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Impact of Natural Gas and Biogas on Engine Lube Oil Condition

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ABSTRACT

The performance of lube oil condition with both natural gas and biogas as fuel has been investigated for a Genset having 1 mega-watt capacity. The algorithm based oil change intervals between 30-1042 hours and 30-300 hours; following a normal distribution, were employed for natural gas and biogas respectively. Test samples after full load operation were collected for laboratory analysis. The results show that there is accelerated lube oil dilution with biogas and oil change interval is one third of natural gas. Significant sulfur deposits on inner cylinder surface with natural gas were observed. Total base number (T.B.N), kinematic viscosity, oxidation and iron debris in lube oil followed similar trends. However, nitration and copper debris showed different patterns for natural gas and biogas during condition monitoring of lube oil.

1. Introduction

Biogas produced from molasses (sugar mill waste) can be helpful in diversifying the energy mix of the countries with sizeable sugar industry. Recently, Brazil, Norway and Germany [1] have employed biogas from various sources for commercial energy generation [2]. Pakistan is ranked as the fifth largest sugar producing country in the world [3] and has an aggregate potential of generating 3000 megawatt power using biogas [4].

Bio gas differs in chemical composition from natural gas (Table 1). Therefore, the performance of gas operated electricity generator is different if it is operated on natural gas or if operated on biogas [5]. This effect is evident from monitoring the condition of engine lube oil [6]. The variations in percentage methane effects the combustion reaction and combustion temperature on one side, and the presence of nitrogen (in natural gas only), hydrogen sulphide (in biogas only) and on the other hand carbon dioxide (in both natural gas and biogas) leads to some undesirable interactions with lube oil additives. As a result, if some lube oil is used for the two gaseous fuels, it may be anticipated that the oil change intervals would be different. Therefore, optimum lube oil running hours for biogas needs to be investigated in a systematic way if use of biogas is to be promoted in near future.

In order to improve the mechanical performance of biogas as fuel in Gensets, certain design modifications are recommended by Gornall [7]. Moreover, in order to reduce odor, lube oils with higher total base number (TBN) and reduction in hydrogen sulphide are recommended [7]. When we use low refined biogas as a fuel for existing gas engines, its compatibility with fuel system, combustion parts and emission needs to be carefully taken in to account to optimally run the engine and enhance its life [8].

Álvarez-Flórezet [9] have pointed out various types of damages and effects on oil and fuel consumption as a result of silicon deposits which are needed to be cleaned to secure the surface of combustion chamber, cylinder and piston rings [9]. Moreover, immediately monitoring the lube oil condition after running for particular hours is difficult due to delay between sampling and laboratory analysis [10].

This paper presents a comparative monitoring study of lube oil condition of a JGS-320 B-NL Jenbacher Genset running on natural gas and biogas. The biogas is produced from waste (spent wash) of an existing sugar mill after purification. The natural gas used in the study is supplied by Sui-Southern Gas Company Ltd. The monitoring of condition of lube oil was done by measuring characteristics like Total base number (T.B.N) (mg KOH/g), Kinematic Viscosity (mm^2/sec), Oxidation (A/cm), Nitration (A/cm) and Wear Debris of select metals (ppm). The condition monitoring for lube oil for both natural and biogas was conducted after selected running hours.

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Table 1: Chemical compositions of biogas and natural gas experimental setup

	(CH_4) %	(C_2H_6) %	(C_3H_8) %	(C_4H_{10}) %	(C_5H_{12} + $C_{10}H_{22}$) %	(N_2) %	(CO_2) %	(H_2S) %	(H_2O) %
NG	82	2.5	0.2	0.06	0.02	1.6	0.7	trace	trace
BG	58	NIL					39	3	trace

Note. NG=natural gas, BG=biogas, Methane= CH_4, Ethane= C_2H_4, Propane= C_3H_8, Butane= C_4H_{10}, Pentanes= (C_5H_{12}+ $C_{10}H_{22}$), Nitrogen= N_2, Carbon dioxide= CO_2, Hydrogen sulphide= H_2S, Water= H_2O

