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DESIGN OF LUBRICANTS FOR CNG-CONVERTED GASOLINE ENGINES

DESAIN FORMULA MINYAK LUMAS UNTUK KENDARAAN BERMOTOR MESIN BENSIN BERBAHANBAKAR CNG

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ABSTRAK

Tujuan penelitian ini adalah membuat formula minyak lumas untuk mesin bensin yang telah dikonversi menjadi berbahan bakar gas alam terkompresi (CNG) dengan spesifikasi pelumas SAE 15W40 API SL. Penelitian ini dilakukan dalam enam tahapan, yaitu; i). desain formula pelumas, ii). blending skala laboratorium, iii). Analisis laboratorium, iv). blending dalam skala pilot dan analisis laboratorium, v). tes kinerja melalui uji bangku atau uji jalan, vi). analisis data dan evaluasi hasil. Pengujian sifat fisika dan kimia pelumas mengacu pada Standar Nasional Indonesia (SNI), dilanjutkan dengan uji jalan hingga jarak tempuh 10.000 kilometer. Hasil penelitian menunjukkan bahwa formula pelumas yang diperoleh dapat bekerja dengan baik sampai 10.000 kilometer.

Kata kunci*: gas alam terkompresi (CNG), minyak lumas, minyak lumas bekas.*

ABSTRACT

The objective of this study is to develop a lubricant formula for the gasoline engine that has been converted to compressed natural gas (CNG-fueled). The lubricant specification is SAE 15W40 API SL. This study was conducted in six stages, namely; i). lubricant formulation, ii). laboratory scale production, iii). Laboratory analysis, iv). pilot scale production and laboratory analysis, v). test performance through bench test or a road test, vi). final data analysis and evaluation. A laboratory test of physical and chemical properties of lubricants refers to the Indonesian National Standard (SNI), followed by road tests up to the mileage of 10,000 kilometers. The result showed that the lubricant formula obtained can work well to 10,000 kilometers.

Keywords: compressed natural gas, lubricant, used oil.

I. INTRODUCTION

The diversification of energy sources has become a global issue, because of the global campaign for the preservation of nature, the depletion of oil reserves and the increases in price. Biofuel and Compress Natural Gas (CNG) are the potential alternatives to be used. Changes in fuel cause a change in the quality requirements of lubricants. The functions of lubricants are to prevent friction, wear, and surface damage in an engine system such as gears and bearings (Pirro 2001). The other functions are to prevent corrosion, as heat transfer media, and to transfer dirt and wear particles. In the hydraulic system lubricating oil is used to deliver power or energy.

Sulfur content in CNG is usually very small and more flammable, consequently, the needs of total base number (TBN) to neutralize acid formation and to clean the engine are less than those in gasoline. The effects of natural gas as fuel in the gasoline engine results in greater wear on the head of the intake valve and the exhaust valve. A larger carbon deposit will be formed on the piston and the cylinder head when using conventional lubricants. Therefore, using CNG and gasoline simultaneously or using a special lubricant have to be applied to avoid excessive wear (Eltantawi and Bosila 2012). The performance of the lubricants used on a diesel engine for public transport which uses CNG and diesel fuel was examined to determine the differences in the effectiveness of CNG and diesel as fuel. The findings were that the lubricants' quality decreased significantly when using CNG fuel (Adril et al. 2009; Mohsin & Majid 2014). Based on the previous research, special lubricants are needed for the engine using CNG as fuel. The lubricants should have higher resistance to oxidation and nitration, to be able to protect engine components from abnormal wear, to maintain the cleanliness of piston, and to provide protection from corrosion.

The objective of this study is to develop a lubricant formula for the gasoline engine that has been converted to compressed natural gas (CNG-fueled). The lubricant specification is SAE 15W40 API SL. Analysis of the lubricant properties that was undertaken includes lubricants viscosity, base number, acid number, and metal contents. Analysis of used oil was aimed at getting an early indication of engine damage and the proper replacement period of lubricants.

