

ISTANBUL TECHNICAL UNIVERSITY
FACULTY OF NAVAL ARCHITECTURE AND OCEAN ENGINEERING

İTÜ



AN INVESTIGATION ON THE EFFECTS OF
FUEL ADDITIVE ON THE PERFORMANCE AND
EXHAUST EMISSIONS OF MARINE DIESEL ENGINES

FINAL REPORT

Prepared by

Professor Selma ERGİN, Project Coordinator

Project Team

Research Asst. Murat Durmaz

Research Asst. Sertaç Bulut

Istanbul Technical University
Faculty of Naval Architecture and Ocean Engineering,
Department of Naval Architecture and Marine Engineering,
34469 Maslak/Istanbul, Turkey.

Phone: 90-212-285 6389 (Office)
90-532-527 3720 (Mobile)

ITUNOVA TEKNOLOJİ email: ergin@itu.edu.tr

İTÜ Ayazaga Yerleşkesi Reşitpaşa Mah.
Hattı Cad. TEKNOKENT ARI 4 Binası
No: 295/10 34467 Sarıyer / İSTANBUL
Tic. Sic. No: 854234

Dr. Ercan Çitil, General Manager

ITUNOVA TTO
Istanbul Technical University,
34469 Maslak/Istanbul, Turkey.

Approved by

S. Mahir Tuğcu, Principle Surveyor

Turkish Loyd
Evliya Çelebi, Tersaneler Cd. No:26,
34944 Tuzla/Istanbul, Turkey.

September 25th, 2019

CONTENTS

ABSTRACT	2
1. INTRODUCTION	3
2. EXPERIMENTAL STUDY	5
3. RESULTS AND DISCUSSION	10
4. CONCLUSIONS	24
ACKNOWLEDGEMENTS	
REFERENCES	

Appendix A. The properties of the ULSD fuel with/without fuel additive.

ABSTRACT

The effects of fuel additive, CleanBoost Gold on the performance and exhaust emissions of a marine diesel engine installed on a ferry is investigated, experimentally. The fuel additive is based on a proprietary formula of Combustion Technologies USA that introduces a very small amount of highly purified catalysts into the fuel. The engine is a four-stroke, turbocharged, medium-speed diesel engine running on ultra-low-sulfur diesel (ULSD) fuel. The experiments were carried out on-board of the ferry, Ord. Prof. Ata Nutku sailing at Marmara Sea in Turkey. During the tests, NO_x, SO_x, CO, CO₂, HC and PM concentrations were measured at different engine loads for ultra low-sulfur diesel fuel with and without fuel additive. The shaft power, exhaust temperature, exhaust mass flow rate and ambient conditions were also measured. The experimental study was carried out using the facilities of ITU Ship Emission Laboratory*. The experimental results show that the use of the CleanBoost Gold fuel additive reduces the brake specific fuel-oil consumption by about 22.6% and the weighted emissions of NO_x, CO₂, CO, SO_x and unburned HC by about 24.8%, 22.9%, 17.4%, 54.5% and 12.2%, respectively. On the other hand, concentration of the O₂ and PM emissions increase by about 6.5% and 22.7 %, respectively. The SO_x and PM emission values are found to be very low. This is as a result of using ultra-low sulfur diesel fuel. It can clearly be seen that the fuel additive, CleanBoost Gold improves the combustion process and decreases the NO_x, CO, CO₂ and unburned HC emissions and brake specific fuel-oil consumption, substantially. Reducing fuel-oil consumption and exhaust emissions for a given voyage will not only provide financial benefit for the ship operator but also bring a positive impact on the environment and human health.

*) ITU Ship Emission Laboratory is one of the recognized laboratory by the Turkish Ministry of Transport and Infrastructure for the ship emission measurements.



SÖ

MT

1. INTRODUCTION

The shipping industry is responsible for the carriage of around 90% of world trade. Therefore, it is the nucleus of the global economy, but, is highly sensitive to fuel prices. Fuel costs represent around 50-60% of the total operating cost of a vessel and contribute a significant portion of the total transportation cost of cargo. Fluctuations in the price of crude oil and stricter environmental regulations on the emission of noxious and greenhouse gases are influential factors in the operation of the shipping industry (Argyros et al. (2014), Ergin (2011), Kim et al. (2014 and 2016), Murphy et al. (2012) and Ronen (1982)).

Exhaust emissions from the transportation are the main source of pollution and contribute to health problems and environmental impacts such as global warming, acidification, eutrophication and degradation of air quality (Cooper (2003), Corbett et al. (1999), Eyring (2005), Ergin et al. (2016 a-b), Kalender et al. (2017), Smith et al. (2014) and Viana et al. (2014)). Key compounds of exhaust emissions from shipping are the carbon dioxide (CO₂), carbon monoxide (CO), sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (VOC), hydrocarbons (HC) and particulate matters (PM). To reduce the impact of these pollutant emissions from shipping, International Maritime Organization (IMO) MARPOL Annex VI convention regulates several pollutants, including carbon dioxide (CO₂) and nitrogen oxides (NO_x) from newly built ships and sulphur oxides (SO_x). Certain maritime regions are designated emission control areas (ECAs) where the regulated emission levels are lower than in the rest of the ocean.

The maximum allowed sulphur content in marine fuels will be 0.5% from 2020 and in sulphur emission control areas it is 0.1% from 2015. These limits will reduce the emissions of SO₂ but are also intended to reduce the emissions of PM since there is a dependence of fuel sulphur content for the PM emission factors. The NO_x the emission limits are sharpened in a tiered system with Tier III being applied in NO_x emission control areas for new engines from 2016 (North American NECA) or 2021 (Baltic and North Seas). Further, the emissions of greenhouse gases from shipping are growing and there is an urgent need for measures to break

this trend. IMO has recently set a goal for greenhouse gas emissions from shipping to be reduced by 50% by 2050, compared with 2008-levels. IMO has also introduced the EEDI (energy efficiency design index) regulations in order to make new ships more fuel efficient. However, with an expected growth in maritime transport further measures are called for (see, for example, Bazari (2011), IMO (2009), IMO (2018) and Smith et al. (2014)).

There are several emission control methods and technologies. The sulphur regulations can be met by using low-sulphur fuel oils, such as marine gasoil (MGO), by using exhaust scrubbers, or by turning to other low-sulphur fuels such as liquefied natural gas (LNG) or methanol. To meet the Tier III NO_x requirements, abatement methods such as selective catalytic reduction (SCR) can be used but engines using LNG can reach Tier III without exhaust abatement systems. The fuel additives are also promising solution to improve diesel engine performance and fuel economy and also decrease harmful exhaust emissions see, for example, Ergin et al. (2018), Karthikeyan et al. (2014), Ryu et al. (2016), Yanfeng et al. (2007) and Yang et al. (2016).

This study aims to investigate the effects of fuel additive, CleanBoost Gold on the performance and exhaust emissions of a marine diesel engine installed on the ferry, Ord. Prof. Ata Nutku, experimentally. The fuel additive is based on a proprietary formula of Combustion Technologies USA that introduces a very small amount of highly purified catalysts into the fuel (see, Restore Solutions (2019)). The engine is a four-stroke, turbocharged, medium-speed diesel engine running on ultra-low-sulfur diesel (ULSD) fuel. The experiments were carried out on-board of the ferry sailing at Marmara Sea between Eskihisar and Topçular in Turkey. During the tests, NO_x, SO_x, CO, CO₂, HC and PM concentrations were measured at different engine loads for ultra low-sulfur diesel fuel with and without fuel additive, CleanBoost Gold. The shaft power, exhaust temperature, exhaust mass flow rate and ambient conditions were also measured.

The experimental results show that the use of fuel additive, CleanBoost Gold reduces the weighted emissions of NO_x, CO₂, CO, HC and SO₂ by about 24.8%, 22.9%, 17.4%, 12.2% and 54.5%, respectively. On the other hand, the O₂ concentration and PM emission values increased



by about 6.5% and 22.7%, respectively when the fuel additive is used. Furthermore, the use of fuel additive reduces the weighted average brake specific fuel-oil consumption by about 22.6%.

2. EXPERIMENTAL STUDY

The experimental study was carried out on-board of the ferry, Ord. Prof. Ata Nutku sailing at Marmara Sea in Turkey. The ferry is 81m long with a tonnage of 1596 GRT and it was built in 2000. Table 1 shows the general properties of the ferry and the photo of the ferry is presented in Figure 1. She is fitted with two main engines which drive two controllable pitch propellers placed at the fore and aft of the ship. The main propulsion engine is a fourstroke, medium-speed and turbocharged diesel engine. Its main specifications are given in Table 2.

The measurements of NO_x, SO_x, CO, CO₂, HC and PM emissions for the main engine were taken by using the ultra-low-sulfur diesel fuel with and without fuel additive. The properties of diesel fuel with/without additive can be obtained in Appendix A. The fuel additive, CleanBoost Gold which is based on a proprietary formula of Combustion Technologies USA was added to the ultra low-sulfur diesel fuel with a ratio of 1:4000 or 250 ppm by volume. This ratio is taken as constant throughout the experimental study. This is recommended value for this type of the engine and fuel by the additive supplier (Restore Solutions (2019)). The tests without fuel additive were carried out from August 5th to 7th, 2019 and the tests with fuel additive from August 19th to 20th, 2019. The fuel additive was added to the fuel tanks of the ferry from August 8th, 2019 until the end of the tests. Namely, the ULSD with fuel additive were used about 200 hours prior to the tests with fuel additive.

Figure 2 shows the experimental set-up for the emission measurements. As can be seen from Figure 2, the sampling port was placed on the exhaust stack at a distance from the main engine according to IMO NO_x Technical Code. Emission measurements for different engine loads were carried out under the steady-state conditions using the E2 test cycle as shown in Table 3 (see, IMO (2009)).

