International Journal of Marine Engineering Innovation and Research, Vol. 8(1), Mar. 2023. 8-15
(pISSN: 2541-5972,eISSN: 2548-1479)

Testing the Inclination of an Industrial Diesel Engine Under Static Conditions According to the International Convention for the Safety of Life at Sea (SOLAS) Regulations

Suardi[1], Muhdar Tasrief[2], Samsu Dlukha Nurcholik[3] , Amalia Ika Wulandari[4], Wira Setiawan [5]

(Received: 26 January 2023 / Revised: 08 February 2023 / Accepted: 13 February 2023)

***Abstract*--many industrial diesel engines are used as the main engine of the ship. Apart from being relatively cheaper, the availability of industrial engine is also very abundant, and the repair process is also not too complicated. However, when viewed from the SOLAS regulations related to the main requirements for a ship propulsion engine, it must also be considered, because it operates at sea, so that ship engines must be tougher than industrial engines, especially related to engine performance when experiencing rolling and trim. The purpose of this research is to test the feasibility of industrial diesel engines being operated on ships. By using a water-cooled single-cylinder diesel engine which is commonly used in small ships. The experimental method was used in this research to obtain optimal results according to the conditions in the field, the engine was made in three variations, namely the normal condition (without inclination angle), the rolling condition of 15^0, and the trim condition of 5^0 which complies with SOLAS regulations related to the inclination angle. The results of the research obtained torque, Specific Fuel Consumption (SFC), and engine thermal efficiency in various engine variations. The highest torque is in the condition of the 15^0 rolling engine, which is 13.87 N.m. The lowest SFC is in the condition of the 15^0 rolling engine, which is 194 gr/kW.h. and the highest thermal efficiency was also obtained at the condition of the 15^0 rolling engine, namely 44.9%. The higher the engine speed, the higher the engine performance value in rolling 15^0 conditions, and the 5^0 trim conditions experience an increasing trend, but in low rotation conditions (750 Rpm) the performance decreases. Seeing the results obtained, a water-cooled single-cylinder diesel engine can be used as a small boat propulsion engine.**

Keywords- Engine Performance, Inclination Angle, Rolling 15^0, SOLAS, Trim 5^0

I. Introduction

International Maritime Organization (IMO) states that more than 90% of the volume of world trade is by sea [1][2] and almost all commercial ships use diesel engines as their prime mover [3]. The main reason marine engines are built differently from industrial engines is the risk of fire and corrosion [4]. Ship engines operate in a working environment with constant humidity and exposure to water. Exposure to salty sea water will damage engine materials more quickly, while industrial machines usually operate in a dry environment [5]. In terms of service life, diesel engines are also far superior to gasoline engines, diesel engines can operate for more than 30 years if routine maintenance is carried out, while gasoline engines are not able to operate for that long [6].

Suardi is with Department of Naval Architecture, Kalimantan Institute of Technology, Balikpapan, 76127, Indonesia. e-mail: suardi@lecturer.itk.ac.id
Muhdar Tasrief is with Biro Klasifikasi Indonesia, Jakarta Utara, 14320, Indonesia. e-mail: muhdar@bki.co.id.
Samsu Dlukha Nurcholik is with Maritime Sciences, Kobe University, 5-1-1 Fukaeminami-machi, Higashinada-ku, Kobe 658-0012, Japan e-mail: 180w901w@stu.kobe-u.ac.jp
Amalia Ika Wulandari is with Department of Naval Architecture, Kalimantan Institute of Technology, Balikpapan, 76127, Indonesia. e-mail: amaliaikaw@lecturer.itk.ac.id
Wira Setiawan is with Department of Naval Architecture, Kalimantan Institute of Technology, Balikpapan, 76127, Indonesia. e-mail : wira@lecturer.itk.ac.id

Diesel engines have good performance if the power and torque produced are large, as well as the thermal efficiency values must also be high (between 30% Thermal Efficiency (ηth) to 50%) and low Specific Fuel Consumption (SFC) values [7][8]. Because ship engines operate longer than industrial engines and the working environment of ship engines is different from the work environment of industrial engines, there must be special requirements met by diesel engines before they are said to be suitable for use on ships. A case regarding the sinking of the EL FARO ship which caused the death of 33 people on board revealed that the incident was due to extreme weather which caused the loss of the ship's propulsion because the engine used experienced extreme tilt which caused the lubricating oil pump and fuel pump to not be able to operate properly. optimally so that the engine turns off [9].

The International Convention for the Safety of Life at Sea (SOLAS), Chapter II-1, Regulation 26.6, stipulates that the ship's main engine must continue to operate even in a dynamic pitching condition of 7.5^0 by bow or stern and 22.5^0 under dynamic conditions (rolling) [10]. This rule is based on shipping conditions which are very different from conditions non-marine because there is often a difference in draft between the stern and the bow of the ship (trim) and it is very rare to get an even keel position and it is often in a state of trim by bow or trim by stern, it is not uncommon for ships to experience hard conditions when operated so that it can be ascertained that the engines that work for ships must be tougher than those that operate in the industry. The influence of the tilt angle on the engine has been studied to determine the effect of engine cooling, the test results show that the engine that is set at an inclination angle of 10 heats up faster because there is an accumulation of oil at one point so that other areas in the engine do not get optimal oil supply [11].

