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Analyzing Thermal Overload and Efficiency Losses in the CAT 3408 Marine Diesel Engine of Boat Yang 1 Using Lubricant and Coolant Assessments

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Abstract

Engine lubricating oil and charge air are cooled by Low Temperature (BT) circuits in the CAT 3408 design, while cylinder liners, cylinder heads, and the body of turbofans are cooled by High Tem-perature (HT) circuits. Based on the analysis, this work will determine the lubrication compliance of the Yacco VX 100 - SAE 15 W-40 oil and the Camwater water used in the Boat Yang 1 engine. This will be done by conducting a series of conventional tests on both the oil and water. For the oil case, these tests will measure density, viscosity, flash point, density, sulphate center content, water content, total acidity index (TAN), total basic number (TBN), and pour point. For the water case, the conventional tests will measure pH, hardness, sodium chloride content [NaCl], and sodium sulphate content [NaSO4]. The results will be compared to the specified requirements to determine if 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 mm2/s, a viscosity (at 100˚C) of 13.99 mm2/s, a viscosity index (VI) of 155.39, a pour point −21˚C, a Flash Point (VO) 215˚C, a Sul- fated ash content of 18%, a density 881.5 kg/m3, 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 cal- cium sulphate content [CaSO4] of 2.38345 mg/L. The water content and sulfated center content data validate the thermal overload and power losses in the Yang 1 boat's marine diesel engine CAT 3408 due to their non-standard values.

Keywords
Reporting, Reasons, Thermal Overload, Power Losses

Introduction

This Diesel engine is designed to maintain a water temperature in the High Temperature (HT) circuit consistently between 40˚C and 80˚C during normal operation, as per the manufacturer's standards as measured by the bulb pressure gauge included into the engine. An indirect cooling system is used by the primary engine cooling circuit of the YANG 1 vessel. In this setup, a heat exchanger uses saltwater to cool the engine, which in turn uses fresh water to cool the engine. So, the system is made up of two circuits: one for freshwater and one for saltwater. Strictly speaking, the fresh-water circuit is a closed loop. A thermostat controls the water temperature in the cylinder head and surrounding areas, blocking water passage in the exchanger. The water is circulated by a volumetric pump that is powered by a motor and placed under the waterline in a through-hull. After the heat exchanger processes the calorie-rich saltwater, it is released into the exhaust manifold. It is common

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practice to treat the circulating water in order to reduce corrosion in the frame's and cylinder heads' many water chambers. The goal of this project is to analyze the engine's spent oil and coolant using a traditional approach for diagnosis. Part II presents the suggested approach to issue solving, which involves determining the primary reason. Part III lays forth the foundational techniques of analysis.

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**.

Principle of Analytical Methods

Conventional Method

Viscosity at 40˚C and at 100˚C

Principle according to the standard:

At temperatures of 40˚C and 100˚C, this method is used to determine how long it takes for a certain amount of lubricant to flow through a capillary that has been marked with two markers. A capillary tube is used to hold the oil that has to be described in the capillary viscometer. Under the influence of gravity, oil moves through the capillary, and its viscosity may be found by measuring its time flow at a constant temperature regulated by a viscometric bath.

We may calculate this kinematic viscosity by plugging the numbers into this formula:

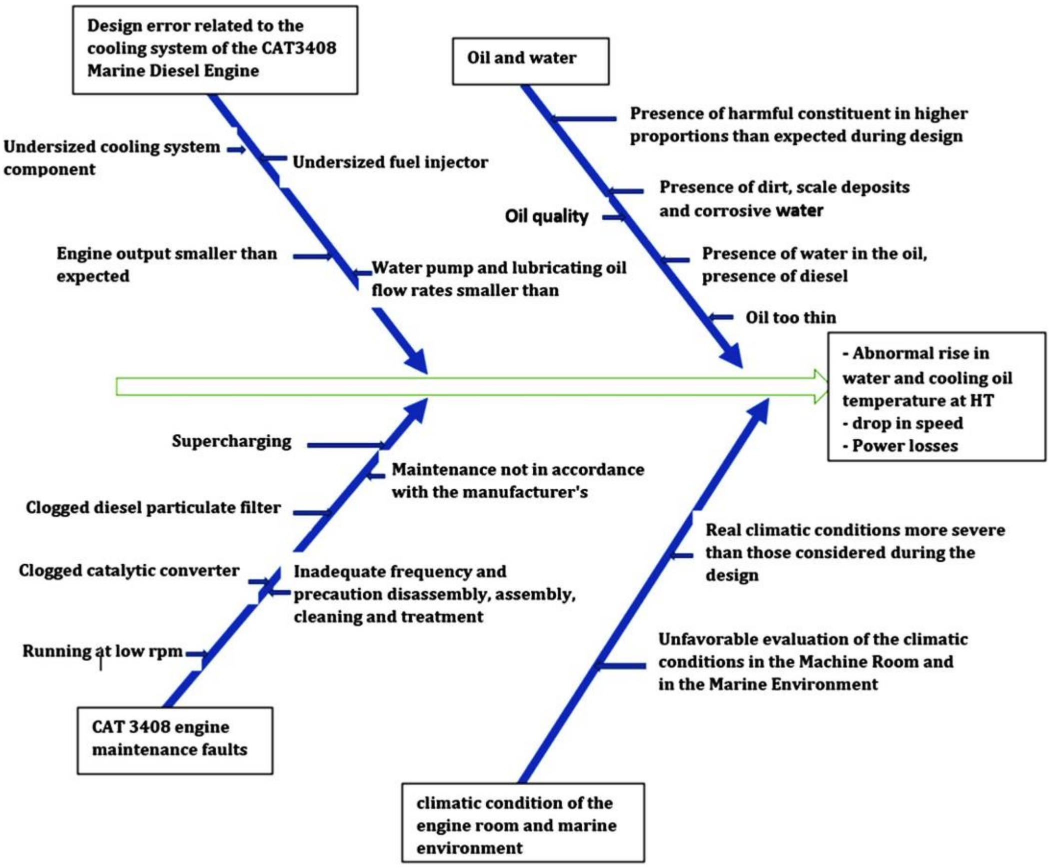

Figure 1. HISHIKAWA cause-effect diagram.

$\upsilon = C * t$

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

Viscosity Index (D2270)

Principle:

The viscosity index is used to characterize the quality of oil, greater is the in- dex, 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.

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.

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 pyc- nometer is used, it is characterized by a very precise volume. Density is deter- mined by weighing.

Pour Point (D97, D2500)

Principle: The preheated oil is cooled, and its flow

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characteristics are observed at 3˚C interval. The minimum temperature at which the oil still flows is noted, it corresponds to the pour point.

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 tem- perature of the sample must be determined precisely.

Hydrogen Potential (pH)

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

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

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

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 solu-

tion 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

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

$[NaCl] = 0.015 * (AB) * 58500/V$ mg/L

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Calcium Sulfate ($CaSO_4$) Content

Principle:

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

Cations: Anions:

Ca^{2+}, Mg^{2+}, Na^+, K^+ NO^-, SO^{2-}, HCO^-, Cl^-

The concentrations in Ca^{2+}, NO^- and SO^{2-} in milliequivalents per liter (meq/L) taking into account the order of grouping, going through complexome- tric dosage and titration in order to apply the following formula:

$$[CaSO\ ] = Minium\left\{\lfloor\lceil Ca^{2+} - NO^- \rceil\rfloor ; SO^{2-}\right\}$$

or all the concentrations are expressed in meq/L.

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 val- ues, 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 maxi- mum decrease which is 15% [4]. These values are also close to their original val- ues, 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	Result Value	Standard Values				
		Minimum	Max	Original value		Deviation
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 in- crease 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 manu- facturer 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 ma- rine 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 con- centration 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 Man- ufacturer 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 ac- cepted 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 stan- dard. 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 sep- arate. The presence of glycol in the oil definitely indicates a communication be- tween 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 wa- ter 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 en- gine.

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). De- termining 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 tempera- ture 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].

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 under- goes 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 po- lymeric 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 for- mation 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 mo- lecules [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 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].

Table 2. Typical coolant analysis results obtained compared to manufacturer's specifica- tions and values.

TESTS	Typical values	Result Value
pH	$7 \leq pH$	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

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 ob- tained 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 instruc- tions, the water or make-up intakes in Douala and Limbe are very detrimental to heat exchange within the cooling circuit.

Conclusion

The presence of oil in the water is indicated by the fact that its water content is 1.8%, which is more than the 0.1% threshold. Not only that, it doesn't fall within the range of 0.8% to 1.6% as specified by the D 874 standard for marine diesel engines, and its quite high sulphate center concentration amounts to an astounding 18%. Overheating of the CAT 3408 Diesel engine, which is utilized by the Yang 1 and was built by Caterpillar, seems to be the cause of the distress that is often shown online via bulb pressure gauges. The low quality of the cooling water is identified as the root cause of this issue, which was brought to our notice during our time aboard the SIPECAM Boat Yang 1 during this investigation.

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