The multi-gas analyzer Horiba PG-250 was used to measure the concentrations of NO_x, SO₂, CO, O₂ and CO₂. Table 4 presents the measurement methods of Horiba PG250 gas analyser for

the NO_x, CO₂, SO₂, CO and O₂ emissions measurements. Horiba Mexa 1170 gas analyzer was employed to measure the unburned HC emissions. Its working principle is based on the Heated Flame Ionization Detection (HFID) method. This gas analyser has 14 measurement ranges between 0-10 ppm to 0-200,000 ppm. The calibration of the gas analysers were carried out using the certified calibration gases before and after the measurements.

For the PM emission measurements, the particle mass was collected by Tecora Isostack isokinetic sampling system which uses 47-mm-diameter glass-microfiber filters. The filters were dried by using the BINDER oven before the sampling. The samples were taken at nearly steady-state conditions for about 30 min ensuring the isokinetic flow rate. The particle mass was analyzed gravimetrically, and it was weighed before and after sampling using a Sortorius SE2F-Micro-Balance in the laboratory. The isokinetic deviation during the sampling was less than 10%, which is in accordance with the ISO 9096 standard.

Table 1. Vessel particulars.

General Properties of the Ferry	
IMO Number	9161144
Name	Ordinaryus Profesör Ata Nutku
Vessel Type	RO-RO/Passenger Ship
Gross Tonnage	1596
Summer DWT	225 t
Length Overall	80.71 m
Breadth Extreme	22 m
Year Build	2000
Flag	Turkey
Home port	Istanbul

mt

ca

50



Figure 1. Photo of the ferry, Ord. Prof. Ata Nutku (URL 1).

Table 2. Specifications of the main engine.

Main Engine	
Model	ABC 8MDX
Type	4-stroke, turbocharged, intercooled
Power	883 kW at 750 rpm
Cylinder arrangement	8 cylinder, in-line
Bore x Stroke	242 mm × 320 mm
Rod length	320
Swept volume	117.8 L
Compression ratio	12.06:1
Injection	Direct, mechanical, one pump per cylinder

MT

Ca

SÖ

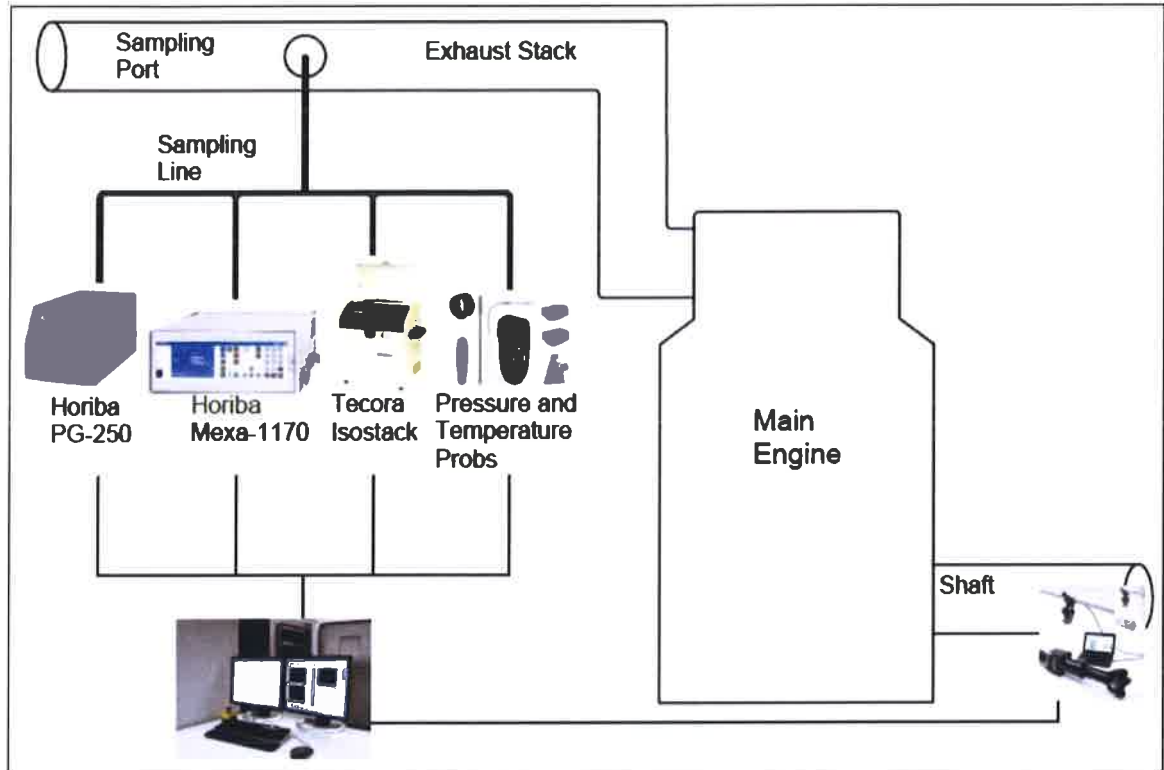


Figure 2. Experimental rig.

Table 3. The test cycle.

Test cycle E2				
Speed	100%	100%	100%	100%
Power	25%	50%	75%	100%
Weighting factor	0.15	0.15	0.5	0.2

MT

Ca

SO

Table 4. The measurement principle of HORIBA PG250 gas analyser.

HORIBA PG250 Gas Analyser		
Gas	Measurement principle	Range
O ₂	Zirconium Oxide sensor	0~5/10/25 vol%
CO ₂	Non-Dispersive Infrared absorption (NDIR)	0~5/10/20 vol%
NO _x	Chemiluminescenc (CLD)	0~25/50/100/250/500/1000/2500 ppm
SO ₂	Non-Dispersive Infrared absorption (NDIR)	0~200/500/1000/3000 ppm
CO	Non-Dispersive Infrared absorption (NDIR)	0~200/500/1000/2000/5000 ppm

The shaft power was measured by using Datum shaft power measurement system, which provides an output of shaft torque, shaft r/min and shaft power with an accuracy of 0.1%. During the measurements, first, the shaft power was set and monitored continuously. After that, sampling gas was taken from the stack and conveyed to the gas conditioning system and then to the gas analyzer. The sampling took around 30 min. Tests were repeated three times and the readings were averaged. The reduction gear losses were considered as 5%.

The fuel consumption of the engine was measured using the KROHNE 6300-Ultrasonic clamp-on flowmeter. The measurement system consists of a measuring sensor and a signal converter. The measuring sensor is fitted on the outside of piping to measure the flowrate of the fuel. The measurement principle of flow meter is based on the ultrasonic transit time.

During the tests, the temperature, humidity and differential pressure of the exhaust gases and the pressure, temperature and humidity of the ambient air were also measured.

MT

Ca

SO

3. RESULTS AND DISCUSSION

The results of the experimental study which is carried out to investigate the effects of the CleanBoost Gold fuel additive on the performance and exhaust emissions of the marine diesel engine installed on the ferry Ord.Prof. Ata Nutku, are presented in Figures 3 to 13. The exhaust temperature and velocity values are presented in Figures 3 to 4. Figures 5-12 show the NO_x, SO₂, CO, CO₂, HC and PM emissions, and O₂ concentration values for the fuel-oil with/without additive at different engine loads (25%, 50%, 75% and 100%). The results of the uncertainty analysis are also shown on Figures 3 to 13 as error bars. Figure 13 presents the brake specific fuel-oil consumption values with and without fuel additive at different engine loads.

Figure 3 shows the measured exhaust temperatures of the engine operated with and without fuel additive at different engine loads of 25%, 50%, 75% and 100%. As can be seen from the figure, exhaust temperature increases as the engine load increases. The exhaust temperatures obtained with using fuel additive are lower than the exhaust temperatures obtained without using fuel additive. The difference between the exhaust temperatures with/without fuel additive decreases as the engine load increases. The maximum temperature difference of 8.4% is obtained at the lowest engine load, 25%.

The measured exhaust velocity values for the engine operated with/without fuel additive are presented at different engine loads in Figure 4. The exhaust velocity increases when the engine load increases. The velocity values for the case with fuel additive at the engine loads of 50% and 75% are higher than the velocity values without fuel additive by about 9.9 % and 1.4 %, respectively. On the other hand, they are lower at the engine loads of 25% and 100% by 9.8% and 6.7%, respectively.

The emission measurements are presented as emission factors (g/kW.h) which are based on the concentration of the measured exhaust pollutants, the measured engine power and the calculated exhaust flow rate. The main engine emissions of gas pollutants and particulate matter were calculated using the methodology given in the IMO NO_x Technical code E2 test cycle.

Figure 5 presents the measured NO_x emission values with and without fuel additive for different

mt

ca

so

engine loads. The NO_x emissions mainly depend on the combustion temperature, so generally they increase with the engine load. The NO_x emission values with additive are lower than the NO_x emission values without additive for the engine loads of 25%, 50%, 75% and 100% by about 40%, 19.2%, 22.2% and 26.8%, respectively. On the other hand, the weighted NO_x emission values in Figure 5 shows that the weighted NO_x emission with additive is about 24.8% less than the weighted NO_x emission without additive. It can be said that the fuel additive reduces the NO_x emissions, substantially.

The CO emissions occur as a result of incomplete combustion of fuel. Figure 6 shows the CO emissions with/without fuel additive for different engine loads. When the engine load increases, the CO emission first decreases and reaches to its minimum value then increases again. At high engine loads, it increases mostly due to the lack of oxygen. But, at low engine loads, it increases due to low temperatures in the combustion chamber which affect fuel atomization. The highest CO emission occurs at the lowest engine load of 25%. As can be seen from Figure 6, the use of fuel additive cause a reduction of 17.4% in the weighted average CO emissions. The maximum reduction in CO emission occurs at 50% engine load as about 27.2%.

