Modern Mechanical Engineering, 2022, 12, 74-82
https://www.scirp.org/journal/mme
ISSN Online: 2164-0181
ISSN Print: 2164-0165

Diagnosis of Thermal Overload and Power Losses in Boat Yang 1's CAT 3408 Marine Diesel Engine from Used Oil and Coolant Analysis

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How to cite this paper: Kontchou, M.V., Emakoua, T. and Pandong, A.N. (2022) Diagnosis of Thermal Overload and Power Losses in Boat Yang 1's CAT 3408 Marine Diesel Engine from Used Oil and Coolant Analysis. *Modern Mechanical Engineering*, **12**, 74-82.
https://doi.org/10.4236/mme.2022.123005

Received: July 18, 2022
Accepted: August 26, 2022
Published: August 29, 2022

Abstract

In the design of the CAT 3408 engine, the Low Temperature (BT) circuits used to cool the engine lubricating oil and the charge air and the High Temperature (HT) circuits for cooling the cylinder liners, cylinder heads and body of turbofans are mainly used to cool the engine, so that it works properly. This work, based on the analysis carried out, to determine the lubrication compliance of the Yacco VX 100 - SAE 15 W-40 oil and that of the Camwater water used in the engine of the Boat Yang 1 by carrying out a series of conventional tests such as that: the density, the viscosity, the viscosity index, the flash point, the density, the sulphate center content, the water content, the total acidity index (TAN), total basic number (TBN) and pour point for the oil case and pH, hardness, sodium chloride content [NaCl], sodium sulphate content [$NaSO_4$] for the water case which will be compared to the specified requirements to determine whether compliance is achieved for each of these characteristics. The results of the oil and water samples taken from the engine after use show that the used oil gives a specific gravity of 0.8822, a viscosity (at 40˚C) of 92.29 mm^2/s, a viscosity (at 100˚C) of 13.99 mm^2/s, a viscosity index (VI) of 155.39, a pour point −21˚C, a Flash Point (VO) 215˚C, a Sulfated ash content of 18%, a density 881.5 kg/m^3, a total basic number (TBN) of 12.60 mgKOH/g, a Total Acid Index (TAN) of 3.096 mgKOH/g, a Water Content of 1.8 % and the water used gives a pH of 6.00, a hardness of 3.2 french degrees, a sodium chloride content [NaCl] of 0.468 mg/L, and a calcium sulphate content [$CaSO_4$] of 2.38345 mg/L. the results of the water content and content of sulfated centers justify the thermal overload and power losses in the marine diesel engine CAT 3408 of the boat Yang 1 because of their values which are not in conformity with the standards.

Keywords

Reporting, Reasons, Thermal Overload, Power Losses

1. Introduction

According to the manufacturer's specifications via the bulb pressure gauge incorporated in the engine, this Diesel engine is designed so that the temperature of the water in the High Temperature (HT) circuit is always between 40˚C and 80˚C for normal operation. This main engine cooling circuit of the YANG 1 vessel has an indirect cooling system. In this system, the engine is not cooled by sea water but by fresh water; itself cooled by seawater via a heat exchanger. The system therefore consists of a freshwater circuit and a seawater circuit. The freshwater circuit is a forced closed circuit. The temperature of the water circulating in the cylinder head and around the cylinders is regulated by a thermostat which prevents the circulation of water in the exchanger. The circulation of the sea water taken by a through-hull located under the waterline is ensured by a volumetric pump driven by a motor. The calorie-laden seawater after passing through the heat exchanger is discharged into the exhaust manifold. This circulating water is generally treated to limit the effects of corrosion in the various water chambers located in the frame and in the cylinder heads. The purpose of this work is to use a conventional method to diagnose the engine from the analysis of used oil and coolant. The recommended method for identifying the major cause to solve the problem is presented in Part II. The principle of the analytical methods used is presented in Part III.

2. Lists of Probable Causes of Overheating and Power Losses

For the possible causes we cannot give an exhaustive list but it will be provided elements which can be at the origin of this increase in temperature. The causes will be presented according to **Figure 1**.

