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Technical, Environmental and Economical Feasibilities of Fuel with Higher Octane Number

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***Abstract*:** *LCGC (Low Cost Green Car) program has been launched. LCGC should be fuel efficient due to its small engine size and relatively high compression ratio. However, appropriate fuel with higher Octane Number is required to prevent engine knocking. It is recommended to use only Pertamax (RON = 92), not other fuels with lower RON. The issues regarding fuel consumption and air pollution become critical because many people can easily buy LCGC and consequently traffic jams occur more frequently. The goal of the research is analyzing the technical, ecological and economical feasibilities of using fuel with higher octane number. A typical 1-liter LCGC is selected to undergo static tests on a chassis dynamometer in order to reveal its performance, such as power, torque, Air-Fuel ratio, etc. Afterward, exhaust gas emissions are measured at idle conditions. Two types of fuels are used, i.e. Pertamax and Premium (RON = 88), therefore their effects are directly comparable. In term of SFC (Specific Fuel Consumption), the car with RON 92 consumes less fuel at low speeds (20 – 30 km/h), which differs between 14.4% up to 71%. Since lower gears are used mostly at city traffics, it means that the RON 92 demonstrates its superiorities in urban transportation. On the contrary, at higher speeds (30 - 40 km/h) RON 88 shows to be slightly better than RON 92 because it consumes up to 5.2% less fuel. Meanwhile the exhaust gas measurements showed that RON 92 emitted 804 ppm of Carbon Monoxide, which was better than RON 88 which discharged 1226 ppm. In term of HC emission, the RON 92 proves to be better than RON 88 as well, where the former emits only 128 ppm and the latter 207.4 ppm. Considering that carbon in the exhaust gas represent combustion perfectness, RON 92 burns better and more efficient in the engine, and thus more environmental friendly. Unfortunately, RON 88 looks to be economically better even at the first gear where RON 92 is technically better. At the second gear, RON 88 is much better, i.e. between 25% and 32% cheaper. Unless the government reduces the Pertamax price, people will have no motivation to use Pertamax as recommended.*

Keywords: *City cars, Fuel consumption, Fuel cost, Gas emission, Research Octane Number*

1. Introduction

In 2013 the Indonesian government launched LCGC (Low Cost Green Car) or city car program in order to support national four-wheeled vehicle industry. LCGC is supposed to be more affordable for medium income families. Such a low price is made possible by using cheaper local components, governmental tax reduction, decreased safety features, etc. The green aspect of such cars is caused by lower fuel consumption and better exhaust gas emission, due to their compact size, light weight body and small engines (usually between 1000 cc and 1200 cc). Moreover, the cars are fuel efficient because of their relatively high compression ratio (between 10 and 10.5). However, appropriate fuel with higher RON (Research Octane Number) is required to prevent engine knocking or detonation due to higher temperatures, which leads to engine damage, as well as unnecessary power and fuel wastages. Therefore, the government and car manufacturers strongly recommend LCGC owners to exclusively use Pertamax, not other commercially sold gasolines like Pertalite and Premium, because of the RON level as shown in Table 1.

Although the RON differences are quite small, but the price disparities are considerable. Pertamax and Pertalite are considered to be expensive, while Premium is the cheapest owing to price subvention from the government. Unfortunately, the government and the car manufacturers can not enforce people for not buying Premium. Finally, they desperately notice that almost all low cost cars understandably consume low price fuel. It is claimed that fuel with a higher RON is not necessarily better, because RON is not a measure of fuel quality, but fuel resistance to engine knock caused by premature ignition. The fuel is simply more expensive due to extra processing to raise the RON [1].