Figure 7 presents the unburned HC emissions with and without fuel additive at different engine loads. In general, the emissions of unburned HC occur as a result of incomplete combustion of the hydrocarbon fuel. As the engine load increases, the unburned HC emission first decreases, then reaches its minimum value and then increases again. When the fuel additive was used the HC emissions are reduced for all engine loads. As can be seen from Figure 7, the reduction in the weighted average HC emission value with fuel additive is about 12.2 %. On the other hand, the maximum reduction in HC emission occurs at 75% load to be about 16.9%.

The effect of fuel additive on the CO₂ emissions can be clearly seen from Figure 8. The CO₂ emissions for all the engine loads reduce when the fuel additive is used. The reduction in the weighted average CO₂ emission is about 22.9 %. On the other hand, the maximum reduction in CO₂ emission occurs at 25% load as 35.7%. Generally, the amount of CO₂ emission increase with the engine load.

MT

CA

50

The emissions of SO₂ are related to the fuel properties. The use of fuel additive resulted in lower emissions of SO₂ for all the engine loads except 25% load. The weighted SO₂ emission value with fuel additive is 54.5% less than the SO₂ emission value without fuel additive (see, Figure 9). This result should be evaluated carefully, since the SO₂ emission values are quite low due to using ultra low-sulfur diesel fuel. This also cause to have high uncertainty values for this case.

Figure 10 compares the total PM emissions with and without fuel additive at different loads. PM emissions mostly depend on sulfur content in the fuel. As can be seen from Figure 10, the PM emissions for all the loads are quite low. This is due to using ultra-low sulfur diesel fuel. The use of fuel additive increase the emissions of PM for all the engine loads except 25% load. The weighted PM emission value with fuel additive is about 22.7% higher than that without fuel additive. Since, the measurements with fuel additive were carried out after 11 days the engine operated with fuel additive. The time may not be enough for the fuel additive to clean up the tanks and piping systems, completely.

Figure 11 shows the O₂ concentration values with/without fuel additive for different loads. As can be seen from the Figure, O₂ concentration decreases as the engine load increases. The weighted average O₂ concentration increased by about 6.5% when the the fuel additive is used.

The weighted average emissions of NO_x, SO₂, CO₂, CO, O₂, HC and PM with/without fuel additive are presented in Figure 12. The results show that the fuel additive reduces the weighted average emissions of NO_x, SO₂, CO₂, CO and HC by about 24.8%, 54.5%, 22.9%, 17.4% and 12.2%, respectively. However, the weighted average emission of PM and O₂ concentration increase by 22.7% and 6.5% when the engine operated with fuel additive.

Figure 13 presents the brake specific fuel-oil consumption with and without fuel additive for different loads. Table 5 shows the brake specific fuel-oil consumption for different operations. The fuel additive reduces the brake specific fuel-oil consumption for all the engine loads. The weighted average brake specific fuel-oil consumption is reduced by about 22.6% when the fuel additive is used. The maximum reduction in the brake specific fuel-oil consumption is 46% and





it occurs at 25% load (see, Figure 13 and Table 5). The results show that the fuel additive has significant effect on the fuel consumption.

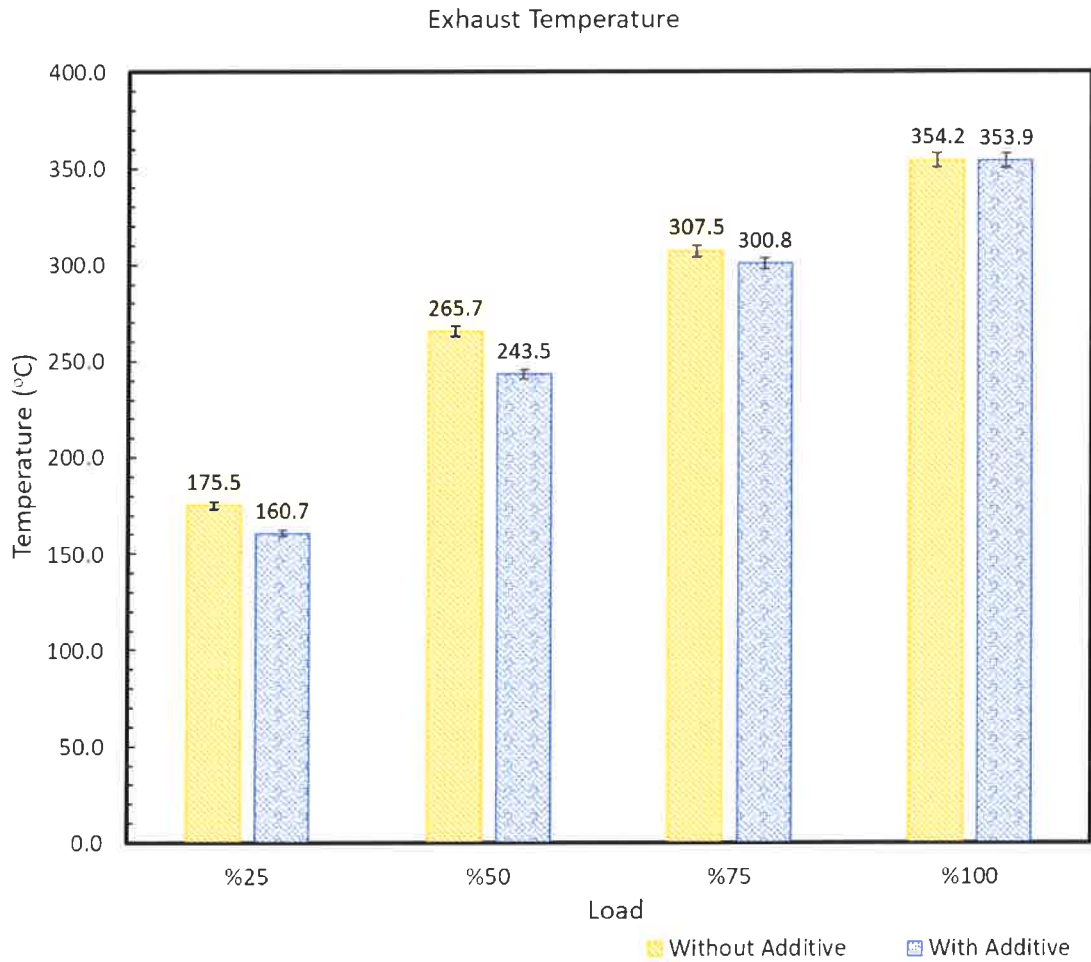


Figure 3. Exhaust temperatures at different loads for the fuel with/without additive .

MT

ca

50

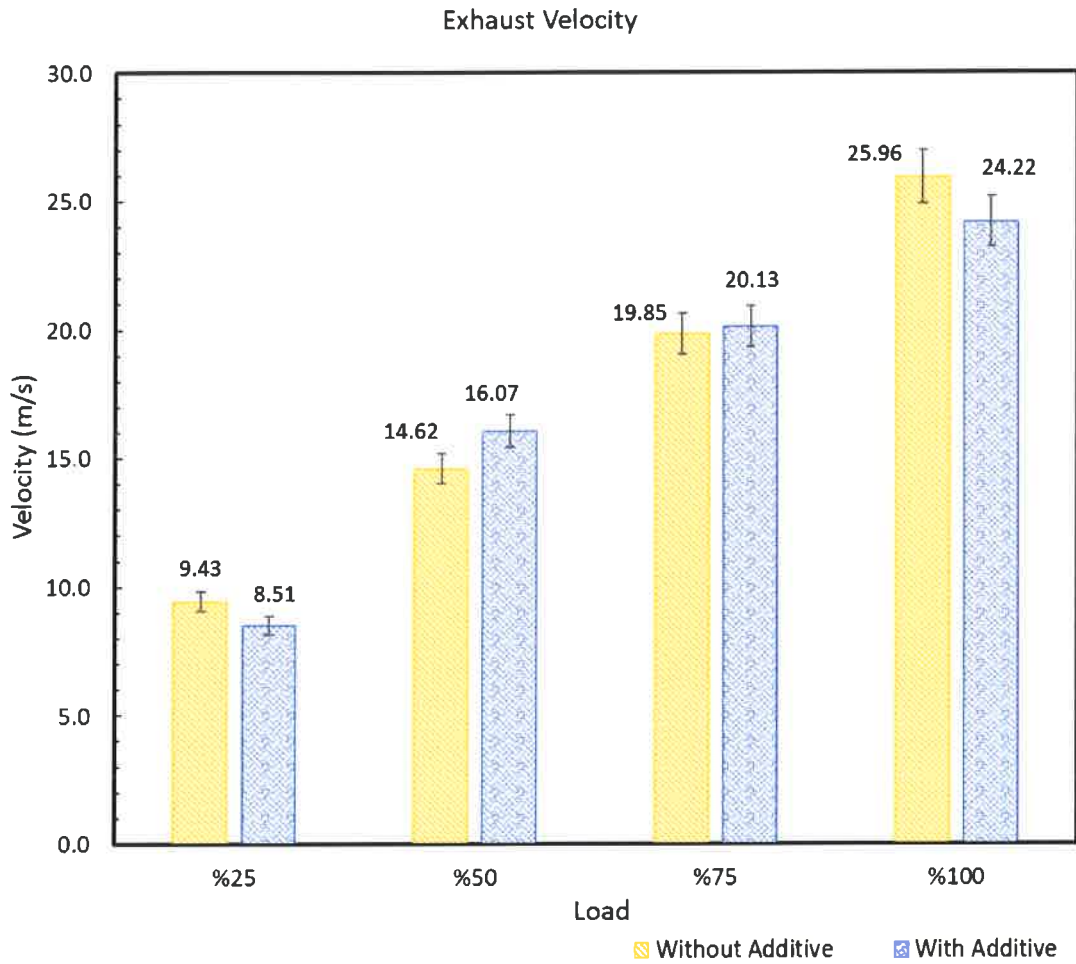


Figure 4. Exhaust velocity at different loads for the fuel with/without additive.

