

Investigating “De Minimis” Level of Fatty Acid Methyl Esters (FAME) in Distillate Marine Gas Oil

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ABSTRACT

According to the existing maritime regulation, the marine diesel equipment will be necessary to operate with low sulfur marine fuels. Low Sulfur Middle Gas Oils (MGOs) often have a viscosity that is lower than that of Heavy Fuel Oil (HFO). The problems in diesel engines are mainly related to high pressure fuel pumps that depend on the fuel oil for their lubrication. A solution to that problem probably will be the addition of Fatty Acid Methyl Esters (FAME) as an additive to the fuel. On the other hand, for the purposes of International Standard ISO 8217:2012 in the case of distillate fuels it is recommended that “de minimis” level of FAME is recommended. “De minimis” level is determined approximately as the 0.1% volume of the fuel.

In this study, Distillate Marine Diesel Oil with good lubricity performance was used blended with FAME fuel, according to national and European Standard (ELOT EN 14214), was used as an additive. The FAME was stored for three months period in a plastic container. Then mixture with concentrations of 0.5%, 1.0%, 2.0%, 3.0%, 4.0% and 5.0% by volume were used.

The obtained results shown that all the mixtures are within the specification limits but the tribological measurements, which were carried out with an applied load of 600 g using the High Frequency Reciprocating Rig (HFRR) with test duration for each test 150 min., revealed an increased wear. This happened because after the storage period the water content of the FAME increased significant.

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INTRODUCTION

Shipping is the most fuel-efficient mode of transportation; when the international maritime transport emissions account for $\pm 3\%$ of global Carbon Dioxide (CO_2) emissions. In this industry fuels represent a significant part of seaborne transportation costs [1]. To reduce emissions from ships, various international regulations and Emission Control Areas (ECA) have been in force since 2005 [2]. Recently, new and stricter fuel sulfur content regulations promulgated by California and the EU have been developed and implemented. The Californian Air Resource Board (CARB) has since 1 July 2009 enforced the use of diesel oils (Middle

Distillate Oil - MDO) or gas oils (Middle Gas Oil - MGO) in Californian waters. In addition, when in berth in European Union (EU) ports, vessels must, as of 1 January 2010, use marine fuels with a sulfur content not exceeding 0.1% by mass.

The International Maritime Organization (IMO) pressures to implement policies that will lead to reduction in emissions of greenhouse gases from shipping [3, 4]. The Ship Energy Efficiency Management Plan (SEEMP), which were adopted by the IMO in July 2011, trying to reduce greenhouse gas emissions through the reduction of fuel consumption. Additionally, the European Commission (EC) issues a

guidance document called Whitepaper Roadmap to a Single European Transport Area in 2011. In this document the European Commission stresses that the carbon dioxide (CO₂) emissions from maritime transport should be reduced with 40% in 2050 compared to 2005 levels in the European Union [5].

Regulations which have been set by International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI limit Sulfur Oxide (SO_x) emissions from shipping. The global sulfur cap is 3.50% from January 1st 2012, and will be 0.50% to 2020 or 2025 depending of the conducted feasibility study [1]. In Sulfur Emission Control Area (SECA) the same cap is 1.00% from July 1st 2010, and will be 0.10% from the January 1st 2015. On the other hand in U.S.A and specifically in California the Ocean Going Vessels (OGV) within the California coastline must use MGO (DMA) or MDO [6, 7] with maximum 0.5% sulfur on the auxiliary and main engines plus auxiliary boilers from 1st of July 2009. From August 2012 the sulfur content of DMA is maximum 1.0%. The perspective is that from January 1st 2014, the maximum sulfur content for MGO/MDO fuels will be 0.1% [1].