Due to the unstable working environment of the ship's engine due to the influence of waves, it is feared that the resulting engine performance value will also not be good, if usually engine performance testing is limited to fuel variations such as the effect of modifying the timing of natural gas injection on engine performance [12], a combination of biodiesel from microalgal [13], variations of biodiesel fuel from animal oils [14], determination of engine performance values with biodiesel from palm oil mill effluent (POME) [8] and calculation of performance values using corn oil [7]. All of these research was carried out under normal engine conditions (not in tilted conditions) or in the sense that they were only to test engine performance, for offshore. Because the specifications are different from industrial engine, the price of boat engines themselves is also much more expensive, for example, almost all traditional fishing boats (wooden boats) and ferries (klotok) in Indonesian territory use industrial engines for their boats [15].

By looking at the background above, research on the feasibility of onshore diesel engines to be used as the main propulsion engines of ships in terms of regulations of The International Convention for the Safety of Life at Sea (SOLAS) is very important to know the performance of these engines when converted into a diesel engine operating at sea.

II. Method

The method used in this study is an experimental method that is commonly used in research testing engine performance such as research testing engine performance with mixed fuel ethanol and gasoline [16] and experimental testing of engine performance with turbulent jet ignition control variations [17].

the fuel used in the test is a fuel with a high cetane number content and it is not recommended to use biodiesel because the cetane number is lower than diesel fuel (43 to 50) [18][19] so Pertamina dex diesel oil (This fuel has a cetane number of 53) [20] was used for fuel without any other fuel mixture and set at a normal temperature of 26^0 C and for the test engine, it was made based on the inclination variation standardized by SOLAS, namely dynamic trim conditions (pitching) $7{,}5^0$ by bow or stern and 22.5^0 under dynamic condition (rolling) or 15^0 static conditions then compared with the condition of the engine with an inclination of 0^0. The Indonesian Classification Bureau (BKI) provides almost the same rules, namely static conditions for the angle of inclination when transverse, namely 15^0, and the inclination angle of the front and the rear end is 5^0 [21]. The engine performance tested was power, torque, SFC, and thermal efficiency.

The flow of testing on the engine can be seen in Figure 1 below:

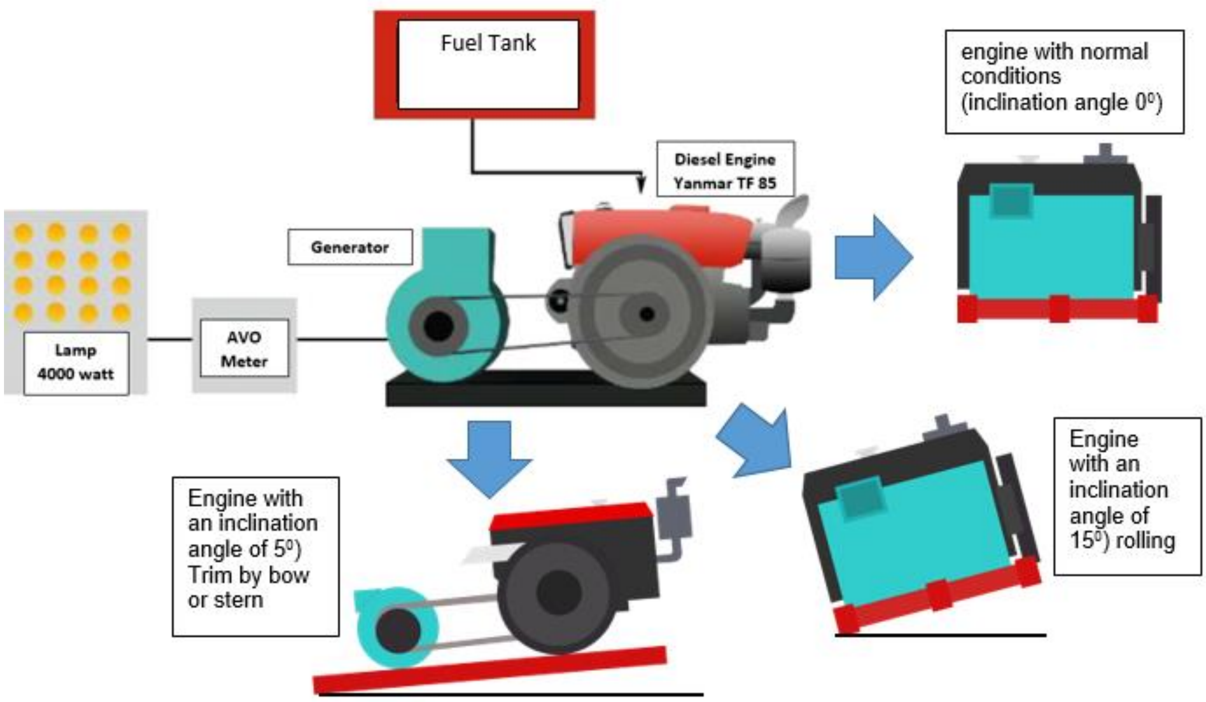

Figure. 1. Experimental System [7]

The engine specifications can be seen in table 1 below.

TABLE 1.
THE SPECIFICATIONS OF ENGINE [8][7].

