Assesment of operational energy efficiency of seagoing vessel

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Abstract. *The problem of climate change imposes significant restrictions on the development of maritime shipping. First of all, this concerns the mandatory planning and calculation of the operational energy efficiency factor on the voyage in order to reduce CO_2 emissions. With the introduction of a ban on high-sulfur marine fuel, from January 2020. the situation has worsened even more, which requires shipowners to give up part of the profits in favor of meeting the limitations on the energy efficiency of the vessel. This paper investigates the influence of the transport operation of the vessel, from the point of view of changing the speed at the crossing, on the operational coefficient of the energy efficiency of the sea vessel.*

Keywords: *sea vessel, CO_2 emissions, energy efficiency, operating speed.*

Climate change is considered today as the most serious threat (from the standpoint of risks restraining economic growth) for all states. With the adoption of the Paris Climate Agreement on December 12, 2015, all parties agreed on a common set of goals to tackle the problems associated with global warming. These goals include the long-term goal of keeping the global average temperature rise below 2°C above pre-industrial levels and continuing efforts to limit temperature rises to 1.5°C above pre-industrial levels [1]. Another important goal is the ability of countries to adapt to the negative impacts of climate change. Of course, both climate change itself and the proposed energy policy in the near future will impose significant restrictions on global economic growth and foreign trade. Global socio-economic trends, population growth, income growth and increased urbanization inevitably lead to an increase in demand for electricity, transport and other energy-intensive services. The unprecedented growth of the global economy over the past century has led to an increase in the use of commodities and associated greenhouse gas emissions. Higher greenhouse gas emissions, in turn, accelerated climate change, which negatively affected the production of goods.

Today, there is an established opinion in the scientific community that global warming, as well as extreme and unfavorable climate changes, are caused by an increase in the concentration of greenhouse gases in the Earth's atmosphere. In particular, the concentration of CO_2 in the atmosphere has increased by 31 percent since the beginning of industrialization (i.e. since the second half of the twentieth century), and CO_2 emissions account for the largest share in greenhouse gas emissions. At the same time, the largest emissions come from the burning of oil, natural gas and their derivatives. Global emissions from human activities by sectors of the economy are presented in table 1.

Table 1.

Greenhouse gas emissions by economic sector [1]

№	**Emission source**	**interest**
1	Electricity and heat production	25
2	Land use	24
3	Industry	21
4	Transport	14
5	Other energy	10
6	Buildings and constructions	6

The climate change debate revolves around finding ways to reduce human-related CO_2 emissions. Under these conditions, it is estimated that the coronavirus pandemic could save many lives by improving urban air quality [2]. Due to the pandemic, a large number of enterprises are forced to change the logistics of supplies, which in the short term is associated with a decrease in foreign trade in global markets. However, since 1990, the total radiative forcing causing global warming has increased by 43%, with CO_2 accounting for about 80 percent of the increase [3].

Maritime transport is at the heart of global supply chains and economic interdependence with shipping and ports, which are estimated to account for over 80 percent of global merchandise trade by volume and over 70 percent of the total value of goods. According to IMO estimates, greenhouse gas emissions from ships in 2012 accounted for about 2.2 percent of anthropogenic carbon dioxide emissions in the world [4]. Today, emissions from international shipping are already about 4 percent, and by 2050 their volume may be (according to forecasts) more than 50 percent [4]. Experts estimate that a range of technical and operational measures can improve the energy efficiency of ships and reduce greenhouse gas emissions by 75 percent.

After the entry into force of the relevant amendments to Annex VI of the International Convention MARPOL 78 on the Prevention of Pollution from Ships, energy efficiency measures have become legally binding in the maritime industry, for ships of 400 gross tonnage or more, from

1 January 2013. The ship must have an Energy Efficiency Management Plan (SEEMP), which may be part of the ship's safety management system or ISO 14001 environmental management system. This plan should aim to reduce CO_2 emissions from ships through better fuel efficiency and voyage planning. For this, the EEOI operational energy efficiency index is calculated and compared with the EEDI constructive energy efficiency index for new ships. The indices have the same physical meaning - the ratio of CO_2 produced during the voyage (voyages) to the amount of the vessel's transport work for a certain period:

$$EEOI = (MTEP_f \times CF) / A_f, \qquad (1)$$

Where MTEPf – is the factual fuel consumption in operation by all consumers, t; A_f – the actual transport operation of the vessel in t x miles; CF – dimensionless conversion factor of fuel consumption to CO_2 emissions.