TABLE I: Gasolines in Indonesia, sold by PT Pertamina

No	Type	RON	Price (IDR per liter)
1	Premium	88	6,550 (subsidized price)
2	Pertalite	90	7,500
3	Pertamax	92	8,250
4	Pertamax plus	95	Not marketed anymore
5	Pertamax turbo	98	9,400

One of several methods to increase RON is blending of mid-level ethanol (between E25 to E40) with conventional gasoline. As a result, higher fuel efficiency and lower overall GHG emissions can be achieved [2]. Increased RON is believed to be able to improve the fuel efficiency and exhaust emission, as demonstrated by Sharma and Lal (2015), who used gasoline-ethanol blends (E0, E5, E10, E15 and E20, corresponding respectively to RON of 88, 92, 92.8, 93.5 and 94.4). Their experiments revealed that E5 and E10 were the best in terms of thermal efficiency, specific fuel consumption, torque, and gaseous emissions, such as CO_2, CO, HC and NO_x [3]. Another investigation revealed that RON 95 emitted less NO_x, CO and total HC compared to that of RON 91. Moreover the BSFC (brake specific fuel consumption) was lower. The only better feature of RON 91 was its brake power [4].

However, some other experiments unexpectedly showed inverse phenomena. Sayin et al. (2005) demonstrated that using RON 95 instead of RON 91 not only increased its BSFC by as much as 5.6%, but also gas emissions, i.e. 5.7% more CO and 3.4% more HC. It was not surprising, because the engine compression ratio was only 8 : 1, and therefore RON 91 was sufficient [5]. An almost similar result was obtained as well, where the powers, torques and specific fuel consumptions from RON 91 fueled engine are astonishingly better than that from RON 95. The reason was presumably the lower energy content of RON 95 due to addition of MTBE (methyl tertiary butyl ether) as octane improver [6].

The above mentioned researches were carried out in an engine dynamometer. Actually, there is another measurement equipment called chassis dynamometer, which is able to simulate the aggregated performance of a vehicle, not only its engine but also its transmission and driveline. Several vehicle tests have been successfully conducted using chassis dynamometer [7, 8].

Unfortunately, issues regarding fuel consumption and air pollution become critical because many people can now easily buy LCGC and consequently traffic jams occur more frequently and intolerably. While a single LCGC is more efficient and cleaner, their huge population must be responsible for worsening atmosphere, especially in city centers. Velocity fluctuations (due to repeated accelerations and decelerations) on a slow moving traffic flow will undeniably increase fuel consumption and consequently exhaust gas emission. The higher the velocity fluctuations, the more severe will be these increases. In average velocities lower than 40 km/h, which likely occur in urban traffics, fuel consumption rates increase highly nonlinear if the vehicle speed changes [9].

The goal of the research is analyzing the technical, ecological and economical feasibilities of using fuel with higher octane number, as endorsed by the government and car manufacturers. The research is expected to show whether RON 92 is better than RON 88, or not. The results can be broadly disseminated in order to convince public to follow, or even disobey, the recommendation.

2. Research Methodology

A typical LCGC is selected to undergo static tests on an AWD 1200 chassis dynamometer in order to reveal its performance, such as power, torque, AFR (Air-Fuel ratio) etc., at various engine rotational speeds and gear positions. The car engine has 3 in-line cylinders with an overall displacement of 998 cubic centimeters, and equipped with 12 valves, DOHC, EFI and 5-speed manual transmission. Two types of fuels are used, i.e. Pertamax and Premium, therefore their effects can be directly compared. Figure 1 shows the measured LCGC on the chassis dynamometer.

Fig. 1: The measured LCGC on the chassis dynamometer.

The obtained data are used to calculate the SFC (specific fuel consumption) which represents the fuel economy. An almost similar procedure is explained elsewhere [8].

The air consumption $\dot{m}_a$ is calculated with the help of the equation 1

$$\dot{m}_a = \eta_V \rho_a V_d \frac{N}{2}, \tag{1}$$

and the fuel consumption $\dot{m}_f$ is calculated with the help of the measured AFR

$$AFR = \frac{\dot{m}_a}{\dot{m}_f}, \tag{2}$$

whereas η_V is volumetric efficiency, ρ_a is air density, V_d is piston displacement, N is the rotational speed, and the number 2 indicates that there are 2 engine rotations for one air intake. The volumetric efficiency η_V actually fluctuates between 0.8 - 0.89 with engine speeds, therefore an assumed constant value of 0.86 is acceptable [10]. The air density $\rho_a = 1.137$ kg/m^3, because the ambient condition is 31 ^{o}C and 992 mbar.

