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NUMERICAL STUDY ON COOLING EFFECT POTENTIAL FROM VAPORIZER DEVICE OF LPG VEHICLE

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Abstract

Over fuel consumption and increased exhaust gas due to the A/C system have become a serious problem. On the other hand, the LPG-fueled vehicle provides potential cooling from LPG phase changes in the vaporizer. Therefore, this article presents the potential cooling effect calculation from 1998 cm^3 spark ignition (SI) engine. A numerical study is used to calculate the potential heat absorption of latent and sensible heat transfer during LPG is expanded in the vaporizer. Various LPG compositions are also simulated through the engine speed range from 1000 to 6000 rpm. The result shows that the 1998 cm^3 engine capable of generating the potential cooling effect of about 1.0 kW at 1000 rpm and a maximum of up to 1.8 kW at 5600 rpm. The potential cooling effects from the LPG vaporizer contributes about 26% to the A/C system works on eco-driving condition.

Keywords: LPG vaporizer, heat absorption, cooling effect

1. Introduction

Nowadays, an Air Conditioning (A/C) system has become the main accessories of the passenger car to increase comfortability. The A/C system has a long history in which the first was installed on Packard in 1939. Along with the vehicles development, many improvements have been made to accommodate the new car design, improve fuel efficiency, gain environment acceptance, improve passenger comfortability, and provide health benefits [1-2]. However, during the A/C system

Nomenclatures

c_p	Specific heat in a constant pressure, kJ/kg.K
h	Specific enthalpy, kJ/kg
m_a	Mass flow rate of air, kg/s
m_L	Mass flow rate of LPG, g/s
n	Engine rotation, rpm
q_{ev}	Total heat absorption, kW
q_l	Latent heat transfer, kW
q_{sen}	Sensible heat transfer, kW
T	Temperature, °C

Greek Symbols

η_v	Volumetric efficiency
ρ_a	Air density, kg/m^3

Abbreviations

AFR	Air Fuel Ratio
A/C	Air Conditioning
COP	Coefficient of Performance

work by vapor compression systems will reduce engine power to drive the compressor. As a consequence, fuel consumption and exhaust emissions will increase due to the A/C work[2-4]. Meanwhile, LPG-fueled vehicles provide the potential cooling effect from LPG phase change in vaporizer device. This potential has not been utilized and lost through the engine coolant [5-6]. Therefore, this study discusses the characteristics of potential cooling effect generated from LPG vaporizer.

Recently, the concept of cooling effect from LPG stream (direct refrigeration) is used for a small cooler and a domestic refrigerator. LPG from the household cylinder is flowed through a capillary tube placed in a closed box before it is flowed to a burner. LPG absorbs heat from the air in the box during phase changes from liquid to vapor in the capillary tube [7]. This concept was discussed further by Ghariya et al. [8] as one of the thermodynamic evolution in refrigeration system. Furthermore, direct refrigeration was observed in the domestic refrigerator by Shah et al. [9]. This study presented a COP of direct refrigeration that is higher than the vapor compression refrigeration. With the same method, Nikam et al. [10]also conducted experiments study on a refrigerator. Finally, direct refrigeration was discussed not only by considering latent heat absorption but also by considering sensible heat transfer [11].

In the previous study [12], the potential cooling effect from LPG vehicle had been studied but the result was too large due to the inaccuracies calculation of thermodynamic properties. The study did not consider the sensible heat transfer from air to LPG, whereas LPG temperature after evaporation is still lower than the ambient air temperature. Therefore, this research considered sensible heat transfer after the evaporation process which is also a correction of the previous work. A numerical study was conducted to calculate the potential cooling effect available at various LPG flow rate and LPG compositions.

2. LPG Vehicle and Vaporizer Study

LPG has been used as a vehicle fuel because it has all key properties for spark ignition engines [13].The environmental problem is the main reason for government in many countries to encourage their people to use LPG as a substitute for gasoline. LPG vehicles increased about 9.4 million in 2003 [14] and more than 17.4 million in 2010 [15]. In 2014, there were more than 25 million LPG vehicles, mostly as light duty vehicles (LDV) and the rest as high duty vehicles (HDV) with consumption of more than 25 thousand tones [16]. In the decades, the use of LPG as an alternative fuel for road vehicles and its comparison with other fuels has been extensively studied. LPG vehicle has been proved to produce lower emissions than the gasoline engine, both in urban cycle and extra-urban cycle test, for all parameters CO, CO_2, HC, and NO_x. In fact, LPG as a fuel has an effect on the volumetric efficiency [6, 17-18]. As a result, some researchers reported that there were various types of the LPG engines which produce lower output power than the gasoline engines, varied from 4-20% [6, 19-21]. The output power can be increased through the improvement of the ignition system, the adjustment of the ignition timing, and the modifications of other engine components [22-26].