The use of alternative fuels such as biofuels offers an additional option to reduce CO₂ emissions [1]. Two promising renewable alternatives to distillate fuels and Liquefied Natural Gas (LNG) are FAME known as biodiesel and biogas respectively; both can be blended with fossil fuels (diesel and natural gas, respectively) [8, 9]. FAME is a fuel tested for marine propulsion by Maersk [9], and the U.S. Navy [10]. It is also promoted as a fuel suitable for marine propulsion various uses [11, 12]. FAME is a renewable clean fuel that is manufactured mainly from vegetable oils, animal fats, and waste cooking oil [13, 14, 15]. FAME has several advantages over petroleum diesel, including lower pollutant emissions, a lower carbon content, higher combustion efficiency and a superior lubricity, and can replace petroleum diesel in proportions from 0% to 100% without need for engine modification.

More Specifically FAME usually contains no compounds of sulfur or aromatics, and thus displays significantly decreased emissions of sulfur oxides, polycyclic aromatics hydrocarbons (PAH), nitrated polycyclic aromatics hydrocarbons (nPAH), and other toxic pollutants. The degree of emission reduction is generally proportional to the ratio of biodiesel added to petroleum diesel [11, 16]. In addition, based on the nature of biodiesel (readily biodegradable), there should be particular emphasis on using biodiesel in boats operating on lakes, rivers and environmentally sensitive areas [17].

With the adoption of ELOT ISO 8217:2010[18] and ELOT ISO 8217:2012 [7] for the first and second time respectively the term “de minimis” level is determined for the use of FAME. More specifically in paragraph 5.4 of the International and national Standard referred that the marine

fuel shall be free from bio-derived material other than “de minimis” levels of FAME, where FAME shall be in accordance with requirements of ELOT EN 14214 [19] or ASTM D 6751 [20]. The definition of the term “de minimis” means an amount that does not render the fuel unacceptable for use in marine applications. The blending of FAME does not allow. Until today the determination of the term “de minimis” level is not straight forward given. Because in many places around the world, for fiscal purposes [15], the distillate marine fuels are colored and thus the provisions of Annex A of ELOT ISO 8217 standard are not applicable.

The aim of this study was to examine the effect of adding FAME in DMZ marine distillate fuel category, attaining the quality specifications of ELOT ISO 8217:2012 [7]. DMZ is generally considered to be one of the main grades supplied as marine gas oil. It is among the four distillate marine fuel categories. The ELOT ISO F-DMZ has been added with the standard ELOT ISO 8216:2010. The only difference with the category ELOT ISO F-DMA distillate marine fuel is that it has minimum viscosity of 3.000 mm²/sec at 40°C. FAME was kept and stored in a plastic tank closed in room temperature away from the sunlight for a seven months period. FAME was taken from Greek refinery tank before blending to the automotive diesel and it was according to ELOT EN 14214 quality standard. DMZ fuel was examined before its colored black according to the Greek tax law. The blends were created at proportions of 0.5%, 1%, 2%, 3%, 4% and 5% by volume in FAME. The blends were examined as marine distillate fuel category DMZ suitable for use in marine engines applications.

MATERIALS AND METHODS

Test Fuels

The aim of this study was to examine the effect of adding FAME in DMZ marine distillate fuel category, attaining the quality specifications of ELOT ISO 8217:2012. FAME was kept and stored in a plastic tank closed in room temperature away from the sunlight for a seven months period trying to simulate a typical storage period of FAME. FAME used in this study was tested according to the national and European standard ELOT EN 14214. DMZ fuel was examined before its colored black according to the Greek tax law.

A total of eight fuels were used in this investigation. Distillate marine fuel oil of the category DMZ was used as the base fuel before enter in the market. Due to the fact that the marketed marine gas oils in Greece and in other countries also are tax free when purchased as fuel for marine engines that propels a commercial passenger or cargo ship, it is dyed in black color, and marked with a proper tracer. When the marine fuels are colored the provision of ELOT ISO 8217 are not applicable. The marine gas oil used meets the ISO 8217:2012 specification for the DMZ category. DMZ is generally considered to be one of the main grades supplied as marine gas oil. One additionally aim was to have a marine fuel with good lubricity property much below the limit value.