II. METHODHOLOGY

The material used in this study consisted of base oil, package additive, and component additives. This study was conducted in six stages, namely; i). lubricant formulation, ii). laboratory scale production, iii). laboratory analysis, iv). pilot scale production and laboratory analysis, v). performance test through bench test or a road test, vi). final data analysis and evaluation. The physical and chemical properties of lubricants were evaluated with reference to the Indonesian National Standard SNI-06-7069.5-2005 (BSN 2005), followed by road tests up to the mileage of 10,000 kilometers. Recondition of the engine before the road test was carried out to restore the engine back to its engine manufacturer's standard, such as the initial time of ignition, valve adjustment, and compression ratio. The next step is to *run-in* the vehicle in order to make sure that the condition of the engine is ready to use. Natural gas (CNG) was used as fuel in a converted gasoline engine purchased from SPBGs station in Jakarta, which meets standard quality and specification in accordance with the Decision of the Director General of Oil and Gas No. 247.K/10/DJM.T/2011.

Table 1
Technical data of the engine (Suzuki 2013)

Engine type	G15A, 16 valves, 4 cylinders
Cylinder volumes	1493 cc
Max. Torque	126 Nm / 3000 rpm
Fuel System	Multi Point Injection (MPI)
Fuel	Gasoline
Diameter x Distance	75.0 mm X 84.5 mm
Max. Power	105 ps / 6000 rpm

The road test was performed on various types of road representing the normal daily operation of the vehicles until 10,000 km. Used oil samples were taken and analyzed every 2000 km, at 0 km, 2,000 km, 4,000 km, 6,000 km, 8,000 km, and 10,000 km to investigate their properties. The technical data of the automotive engine used in this study was APV Arena 2013, as described in Table 1.

III. RESULT AND DISCUSSION

A. The Properties of Lubricant Formula

The properties of lubricant that were evaluated refers to the Indonesian National Standard SNI-06-7069.5-2005, as described in Table 2, explaining that the specification meets standard requirements.

The characteristics of used oil such as kinematic viscosity, base number, acid number, pH, metal content, and oil losses were analyzed and were compared to the standard as shown in Table 3.

B. Road Test Result

Kinematic Viscosity

Lubricants are incompressible fluid, which under ideal conditions, have a protective layer with a constant thickness. The thickness of the layer is often referred to as the strength of the protective layer, to separate the components from moving. Wear can be considered as not happening since there is no direct contact between two metals. When the load exceeds the ability of lubricants to separate two components, the lubricants layer was damaged, causing friction (direct contact). The higher viscosity, results in the heavier load carrying of lubricants in the engines. However, using higher viscosity of lubricants increases the difficulty of lubricants circulating especially at low temperature, reducing wear protective functions, increasing the energy requirement to circulate, and reducing fuel economy. The higher viscosity has higher internal custody intermolecular (intra-fluid friction), leading to easier heating of lubricants. Using higher viscosity of lubricants or lower than requirements results in bad lubrication properties especially on load bearing capability of the equipment. The viscosity of lubricants during use are presented in Figure 1.

The viscosity of lubricants changes because of temperature, degradation due to shear, dilution by fuel, and the impact of contaminants. The test results explain that the viscosity was changed during the road test. The viscosity of new lubricants SAE 15W40 API SL is 15.28 centistokes, "*stay in grade*" correspond to the specification limit is 12.5 to 16.3 cSt at 100°C test temperature (see Table 2). The high temperature of engine co-currently with the shear forces in the engine causes degradation of the polymer in lubricants. The high temperature of the engine also increases the oxidation of some components in the lubricants.

The major factors causing degradation of the lubricant's viscosity are fuel diluents and degradation of polymer additives derives from shear forces from the oil pump. The laboratory analysis shows that the value of kinematic viscosity decreases about 10.67% from 15.28 cSt to 13.65 cSt (see Figure 1). The curve describes a significant decline at the first 4000 kilometers, then decrease asymptotically.