Engine Type	Yanmar TF 75/85 Series
No of Cylinder	Cylinder 4 Stroke
Displacement	493 cc
Continuous Power	7,5 Kw/2200 rpm
Compression Ratio	1:18
Specific Fuel Consumption	171 gr/HP h

The research test scenario in Figure 1 shows that there are three engine conditions, namely the normal condition or without an inclination angle (0^0), a rolling condition with an inclination angle of 15^0, and a trim condition with an inclination angle of 5^0.

III. Results and Discussion

As previously explained, the research process is carried out by comparing the engine performance values under normal conditions and trim and rolling conditions.

A. Diesel engine performance testing process

The process of testing engine performance is carried out to find out whether by changing the position of the engine (both trim and rolling positions) the resulting engine performance value remains good or not, it is necessary to compare the results of engine performance under normal conditions or without any angle of inclination, in this case, the test was carried out on a YANMAR TF 85 Diesel engine. The testing process begins by putting fuel in the tank. Then the crank lever is rotated manually clockwise while raising the clutch, after playing, release the crank lever and clutch simultaneously. After the engine is active, wait a few moments to turn on the light load. The next step is to record the amount of current and voltage obtained at each step and calculate the fuel consumption time.

Testing on the engine was carried out in stages, namely with 20 ml of pure diesel fuel and then in 3 rpm variations (750 rpm, 1000 rpm, and 1250 rpm) and 4 lamp load variations (800 Watt, 1600 Watt, 2400 Watt, and 3200 Watt). on the lamps which amount to 32 lamps, each of which has a power of 100 Watts.

Figure 2 shows the condition of the diesel engine which has been set at the trim position of 5^0 and Figure 3 shows the position of the engine which is set at the rolling position of 15^0.

a) 

b) 

Figure. 2. a) Diesel Engines and Generators. b) Trim 5^0 engine condition

a) 

b) 

Figure. 3. a) Diesel Engines and Generators. b) Rolling 15^0 engine condition

TABLE 2.
ENGINE TEST RESULT DATA IN FOUR LOAD CONDITIONS

Fuel	Load (watt)	Rpm	V (Volt)	A (Ampere)	Time (s)	V (Volt)	A (Ampere)	Time (s)	V (Volt)	A (Ampere)	Time (s)
			Normal Condition (0^0)			Inclination angle of 15^0 (Rolling)			Inclination angle of 5^0 (Trim)		
Diesel Oil	800	750	69	1.7	228	35	1.59	303	56	1.51	251
	1600		71	3.42	187	47	2.55	283	64	2.12	229
	2400		78	5.12	149	48	3.8	242	72	2.91	203
	3200		82	6.06	127	52	4.7	229	76	3.32	185
Diesel Oil	800	1000	85	2.2	203	97	1.79	246	85	2.02	212
	1600		94	4.5	143	102	4.27	198	98	3.11	191
	2400		110	5.6	127	102	6.29	163	112	4.31	174
	3200		118	7.52	102	103	7.62	133	113	5.4	161
Diesel Oil	800	1250	91	3.21	147	121	2.93	158	118	2.04	169
	1600		101	5.2	116	143	5.3	136	138	4.14	132
	2400		121	6.44	80	158	7.9	104	159	5.47	118
	3200		132	7.8	62	167	8.7	85	172	7.26	94

1. Comparative analysis of Torque, SFC, and Thermal Efficiency vs. Power

Based on the data from the test results above, it can be calculated Power, torque, SFC, and Thermal Efficiency, while an example of the calculation is a sample engine test with a rotation of 750 Rpm with a load of 1000 watts with a variable position of the rolling engine 15^0.

$$P = 2\ (\pi n/60)\ T \qquad (1)$$

Where:
P = Power (W)
n = Engine Rotation (Rpm)
T = Torque (N.m)

Because during the engine test, the current and voltage values are obtained.

P = (Current x voltage x 0,001) / Load Factor
= (1,59 x 35 x 0,001) / 0,8
= 0,0696 kW

So, to get the torque value, the equation is:

$$T = (n/2)\ \pi\ (P/1000) \qquad (2)$$

With the above equation, it can be calculated torque as follows:

T = (750/2) 3,14 (69,6/1000)
T = 0,82 N.m

SFC calculation generated on a diesel engine with the following equation:

$$SFC = (mf \times 10000) / P \qquad (3)$$

Where:
SFC = Specific Fuel Consumption (gr/kWh)
mf = Fuel Consumption (kg/jam)
= ((ρ x vf) / tf) x 3600
P = Power (kW)
ρ = Fuel Density (kg/L)
vf = Fuel Volume (L)
tf = Fuel Consumption Time (s)

With the above equation, the SFC calculation can be performed as follows:

mf = ((ρ x vf) / tf) x 3600
= ((0.00001 x 833)/303) x 3600
= 0.09897 kg/h

SFC = (0.09897 x 10^3) / 0.0695625
= 1422.7536 gr / kW.h

The value of thermal efficiency can be calculated using the formula.

$$\eta_{th} = (P / (mf \times LHV) \times 3600) \times 100 \qquad (4)$$

Where:
P = Power (W)
mf = Fuel Consumption (kg/jam)
LHV = Low Heating Value (kj/kg), for diesel oil
= 43400 kj/kg [22]

η_{th} = (0.0695625/(0.09897 x 43400) x 3600) x 100
= ((0.88 x 0.1) / 309) x 3600
= 5.83%

The results of calculating Torque, Power, and SFC from three fuel samples at four load variations in full can be seen in table 4 below.