LPG become the choice among other alternative fuels, such as alcohol, CNG, and hydrogen, because to run the vehicles with LPG, either as a fully dedicated fuel or bi-fuel (LPG and gasoline can be used interchangeably) only needs slight modifications to the fuel system [13]. LPG has a lower pressure than CNG so that the LPG infrastructure is reasonable.The commercial LPG for road vehicle is commonly a mixture of propane (C_3H_8) and butane (C_4H_{10}), because of their properties and characteristics [27]. However, in some countries such as Germany and Finland, the commercial LPG only consists of propane. The composition of LPG may also vary between summer and winter, with a higher percentage of propane in the winter months. It was taken to prevent from freezing [5]. Around the world, approximately 60% of LPG is obtained from crude oil and natural gas extraction, while, about 40% is produced from the refinery production [27-29].

Up to now, there are four main types of LPG fuel systems. They are Converter-Mixer (CM), Vapor Phase Injection (VPI) Liquid Phase Injection (LPI), and Liquid Phase Direct Injection (LPDI). The CM is the first generation of LPG kit which is similar to a carburetor system on the gasoline engine. The LPG flows from the evaporator to intake manifold based on vacuum within the mixer. This type is the oldest system which has been widely used since 1940, especially on vehicles that have not accommodated LPG fuel systems when manufactured. The VPI uses an evaporator like the first generation but with a few improvements. The gas flows from the evaporator at the higher pressure than the old system. The LPI does not use an evaporator but it provides a liquid fuel directly into the fuel rail such as gasoline injection system. This system supplies LPG to the engine with an accurate volume. Finally, LPDI is the most advanced among the others, because it uses the high-pressure pump and injector to inject the liquid LPG into the combustion chamber [16].

Among the four existing systems, converter-mixer (CM) is widely applied to the majority existing vehicles technologies. The basic scheme of CM LPG kits is presented in Fig. 1 [24]. However, in CM types, evaporation does not improve volumetric efficiency. The temperature drops after expansion process which theoretically increases the mixture density. It will not happen in this type because the phase change occurs in the vaporizer, not in the intake manifold or cylinder. In the existing system, circulating few engine coolants through the vaporizer cavities evaporates LPG and prevent from icing (ice formation layer) on vaporizer wall [5-6].

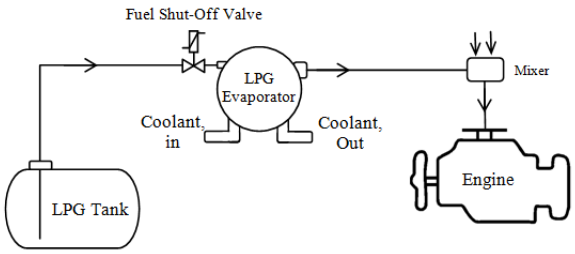
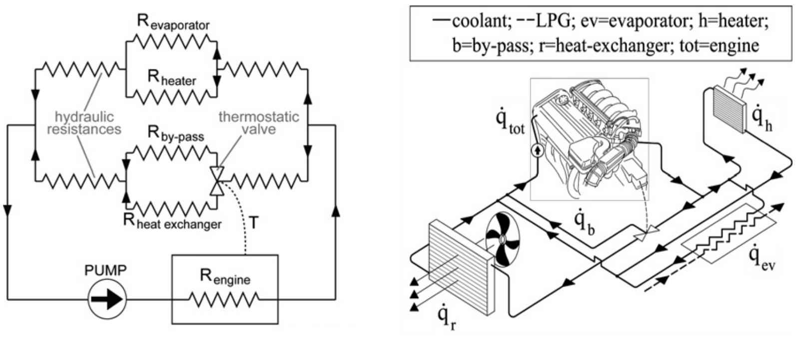


Fig. 1. Basic installation of CM LPG kits.