Finally, the SFC (specific fuel consumption) at different speeds and gear positions can be estimated using the equation

$$\mathrm{SFC} = \frac{\dot{m}_f}{Power}, \tag{3}$$

whereas the vehicle power is obtained from the dynamometer tests. The fuel densities of the two fuels are the same, i.e. between 715 and 770 kg/m^3, therefore an average value of 742.5 kg/m^3 is used in the subsequent calculations.

Afterward, a simple economical analysis is carried out to show whether higher octane number more expensive or not.

Finally, exhaust gas emissions, especially CO and HC, are measured at several idle conditions, which are without any load at rotations of 900 - 1000 rpm. The measurements are conducted according to SNI 19-7118.1-2005 standard, using a Stargas 898 gas analyzer, as shown in Figure 2. The measurements are carried out 5 times and the average value is used to draw the conclusion. Likewise, Pertamax and Premium are tested, therefore their effects can be immediately contrasted.

Fig. 2: The gas analyzer.

3. Results and Discussions

3.1. Fuel Consumption

The results of the dynamometer tests exclusively for the first and second gear are displayed in Figures 3 and 4. Other figures representing the third up to fifth gears are not shown because typical urban traffics use mostly the first and second gears. The vehicle with RON 92 consistently demonstrates higher power and torque compared to that with RON 88. The differences of the maximum powers were very large at the first gear, i.e. 32.7%, but small at the second gear position, i.e. about 2.37%. During the test at the first gear, the AFR of RON 92 is always higher than that of RON 88, which means that the engine operates with leaner mixture and thus more fuel efficient, but at the second gear the AFR of RON 88 is mostly higher.

