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Alternative solutions for marine fuel's composition towards Marine Strategy Directive performance

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Abstract. In April 2018, the IMO adopted an ambitious GHG emissions reduction strategy for shipping. It will shape the future fleet decarbonisation pathway and helps to choose alternative fuels and technologies. Methanol as marine fuel leads to drastically reducing sulphur and PM compared to conventional marine fuel. Meanwhile, biodiesel, as sustainable energy source, is characterized by high cetane index, low toxicity, and good biodegradation. Methanol-biodiesel-diesel blends require only limited modification to engines and fuel systems. For this reason, methanol and biodiesel may be well suited partly substitute oil-based fuels in the existing ship fleet. In order to replace the larger portion of fossil compound in marine fuel by components from renewable sources, it is necessary to develop multi-component blends. However, an increase in the proportion of components in a blend could be critical for the final properties of the blend and requires detailed research. The physical-chemical properties of the methanol (up to 30 %), biodiesel (up to 10 %) and diesel components as well as their mixtures have been analysed. It has been found that considering to ISO 8217:2012 standard and environmental requirements a blend with 10 % methanol and 10 % biodiesel is the most suitable alternative for marine applications.

1 Introduction

Baltic sea is the artery of exclusive traffic shipping intensity when compared to other seas; therefore, navigation of the Baltic has a multi-faceted effect on the environment. According to data from the Automatic Identification System (AIS), the Baltic Sea is

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entered/shipped out by more than 60 000 vessels annually, and at any moment about 2000 registered large ships are moving around in the Baltic Sea. Intensive shipping activities contribute significantly to the air pollution in the Baltic Sea region, which in 2006 has been assigned as Sulphur Emission Control Area (SECA). Short-term emission control areas NO_x and SO_x reductions are the most pressing issues as well as long-term GHGs and PM emissions limits will provide further environmental challenges. The ever-increasing environmental requirements force shipowners to look at alternative fuels as a way of complying with the new limits.

The majority of ships use diesel engine which fuel quality is lower than the quality of land-based fuel. The using of methanol as marine fuel leads to reducing (up to 35 %) of sulphur and particle emissions compared to conventional marine diesel. Moreover, when methanol is producing from renewable sources (biomethane, synthesis gas, wood and its waste etc.) it leads to lower CO_2 emissions over the entire fuel lifecycle [1]. Furthermore, it was found that engine performance is most effective when using methanol compared to MDO or MGO [2]. The combustion of low-sulphur fuel in diesel engine has soot content of $0.1 \text{ g}\cdot\text{kWh}^{-1}$ however methanol – only $0.01 \text{ g}\cdot\text{kWh}^{-1}$. Methanol has higher burning rate, heat of evaporation ($1178 \text{ kJ}\cdot\text{kg}^{-1}$) as well as oxygen content (49.93%), and lower carbon content (37.50%) [3].

The main disadvantage of pure methanol is calorific value which is almost two times lower than diesel fuel. For this reason, methanol fuel tanks should be doubled to provide the same calorific values as traditional diesel fuel. The safety requirements for methanol are higher comparing with different types marine fuels, as its flash point is very low (IGF code).

One of the alternatives for using methanol is to use methanol blends with other components such as diesel and / or biodiesel [4]. The use of methanol blends in marine applications is closely linked to the objectives of the EU Strategy for the Baltic Sea Region, one of which is towards a maritime activities carried out in an environmentally friendly way, i.e. reduce air pollution from ships (Marine Strategy Framework Directive 2008/56/EB). Additionally, the use of methanol blends for marine application can also contribute to the priority areas identified by the HELCOM Commission, such as the development of sustainable shipping and environment of the Baltic Sea region.

The aim of this research is to investigate the use of methanol-biodiesel-diesel blends in diesel engines for marine application.

2 Materials and methods

The research object of this study is methanol-biodiesel-diesel blends composition that has been chosen after in-depth analysis of the state-of-the-art in target area. 12 blends with different methanol, biodiesel, and diesel ratios were studied. More than 200 analyses have been done. Methanol content varies from 0 to 30 % (volume basis), and biodiesel from 7 to 10 % (volume basis). In order to produce homogeneous blends 1.0 % (volume basis) of dodecanol and 0.5 % (volume basis) of 2-ethylhexyl nitrate was added to each blend [5, 6].

The investigated physical and chemical properties of single blends components and the standards on which the analysis was based are presented in Table 1.