3. Principle of Analytical Methods

3.1. Conventional Method

3.1.1. Viscosity at 40˚C and at 100˚C

- Principle according to the standard:

This technique aims to measure the flow time of a quantity of lubricant through a capillary provided with two markers at a given temperature, it is carried out at temperatures of 40˚C and 100˚C. The capillary viscometer used consists of a capillary tube containing the oil to be characterized. The oil flows through the capillary under the action of gravity, the measurement of time flow makes possible the determination of the viscosity of the oil, at a constant temperature controlled by a viscometric bath.

This kinematic viscosity is determined using the following relationship:

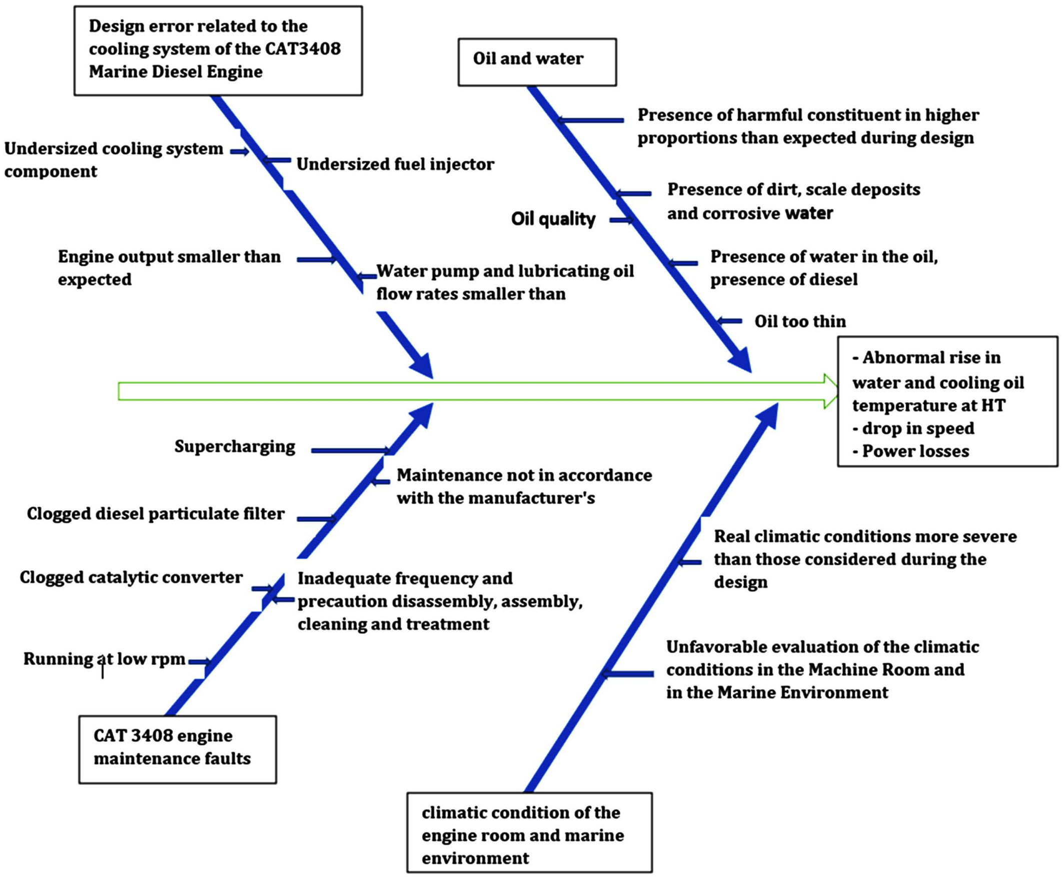

Figure 1. HISHIKAWA cause-effect diagram.

$$\upsilon = C * t$$

where C is calibration constant of the viscosimeter, (mm^2/s), and t is mean flow time, s.