The function of vaporizer in the LPG fuel system is to transfer heat energy to LPG, as well as to reduce the pressure from the fuel tank from 0.4 - 0.8 MPa to 0.15 MPa, so that the LPG evaporates (Fig. 1). Through the evaporation process, heat absorption occurs. In the original design, the evaporation energy is supplied from engine coolant. Figure 2 shows the hydraulic sketch and layout of the engine coolant through the LPG vaporizer [6].



(a) Hydraulic sketch. **(b) Layout of the engine coolant flow.**

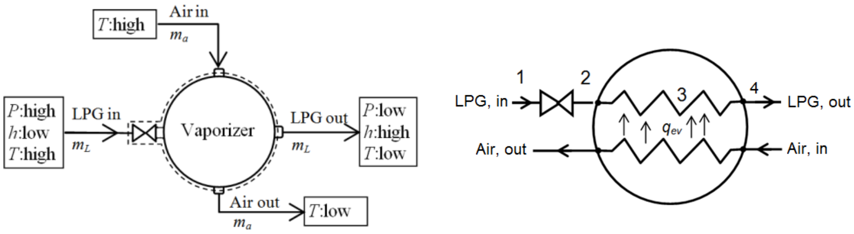
Fig. 2. Engine coolant flow path in the existing LPG engine.

Referring the Price study [5], the use of engine coolant as vaporizer fluid increasing the temperature of LPG vapor more than 50°C when it exits from the evaporator. In this condition, the specific volume of LPG vapor becomes large and reduces air mass sucked into the engine. Meanwhile, LPG has relatively low boiling points ranges from -32°C to -8.0°C at 0.15 MPa, depending on its compositions. This provides an opportunity to vaporize LPG by ambient air to produce a cooling effect.

3. Method and Parameter

3.1. Heat transfer process

In this study, LPG entered vaporizer in pressurized liquid and exit vaporizer in the superheated vapor. LPG absorbs heat from the air stream through a vaporizer. Thus, the air temperature exiting the vaporizer is lower than it enters the vaporizer. Boundary condition of LPG vaporizer and heat transfer process are presented in Fig. 3.



(a) Boundary layer. **(b) Heat transfer (q_{ev}).**

Fig. 3. Heat transfer process in the vaporizer.

Referring to Fig. 3, the expansion process (1→2) make the pressure drop and generates wet mixture. After expansion, LPG will change into saturated vapor (2→3) and it requires the latent heat transfer (q_L). LPG absorbs heat from air to improve the mixture quality before it enters the engine. In fact, the temperature of LPG at the point (3) is still lower than the ambient air temperature. Furthermore, sensible heat transfer (q_{sen}) occurs between LPG and air (3→4). Figure 4 presents the total heat transfer process of LPG in the vaporizer.

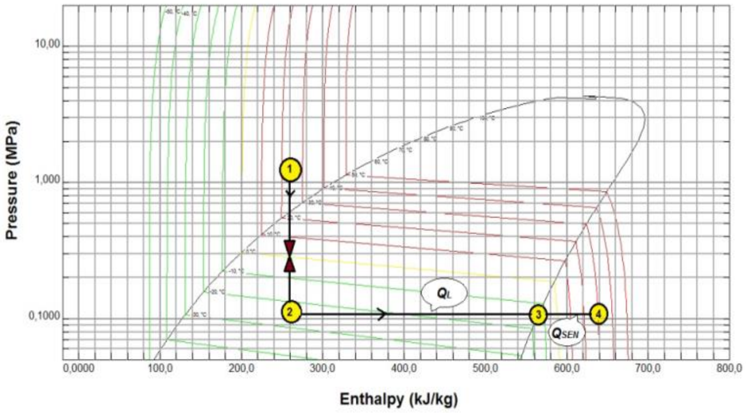


Fig. 4. Total of potential heat transfer in LPG vaporizer.

3.2. Potential heat transfer

According to the LPG evaporation process in vaporizer (Fig. 4), the requirement of heat energy is presented as follows.

$$q_{ev} = q_l + q_{sen} \tag{1}$$

$$q_{ev} = [m_L \cdot \Delta h] + [m_L \cdot c_p \cdot \Delta T] \tag{2}$$

where q_{ev} is the total heat requirement for evaporating process in kW. m_L is the LPG flow rate in g/s. Δh is the enthalpy difference of LPG from evaporating process in kJ/kg. $c_p$is the specific heat in a constant pressure in kJ/kg.K. Finally, ΔT is temperature difference of LPG from saturated vapor to superheated vapor.