Of course, of the greatest interest for shipping is the issue of determining the factors affecting the change in the operational energy efficiency index.

To determine the main operational parameters affecting the operational energy efficiency index, we carried out field experiments at the trans-Pacific crossing of the RO-RO vessel – "GALAXY ACE" with a gross tonnage of 59.583 reg.t. Operational measures have been identified that can improve the energy efficiency of the vessel by reducing CO2 emissions at the sea crossing without equipment modification (see fig. 1) by managing transport operations and vessel speed while planning voyages efficiently.

Total Fuel consumption and CO_2 emissions

Parameter	Value
Total fuel consumption	2322.65 m tonnes
Fuel consumptions assigned to on laden	2269.30 m tonnes
Total CO_2 emissions	7291.9579 m tonnes
CO_2 emissions from all voyages between ports under a MS jurisdiction	1940.88 m tonnes
CO_2 emissions from all voyages which departed from ports under a MS jurisdiction	3000.12 m tonnes
CO_2 emissions from all voyages to ports under a MS jurisdiction	2179.92 m tonnes
CO_2 emissions which occurred within ports under a MS jurisdiction at berth	171.04 m tonnes
CO_2 emissions assigned to on laden	7120.9178 m tonnes

DISTANCE TRAVELLED, TIME SPENT AT SEA AND TRANSPORT WORK

Parameter	Value
Total distance travelled	23177 n miles
Regular navigation	23177 n miles
Total time spent at sea	1554.82 hours
Regular navigation	1554.82 hours
At anchorage	0 hours
Total transport work (mass)	96553994 m tonnes · n miles

ENERGY EFFICIENCY

Parameter	Value
Fuel consumption per distance	100.2136 kg / n mile
Fuel consumption per transport work (mass)	24.0555 g / m tonnes · n miles
Fuel consumption per distance on laden voyages	Missing source values! kg / n mile
Fuel consumption per transport work (mass) on laden voyages	23.5029 g / m tonnes · n miles
CO_2 emissions per distance	314.6204 kg CO_2 / n mile
CO_2 emissions per transport work (mass)	75.5221 g CO_2 / m tonnes · n miles
CO_2 emissions per distance on laden voyages	Missing source values! kg CO_2 / n mile
CO_2 emissions per transport work (mass) on laden voyages	73.7506 g CO_2 / m tonnes · n miles

Figure 1. Transport work and ship energy efficiency

The volume of fuel consumption at the crossing was accurately described by the formula:

$$Q = Q_T \, (V/V_T)^3, \qquad (2)$$

Where: Q - actual fuel consumption in t/day.;

V - operating speed, knots (see fig. 2);

Q_T - fuel consumption corresponding to the technical speed in t/day.;

V_T - technical speed, knots.

It can be seen from formula (2) that for marine diesel engines the level of fuel consumption depends significantly on speed. For example, a decrease in operating speed from 16 to 11 knots leads to a 2/3 saving in fuel consumption per day. When the vessel's speed decreases, one should take into account the fact that incomplete combustion of fuel and an increase in the toxicity of exhaust gases may occur. With an increase in the load on the main engine and the speed of the vessel, the concentration of harmful substances in the exhaust gases decreases. Therefore, the specific amount of exhaust gases, referred to power, mainly depends on the operating mode of the engine and its type and has the character of a hyperbolic dependence.