Table 1. Physical and chemical properties of methanol, biodiesel, and diesel

Parameter	ISO 8217:2017	Methanol	Biodiesel (source: rapeseed oil)	Diesel	Standard
Density at 15°C, kg·m ⁻³	900	797	877	843	LST EN ISO 3675:1999
Kinematic viscosity, m ² ·s ⁻¹	2–11	1.01	4.30	2.80	LST EN ISO 3104:2000
Calorific value, MJ·kg ⁻¹	-	23	40	-	DIN 51900-3:2000
Flash point, °C	60	11	120	62	LST EN ISO 2719:2016
Distillation	-	-	-	250°C – 33%; 350°C – 95%	ASTM D86-96
Cetane index	35	5	50	51	ASTM D976-06(16)
Pour point, °C	0	Minus 98	Minus 12	Minus 19	LST ISO 3016:1999

The research results were compared with ISO 8217:2012 standard “Petroleum Products – Fuels (class F) – Specifications of Marine Fuels” according to the IMO requirements for marine fuels.

3 Results

In this study the analysis of the blend’s density, kinematic viscosity, calorific values pour point and flashpoint temperatures, distillation, as well as cetane index were performed. The analysis results are shown in Table 2.

Table 2. Results of methanol-biodiesel-diesel blends analysis

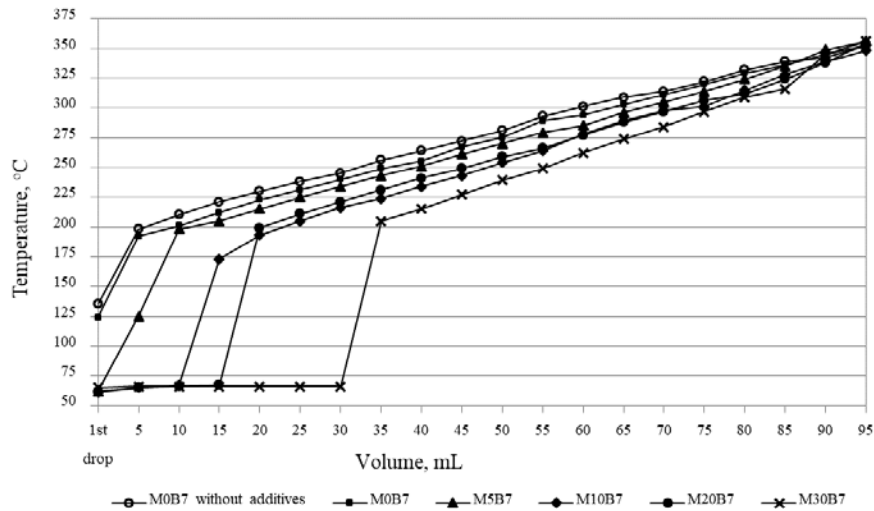
Blends	Density	Kinematic viscosity	Calorific Value	Pour point	Flash point	Cetane index
	kg·m ⁻³	mm ² ·s ⁻¹	MJ·kg ⁻¹	°C	°C	-
B7M0*	839±4.20	3.04±0.19	44.95±0.02	-4±1.0	63.2±3	53.72±2
B7M0	840±4.20	3.15±0.20	44.83±0.02	-4±1.0	64.6±3	52.22±2
B7M5	840±4.20	2.94±0.15	45.04±0.02	-12±1.0	39.6±3	51.19±2
B7M10	838±4.19	2.90±0.17	44.75±0.02	-13±1.0	22.7±3	48.19±2
B7M20	833±4.17	2.69±0.28	40.92±0.02	-13±1.0	21.7±3	51.14±2
B7M30	830±4.15	2.48±0.09	39.42±0.02	-11±1.0	20.7±3	46.93±2
B10M0*	845±4.23	2.80±0.15	45.36±0.02	-3±1.0	62.1±3	51.13±2
B10M0	847±4.24	2.95±0.21	45.03±0.02	-3±1.0	67.6±3	50.27±2
B10M5	843±4.22	2.81±0.28	44.89±0.02	-10±1.0	40.6±3	50.00±2
B10M10	840±4.20	2.65±0.30	43.32±0.02	-12±1.0	40.4±3	49.66±2
B10M20	835±4.18	2.32±0.29	39.89±0.02	-14±1.0	22.7±3	48.72±2
B10M30	832±4.16	2.05±0.18	38.12±0.02	-10±1.0	20.7±3	44.73±2

* - blends without additives

It was investigated that the lowest density value has blend of 30% methanol and 7% biodiesel; compared to the same biodiesel blend without methanol, the density decreased by 4%, to 830 kg·m⁻³. However, the highest density has the blend without

methanol and 10% (volume basis) of biodiesel – $847 \text{ kg}\cdot\text{m}^{-3}$. Nevertheless, same trends can be widely observed in other research studies [7–10].