3.1.2. Viscosity Index (D2270)

➢ Principle:

The viscosity index is used to characterize the quality of oil, greater is the index, less the viscosity varies according to the temperature. The viscosity index is determined either from the measurements of the kinematic viscosities carried out respectively at 40˚C and at 100˚C. And using the Groff chart, or by using a specific calculation program.

3.1.3. Flash Point (D92)

➢ Principle:

The flash point is the temperature at which oil vapors ignite in the presence of a flame. Its test consists in heating a sample of the product in an open vessel at a determined rate until a sufficient quantity of volatile elements is vaporized and can be ignited by a small flame which is moved below the vessel. As soon as a flash appears, the temperature of the product is noted, which corresponds to the flash point.

3.1.4. Specific Gravity (D1298)

- Principle:

The density of oil is the ratio of its density according to the quantity of water taken as a reference at a temperature of 4˚C. The measurement technique varies according to the desired measurement accuracy. Routine measurements are most often made with a standard hydrometer. For more precise measurement, a pycnometer is used, it is characterized by a very precise volume. Density is determined by weighing.

3.1.5. Pour Point (D97, D2500)

- Principle: The preheated oil is cooled, and its flow characteristics are observed at 3˚C interval. The minimum temperature at which the oil still flows is noted, it corresponds to the pour point.

3.1.6. Density D1298

- Principle: The principle of the oscillating U-tube, the sample is poured into a borosilicate glass U-tube, which is electronically oscillated at its characteristic frequency. The characteristic frequency varies with the density of the sample. The density of the sample can be calculated by determining the characteristic frequency. Since the value of the density depends on the temperature, the temperature of the sample must be determined precisely.

3.1.7. Hydrogen Potential (pH)

- Principle: The pH was determined at 25˚C using a multi-parameter pH meter.

3.1.8. Total Hardness

- Principle: It was measured by the complexometric method.
- V: sample volume (mL)
- A: volume of assay solution needed to assay sample V (mL)

EDTA method:

- Determination of correction B by dosing distilled water with a 0.02 eq/L EDTA solution in the presence of Net indicator
- Assay of V sample, with the EDTA solution, in the presence of Net indicator: A is obtained

$$\text{Total hardness} = (AB)*1000/V \text{ mg/L of } [CaCO_3]$$

3.1.9. Sodium Chloride (NaCl) Content

- Principle: We measured the chlorides by the Mohr method.

Mohr's method:

- Determination of the correction B by titration of distilled water, with a solution of $AgNO_3$ 0.015 eq/L, in the presence of the indicator K_2CrO_4
- Assay of V sample, with the solution of $AgNO_3$, in the presence

$$[Cl^-] = 0.015*(AB)/V \text{ eq/L};$$

$$[NaCl] = 0.015*(AB)*58500/V \text{ mg/L}$$

3.1.10. Calcium Sulfate ($CaSO_4$) Content

➢ Principle:

In order to know the $[CaSO_4]$ concentration, we will consider the most commonly used grouping order for ions:

Cations: $Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}$

Anions: $NO_3^-, SO_4^{2-}, HCO_3^-, Cl^-$

The concentrations in Ca^{2+}, NO_3^- and SO_4^{2-} in milliequivalents per liter (meq/L) taking into account the order of grouping, going through complexometric dosage and titration in order to apply the following formula:

$$[CaSO_4] = \text{Minium}\left\{\left[Ca^{2+} - NO_3^-\right]; SO_4^{2-}\right\}$$

or all the concentrations are expressed in meq/L.

4. Results and Discussion

The results obtained from the physico-chemical analysis of the oil are presented in the Table 1.

Table 1 presents the results of the physicochemical characteristics of oils Ref [1], Ref [2], Ref [3], obtained compared to specifications. Note that the density is 0.8822, the density is 881.5. These values respectively approach the original values, and belong respectively to the intervals (0.85 - 0.95) and (850 - 920) so we can deduce that they are consistent.