TABLE 3.
DATA RESULTS OF THE CALCULATION OF POWER, TORQUE, AND THERMAL EFFICIENCY IN TOTAL.

Load (watt)	Rpm	Ne (kW)	Torque (N.m)	SFC (gr/kWh)	ηth (%)	Ne (kW)	Torque (N.m)	SFC (gr/kWh)	ηth (%)	Ne (kW)	Torque (N.m)	SFC (gr/kWh)	ηth (%)
		Normal Condition (0^0)				Inclination angle of 15^0 (Rolling)				Inclination angle of 5^0 (Trim)			
800	750	0.15	1.87	897	9.3	0.07	0.89	1423	5.8	0.11	1.35	1130	7.3
1600		0.30	3.86	528	15.7	0.15	1.91	707	11.7	0.17	2.16	772	10.7
2400		0.50	6.35	403	20.6	0.23	2.90	543	15.3	0.26	3.33	564	14.7
3200		0.62	7.91	380	21.8	0.31	3.89	429	19.4	0.32	4.01	514	16.1
800	1000	0.23	2.23	632	13.1	0.22	2.07	562	14.8	0.21	2.05	659	12.6
1600		0.53	5.05	397	20.9	0.54	5.20	278	29.8	0.38	3.64	412	20.1
2400		0.77	7.35	307	27.1	0.80	7.66	229	36.2	0.60	5.76	286	29.0
3200		1.11	10.59	265	31.3	0.98	9.36	230	36.1	0.76	7.28	244	34.0
800	1250	0.37	2.79	559	14.9	0.44	3.38	428	19.4	0.30	2.30	590	14.1
1600		0.66	5.01	394	21.1	0.95	7.23	233	35.6	0.71	5.45	318	26.1
2400		0.97	7.44	385	21.6	1.56	11.91	185	44.9	1.09	8.30	234	35.5
3200		1.29	9.83	376	22.1	1.82	13.87	194	42.7	1.56	11.92	204	40.6

2. Comparative analysis between SFC vs Load

With variations in the angle of inclination of the engine, the value of engine performance can be compared in terms of the power generated and the amount of fuel consumption experienced by the engine (SFC). In Figure 4 you can see a comparison chart between SFC and load at three variations of engine speed.