A



B

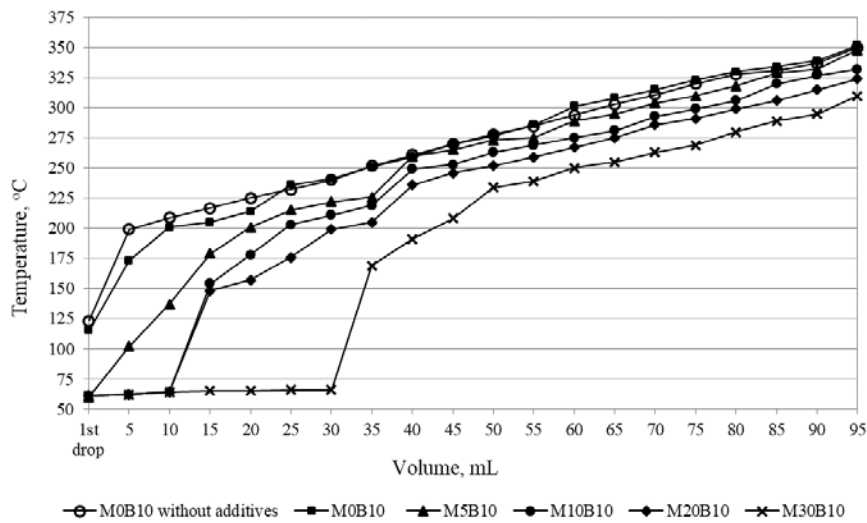


Fig. 1. Results of the test of the distillation of methanol-biodiesel-diesel blends:

A: biodiesel content – 7 % (volume basis); B: 10 % (volume basis)

According to the ISO 8217: 2017 standard, the maximum MDO density should be up to $900 \text{ kg}\cdot\text{m}^{-3}$. Hereby, the density results are in line with the standard requirements.

It was analysed that kinematic viscosity of the blends with 7 % (volume basis) biodiesel varies from 2.48 to $3.15 \text{ mm}^2\cdot\text{s}^{-1}$ and from 2.05 to $2.95 \text{ mm}^2\cdot\text{s}^{-1}$ of the blends with 10 % (volume basis) biodiesel. An [8] and [10] obtained similar results.

According to the ISO 8217: 2017 standard, the kinematic viscosity of marine diesel must be between $2 \text{ mm}^2 \cdot \text{s}^{-1}$ and $11 \text{ mm}^2 \cdot \text{s}^{-1}$. Hereby, the results of studied blends fall within these limits.

Calorific value of the blend with 7 % biodiesel (volume basis) is higher than blends with 10 % (volume basis) and decreased 12 % by increasing methanol up to 30 % (volume basis).

It is important to mention, that all analysed blends pour point temperatures are in line with the standard.

It was investigated that higher biodiesel content in the blend increases the flash point of the blends, however methanol adding decrease the flash point of the blends and they become out of specification (ISO 8217:2017). Moreover, blends with 5 and 10 % (volume basis) methanol homogenized, their flash point remained higher compared to M20–M30 blends. In order to avoid inconsistencies with this standard, flash-point additives must be used, or new standards should be developed for the alternatives low flash point fuels.

Methanol-biodiesel-diesel blends distillation results are presented in Figure 1. It can be seen that methanol-free blends have higher boiling point. Moreover, B7M0 blends without additives and B7M0 with additives began to condense at 135 and 124 °C, respectively. After adding 5 % (volume basis) methanol in a blend, it starts to boil at 62 °C and fluctuates in a small range, increasing the methanol content up to 30 % (volume basis).

Furthermore, it was found that increasing the amount of methanol up to 30 % (volume basis) in the blends decreases its cetane index up to 13%.

4 Discussion

It was investigated that after increasing the amount of biodiesel part in methanol-biodiesel-diesel blend from 7 to 10 % (volume basis) the density of the blends increasing up to 1 %, gross calorific value – 1 %, flash point – 4 %, kinematic viscosity – 7 %. Moreover, it is noticed that biodiesel decreasing pour point temperature of the blends by 2 °C and reducing cetane index by 5 %.

Furthermore, it was found that by increasing amount of methanol in blend with 7 % (volume basis) and biodiesel from 5 to 30 % (volume basis), density decreasing 1 %, gross calorific value by – 12 %, kinematic viscosity – 21 %, cetane index by 10 % as well as pour point temperature increasing by 7 °C.

However, by increasing amount of methanol in blends with 10 % (volume) and biodiesel from 5 to 30 % (volume basis), density decreasing 2 %, gross calorific value by – 15 %, kinematic viscosity – 30 %, cetane index by 11 % as well as pour point temperature increasing by 7 °C.

5 Conclusion

It has been found that methanol-biodiesel-diesel blend with 10% (volume basis) of methanol and 10% (volume basis) of biodiesel with 1 % (volume basis) dodecanol and 0.5 % (volume basis) 2-ethylhexyl nitrate is very close to the ISO 8217:2017 standard and allow to replace up to 20% of fossil part of marine diesel fuel. This is in good agreement with the methods and results presented in [11-13].

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