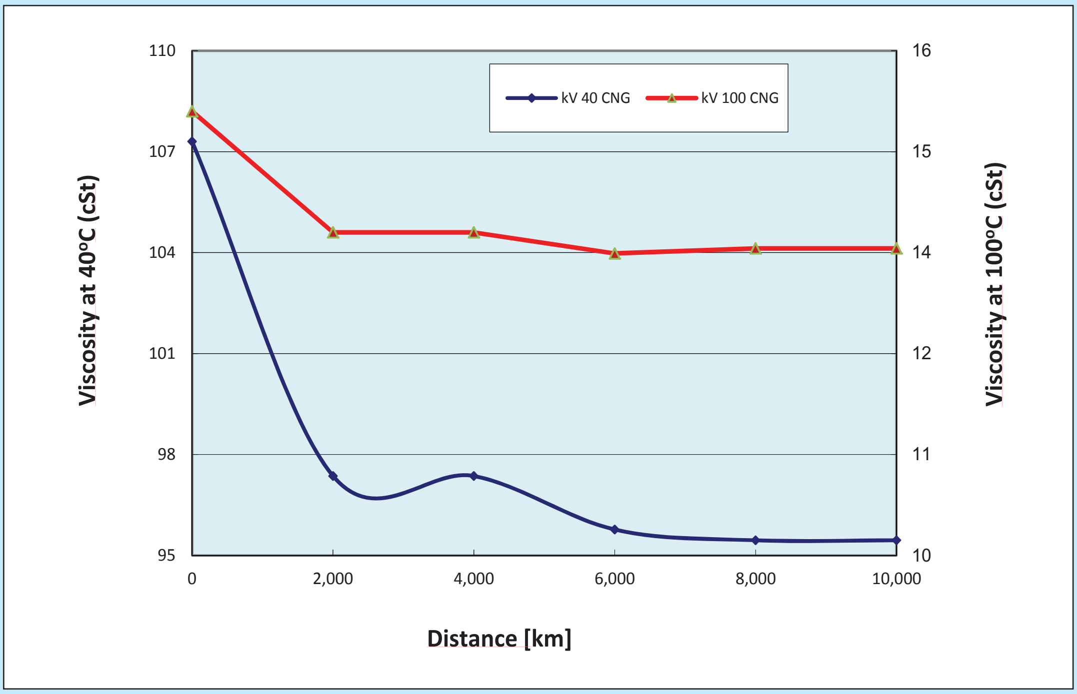
Table 3
Standard value of used oil

Ironi (Fe)	Wear	Max. 100 ppm
Aluminium (Al)	Wear	Max. 25 ppm
Copper (Cu)	Wear	50 ppm/spec.
Lead (Pb)	Wear	Max. 50 ppm
Chrom (Cr)	Wear	Changes 100%
Silicon (Si)	dirt	Max. 25 ppm
Boron (Br)	Cooler/refrigerator	Max. 25 ppm
Vanadium (V)	Wear	Canghes 100%
Nickel (Ni)	Wear	Canghes 100%
Water	Contamination	Max. 500 ppm
TBN	Oxydation	Min. 7 mgKOH/g
Viskositas	Oxydation	Changes 20%
Fuel dilution	Ring wear	5-10% volume

Source: Hanifuddin, M., & S.S. Hastuningtyas, 2001

Table 2
Characteristics of lubricant formula SAE 15W40/API SL

Characteristics	Method	Unit	Typical Value	SNI-06-7069.1-2005
kV 40	ASTM D 445	cSt	107.3	-
kV 100			15.3	12.5 - 16.3
VI	ASTM D 2270		150	Min. 125
CCS	ASTM D 5293	cP	4197	Max. 7000
TBN	ASTM D 2896	mg.KOH/gr	9.4426	Min. 5
PP	ASTM D 92	°C	-33	Max. -23
FP	ASTM D 97	°C	248	Min. 200
Sulfated Ash	ASTM D 874	%-mass	1.135	Min. 0.6
Noack	ASTM D 5800	%-mass	7.147	Max. 15
Ca	ASTM D 4628/ 5185/ 6595	%-mass	0.2112	Product spec.
Mg			0.0098	Product spec.
Zn			0.1067	Min. 0.08
Foaming	ASTM D 892			
Sq.1		ml/ml	Nil/nil	20/nil
Sq.2		ml/ml	5/nil	50/nil
Sq.3		ml/ml	Nil/nil	20/nil



Figue 1
Kinematic viscosity of used oils.