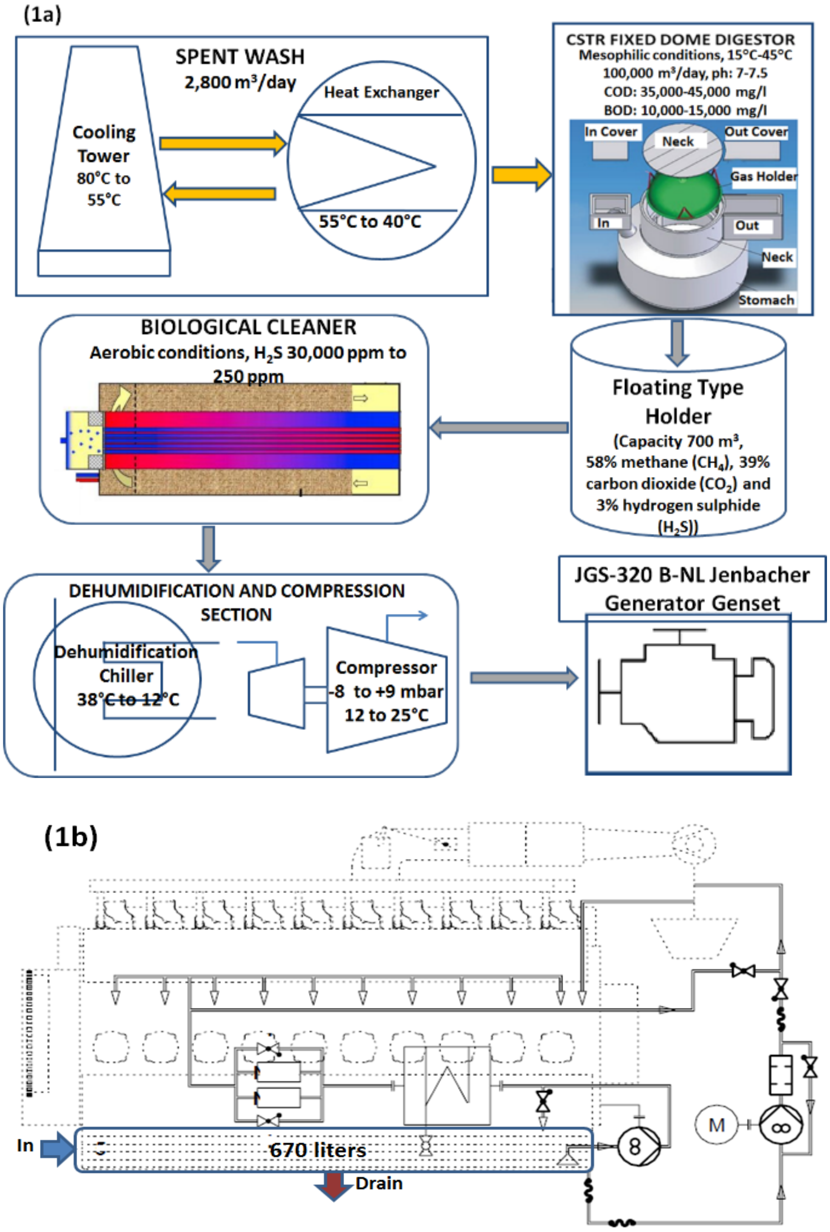


Fig. 1: (a) Schematic diagram of biogas generation starting with mixing of spent wash with cow dung, followed by anaerobic digestion, then by bacteria assisted biological purification, followed by chilling compression in heat exchangers and loading into the JGS-320 B-NL Jenbacher, (b) Lube oil circulation circuit diagram for JGS-320 B-NL Jenbacher generator Genset which was employed in the experimental study

The present investigations were carried out at a sugar Mill where the molasses undergoes processing as shown in Fig. 1a, to produce biogas. Fig. 1b shows the lube oil circuit diagram. The biogas is cleaned, dehumidified and compressed before injecting into the Genset. The specifications of the Genset are shown in Table 2.

Table 2: Specifications of JGS-320 B-NL Jenbacher generator Genset

Manufacturer	General Electric Jenbacher*JGS-320 B/NL* generator Genset
Type	20 cylinder engine, V-type, turbocharger four stroke
Fuel type	Special gas street for biogas
Cooling system	Water/Air cooled remote radiator for J/W and intercooler
Fuel Consumption at full load (biogas)	At full load 0.5 Nm^3/kwh
Fuel Consumption at full load (natural gas)	0.305 Nm^3/kwh
Lube Oil Consumption at Natural gas	0.2g/kwh
Lube Oil Consumption at Natural gas	0.25g/kwh
Lube Oil operating temp.	80 to 90 °C
JGS-320 B-NL	Type 01
Lube Oil Type	Synthetic, SAE 40, Medium Ash, Class B

2.1 Experimental Procedure

At the beginning of each experiment the lube oil circuit of the engine was cleaned by pressurized flushing. About 670 liters of Synthetic, SAE 40, Medium Ash, Class B type lube oil was loaded into the sump before each run of biogas. The cleaned dehumidified and compressed biogas (composition shown in Table 1) was directly injected into the Genset and it was run on full load. For the purpose of comparison, the Genset was also run on natural gas (composition shown in Table 1) on full load.