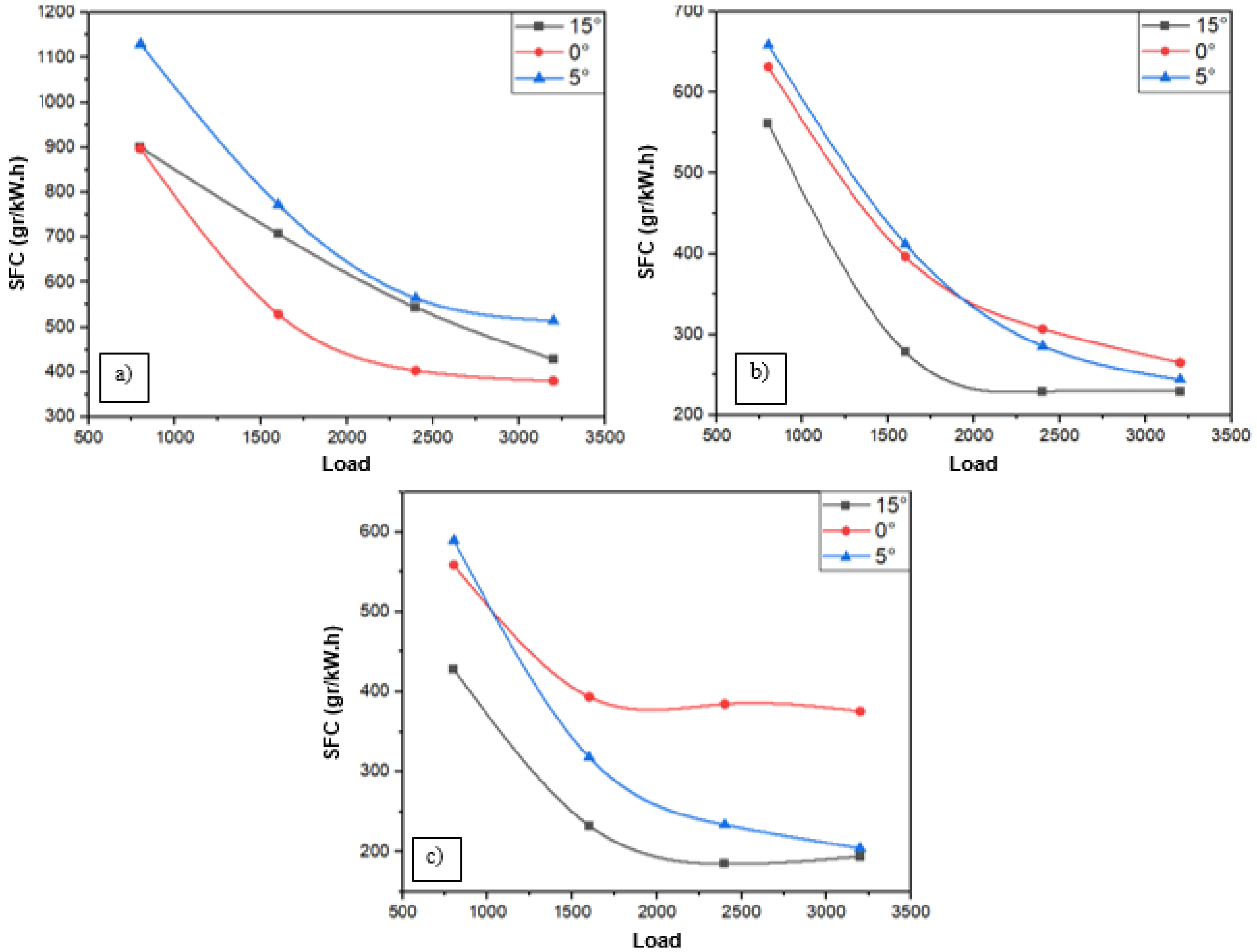

Figure. 4. Comparison graph of SFC with load for each Rpm (a) 750 Rpm, (b) 1000 Rpm, (c) 1250 Rpm

Figure 4. a) is a comparison graph of SFC vs load with variations in the position of the engine rolling 15^0, flat engine position 0^0, and trim aft engine position 5^0, the graph above shows the SFC value of Rpm 750 which is the largest value found on the 15^0 rolling graphs with SFC value of 1422.7 gr/kWh. While the lowest is found on the graph with a flat inclination of 0^0 of 380.1 gr/kWh. Figure 4. b) shows the SFC value of Rpm 1000 where the highest value is found on the 5^0 trim chart with an SFC value of 659.06 gr/kWh. Meanwhile, the lowest is found on the graph with a left tilt of 15^0 of 229.8 gr/kWh. Figure 4. c) shows the highest Rpm 1250 SFC value found on the 5^0 stern trim charts with an SFC value of 589.7 gr/kWh. While the lowest is found on the graph with a 15^0 rolling of 184.8 gr/kWh.

The level of fuel consumption under normal circumstances (without tilt) looks better when compared to the condition of the rolling 15^0 and trim 5^0 engines. However, when the engine speed rises to Rpm 1250 it makes the engine SFC much more efficient. By looking at the results of these tests, it can be concluded that the influence of the tilt of the engine greatly affects the value of fuel consumption, the greater the angle of inclination of the engine at a lower Rpm, the higher the SFC of the engine. but when the Rpm is high, the engine with rolling 15^0 is even more efficient.

3. Comparative analysis between Torque vs Load

Another engine performance parameter is the torque, the engine torque itself is the boost from the engine that occurs between the piston and the crankshaft. the value of engine torque in three variations of inclination angle can be seen in Figure 5 below.