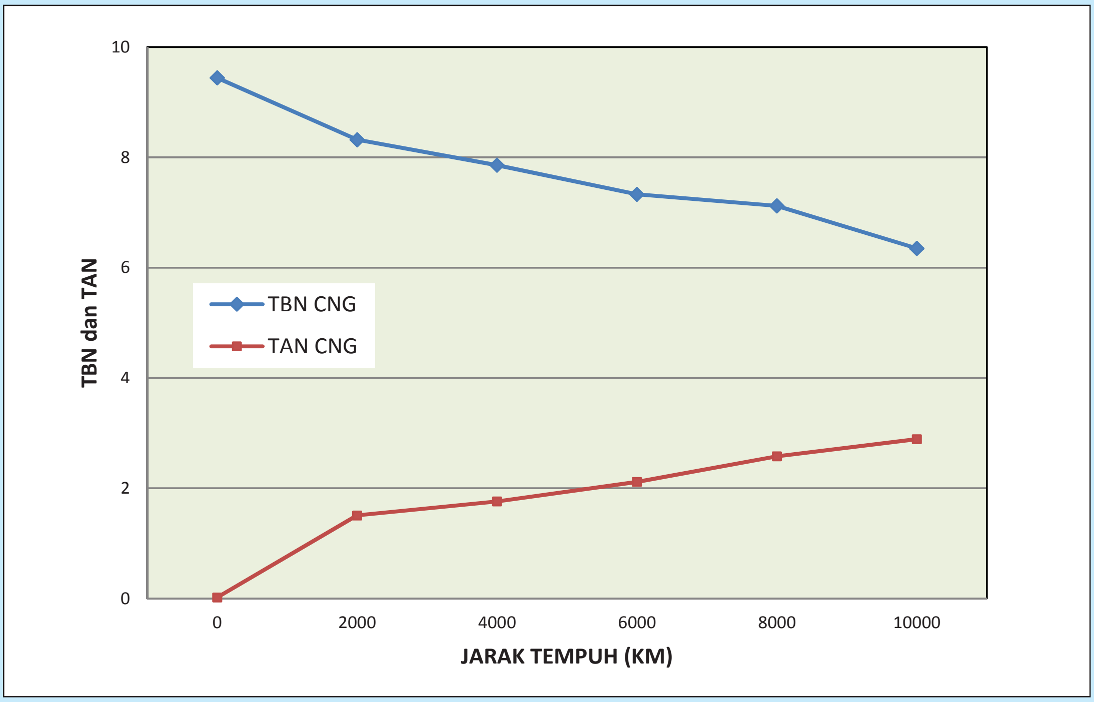


Figure 2
Value of TBN and TAN.