The lube oil is directly loaded into the sump at the base of the JGS-320 B-NL Jenbacher generator Genset at the start of each run. The loading and unloading ports and the lube oil circulation circuit diagram are shown in Fig. 1(b). Preliminary experiments were carried out to determine the oil change interval for two types of gases. The oil change intervals were selected between 30 to 300 lube oil running hours and 30-1042 lube oil running hours for bio gas and natural gas respectively. The algorithm based oil change intervals [11] followed a normal distribution as shown in Table 3. The lube oil condition was monitored by measuring the characteristics listed in Table 4.

These experiments revealed that during biogas operation the TBN value of lube oil approached zero at around 350 running hours. Therefore, in order to ensure operational efficiency of the Genset the maximum running hours for biogas operation were set to a value of 300 hours. The oil change intervals were grouped in to five groups with each group comprising of five values of lube oil life in ascending order. The averages of each measured characteristic were plotted against the average of the corresponding group of lube oil life.

Table 3: Lube oil condition monitoring intervals

No.	Oil Change Intervals (Hours)	
	On Natural Gas	On Biogas
1.	30	30
2.	59	59
3.	64	64
4.	66	66
5.	85	85
6.	115	115
7.	135	135
8.	155	155
9.	160	160
10.	180	180
11.	200	200
12.	210	210
13.	250	250
14.	300	300
15.	430	-
16.	569	-
17.	640	-
18.	741	-
19.	1042	-

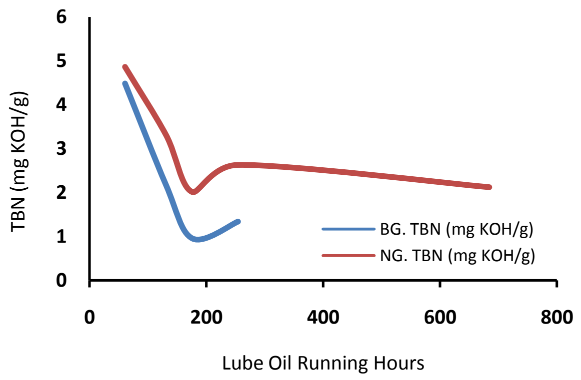
Table 4: Lube oil characteristics testing

Test	Method and Instrumentation
Total base number (T.B.N) (mgKOH/g)	Potentiometric Perchloric Acid Titration, ASTM D 2896-06
Kinematic viscosity (mm^2/s at 100° C)	Viscometer, ASTM D 445-04
Oxidation (A/cm)	Fourier Transform Infrared Imaging (FTIR)
Nitration (A/cm)	Fourier Transform Infrared Imaging (FTIR)
Wear metals content (Cu and Fe) (ppm)	Metrohm Karl Fisher atomic absorption spectrometer model MM 1011-85

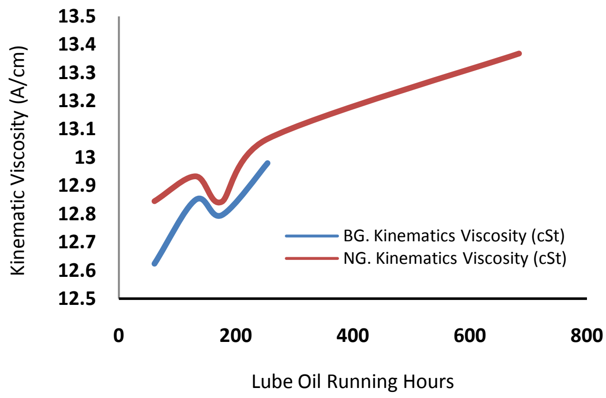
At the end of each run, the lube oil condition was monitored by testing the characteristics as per standard and instrumentation mentioned in Table 4, to quantitatively explore the effect of biogas and natural gas on lube oil. In order to ensure repeatability, three samples for each reading of lube oil running hours were analyzed and the average values for the test of all characteristics for every lube oil running hour reading were used for analysis. After completion of 19539 hours of engine operation the Genset running on biogas was disassembled and various components were visually inspected. The wear metal debris (Cu and Fe) was examined to ascertain the metal contents and reveal the wear pattern. The wear metal characterization was conducted using atomic absorption spectrometer. At the end of each run the lube oil was drained out form the engine Genset sump and collected in clean dehydrated containers. Moreover, lube oil life with respect to each fuel was also compared. The samples were sealed in air tight containers and moved to the testing facility. The causes of variations in lube oil characteristics with both fuels used (i.e., Natural gas and biogas) were analyzed and recommendations are made for the increase of lube oil life (in terms of running hours) for engines running on biogas.