The value 92.29 Cst of viscosity at 40˚C to undergo a change of 9.52% which remains lower than the maximum change which is 25% [4]. The viscosity value 13.99 Cst at 100˚C undergoes a decrease of 3.5% which is less than the maximum decrease which is 15% [4]. These values are also close to their original values, moreover the viscosity at 100˚C. obtained meets the D 445 standard and

Table 1. Characteristic physico-chemical results of Yacco VX 100-SAE 15 W 40 oil obtained compared to ASTM specifications.

TESTS	STANDARDS	Values			Result Value	Standard Deviation
		Minimum	Max	Original value		
Specific gravity	D1298	0.85	0.95	0.8725	0.8822	±0.00048
Viscosity (at 40˚C) (mm^2/s) = [Cst]	D445	-	-	102	92.29	±6.86601
Viscosity (at 100˚C) (mm^2/s) = [Cst]	D2270	12.5	16.3	14.5	13.99	±0.36062
Viscosity index (VI)	D2896	-	-	143	155.39	±8.76105
Pour point (˚C)	D97	-	-	−33	−21	±8.48528
Flash Point (VO) (˚C)	D93	-	-	220	215	±3.53553
Sulfated ash content (% masse)	D874	-	-	1.36	18	±11.8086
Density (Kg/m^3)	D1298	850	920	871	881.5	±7.42462
total basic number (TBN) (mgKOH/g)	D2896	-	-	11	12.60	±1.13137
Total Acid Number (TAN) (mgKOH/g)	D664	-	-	15.2	3,096	±8.55882
Water content (% masse)	D64	-	-	-	1.8	±0.00000

belongs to the interval (12.5 Cst - 16.3 Cst). The viscosity decreases with the increase in temperature, in fact, more the oil is at low temperature, the thicker it is, and higher the temperature, more is the fluid of oil [5].

The viscosity index is 155.39, this value complies with the D 2270 standard which imposes a minimum value of 126, and it characterizes the ability of the lubricant to keep its constant viscosity in a wide temperature range, higher is this index, less is the viscosity of this oil, and is influenced by temperature [6].

The flash point value obtained is 215˚C, it complies with the D 93 standard which requires a minimum value of 215˚C, this flash point provides information on the volatility of the oil, and possibly on the release capacity of the lubricant remove flammable vapors [7].

For the pour point, the specification gives a maximum value of −27˚C, the value obtained is −21˚C, so we can deduce that this value is not compliant.

The value of total basic number (TBN) found is 12.60 and that of the manufacturer is 11 so these values are in accordance with ATSM because the original starting values for most diesel engine oils vary between 10 and 14, although marine engines running on heavy fuel oil need a much higher TBN, even up to 80, to withstand the harsh combustion conditions of fuel oils containing a high concentration of sulfur [8]. The rule of thumb in general is that it is time to dispose of the oil when the TBN drops to 70% and 50% of its original value signaling a Danger and a Warning respectively [4].

The value of the Total Acid Index (TAN) found is 3.096 and that of the Manufacturer is 15.2. These values conform according to the ASTM classification. TAN limits vary widely and depend on OEM specifications and the oil itself. In some cases, a TAN of more than 0.05 is unacceptable. In others, it remains accepted able up to 2.00 [8]. The acid number cannot increase by more than 0.5 AN compared to new oil. If an increase of more than 1 AN is observed, action should be taken immediately (if the new oil has an index of 0.5 AN, then 1.0 AN corresponds to a warning value and 1.5 AN to an alarm value) [4].

For water content, many oil analysis reports very inaccurately state the water content as "<0.1%", *i.e.* less than 1000 mg/L. Yet that found is 1.8% or 18,000 ppm which is well above 0.1% so this value does not comply with the D 64 standard. So we will say that in the CAT 3408 engine, there is a sealing problem.

It can be at the cylinder head gasket, the turbocharger because the coolant contains glycol and distilled water. The cooling and lubrication circuits are separate. The presence of glycol in the oil definitely indicates a communication between these two circuits. It is often the cylinder head gasket that has a defect, unless it is the cylinder head and its gasket surface or, more seriously, a crack on a cylinder.