MF

CS

SÖ

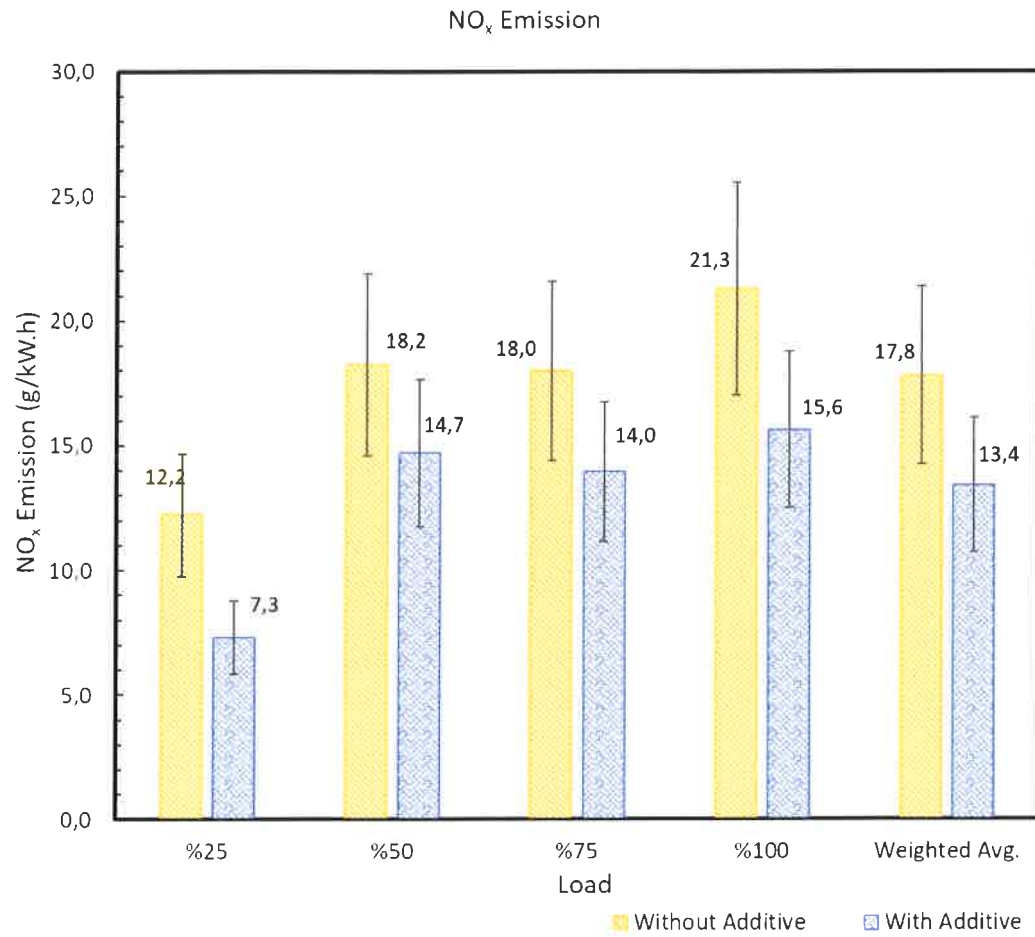


Figure 5. NO_x emission values with/without fuel additive at different loads.

MT

ca

so

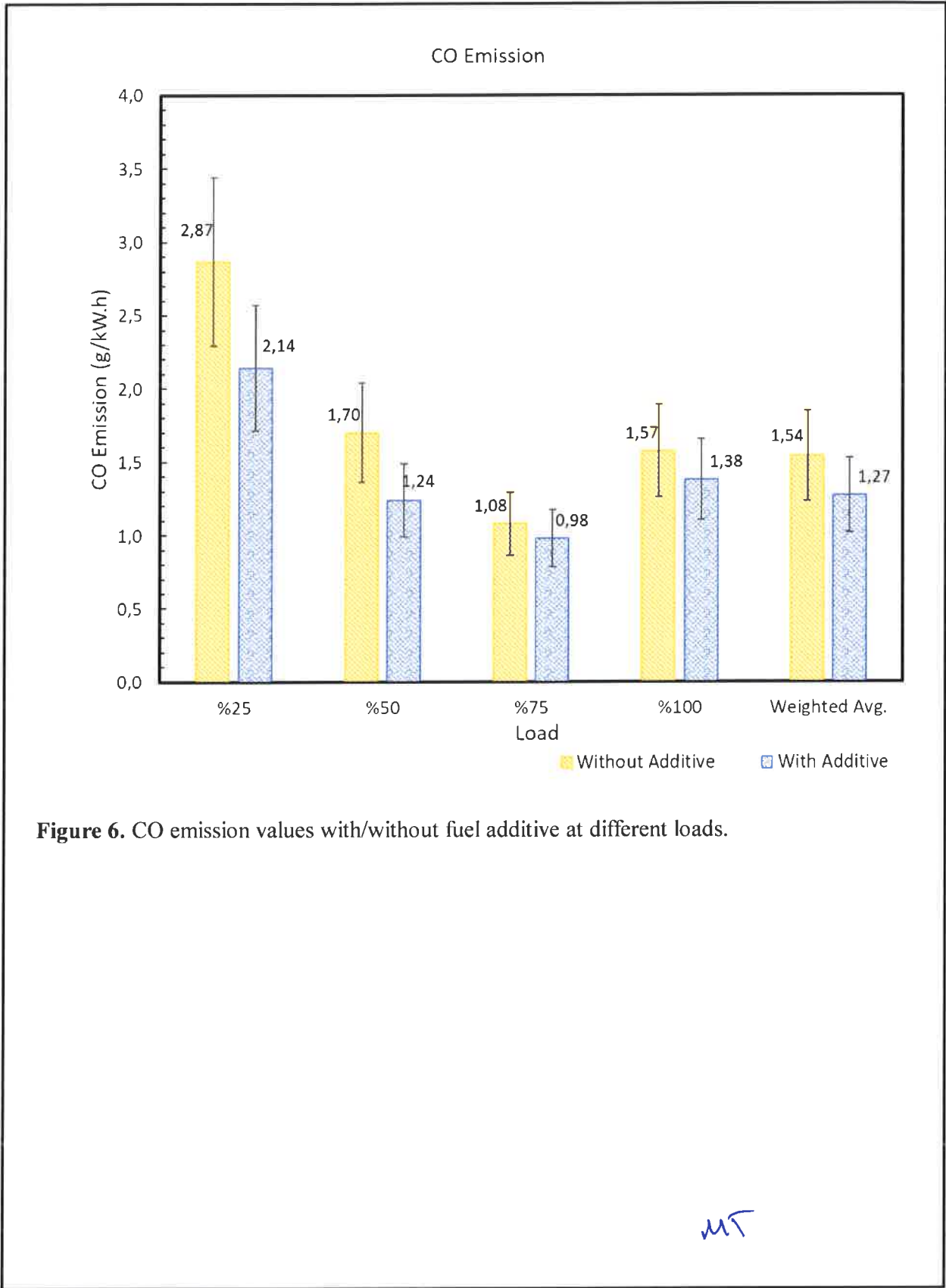


Figure 6. CO emission values with/without fuel additive at different loads.