3. Results and Discussion

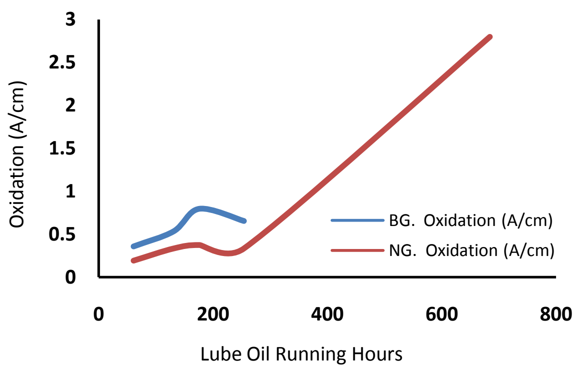
Figs. 2 (a-f) show the variation in measured characteristics (as given in Table 4) for samples of lube oil



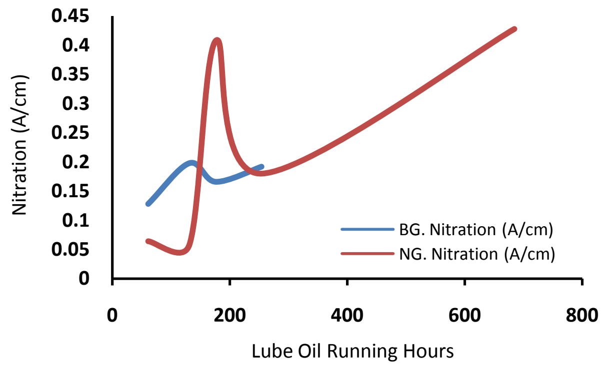
(a) Variation in T.B.N with lube oil running hours



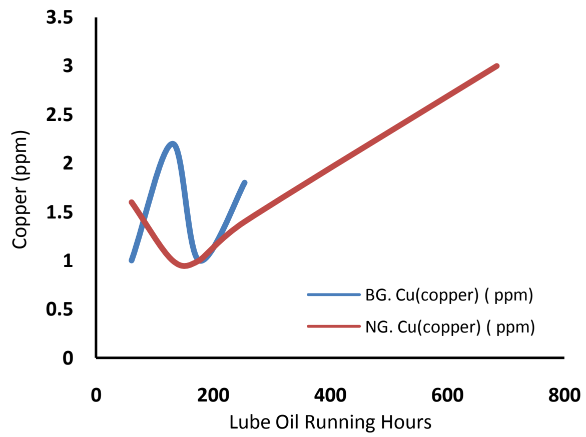
(b) Variation in kinematic viscosity with lube oil running hours



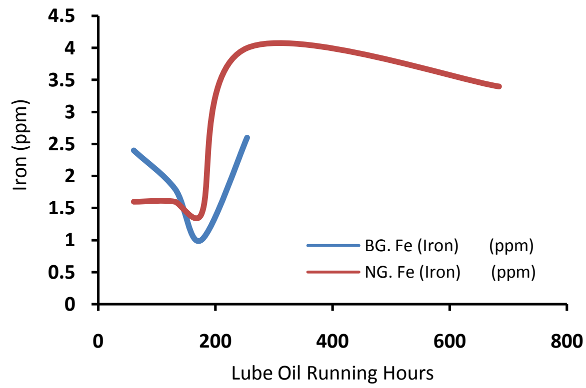
(c) Variation in oxidation with lube oil running hours