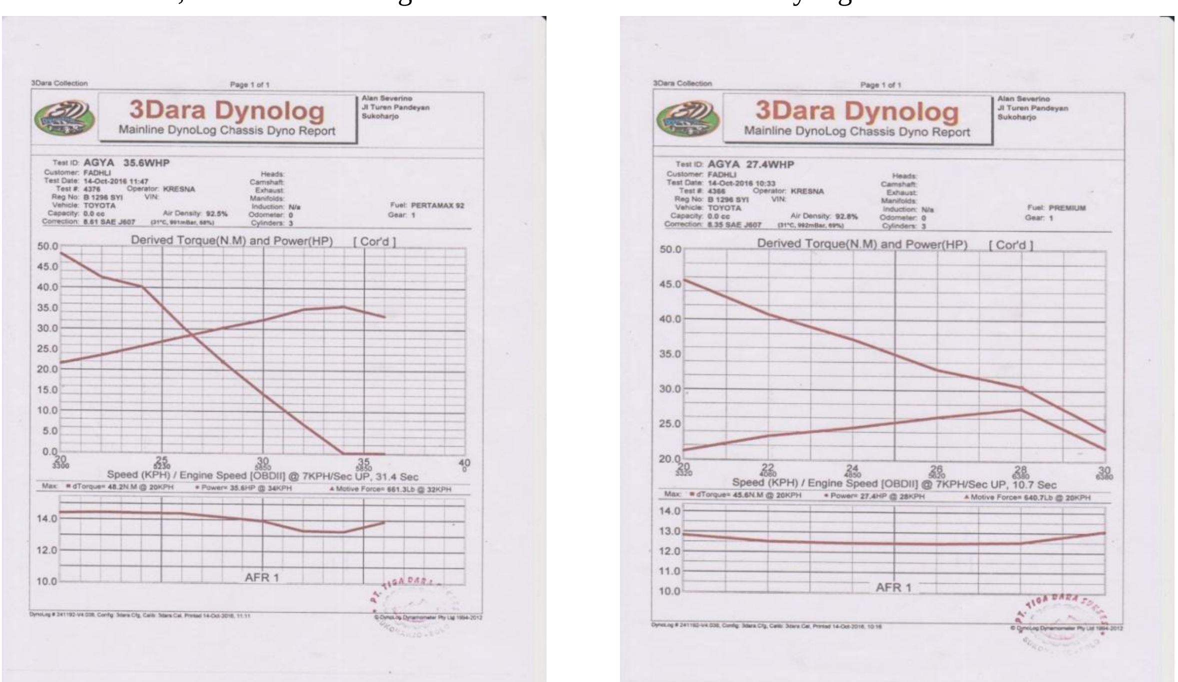

Fig. 3: Results of the first gear : RON 92 (left) and RON 88 (right)

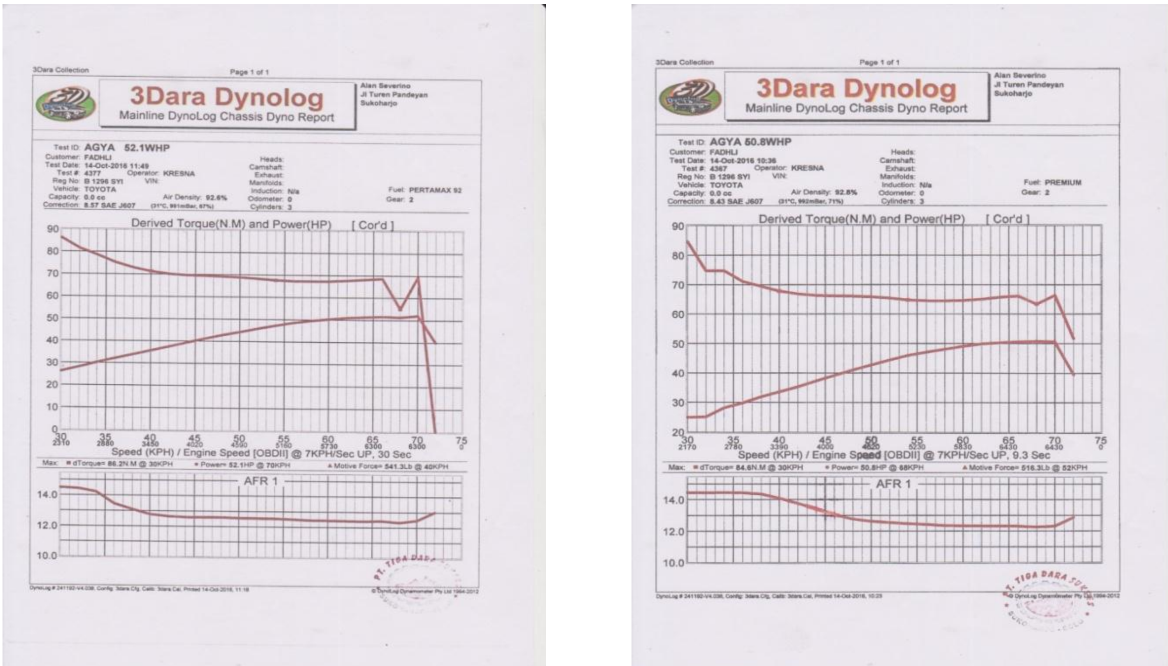

Fig. 4: Results of the second gear: RON 92 (left) and RON 88 (right)

Based on thorough analysis of the dynamometer tests, with the help of equations 1 – 3, the effects of fuel RON at several low vehicle speeds are revealed in Table 2.

TABLE II: The Effects of RON on the Fuel Economy.