Or at the level of the exhaust pipe because a faulty exhaust system can let sea water enter in the cylinders. This is a serious problem that often comes from a bad design of the anti-siphon mounted on the line. Sea water being salty, this water has a high corrosion power on the cylinders made of cast iron.

For the sulphate center content is quite very high, a value found of 18% which is largely enormous for a marine diesel engine. However, the D 874 standard requires that this content must be between 0.8% and 1.6%. So our found value does not conform. So this reflects poor combustion quality in the CAT 3408 engine.

4.1. Checking Oil Viscosity Yacco VX 100 - SAE 15 W-40 through the Groff Chart

The Groff abacus allows us to represent the oil used by a point, it is obtained by the intersection of two straight lines each passing through the viscosity value and the corresponding temperature value (V_1, T_1 = 100˚C and V_2, T_2 = −15˚C). Determining the location of this point gives the specifications that this oil meets [9] [10].

According to the results found, the viscosity value at −15˚C is 3301 Cp, it is in the SAE 15 W category which requires a maximum value of 3500 Cp [11], the value of viscosity obtained at 100˚C is 14.27 Cst. This value is part of the SAE 40 category, and belongs to the interval (12.5 Cst - 16.3 Cst) [12]. At low temperature the viscosity must be low enough to facilitate engine starting, and at high temperature the viscosity must be high enough to protect the engine [13].

4.2. Discussion of These Results on the Degradation of the Lubricant Used in the Engine

From **Table 1** we notice that the viscosity at 40˚C and at 100˚C of the oil undergoes a decrease. This decrease is mainly due to the dilution of the oil by the fuel, it can also come from the mechanical shear which causes the degradation of the additives improving the viscosity index [14]. Similar to viscosity, the viscosity index of engine oil in service increases, and this is due to the degradation of polymeric viscosity index improver additives by mechanical shear [15].

Always from **Table 1** we notice an increase in the density of the oil, this is due to the different quantities of water or fuel present in the oil, which come from the combustion of the fuel in the engine [16].

There is an increase in the pour point of the lubricating oil, which is due to the decrease in the function of the pour point depressant additives, and the formation on paraffin crystals [17] [18].

We notice a decrease in the flash point of the engine oil, this decrease could be the result of the presence of unburned fuel, or the cracking of thermic of oil molecules [19].

There is an excessive increase in the sulfated center content, this increase could be the presence of additives consisting of organometallic salts which lead, by complete calcination, to the formation of ashes such as; calcium, magnesium, zinc, potassium, sodium, tin or in the combined form of sulphur, phosphorus and chlorine.

We notice an excessive increase in the water content, this increase could be the presence of free hydrogen ions in the water which can further aggravate the

Table 2. Typical coolant analysis results obtained compared to manufacturer's specifications and values.

TESTS	Typical values	Result Value
pH	7 ≤ pH	6.00
Hardness	≤25 degrees french	3.2
[NaCl] (mg/L)	≤60 mg/L	0.468
[$CaSO_4$] (mg/L)	≤40 mg/L	2.38345

situation, because they migrate into the engine components, making the steel brittle and susceptible to crack. Water also causes corrosion and erosion, leading to pitting damage [4].

4.3. Typical Coolant Analysis Results Obtained Compared to Manufacturer's Specifications and Values

In order to know the behavior of the coolant in the engines, an analysis of the latter was carried out and the results are recorded in Table 2. All the values obtained are below the norm. This can be explained by the composition of seawater with its impurities.

The results of the analysis reveal that, according to the manufacturer's instructions, the water or make-up intakes in Douala and Limbe are very detrimental to heat exchange within the cooling circuit.