(d) Variation in nitration with lube oil running hours

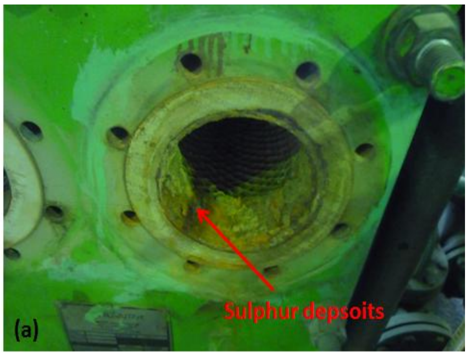


(e) Variation in Cu debris with lube oil running hours

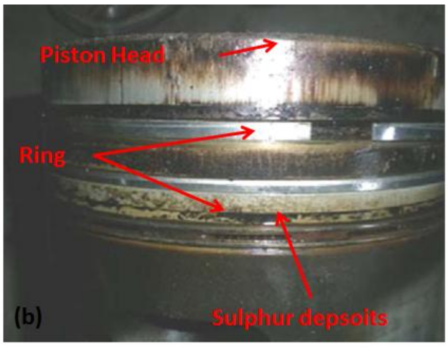


(f) Variation in Fe debris with lube oil running hours

Fig. 2: Test results of lube oil with natural gas and biogas



(a) Sulfur deposits on lube oil cooler



(b) Sulfur deposits on piston rings

Fig. 3: Sulfur deposits in lube oil circuit with biogas as a fuel

collected at the end of oil change intervals for both natural gas and biogas respectively. The burnt oxides of sulfur and unburnt hydrogen sulfide content conveniently consume the potassium hydroxide content (the T.B.N) in lube oil. Fig. 2(a) shows a sharp decrease in lube oil T.B.N from a range of 6 mg KOH/g to 1 mg KOH/g within 200 hours of engine operation for biogas. In comparison; for natural gas, the decline in T.B.N value is from 6 mg KOH/g - 2.5 mg KOH/g for the first 300 hours and there is negligible decrease in the T.B.N value beyond 2.5 mg KOH/g, up to 700 engine running hours. Therefore, it is mandatory to reduce the hydrogen sulfide content to trace level in biogas for better performance of lube oil in terms of alkalinity. The evidence of formation of sulfur oxides in lube oil circuit can be seen in Fig. 3 (a) and Fig. 3 (b).

Fig. 2 (b) shows the comparison of biogas and natural gas based, increase in the kinematic viscosity of the lube oil versus engine lube oil running hours. The increase in kinematic viscosity of lube oil for natural gas is relatively higher than biogas within comparable range of up to 300 lube oil running hours. Beyond 300 lube oil running hours there is a sharp increase in kinematic viscosity of lube oil for natural gas. This is fundamentally, because of the higher wear metal debris addition during natural gas operation of the gas engine. The flame temperature, of biogas is ~ 700 °C [12] and the flame temperature of natural gas is ~ 1200°C [13]. This is because of relatively lower content of methane in biogas as compared to natural gas as shown in Table 1. The higher combustion temperature of natural gas along with the acidic residues of the combustion process is likely to generate more iron metal debris from the piston and cylinder surfaces which enter the lube oil and increase its kinematic viscosity. For extended engine operating time i.e., lube oil running hours beyond 300 hours the kinematic viscosity of lube oil continuously increases as shown in Fig. 2 (b).

Fig. 2 (c) presents the comparison between biogas and natural gas for the variations in oxidation (A/cm) of lube oil with respect to increasing lube oil running hours. Owing to the higher contents of biogas combustion the oxidation of the lube oil is greater than natural gas for comparable range of up to 300 lube oil running hours. However, as the lube oil running hours extend beyond 300 hours to 700 hours the continuous addition of oxides from natural gas combustion continuously increase the oxidation of lube hours at a constant rate.

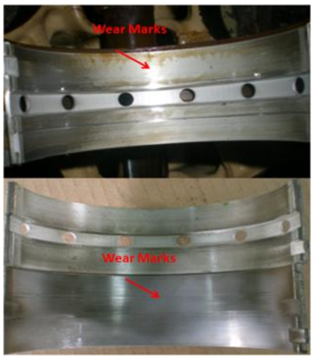
Fig. 2 (d) shows the comparison of biogas and natural gas in terms of variation in nitration of the lube oil with increasing lube oil running hours. The main contributing factors for nitration of lube oil are the various oxides of nitrogen generated as a result of gas combustion reaction. The combustion reaction of natural gas emits total nitrides on the order of ~ 2.264 (lb/106 scf) [14]. However, the total nitrides emission from combustion of biogas are much higher, i.e., ~ 0.12 (lb/106 scf) [15]. Therefore, from Fig. 2 (d) we can clearly see that nitration of lube oil for biogas operation is higher than nitration of lube oil for natural gas operation up to the comparable range of 300 lube oil running hours. However, if lube oil running hours are extended the nitride residues from natural gas combustion increases the nitration of lube oil at a constant rate.