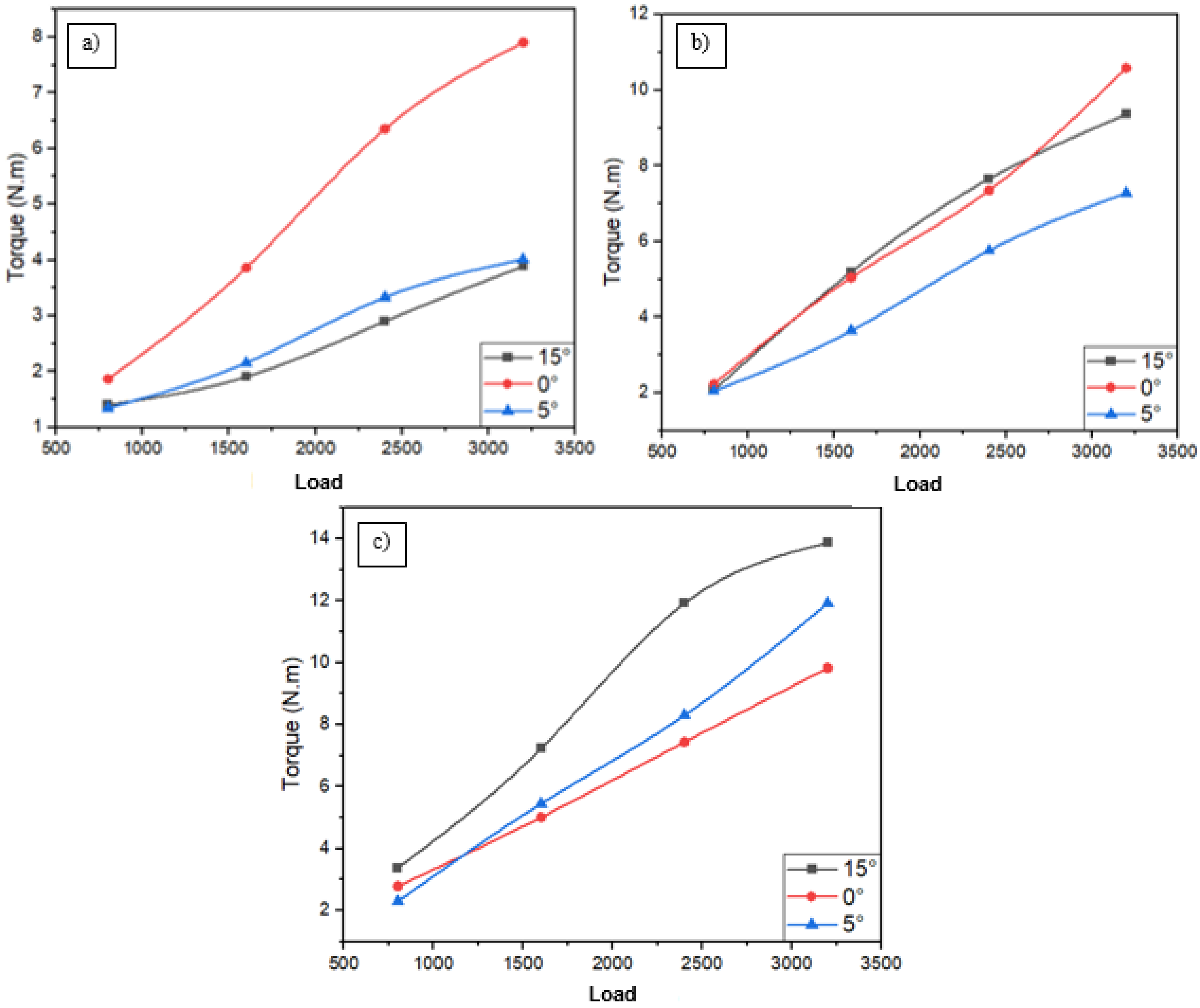

Figure. 5. Comparison graph of Torque with load for each Rpm (a) 750 Rpm, (b) 1000 Rpm, (c) 1250 Rpm

Figure 5. a) is a Torque vs. load comparison chart with diesel fuel which shows a comparison between 15^0, 0^0, and 5^0. The graph above shows the highest torque value of Rpm 750 found on graph 0^0 with a torque value of 7.91 Nm. While the lowest is found on the graph with a left tilt of 15^0 of 0.89 Nm. Figure 5. b) shows the highest torque value at Rpm 1000 on graph 0^0 with a torque value of 10.59 Nm. While the lowest is on the trim 5^0 inclination of 2.05 Nm. Figure 5. c) shows the highest Torque value at Rpm 1250 on a graph with an inclination of 15^0 with a Torque value of 13.87 Nm. While the lowest is found on the graph with the stern trim inclination of 5^0 of 2.29 Nm.

The torque value when the engine is in normal condition (without tilt) at Rpm 750 looks better when compared to the rolling 15^0 and trim 5^0 engine conditions.

However, when the maximum Rpm is (1250), the engine torque value in rolling 15^0 and trim 5^0 conditions increase. for the results of these tests, it can be concluded that the greater the angle of inclination of the engine makes the engine Torque decrease, but the torque will increase if the engine is operated at 1250 Rpm rotation.

3. Comparative analysis between Thermal Efficiency vs Load

Another engine performance parameter is thermal efficiency, the thermal efficiency of the engine itself can be said to be the amount of energy produced by burning fuel that the engine converts into power. the value of the thermal efficiency of the engine in three variations of the inclination angle can be seen in Figure 6 below.

