reducing the amount of fuel spent and reduce the amount of carbon dioxide. Fagherholt et al (2010) modelled to find the optimal speed on a specific route with a time window in which services must start at each port and solution is based on the shortest path problem on a directed acylic graph. Carlou (2011) calculated effects of relation of CO_2 emisison and reducing of speed which included various factors such as size, speed number of days at sea, seaport, fuel consumption for container vessels [5]. Lindstad et al (2011) presented findings that low speed in shipping reduces CO_2 emissions and showed ways in which shipping firms can be persuaded by certain rules to reduce the speed of ships in the competitive world. Qi and Song (2012), by emphasizing port uncertainties in liner shipping, aimed to minimize the fuel consumption and emissions of a ship by optimizing vessel schedule. Christiansen et al (2012) compiled to 131 articles which are published journals about subject of ship routing and scheduling between 2002-2012. They presented methods which used in their study [6]. Kim et al (2012) determined amount of fuel and optimum vessel speed for a specific vessel route. The study was solved the problem by using epsilon-optimal algorithm [7]. Gkonis and Psaraftis (2013) by referring to the previous studies assuming a constant speed in their analyzes, conducted a study aiming to obtain the optimal speed and accordingly emission rates in an environment where the companies determined their speed according to more than one parameter such as bunker price, freight rates. Notteboom and Cariou (2013) researched effects of slow speed applications. Also they analyzed fuel consumption and BAF which paid by shippers [8]. Khor et al (2013) set up a software to optimize speed of ultra container vessels. They found out optimum speed as 19.5 knot [9]. Fagerholt et al (2010) solved the optimal speed on a specific route problem [10]. Mersin et al found a new formula which did not neglect load of cargo and time. Tokuslu (2020) used Energy Efficiency Design Index (EEDI) to analyse the performance of a container ship.

4.Conclusions

Altough sea transportation is the mode of transportation that causes minimum flue gas emission per piece, it also puts human health risk at the such level. Especially SO_X and PM oscillations cause cancer, heart diseases, respiratory diseases and infant deaths. Studies are carried out to reduce these effects. Using marine diesel instead of HFO on ships, using wind-assisted cruising an deven biodiesel will help to reduce sulfur oxide and particulate matter emissions

Since the fuels used in ships are fossil fuel based, they cause emission of many chemicals together with combustion. CO, NO_X, SO_X, VOC, PM, CO_2 are the most well-known of these. In this study we examined the CO_2 emission which effects globallyand SOX, PM emissions that directly affect human health. Especially as Sulfur dioxide causes acid rain which causes irritation to the eyes, mucous membranes, skin and respiratory tract. In addition, high exposure can lead to bronchospasm, pulmonary edema, bronchial inflammation, laryngeal spasm. (https://www.toraks.org.tr/news.aspx?detail=3346)

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