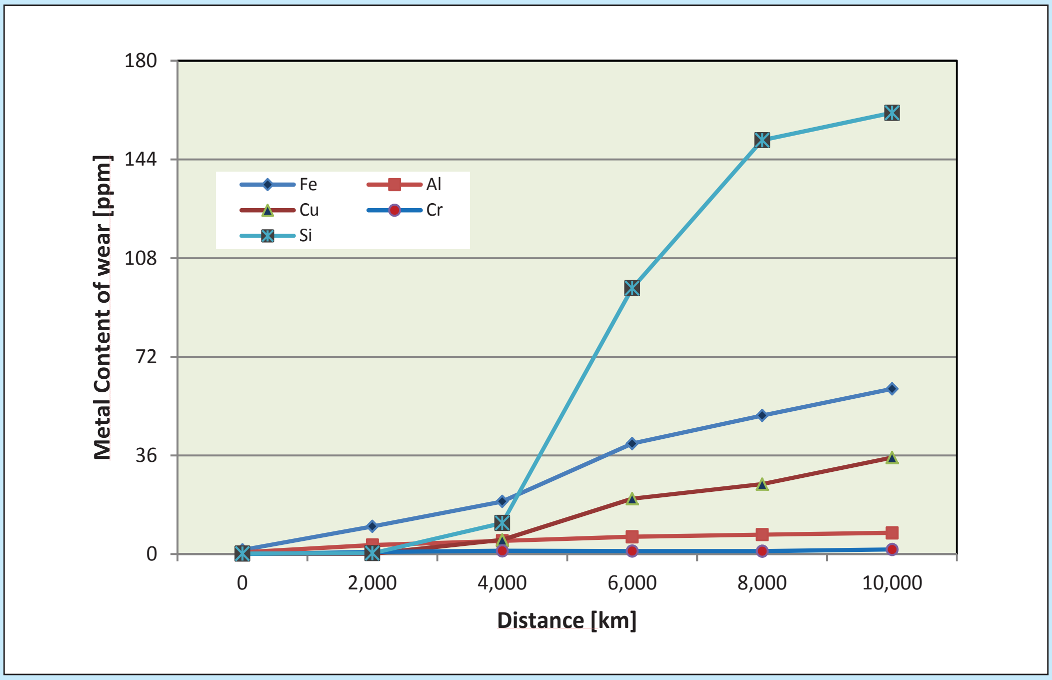


Figure 3
Wear metal contents in lubricants

This phenomenon has commonly happened in lubricants application. However, the overall value of kinematic viscosity is within the range of specifications, or "stay in grade".

Total Base Number

The total base number (TBN) is a characteristic which indicates the ability of detergency, dispersant and neutralization of the acid produced from the oxidation of lubricants. The SO_3, SO_2, from the combustion system, react with water vapor (H_2O) to produce H_2SO_4. The detergents neutralize the acids formed by the combustion reaction. Sulfur content in CNG was almost zero and a maximum of 10 ppm H_2S, in accordance with the decision of the Director General of Oil and Gas No. 247.K/10/DJM.T/2011 on fuel specifications for CNG as gas transportation. Despite the sulfur contents of CNG not being significant, the value of the base number is still one of the most important properties especially as dispersant and detergent to prevent and clean up the dirt on engine components such as pistons and rings.

Figure 2 illustrates the values of TBN which are continuing to drop during the road test. The base number decreases gradually about 33% from the initial value of 9.44 mg.KOH/g to the final value of 6.35 mg.KOH/g conditions at 10,000 km. In general, the base number decreases with the increase in acidity as the product of oxidation during the mileage of road test or the times of engine operation. TBN values are recognized as references on the replacement of lubricants (drain interval). Decreasing more than 50% from its initial value is considered as the time to replace the lubricants. TBN value is limited by the minimum value, so the lubricants can be used as long as they meet the minimum threshold. The acidity of lubricants increases while they are used. This phenomenon is indicated from increases of the acid number (TAN). The total acid number is not included in the specifications set by SNI, but is one important indicator to determine the quality of lubricants during services.

Metal Contents

The metal contents in lubricants are derived from the additives and wear of engine components. Wear metals generally come from bearings, rings, piston cylinders, and the moving parts of the engine, and are mostly cast iron. Metal contents were derived from additives such as Calcium, Barium, Magnesium, and Zinc, whereas from wear of metals detected after the engine is operated, were from copper, iron, chromium, aluminum, silicon, molybdenum, lead, and others (Gómez-Rico et al. 2003; Tyson-Young 2008; Kamal, A., & F. Khan 2009; Durrani et al. 2012; Danane et al. 2014; Mensah-Brown 2015; Merai-Yash 2016). The presence of magnesium and sodium are an indicator of water contamination while silicone and Calcium are the results of dust contamination. Analysis of the metal content can be used as a guide in determining the point of wear that has occurred and the source of contamination in the lubricants as presented in Table 4.

Wear metals are metals debris derived from engine components. Wear metals observed in this study were Fe, Al, Cu, Cr, Si. Wear can be defined as the loss of material from the surface due to the metal to metal contact between surfaces. Almost all engines lose durability and reliability due to wear and tear. Wear caused material loss partly due to the physical separation because of micro-fractures, and chemically dissolving or melting at the contact point. Several types of wear are adhesive, abrasive, fatigue, and corrosive.

The laboratory test indicated the increase in metal contents during services, as shown in Figure

Table 4
Metals in used oil and their potential sources

No	Sources of wear	Types of metal
1.	Piston	Aluminium (Al), copper (Cu) dan iron (Fe)
2.	Ring Piston	Chromium (Cr), Nickel (Ni), Molybdenum (Mo)
3.	Bearing	Aluminium (Al), Antimon (Sb), Cadmium (Cd), Cobal (Co), Copper (Cu), Lead (Pb), Magnesium (Mg), Silver (Ag), Tin (Sn), Zinc (Zn)
4.	Cylinder Liner	Chromium (Cr), Iron (Fe)