Car Speed (km / h)	Gear Position	Specific Fuel Consumption (g / kWh)		Fuel Cost (IDR / kWh)	
		RON 88	RON 92	RON 88	RON 92
20	1	476.66	416.53	4204.9	4628.1
25		648.34	533.30	5719.3	5925.5
30		875.08	511.29	7719.5	5681.0
30	2	235.83	243.52	2080.3	2705.8
35		261.71	259.93	2308.7	2888.1
40		282.36	297.90	2490.8	3310.1

In term of SFC (Specific Fuel Consumption), the car with RON 92 consumed less fuel at low speeds (gear 1). The differences were significant, i.e. 14.4% at 20 km/h, 21% at 25 km/h, and shockingly 71% at 30 km/h. It proves obviously that RON 92 is better than RON 88 at slow moving traffics. The very high fuel consumption at 30 km/h is caused by too high engine rotational speed which consequently takes in too much air (and fuel as well). In such a condition the driver must switch the gear up to the second gear, whereas the SFC will decrease to as low as 26.95% (RON 88) and 47.62% (RON 92) from the previous values. On the contrary, now at higher speeds (gear 2) RON 88 shows to be slightly better than RON 92, i.e. up to 5.2% less fuel.

In term of fuel cost, since the price of RON 92 is around 26% higher, RON 88 looks to be economically better even at the first gear where RON 92 is technically better. As predicted, at the second gear (between 30 – 40 km/h), RON 88 is economically much better, i.e. between 25% and 32% cheaper. Unless the government reduces the Pertamax price, or increases the Premium price, or both, people will have no motivation to use Pertamax as recommended.

3.2. Gas Emission

One example of the measurement results of exhaust gas emission is shown in Figure 5. The complete results are shown in Table 3.

The exhaust gas measurements show that RON 92 emits 804 ppm of Carbon Monoxide, which is better than RON 88 that discharges 1226 ppm, which is 52.5% higher. Whereas in term of Hydrocarbon emission, the RON 92 proves to be better than RON 88 as well, where the former emits only 128 ppm and the latter 207.4 ppm, which represents 62% higher value.

EXHAUST GAS ANALYSIS
Serial nr. 1711960
TECNOTEST
TYPE STARGAS 898
OIML CLASS 0
REPORT N.
545/OIML/04/RM
10/07/2004

RPM	0	[1/min]
CO	0.066	[% vol]
CO2	11.06	[% vol]
HC	136	[ppm vol]
O2	5.04	[% vol]
NO	----	[ppm vol]
CO cor	0.088	[% vol]
λ	1.299	[-]
TEMP.	---	[°C]

ENVIRONMENT CONDITIONS

Temperature	38	[°C]
Pressure	985	[hPa]
Rel. Humidity	44	[%HR]

DATE: 25/10/2016
TIME : 13:46

CAR DATA
FUEL: GASOLINE
BRAND:
MODEL:
LIC.PLATE:
CHASSIS:
Km:

WORKSHOP
AOTOMOTIF
AFT-UNY
VANDIKUOTO
AA
A
EXAMINER:

EXHAUST GAS ANALYSIS
Serial nr. 1711960
TECNOTEST
TYPE STARGAS 898
OIML CLASS 0
REPORT N.
545/OIML/04/RM
10/07/2004

RPM	0	[1/min]
CO	0.090	[% vol]
CO2	11.36	[% vol]
HC	134	[ppm vol]
O2	4.60	[% vol]
NO	----	[ppm vol]
CO cor	0.117	[% vol]
λ	1.263	[-]
TEMP.	---	[°C]

ENVIRONMENT CONDITIONS

Temperature	38	[°C]
Pressure	985	[hPa]
Rel. Humidity	44	[%HR]

DATE: 25/10/2016
TIME : 13:52

CAR DATA
FUEL: GASOLINE
BRAND:
MODEL:
LIC.PLATE:
CHASSIS:
Km:

WORKSHOP
AOTOMOTIF
AFT-UNY
VANDIKUOTO
AA
A
EXAMINER:

Fig. 5: Results of exhaust gas measurements.

TABLE III: The Measurement Results of CO and HC

Sampling		1	2	3	4	5	Average
CO (ppm)	RON 88	710	1040	1230	1330	1820	1226
	RON 92	480	770	1210	660	900	804
HC (ppm)	RON 88	357	237	192	114	137	207.4
	RON 92	151	123	96	136	134	128

Considering that carbon in the exhaust gas denotes combustion perfectness, the RON 92 burns better and more efficient in the engine, and thus more environmental friendly.