5. Conclusion

This work has a water content of 1.8% which is greater than 0.1%, which indicates contamination of the water with oil. It also has a fairly high sulphate center content that means a found value of 18%, which is largely enormous for a marine diesel engine, not belonging to the interval (0.8% - 1.6%) according to the D 874 standard. It appears that the excessive rise in temperature from overheating in the CAT 3408 Diesel engine Built by Caterpillar, and used by the vessel Yang 1 is responsible for the distress frequently observed online through bulb pressure gauges. This problem, which particularly caught our attention on board the SIPECAM Boat Yang 1, finds, at the end of this study, its causes within the poor quality of the cooling water.

Acknowledgements

This work was implemented within the framework of the end-of-study project with a view to obtaining the engineering diploma at the National Higher Polytechnic School of Douala-Cameroon, Maritime and Port Engineering Department, which sent us to carry out our internship in the company SIPECAM. This project, which aims to solve the problem of thermal overload and power losses in the CAT 3408 marine diesel engine by carrying out diagnostics by passing through the analysis of used oil and coolant, is financed by the Dr. Vanlie Kontchou Maurice, Eng. EMAKOUA Théophile and HYDRAC company. The authors would like to thank the company HYDRAC for having provided the facilities and equipment of its laboratory within the framework of this project.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

References

[1] VX 100-SAE 15W-40 (2021) Premium Mineral Oil for Engines Powerful Petrol and Diesel. 1, Ref. Documentary: 005-LAB/FTM/03-2021/3037.

[2] Marine 9X (2015) 15W40. 3, Ref. Documentary: III-96-C-1507.

[3] Marine MTX (2018) Marine Diesel Engine Oil. 1.

[4] Arvidsson, L. (2019) Guide to Clean Oil. Noria Coororation Inc., Svendborg, Danemark, 26.

[5] Rammal, H., *et al.* (2006) Supercharged Diesel Engine Basics and Real, Theoretical and Thermodynamic Cycle Calculations. LREE-02.

[6] lerat, P. (2015) Agricultural Machinery. Lavoisier TEC, p. 247.

[7] Wauquier, J. (1994) Petroleum Refining. Technip, Paris.

[8] Mayer, A. (2016) Basic Notion for Beginners (Part) or the Other Tests and What They Teach Us. HAS.

[9] Ayel, J. and Born, M. (1998) Automotive Lubricants and Fluids. Technip, Paris.

[10] Bououdina, M. (2010) Used Oils in Algeria. *Producing Cleaner*, **7**, Article No. 0208.

[11] Samir, D. (1983) Maintenance of Diesel Engines.

[12] Ayel, J. (1996) Lubricants-Properties and Characteristics. Technip, Paris.

[13] Fedoul, M. (2017) Study of the Quality of Lubricating Oils by Methods Chemometrics. Master's Thesis, University of FES-SAISS, Fès Maroc.

[14] Ljubas, D., Krpan, H. and Matanovic, I. (2010) Influence of Engine Oils Dilution by Fuels on Their Viscosity, Flash Point, and Fire Point. *NAFTA*, **61**, 73-79.

[15] Denis, J., Briant, J. and Hipeaux, J. (1997) Physico-Chemistry of Lubricants: Analyzes and Tests. Technip, Paris.

[16] Mazouzi, R., Khelidj, B. and Kellaci, A. (2014) Oil Regeneration Used Lubricants by Acid Treatment Process. *Renewable Energy*, **4**, 631-637.

[17] Udonne, J. (2011) A Comparative Study of Recycling of Used Lubrication Oils Using Distillation, Acid and Activated Charcoal with Clay Methods. *Petroleum and Gas Engineering*, **2**, 12-19.

[18] Rajagopalan, B., Hayagrivan, M. and Praveenkumar, M. (2012) Ferrofluid Actuated Thermal Overload Relay. *Smart Grid and Renewable Energy*, **3**, 62-66. https://doi.org/10.4236/sgre.2012.31009

[19] Ksam, A., Hany, E., Hassan, M. and Nour, M. (2018) Using Thermal Analysis Techniques for Identifying the Flash Point Temperatures of Some Lubricant and Base Oils. *Petroleum*, **27**, 131-136. https://doi.org/10.1016/j.ejpe.2017.02.006