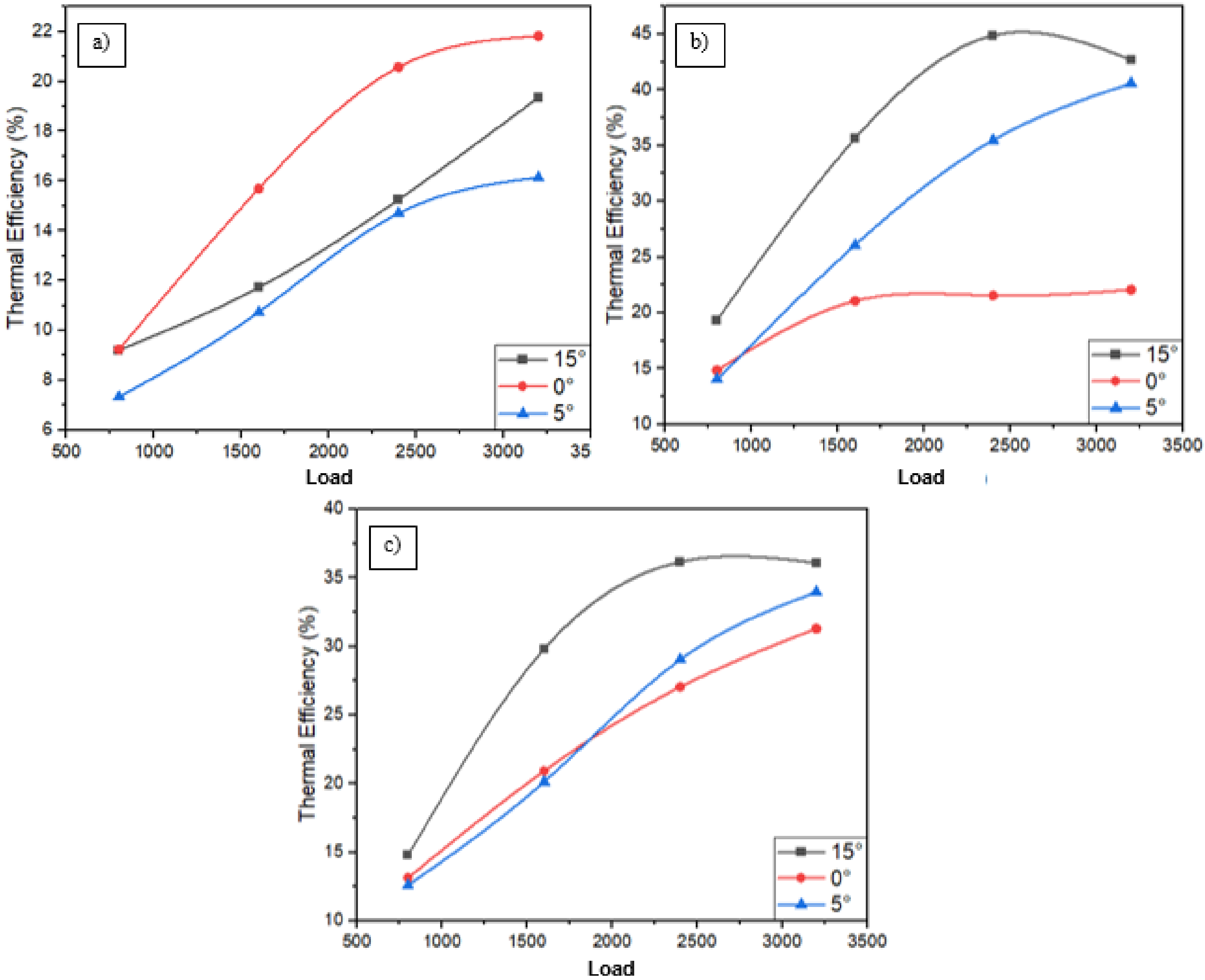

Figure. 6. Comparison graph of Thermal Eff with load for each Rpm (a) 750 Rpm, (b) 1000 Rpm, (c) 1250 Rpm

Figure 6. a) is a graph of the comparison of Thermal Efficiency against loads with diesel fuel which shows a comparison between 15^0, 0^0, and 5^0. The graph above shows the highest Rpm 750 Thermal Efficiency value found on graph 0^0 with a Thermal Efficiency value of 21.82%. While the lowest is found on the graph with a rolling of 15^0 of 5.83%. Figure 6. b) shows the highest Rpm 1000 Thermal Efficiency value on the rolling 15^0 charts with a Thermal Efficiency value of 36.16%. While the lowest is found on the graph with a stern trim of 5^0 of 12.59%. Figure 6. c) shows the highest Rpm 1250 Thermal Efficiency value on the rolling 15^0 charts with a Thermal Efficiency value of 44.88%. While the lowest is found on the graph with a trim of 5^0 of 14.07%.

The results of testing the engine show that the value of thermal efficiency has an increasing trend on the variation engine with a rolling of 15^0 when the engine operates at 1000 Rpm and above. But at low rotation (750 Rpm) the best value is in normal engine conditions.

IV. Conclusion

Regarding the many ships that use industrial engines as the prime mover so that feasibility tests are carried out in terms of the SOLAS regulations regarding the angle of inclination of the ship's engines, the results obtained in this study indicate that although the engines are still capable of operating in a state of rolling 15^0 and trim 5^0 In terms of performance values, the engine has decreased. Engine torque under normal conditions at low speed (750 Rpm) is better than torque when the engine is rolling 15^0 and trim 5^0, which is 7.91 N.m. The lowest SFC is also shown when the engine is normal at low speeds, namely 350 gr/kW.h, but at Rpm 1000 and above the SFC of an engine with a rolling of 15^0 and a trim of 5^0 is even better. and the value of thermal efficiency for engines with a rolling of 15^0 and trim 5^0 also shows a better trend with the highest value of 44.9%, while the thermal efficiency of the engine under normal circumstances does not reach 30%. Overall, the value of engine performance both in terms of power, torque, and SFC is still better if the engine is in normal conditions or without a tilt angle.

References

[1] S. Zhang *et al.*, “Challenges and countermeasures for international ship waste management: IMO, China, United States, and EU,” *Ocean Coast. Manag.*, vol. 213, no. July, p. 105836, 2021, doi: 10.1016/j.ocecoaman.2021.105836.

[2] G. Xie, W. Yue, and S. Wang, “Energy efficiency decision and selection of main engines in a sustainable shipbuilding supply chain,” *Transp. Res. Part D Transp. Environ.*, vol. 53, pp. 290–305, 2017, doi: 10.1016/j.trd.2017.04.022.

[3] M. Rovira, K. Engvall, and C. Duwig, “Sensitivity analysis of an ammonium salt formation model applied to pollutant removal in marine diesel exhaust gases,” *Fuel*, vol. 332, no. P1, p. 126001, 2023, doi: 10.1016/j.fuel.2022.126001.

[4] J. Fragasso and L. Moro, “Structure-borne noise of marine diesel engines: Dynamic characterization of resilient mounts,” *Ocean Eng.*, vol. 261, no. August, 2022, doi: 10.1016/j.oceaneng.2022.112116.