ca

sö

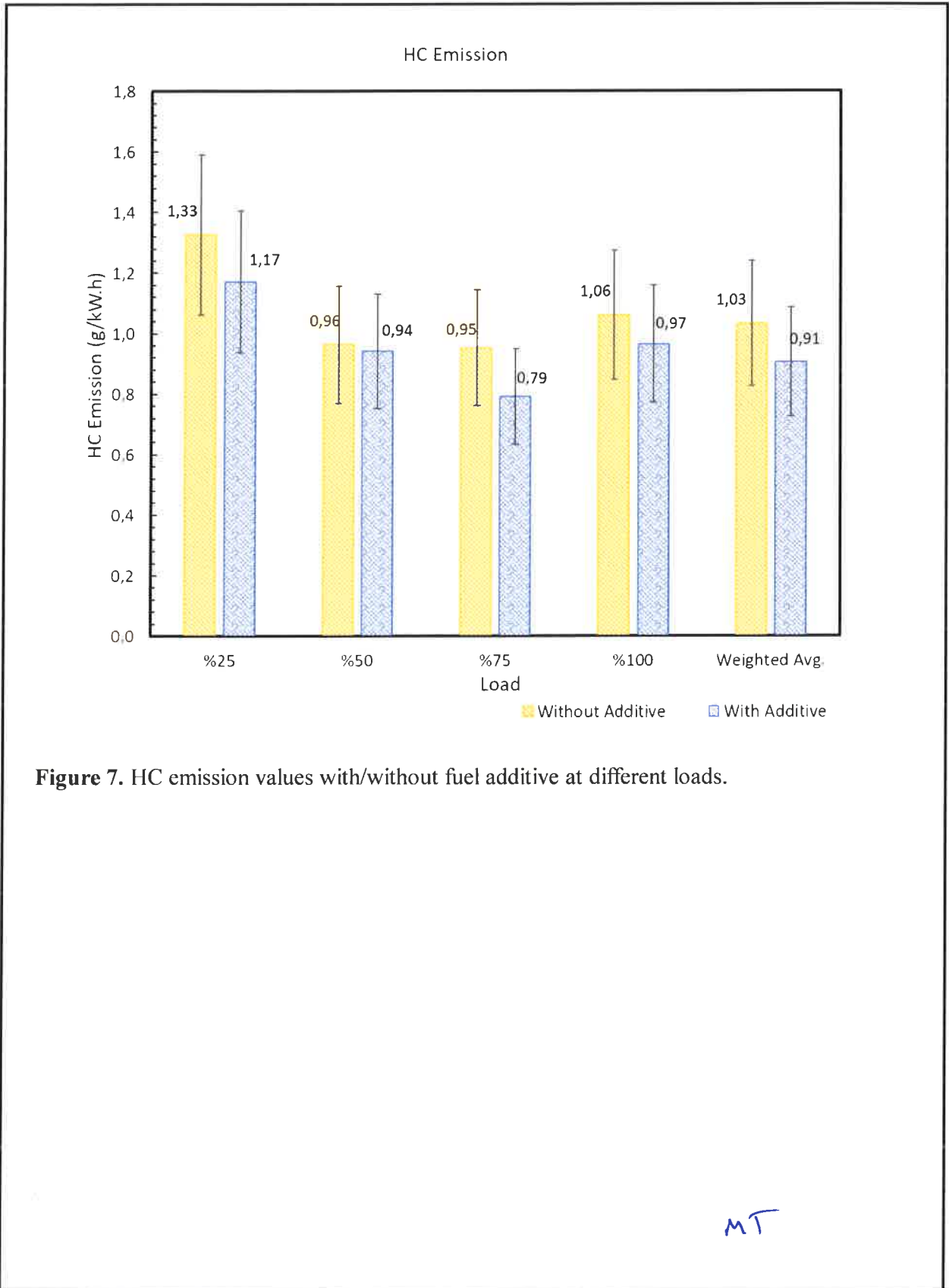


Figure 7. HC emission values with/without fuel additive at different loads.

ca

so

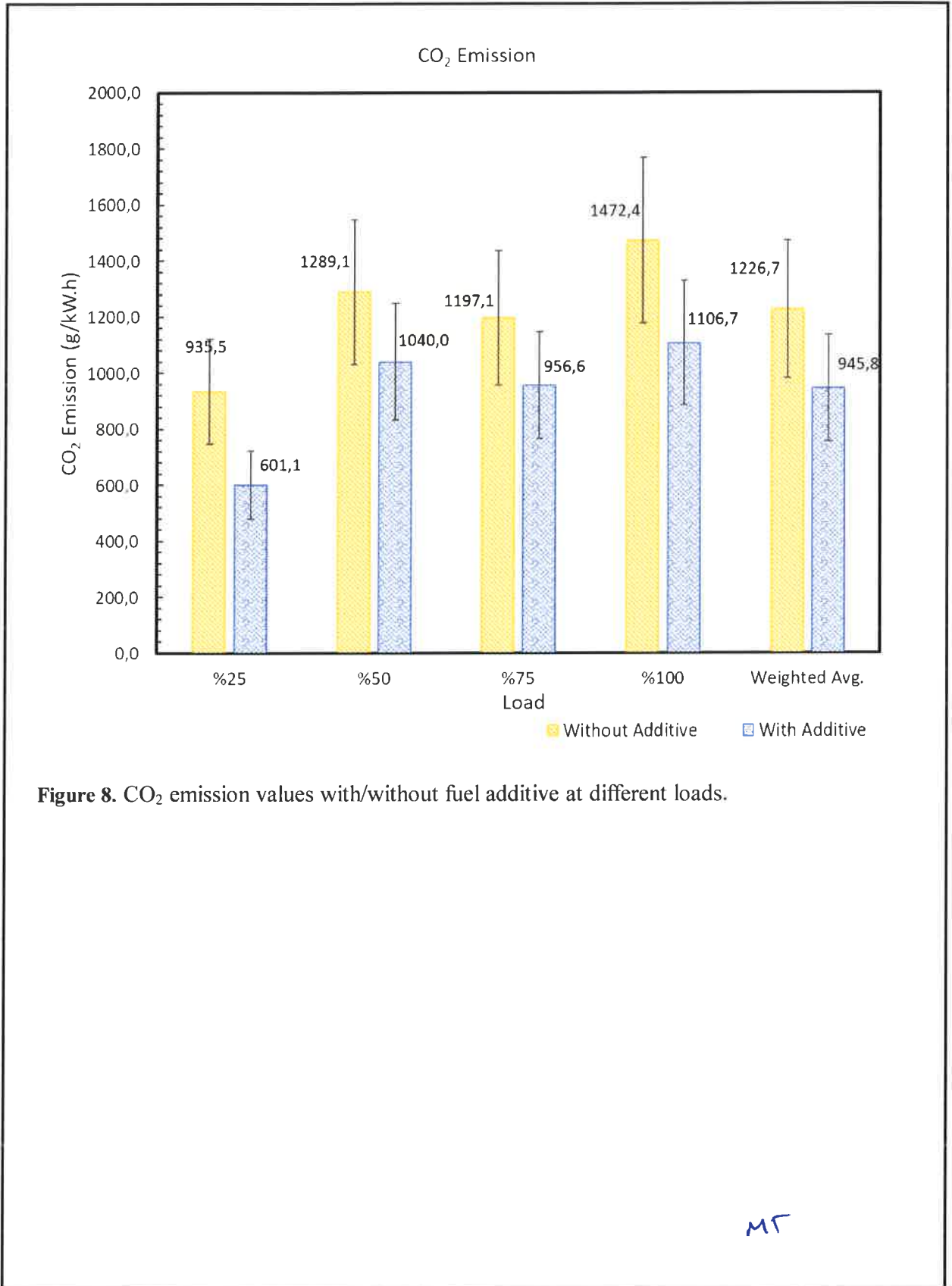


Figure 8. CO₂ emission values with/without fuel additive at different loads.

CA

SO

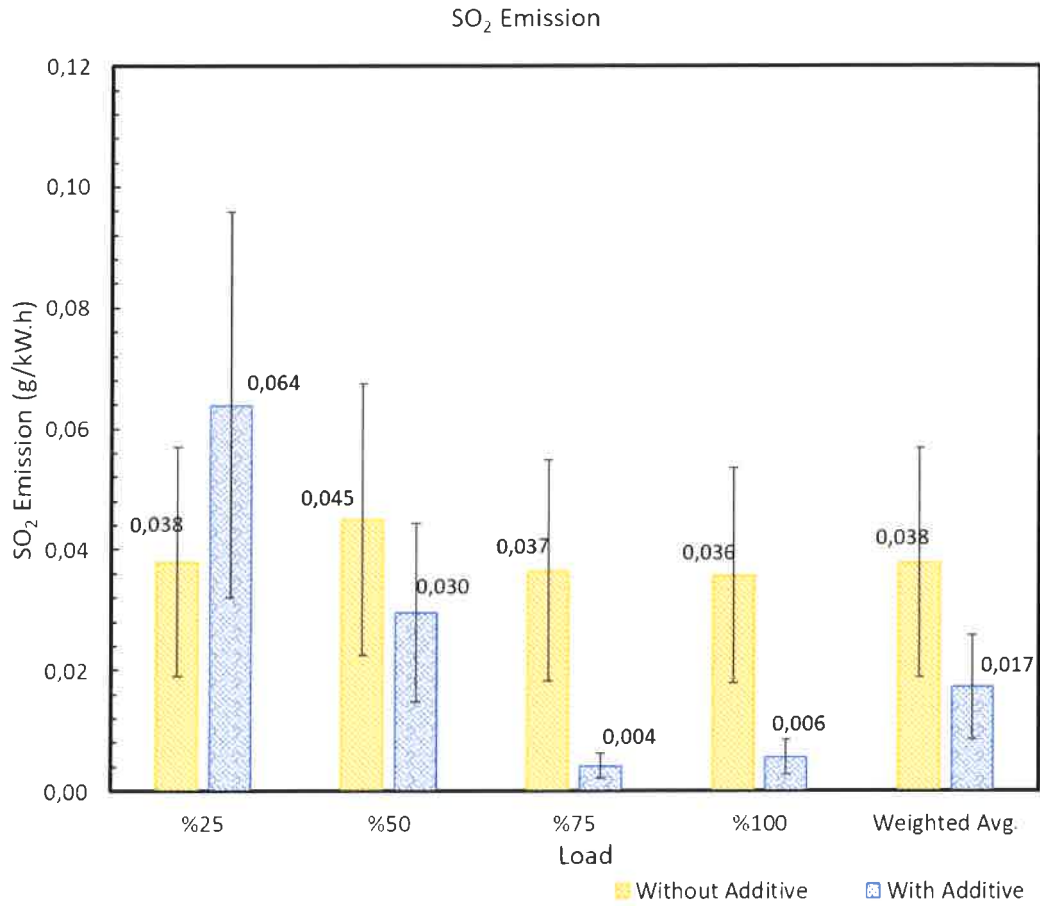


Figure 9. SO₂ emission values with/without fuel additive at different loads.