3.3. Potential cooling effect calculation

In this study, the potential heat absorption available in vaporizer was calculated from 1000 to 6000 rpm. The engine used in this work refers to the Irimescu study [17].The LPG flow rate was calculated by equation as follows.

$$m_L = \frac{m_a}{AFR} \tag{3}$$

where AFR is air to fuel ratio and it is assuming constant throughout the engine speed at 15.7. $m_a$is the air mass flow in kg/s that is calculated by the equation as follows.

$$m_a = \frac{\eta_v \cdot \rho_a \cdot V_d \cdot n}{12 \cdot 10^7} \tag{4}$$

where ρ_a is the air density and assuming constant at 1.21 kg/m^3. η_v is the volumetric efficiency.$V_d$is the engine displacement in cm^3 and n is the engine speed in rpm.

In fact, the differences in fuel properties have an effect on the engine volumetric efficiency. Irimescu [17] presents the results of his study on alternative fuels compared to gasoline. LPG, ethanol, methane, and hydrogen were examined and applied to 1998 cm^3 engine with the compression ratio of 9.2. This study found that volumetric efficiency of LPG was lower than gasoline and ethanol but higher than methanol and hydrogen (Fig. 5).

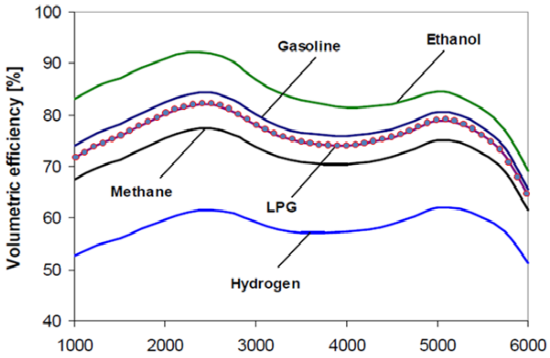


Fig. 5. LPG volumetric efficiency compared to other fuels.

From Fig. 5, the volumetric efficiency of LPG throughout the engine speeds is estimated in Table 1.

Table 1. Volumetric efficiency of LPG engine.

Engine speed, *n* (rpm)	Volumetric efficiency, η_v	Engine speed, *n* (rpm)	Volumetric efficiency, η_v
1000	0.720	3600	0.747
1200	0.740	3800	0.743
1400	0.755	4000	0.742
1600	0.771	4200	0.747
1800	0.789	4400	0.755
2000	0.805	4600	0.764
2200	0.817	4800	0.779
2400	0.824	5000	0.792
2600	0.820	5200	0.790
2800	0.803	5400	0.775
3000	0.782	5600	0.750
3200	0.766	5800	0.710
3400	0.755	6000	0.650

In fact the LPG compositions are different in each country, LPG composition was simulated ranging among 100/0; 90/10; 80/20; 70/30; 60/40; 50/50; 40/60; and 30/70. The composition is assumed constant during the tank discharging. Then the LPG properties are taken from Refprop NIST. This study used the assumption that the air temperatures in entering and exiting vaporizer are at 33°C and 23°C, respectively. Then, the superheated vapor exits from vaporizer at 20°C. Total heat absorption was calculated using algorithm presented in Fig. 6. The properties data for various LPG compositions after expanded from pressurized cylinder to 0.15 MPa are presented in Table 2.

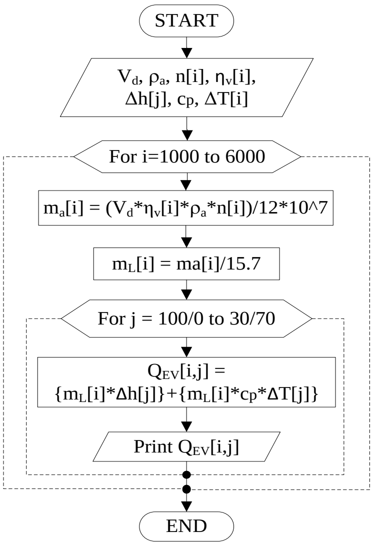


Fig. 6. Basic step of potential cooling effect calculation.

Table 2. Properties data for various LPG compositions after expanded from pressurized cylinder (0.7 MPa) to 0.15 MPa.