Table 5
Warning level of metal content in lubricants

Metal	Warning level [ppm]
Fe	>100
Al	>30
Cu	>40
Cr	>20
Si	>30 (higher for new engine)

Source*: Hanifuddin, M., & Hastuningtyas, S.S.(2011)*

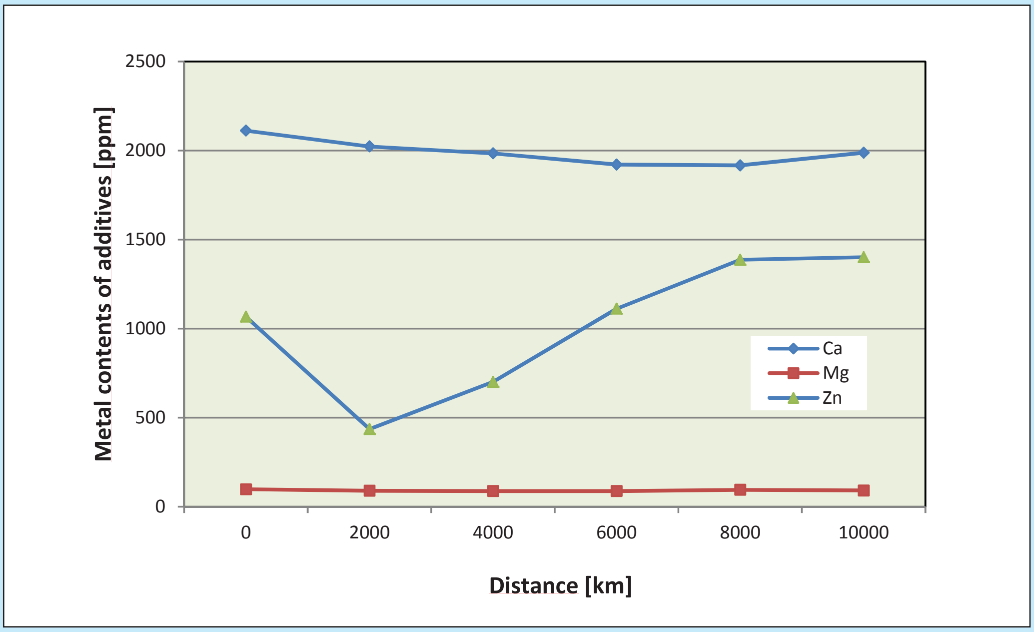


Figure 4
Metal content of additives in lubricant.

3. This is an indication of wear on the engine components.

Metal contents in the lubricants are limited by the warning level value as presented in Table 5. The values listed in the table are threshold warning values where the lubricants should be changed since the higher metal content could result in engine damage.

This result, described in figure 3, demonstrates that the values of metal content are under the maximum level, except the silicone which exceeded the warning level. Silicone normally gets into the lubricants from the environment such as the air, and dirt. In this research, the most potential source of silicon is the dirt carried along with the air into the engine.

Metals content derived from additives illustrate a relatively constant value as shown in Figure 4. This is because they only transform into a different form of chemical compounds as the additives react during the lubricants being used. The curve of zinc illustrates a decrease at the early service until reaching 2000 km but an increase for the further application. This phenomenon has occurred due to the Zinc Dialkyl Dithiophosphates (ZDDP) as anti-wear additives were activated and formed a protective coating onto the surface of engine components. At this time, measurement of zinc content in used oil will be lower. In a longer application, this protective layer is peeled and recombined with the wear, as a result the zinc content in used oil increases.

IV. CONCLUSION

The study demonstrates that the performance of the lubricant which is formulated for CNG-converted gasoline engine is still excellent. Specially formulated lubricants are required to support the engines, particularly in the extreme operation condition. The results show that the formula of lubricant derived from this study has a good performance during services up to 10.000 kilometers. The value of the kinematic viscosity indicate the degradation of lubricants occurs during services decreases only about 10.67% from the initial value of 15.28 cSt to 13.65 cSt. The base number decreases about 33% from the original TBN value of 9.44 mg.KOH/g to 6.35 mg.KOH/g at the end of road test. Metal contents as an indicator of the occurrence of wear show that the values are still under their maximum level, except the silicone which exceeded the warning level. Overall, the lubricants resulting from this study give a good performance for CNG-converted gasoline engine.

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