MT

Ca

Sö

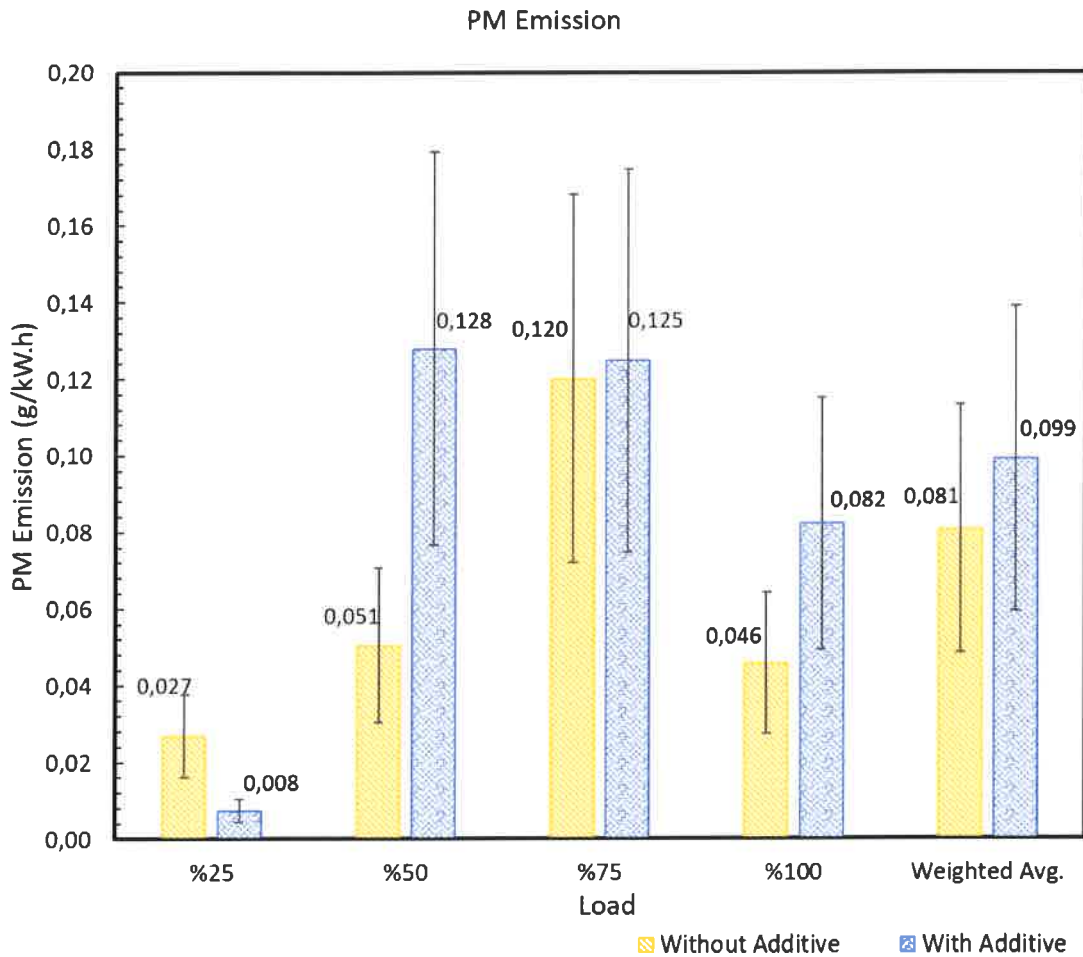


Figure 10. PM emission values with/without fuel additive at different loads.

MT

ca

so

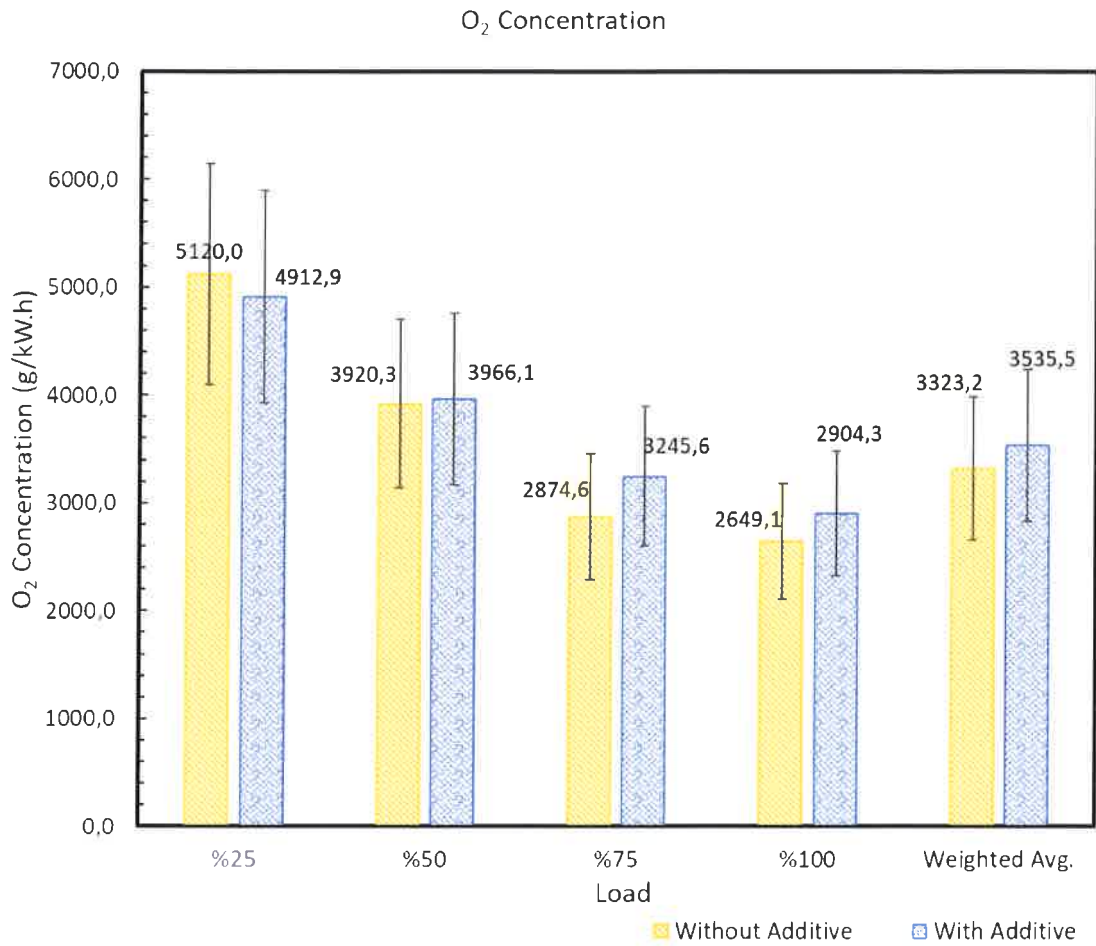


Figure 11. O₂ concentration values with/without fuel additive at different loads.

MT

Ca

50

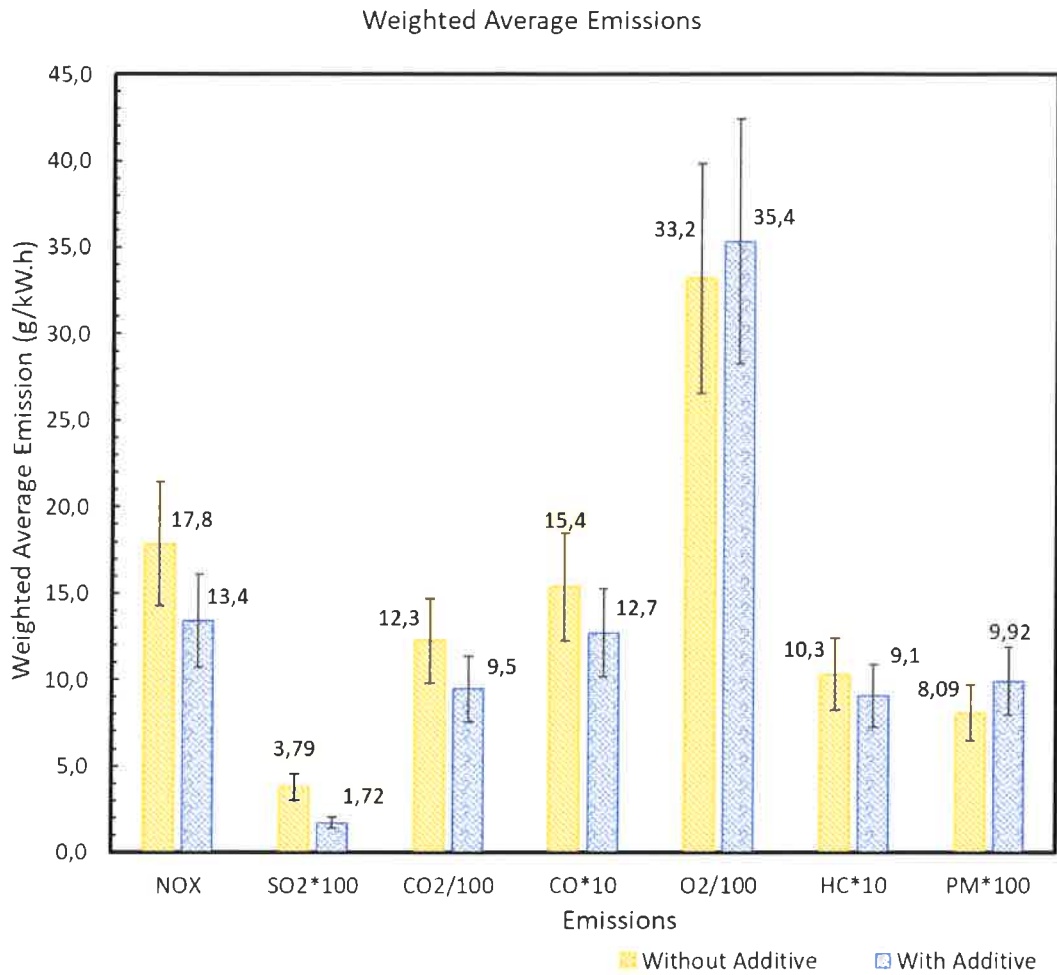


Figure 12. Weighted average emissions with/without fuel additive.