[5] “Common Differences Between Marine and Industrial Diesel Engines - Capital Reman Exchange.” https://www.capitalremanexchange.com/common-differences-between-marine-industrial-diesel-engines/ (accessed Jan. 21, 2023).

[6] I. Veza *et al.*, “Review of artificial neural networks for gasoline, diesel and homogeneous charge compression ignition engine: Review of ANN for gasoline, diesel and HCCI engine,” *Alexandria Eng. J.*, vol. 61, no. 11, pp. 8363–8391, 2022, doi: 10.1016/j.aej.2022.01.072.

[7] S. S. Suardi, “Analisa Penggunaan Biodiesel Minyak Jagung Sebagai Campuran Bahan Bakar Alternatif Mesin Diesel,” *Inovtek Polbeng*, vol. 9, no. 2, p. 280, 2019, doi: 10.35314/ip.v9i2.1041.

[8] Suardi, M. Purwanto, A. Y. Kyaw, W. Setiawan, and M. U. Pawara, “Biodiesel Production from POME (Palm Oil Mill Effluent) and Effects on Diesel Engine Perfor- mance,” *Int. J. Mar. Eng. Innov. Res.*, vol. 7, no. 4, pp. 292–299, 2022, doi: 10.12962/j25481479.v7i4.14492.

[9] L. Learned and S. S. E. L. Faro, “Compliance with SOLAS and USCG Regulations for Operation of Main Propulsion and Essential Auxiliary Machinery,” 2018.

[10] International Maritime Organization, *SOLAS : consolidated text of the International Convention for the Safety of Life at Sea, 1974, and its Protocol of 1988 : articles, annexes and certificates*. 2004, p. 566.

[11] G. Xie *et al.*, “Study on the effect of inclination angle on two-phase oscillating flow and heat transfer characteristics of piston cooling galleries,” *Case Stud. Therm. Eng.*, vol. 38, no. June, p. 102355, 2022, doi: 10.1016/j.csite.2022.102355.

[12] S. Semin, B. Cahyono, Y. Prasetiyo, and F. M. Felayati, “Experimental Analysis of Gas Split Injection Effect on Dual-Fuel Engine Performance,” *Int. J. Mar. Eng. Innov. Res.*, vol. 6, no. 2, pp. 98–108, 2021, doi: 10.12962/j25481479.v6i2.5632.

[13] N. A. Azeez *et al.*, “Biodiesel potentials of microalgal strains isolated from fresh water environment,” *Environ. Challenges*, vol. 5, no. August, p. 100367, 2021, doi: 10.1016/j.envc.2021.100367.

[14] G. A. C. Jayaseelan, A. Anderson, M. K. Poduva, P. V. Sudheesh, and Roshith, “Synthesis and performances characteristics of biodiesel from animal fat,” *Mater. Today Proc.*, vol. 45, pp. 6053–6056, 2020, doi: 10.1016/j.matpr.2020.10.002.

[15] S/adv/mra/luc/k8, “Teknik Perkapalan ITK Peduli Masyarakat,” *Kaltim Post*, Balikpapan, p. 8, Jul. 2020.

[16] S. V. Kumbhar and S. A. Khot, “Experimental investigations of ethanol-gasoline blends on the performance, combustion, and emission characteristics of spark ignition engine spark ignition (S.I) engine with partial addition of n-pentane,” *Mater. Today Proc.*, no. xxxx, 2022, doi: 10.1016/j.matpr.2022.11.284.

[17] Z. Liu, L. Zhou, and H. Wei, “Experimental investigation on the performance of pure ammonia engine based on reactivity controlled turbulent jet ignition,” *Fuel*, vol. 335, no. November 2022, p. 127116, 2023, doi: 10.1016/j.fuel.2022.127116.

[18] S. kumar, M. K. Singhal, and M. P. Sharma, “Analysis of Oil Mixing for Improvement of Biodiesel Quality with the Application of Mixture Design Method,” *SSRN Electron. J.*, vol. 202, no. November 2022, pp. 809–821, 2022, doi: 10.2139/ssrn.4012739.

[19] A. Kolakoti, A. V. Kumar, R. Metta, M. Setiyo, and M. L. Rochman, “Experimental studies on in-cylinder combustion, exergy performance, and exhaust emission in a Compression Ignition engine fuelled with neat biodiesels,” *Indones. J. Sci. Technol.*, vol. 7, no. 2, pp. 219–236, 2022, doi: 10.17509/ijost.v7i2.49680.

[20] A. R. Wijaya *et al.*, “Road-side dust from central Jakarta, Indonesia: Assessment of metal(loid) content, mineralogy, and bioaccessibility,” *Environ. Technol. Innov.*, vol. 28, p. 102934, 2022, doi: 10.1016/j.eti.2022.102934.

[21] BKI vol III (Rules for Machinery Installation), *No Tit.צכןle*. Indonesia, 2023, pp. 1–11. [Online]. Available: https://www.ptonline.com/articles/how-to-get-better-mfi-results

[22] E. Purwanto, B. Cahyono, P. Syamrahmadi, and A. Faisol, “Analysis of Diesel Engine Components Durability on Fishing Vessel Fueled with Biodiesel (B30),” *Int. J. Mar. Eng. Innov. Res.*, vol. 6, no. 3, pp. 204–209, 2021, doi: 10.12962/j25481479.v6i3.9451.