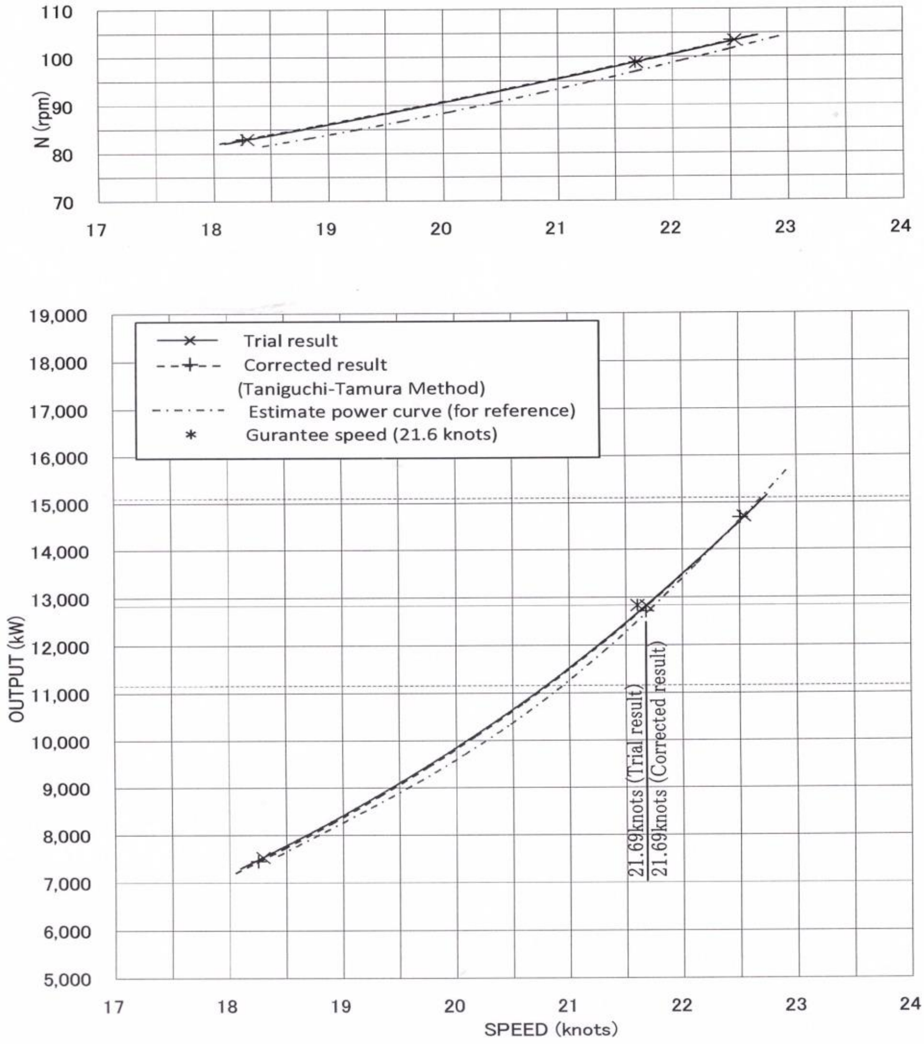

Figure 2. Specification of the vessel

Calculations of the operational coefficient of the ship's energy efficiency according to the formula (1) showed quite good results (see fig. 1).

For the purpose of analyzing the significant factors affecting the operational energy efficiency of a sea vessel, we transform formula (1) using the concept of material flow – M_p (tons of cargo per day), we get the following expression:

$$EEOI = CF \times [(Q \times V) / (M_p \times T)], \quad (3)$$

where: T- flight time per day

Conclusions

From (3) it can be seen that with an increase in the range and a decrease in speed, the energy efficiency of a sea vessel increases. Field experiments have shown that reducing the speed alone can increase the operational energy efficiency of a marine vessel by up to 34 percent. Such decisions are usually made when transporting large consignments of relatively inexpensive bulk cargo (for bulk carriers and tankers), or when the price of marine bunker fuel for container ships rises, in order not to decommission ships. Additional factors that improve the operational energy efficiency of a marine vessel in operation can be optimization of the route of passage and the removal of the vessel for departure.

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