MT

04

50

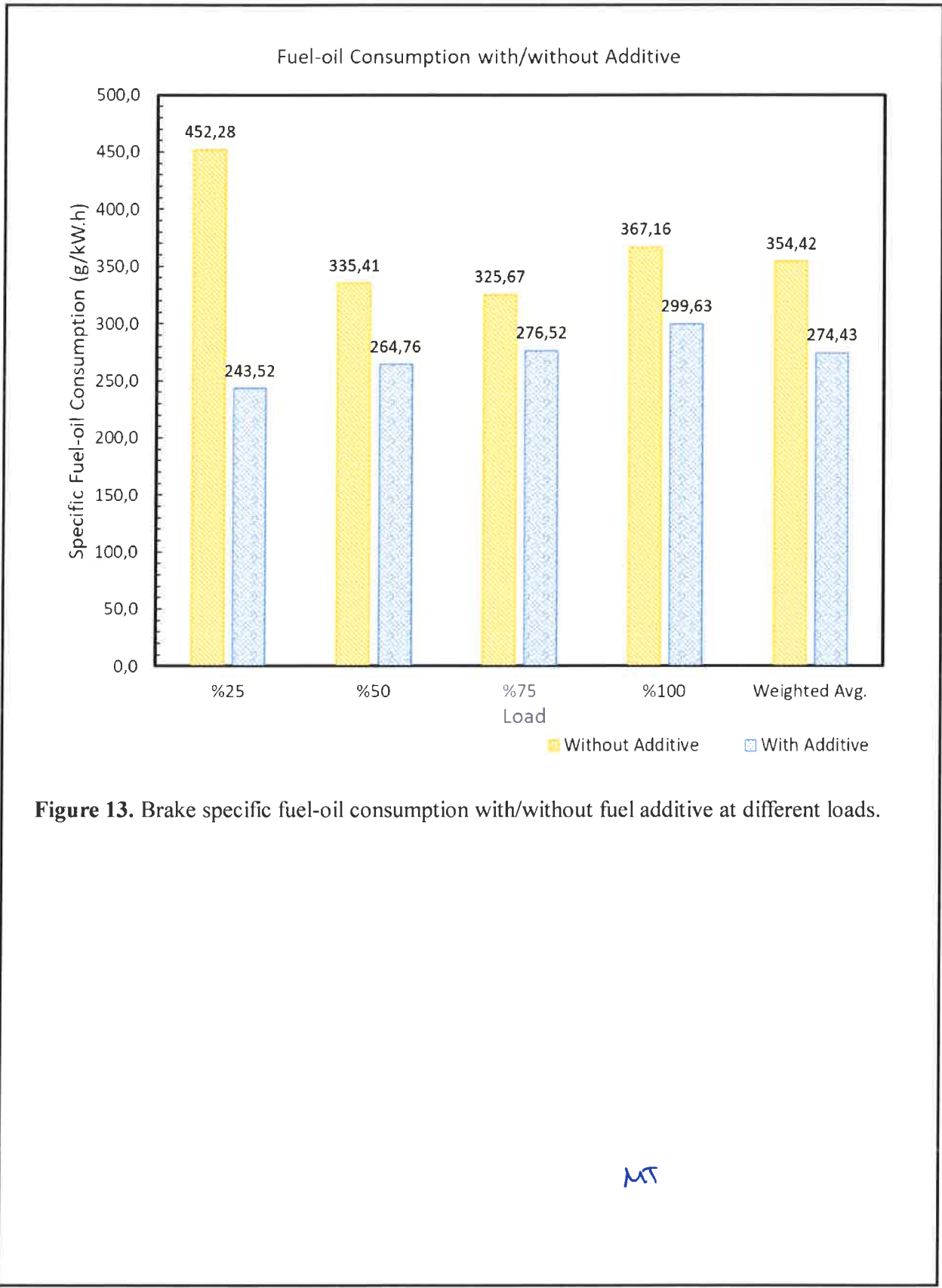


Figure 13. Brake specific fuel-oil consumption with/without fuel additive at different loads.

Table 5. Brake specific fuel-oil consumption for different ferry operations.

Brake specific fuel-oil consumption (g/kW.h)			
Load	Without fuel Additive	With fuel Additive	Change (%)
Idle	690.30	614.45	10.99
Cruise	356.53	263.34	26.14
25%	452.28	243.52	46.16
50%	335.41	264.76	21.06
75%	325.67	276.52	15.09
100%	367.16	299.63	18.39
Weighted Average	354.40	274.43	22.57

4. CONCLUSIONS

The study presents the the effects of fuel additive CleanBoost Gold on the performance and exhaust emissions of a marine diesel engine installed on a ferry. The measurements were carried out on-board of the ferry, Ord. Prof. Ata Nutku sailing between Eskihisar and Topçular at Marmara Sea, Turkey in accordance with the regulations of MARPOL Annex VI, NOx Technical Code.

The weighted emission factors of NO_x, SO₂, CO, CO₂, HC and PM emissions for the main engine of the ferry without fuel additive are obtained as 17.8, 0.0379, 1.54, 1230, 1.03 and 0.0809 g/kWh, respectively. The weighted emission factors with fuel additive are obtained as 13.4, 0.0172, 1.27, 950, 0.91 and 0.092 g/kWh, respectively. As can be seen from the results, the use of fuel additive resulted in lower emissions of NO_x, SO₂, CO, CO₂ and HC by 24.8%, 54.5%, 17.4%, 22.9 and 12.19%, respectively. There is an increase in the PM emissions by 22.7% and O₂ concentration increased from 3320 g/kWh to 3540 g/kWh by 6.4%. However,

MJ

ca

50

the SO_x and PM emissions in the exhaust are very low. This is due to using ultra-low-sulfur content fuel. Substantial reductions, especially in the NO_x emissions, are obtained with using the fuel additive.

The results show that there is significant reduction in the brake specific fuel-oil consumption, when the fuel additive is used. The brake specific fuel-oil consumption with fuel additive is reduced by about 46.2%, 21.1%, 15.1% and 18.4% for the engine loads of 25%, 50%, 75% and 100%, respectively. On the other hand, the weighted average brake specific fuel-oil consumption is reduced by about 22.6%.

It can be concluded that the fuel additive, CleanBoost Gold improves the combustion process and decreases the NO_x, CO, CO₂ and unburned HC emissions and brake specific fuel-oil consumption, substantially. Reducing fuel-oil consumption and exhaust emissions will not only provide financial benefit for the ship operators, but also make positive environmental and health impacts.

ACKNOWLEDGEMENTS

The authors would like to acknowledge and show their gratitude and appreciation for the support of the ship owner company (IDO) and masters, chief engineers and crew of the ferry during measurements.

The authors would like to thank graduate students Mr. Selahattin Özsayan, Mr. Cihad Çelik and Mr. Burak Güngüder from Istanbul Technical University, Faculty of Naval Architecture and Ocean Engineering for their assistance during measurements on board ferry.

REFERENCES

Argyros, D., Raucci, C., Sabio, N., Smith T. (2014). Global marine fuel trend 2030.
http://discovery.ucl.ac.uk/1472843/1/Global_Marine_Fuel_Trends_2030.pdf

MT

U

SÖ

Bazari, Z., Longva, T. (2011). Assessment of IMO mandated energy efficiency measures for international shipping. Final Report, MEPC 63/INF.2.

Restore Solutions (2019), <http://www.restoreolutionsinc.net/cleanboost-gold-32oz-bottle/> and <https://www.combustionusa.com/cleanboost-gold.html>

Cooper DA. (2003) Exhaust emissions from ships at berth. Atmos Environ; 37(27): 3817–3830.

Corbett JJ, Fischbeck PS and Pandis SN. (1999) Global nitrogen and sulfur inventories for oceangoing ships. J Geophys Res; 104(D3): 3457–3470.

Durmaz M, Kalender SS and Ergin S. (2017) Experimental study on the effects of ultra-low sulfur diesel fuel to the exhaust emissions of a ferry. Fresen Environ Bull; 26(10): 5833–5840.

Durmaz M, Kalender SS and Ergin S. (2016) Measurements of particulate emissions from a ferry. In: Proceedings of the 2nd global conference on innovation in marine technology and the future of maritime transportation, Mugla, Turkey, 24–25 October 2016.

Ergin S. (2011) Controlling of ship-source air pollution. Final Report, Ministry of Environment and Urban Planning, Ankara, Turkey, 31 December 2011.

Ergin S, Kalender SS and Durmaz M. (2016a) On board measurements of exhaust emissions from a ferry sailing at Marmara Sea. In: Proceedings of the 1st international congress on ship and marine technology, Cenkler Matbaası, Istanbul, Turkey, 8–9 December 2016.

Ergin S, Durmaz M and Kalender SS. (2016b) An experimental investigation of exhaust emissions from a ferry. In: Proceedings of the 30th Asian-Pacific technical exchange and advisory meeting on marine structures, Mokpo University, Republic of Korea, 10–13 October 2016, pp.406–412.

MT

CS

SÖ

Ergin, S, Durmaz, M, Kalender, SS. (2018) An experimental investigation on the effects of fuel additive on the exhaust emissions of a ferry Proc IMechE Part M: J Engineering for the Maritime Environment,1-7, DOI: 10.1177/1475090218806709.

Eyring V, Koehler HW, van Aardenne J, et al. (2005) Emissions from international shipping: 1. The last 50 years. J Geophys Res; 110(D17): 1–12.

Heywood, J. B. (1988). Internal combustion engine fundamentals, McGraw-Hill New York.

IMO (2009) Revised MARPOL Annex VI: Regulations for the Prevention of Air Pollution from Ships and NOx Technical Code 2008: International Maritime Organization.

IMO (2018), Low carbon shipping and air pollution control;
<http://www.imo.org/en/MediaCentre/HotTopics/GHG/Pages/default.aspx>

Kalender SS and Ergin S. (2017) An experimental investigation into the particulate emissions of a ferry fuelled with ultralow sulfur diesel. J Mar Sci Technol; 25(5): 499–507.

Karthikeyan S, Elango A and Prathima (2014) A. An environmental effect of GSO methyl ester with ZnO additive fuelled marine engine. Indian J Geo-Mar Sci 2014; 43(4):564–570.