Figs. 2 (e) and 2 (f) show the comparison of biogas and natural gas in terms of variations in copper and iron metal debris in lube oil with increase in the lube oil running hours. The metal debris settles in lube oil as a result of three factors; (a) chemical reaction between the lube oil contents and metallic components of engine in the lube oil circuit, (b) reactivity of lube oil constituents and (c) the operating temperature of the select area in the lube oil circuit. Owing to the lower flame temperature of biogas than natural gas [16] the debris of copper and iron in lube oil were found to be lesser. The percentage content of iron and copper debris in natural gas was within comparable range, i.e. up to 300 lube oil running hours is almost same as biogas based engine operation. However, extended operation of engine on natural gas, i.e., beyond 300 lube oil running hours shows sharp increase in iron debris as shown in Fig. 2 (f). This is again due to the sustained high temperature in the hottest spot in lube oil circuit i.e., the piston cylinder assembly (combustion chamber). As evidence of this phenomenon, the picture showing iron oxide deposits on the internal walls of the cylinder lining of the engine is shown in Fig. 4.

Fig. 5 shows the various components of disassembled Genset. Excessive wear marks can be observed, as shown in Fig. 5a, on shell bearing after completion of specified life. Silica and sulfur deposits were seen on valve seats and valve guide areas as shown in Fig. 5b.

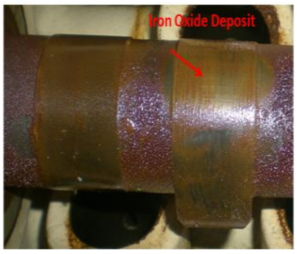
Heavy presence of iron oxide was observed on the surface of cam shaft and roller bearings as shown in Figs. 5c and 5d). Connecting rod exhibited excessive erosion on the completion of specified life running on biogas (Fig. 5e). Due to erosion of connecting rod the gudgeon pin also failed as shown in Fig. 5f. The presence of hydrogen sulfide and iron oxide increases the wear potential and acid attack on the corrosive engine components in the case of biogas.

Fig. 4: The iron oxide deposits on the internal surface of the cylinder liner with natural gas as fuel



(a) Worn out Shell Bearing

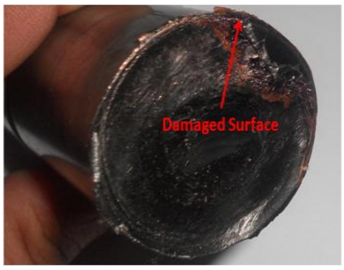
(b) Deposition and Damage of Valves and Seat Area



(c) Deposition of FeO on Cam Shaft

(d) Deposition of FeO on Roller Bearing

(e) Eroded Connecting Rod



(f) Failed Gudgeon Pin

Fig. 5: Disassembled views of various components after running on biogas

4. Conclusions

- Initial trends were similar for T.B.N and kinematic viscosity initially for a certain lube oil running hours for both natural gas and biogas. T.B.N decrease sharply for both gases; however, it completely dilutes at approximately 300 hours of engine operation for biogas. During this time period, kinematic viscosity first increases and then decreases at almost the same rate. For natural gas; however, the kinematic viscosity increases after 300 lube oil running hours.
- Similar pattern was observed for both gases in case of oxidation. It increases at almost the same rate followed by a decrease till lube oil dilutes in case of biogas. Afterwards, oxidation shows a sharp increase in natural gas. Contrary to this; nitration shows different behavior for both gases till the complete dilution of lube oil. Nitration shows a visibly severe intensity in case of natural gas as compared to biogas.
- Wear debris shows a similar trend for iron in case of both gases. However, copper debris shows an entirely reverse pattern for both gases.
- Sulfur deposits were observed in lube oil circuit for biogas. Iron oxide deposits were observed on the inner surface of cylinder for natural gas.
- In order to address the issue of Sulfur and Iron oxide deposits a need for special design and materials for engine in case of either of the two gases is required to enhance engine life.
- Presence of hydrogen sulfide and iron oxide increases the wear potential and acid attack on the corrosive engine components in the case of biogas

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