Additionally the specific energy was calculated according to equations E.3 and E.4 of ELOT ISO 8217. It expresses the amount of heat which is released when the fuel is burned. The specific energy is not controlled in the manufacture of the fuel except in the secondary manner by the specifications of other properties and is measured in MJ/kg. The blends were created at proportions of 0.5%, 1%, 2%, 3%, 4% and 5% by volume in FAME. The blends were properly mixed and mechanically agitated prior to each analysis to ensure fuel homogeneity. The fuel blends were examined according to ELOT ISO 8217:2012. The major physicochemical properties of the marine distillate fuel category DMZ and the test methods used of the fuels used in this study are presented in [Table 1](#). Additionally the major physicochemical characteristics of the FAME before the storage time and after it are presented in [Table 2](#).

Table 1. DMZ marine fuel properties and test methods.

Property	DMZ	ELOT ISO 8217 limits	Test Method
Density at 15°C (kg/m ³)	854.9 ± 0.001	max. 890.0	ELOT ISO 3675
Sulfur (% mass)	0.094 ± 0.00131	max. 1.50	ELOT ISO 8754
Cetane Index	51.0 ± 0.1	min 40	ASTM D 976
Distillation (°C)			ASTM D 86
IBP	179 ± 1		
10%	221 ± 1		
30%	264 ± 1		
50%	296 ± 1		
70%	325 ± 1		
85%	350 ± 1		
90%	360 ± 1		
95%	374 ± 1		
FBP	382 ± 1		
Flash Point (°C)	68 ± 1	min. 60	ELOT ISO 2719
Water (mg/kg)	100 ± 2	200	ELOT ISO 3733
Metals (mg/kg)			IP 501
Na+K	0	-	
Ca+Mg	0	-	
P	0	-	
Kinematic Viscosity at 40°C	3.404 ± 0.005	3.000 – 6.000	ELOT ISO 3104
Lubricity corrected scar diameter (wsd 1,4) at 60°C (µm)	280 ± 2	max. 520	ELOT ISO 12156-1
Gross Specific Energy (MJ/kg)	45.44 ± 0.01	-	ELOT ISO 8217
Net Specific Energy (MJ/kg)	42.66 ± 0.01	-	ELOT ISO 8217

Table 2. FAME (before and after storage) fuel properties and test methods.

Property	FAME before	FAME after	ELOT EN 14214	Test Method
Density at 15°C (kg/m ³)	878.5 ± 0.003	885.0 ± 0.002	860.0 – 900.0	ELOT ISO 3675
Sulfur (% mass)	0.00077	0.00078± 0,00001	max. 0.001	ELOT ISO 8754
Cetane Index	48.7 ± -.1	47.0 ± 0.1		ASTM D 976
Distillation (°C)				ASTM D 86
IBP	292± 1	293± 1		
10%	327± 1	228± 1		
30%	335± 1	335± 1		
50%	336± 1	337± 1		
70%	338± 1	339± 1		
85%	340± 1	340± 1	-	
90%	342± 1	342± 1	-	
95%	343± 1	343± 1	-	
FBP	344± 1	345± 1	-	
Flash Point (°C)	130±1	128±1	min. 120	ELOT ISO 2719
Water (mg/kg)	425 ± 12	789 ± 16	500	ELOT ISO 3733
Metals				IP 501
Na+K	4	4	5	
Ca+Mg	3	3	-	
P	2	2	10	
Kinematic Viscosity at 40°C	4.640 ± 0.007	4.264 ± 0.003	3.500 – 5.000	ELOT ISO 3104
Gross Specific Energy (MJ/kg)	44.94 ± 0.01	44.67 ± 0.01	-	ELOT ISO 8217
Net Specific Energy (MJ/kg)	42.23 ± 0.01	41.99 ± 0.01	-	ELOT ISO 8217

Fuel Properties

The kinematic viscosities of all fuels were within the specification limits. Viscosity is traditionally the main and often the only characteristic quoted in the purchase of marine