Kim, J.D., Kim, H.J., Lee, P.T.W. (2014). Optimizing ship speed to minimize fuel consumption. Transportation Letters, 6(3), 109–117.

Kim, J.D., Kim, H.J., Jun, H.B., Kim, C.M. (2016). Optimizing Ship Speed to Minimize Total Fuel Consumption with Multiple Time Windows. Hindawi Publishing Corporation Mathematical Problems in Engineering Volume 2016.

Murphy, A.J., Weston, S.J., Young, J.R. (2012), “Reducing fuel usage and exhaust gas emissions from tugboat fleets: Sea trials and theoretical modelling”, Transactions of the Royal

NT

ca

so

Institute of Naval Architecture, Part A: 420 International Journal of Marine Engineering, 154, A31-A41.

Ronen, D. (1982). Effect of oil price on the optimal speed of ships, Journal of the operational research Society, 33(11), 1035 -1040.

Ryu Y, Lee Y and Nam J. (2016) Performance and emission characteristics of additives-enhanced heavy fuel oil in large two-stroke marine diesel engine. Fuel 2016; 182: 850–856.

Smith TWP, Jalkanen JP, Anderson BA, et al. (2014) Third IMO GHG study 2014. 2014; 328, https://www.cedelft.eu/publicatie/third_imo_ghg_study_2014/1525.

URL1: https://www.fleetmon.com/vessels/ord-prof-ata-nutku_0_22901/photos/957157/
Accessed on September 2nd, 2019.

Viana M, Hammingh P, Colette A, et al. (2014) Impact of maritime transport emissions on coastal air quality in Europe. Atmos Environ; 90: 96–105.

Yang PM, Lin KC, Lin YC, et al.(2016) Emission evaluation of a diesel engine generator operating with a proportion of isobutanol as a fuel additive in biodiesel blends. Appl Therm Eng; 100: 628–635.

Yanfeng G, Shenghua L, Hejun G, et al. (2007) A new diesel oxygenate additive and its effects on engine combustion and emissions. Appl Therm Eng; 27(1): 202–207.

MT

CZ

SÖ

Appendix A. The properties of the ULSD fuel with/without fuel additive.

MT

CL

SÖ



**THE SCIENTIFIC AND TECHNOLOGICAL RESEARCH COUNCIL OF TURKEY
MARMARA RESEARCH CENTER
ENERGY INSTITUTE**

P.O. Box 21, 41470 GEBZE – KOCAELI / TURKEY
T +90 262 677 20 00 F +90 262 641 23 09
<http://mam.tubitak.gov.tr>

AB-0378-T

4599

09-19

**ANALYSIS REPORT
(Industrial Services)**

Report no : 35487319-125.05-823-4599
Report date : 05.09.2019
Requested by : Restore Solutions, Inc. Chuck Rice President
Address : 3198 Royal Lane Suite 207 Dallas, Texas 75229
Subject : Petroleum Product Analysis

The results in this report are valid only for the analyzed samples.

Approved by

**Dr. Çiğdem TIRIS
Industrial Services Responsible of Energy Institute**

This report and results can not be used for commercial and advertisement purposes by the demanding enterprise or its customers. Complete or part of this report cannot be copied or published.

The marked (*) analyses are accredited. Analysis reports without authorized signature are not legitimate. Energy Institute accredited by TÜRKAK under registration number AB-0378-T for TS EN ISO/IEC 17025:2012 as Calibration Laboratory* Turkish Accreditation Agency (TURKAK) is a signatory to the European co-operation for Accreditation (EA) Multilateral Agreement (MLA) and to the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Agreement (MRA) for the recognition of calibration certificates.

The Turkish Accreditation Agency (TURKAK) is signatory to the multilateral agreements of the European co-operation for the Accreditation (EA) and of the International Laboratory Accreditation (ILAC) for the Mutual recognition of test reports.

The test and/or measurement results, the uncertainties (if applicable) with confidence probability and test methods are given on the following pages which are part of this report

This report is prepared as two originals (one for the customer, one for the institute archives) and contains 3 pages.

Page 1/3



T.C. ÇEVRE VE
ŞEHİRCİLİK BAKANLIĞI

MT
SÖ



AB-0378-T
4599
09-19

Report no : 35487319-125.05-823-4599
Requested by : Restore Solutions, Inc. Chuck Rice President
Address : 3198 Royal Lane Suite 207 Dallas, Texas 75229
Sample : Gasoil
Number of samples : 2
Sample handling : By Customer
Condition of sample at reception: Unsealed and Conditional
Expiry date : -
Institute sample register no: 19/379/1-2
Reception date and time : 04.09.2019
Date of the analysis : 05.09.2019

Information on retention samples:
 Sample returned to the customer Retention sample available Retention sample is not taken

19/379/1 : Mehmet AKİF

Parameter	Unit	Limits		Result	Measurement Uncertainty	Method
		Min.	Max			
*Cetane number	-	51,0	-	53,6	0,5	EN ISO 5165
*Cetane index	-	46,0	-	51,7	0,4	EN ISO 4264
*Density at 15 °C	kg/m ³	820,0	845,0	840,6	0,1	EN ISO 12185
*Polycyclicaromatic hydrocarbons	% (m/m)	-	8,0	1,9	0,1	EN 12916
*Sulfur content	mg/kg	-	10,0	7,4	0,5	EN ISO 20846
*Manganese content	mg/l	-	2,0	<0,5	-	EN 16576
*Flash point	°C	>55,0	-	69,5	2,0	EN ISO 2719
*Carbon residue (on 10 % distillation residue)	% (m/m)	-	0,30	<0,1	-	EN ISO 10370
*Ash content	% (m/m)	-	0,01	0,001	0,0002	EN ISO 6245
*Water content	% (m/m)	-	0,020	0,0044	0,0004	EN ISO 12937
*Total contamination	mg/kg	-	24	<12	-	EN 12662
*Copper strip corrosion (3 h at 50 °C)	rating	class 1		1a	-	EN ISO 2160
*Fatty acid methyl ester (FAME) content	% (V/V)	-	7,0	0,06	0,002	EN 14078
*Oxidation stability	g/m ³	-	25	1	0,3	EN ISO 12205
*Lubricity, wear scar diameter (WSD) at 60°C	µm	-	460	330	27	EN ISO 12156-1
*Viscosity at 40 °C	mm ² /s	2,00	4,50	2,986	0,013	EN ISO 3104
*Distillation						
% (V/V) recovered at 250 °C	% (V/V)		< 65	32,3	1,0	EN ISO 3405
% (V/V) recovered at 350 °C	% (V/V)	85		92,6	0,8	
95 % (V/V) recovered at	°C		360	359,6	4,3	
*CFPP	°C	-	+5 Summer -15 Winter	-5	0,9	EN 116

Notes:

Authorized Signatures:

 53398

This report and results can not be used for commercial and advertisement purposes by the demanding enterprise or its customers. Complete or part of this report cannot be copied or published.

The marked (*) analyses are accredited.

Analysis reports without authorized signature are not legitimate.

This report is prepared as two originals (one for the customer, one for the institute archives) and contains 3 pages. Page 2/3

CR

56 MT

Report no : 35487319-125.05-823-4599
Requested by : Restore Solitions, Inc. Chuck Rice President
Address : 3198 Royal Lane Suite 207 Dallas, Texas 75229

19/379/2 : KATKILI

Parameter	Unit	Limits		Result	Measurement Uncertainty	Method
		Min.	Max			
*Cetane number	-	51,0	-	53,3	0,5	EN SO 5165
*Cetane index	-	46,0	-	51,5	0,4	EN ISO 4264
*Density at 15 °C	kg/m ³	820,0	845,0	840,6	0,1	EN ISO 12185
*Polycyclicaromatic hydrocarbons	% (m/m)	-	8,0	1,9	0,1	EN 12916
*Sulfur content	mg/kg	-	10,0	7,5	0,5	EN ISO 20846
*Manganese content	mg/l	-	2,0	<0,5	-	EN 16576
*Flash point	°C	>55,0	-	68,5	2,0	EN ISO 2719
*Carbon residue (on 10 % distillation residue)	% (m/m)	-	0,30	<0,1	-	EN ISO 10370
*Ash content	% (m/m)	-	0,01	0,001	0,0002	EN ISO 6245
*Water content	% (m/m)	-	0,020	0,0048	0,0004	EN ISO 12937
*Total contamination	mg/kg	-	24	<12	-	EN 12662
*Copper strip corrosion (3 h at 50 °C)	rating	class 1		1a	-	EN ISO 2160
*Fatty acid methyl ester (FAME) content	% (V/V)	-	7,0	0,06	0,003	EN 14078
*Oxidation stability	g/m ³	-	25	1	0,4	EN ISO 12205
*Lubricity, wear scar diameter (WSD) at 60°C	µm	-	460	330	27	EN ISO 12156-1
*Viscosity at 40 °C	mm ² /s	2,00	4,50	2,979	0,013	EN ISO 3104
*Distillation						
% (V/V) recovered at 250 °C	% (V/V)		< 65	33,0	1,1	EN ISO 3405
% (V/V) recovered at 350 °C	% (V/V)	85		94,4	0,8	
95 % (V/V) recovered at	°C		360	351,8	4,2	
*CFPP	°C	-	+5 Summer -15 Winter	-5	0,9	EN 116

Summer: 16 March to 15 October inclusive

Winter: 16 October to 15 March inclusive

Notes:

Authorized Signatures:

53398

This report and results can not be used for commercial and advertisement purposes by the demanding enterprise or its customers. Complete or part of this report cannot be copied or published.

The marked (*) analyses are accredited.

Analysis reports without authorized signature are not legitimate.

This report is prepared as two originals (one for the customer, one for the institute archives) and contains 3 pages.

Page 3/3



nt

so