4. Conclusions

Based on those discussions, the following conclusions can be drawn:

1. The car with RON 92 consumes less fuel than RON 88 at low speeds. The differences are: 14.4% at 20 km/h, 21% at 25 km/h, and 71% at 30 km/h. It proves that RON 92 is better than RON 88 at slow moving traffics. On the contrary, at higher speeds (between 30 and 40 km/h) RON 88 shows to be slightly better than RON 92 because it consumes up to 5.2% less fuel.
2. The car with RON 92 emits 804 ppm CO, while RON 88 discharges 1226 ppm, which is 52.5% higher. In term of HC, the RON 92 proves to be better than RON 88 as well, where the former emits 128 ppm and the latter 207.4 ppm, which represents 62% higher value. RON 92 burns better and more efficient in the engine, and thus more environmental friendly.

3. Since the price of RON 92 is around 26% higher, RON 88 looks to be economically better even at the first gear where RON 92 is technically better. At the second gear, RON 88 is much better, i.e. between 25% and 32% cheaper. Unless the government reduces the Pertamax price, people will have no motivation to use Pertamax as recommended.

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6. References

[1] Y.A. Cengel and M.A. Boles, *Thermodynamics: an Engineering Approach*, 4th ed. New York, USA: McGraw-Hill, 2002, ch. 8, pp. 493-499.

[2] J. Stolark. (June 2015). High octane fuels: Challenges & Opportunities. *EESI fact sheet*. Washington, DC. Available: www.eesi.org/papers.

[3] G. Sharma, and H. Lal, "Effects of ethanol-gasoline blends on engine performance and exhaust emissions in a spark ignition," *International Journal on Emerging Technologies* 6 (2), pp. 184 – 188, 2015.

[4] S. Binjuwair, T.I. Mohamad, A. Almaleki, A. Alkudsi, and I. Alshunaifi, "The effects of research octane number and fuel systems on the performance and emissions of a spark ignition engine: A study on Saudi Arabian RON91 and RON95 with port injection and direct injection systems," *Fuel* 158, pp. 351 – 360, 2015.

[5] C. Sayin, I. Kilicaslan, M. Canakci, and N. Ozsezen, "An experimental study of the effect of octane number higher than engine requirement on the engine performance and emissions," *Applied Thermal Engineering* 25, pp. 1315 – 1324, 2005.

[6] D.U. Lawal, B.A. Imteyaz, A.M. Abdelkarim, and A.E. Khalifa, "Performance of spark ignition engine using Gasoline 91 and Gasoline 95," *International Journal of Innovative Science, Engineering and Technology*, vol 1, issue 6, pp.464 – 469, 2014.

[7] A. Moskalik, P. Dekraker, J. Kargul, and D. Barba, "Vehicle component benchmarking using a chassis dynamometer," *SAE International Journal of Material Manufacture* 8 (3), 2015.

[8] H. Saptoadi, "Dynamometer tests to estimate efficiencies of slow moving vehicles," in *Proceedings of international conference on engineering research & applications*, May 2017, Istanbul (Turkey), pp. 267 – 271.

[9] J.A. Montemayor-Aldrete, P. Ugalde-Velez, M. del Castillo-Mussot, C.A. Vazquez-Villanueva, G.J. Vazquez, and A. Mendoza-Allende, "Steady state traffic flow, entropy production rate, temporal fluctuations and fuel consumption," *Physica A* 361, pp. 630 -642, 2006.

[10] A.H. Shamekhi, N. Khatibzadeh, and A. Shamekhi, "A comprehensive comparative investigation of CNG as an alternative fuel in a bi-fuel spark ignition engine," *Iranian Journal of Chemistry and Chemical Engineering*, vol. 27, no. 1, pp. 73 – 83, 2008.