Specific state point		Propane/Butane mass fraction (%)							
		100/0	90/10	80/20	70/30	60/40	50/50	40/60	30/70
Liquid temp (°C)	[1]	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Mixture temp.(°C)	[2]	-32.8	-30.3	-27.5	-24.4	-20.9	-17.0	-12.8	-8.1
Saturated vapor temp (°C)	[3]	-32.8	-25.1	-19.2	-14.3	-9.9	-6.0	-2.4	0.9
Superheated vapor temp (°C)	[4]	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Mixture enthalpy (kJ/kg)	[2]	279.5	279.2	278.8	278.5	278.1	277.8	277.5	277.3
Vapor enthalpy (kJ/kg)	[3]	537.9	548.3	556.9	564.2	570.6	576.4	581.7	586.4
Δ*T*, vapor (°C)	[4-3]	52.8	45.1	39.2	34.3	29.9	26.0	22.4	19.1
Δ*h*(kJ/kg)	[3-2]	254.4	269.1	278.1	285.7	292.5	298.6	304.2	309.1

4. Results and Discussion

4.1. Potential cooling effect

In this work, the potential cooling effect was calculated based on the number of assumptions which are 1) heat transfer process is fully occurring in the vaporizer and no interaction with the environment; 2) heat absorption is generated from latent and sensible heat transfer; 3) pressure drop occurred on expansion valve is an isenthalpic process; and 4) kinetic and potential energy are neglected. Figure 7 shows the potential cooling effect from latent heat absorption (q_l) and sensible heat transfer (q_{sen}) at various LPG mix throughout the engine speed.

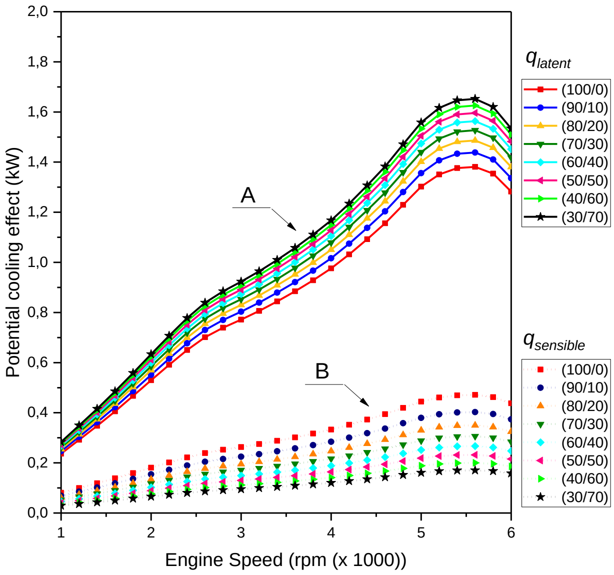


Fig. 7. The potential heat absorption from LPG vaporizer at various LPG composition.

Figure 7 shows two groups of curves with different trends. The curves with the connected line (A) show the potential cooling effect of latent heat absorption and curves with dotted lines (B) show the potential cooling effect of sensible heat transfer, representing the entire composition of LPG is being investigated. The data is showed in appendix 1. Some of the findings may be obtained from Fig. 7. Firstly, the potential cooling effect from latent heat absorption is greater than the sensible heat transfer. In view of thermodynamics data in Table 2, with LPG flow rate calculated using Eq. (3) and potential cooling effect calculated using Eq. (2), the ratio of sensible heat transfer to latent heat absorption is 34, 28, 24, 20, 17, 15, 12, and 10% for the composition of LPG 100/0, 90/10, 80/20, 70/30, 60/40, 50/50, 40/60, and 30/70, respectively. Secondly, the greater the butane in LPG composition, the greater the potential cooling effect on the absorption of latent heat. On the other hand, the greater the butane in the LPG, the smaller its sensible heat transfers. For example, pure propane produces (q_l) smaller than LPG mix but produces (q_{sen}) greater than LPG mix. This condition occurs due to the evaporation process is assumed in the constant pressure. Given that the propane and butane mix will form a gliding temperature when evaporation, then the temperature of vapor at the end of evaporation will be greater than that at the beginning of evaporation. The greatest of gliding temperature obtained in the mass fraction of 50% propane and 50% butane. Furthermore, total potential cooling effect is presented in Fig. 8.

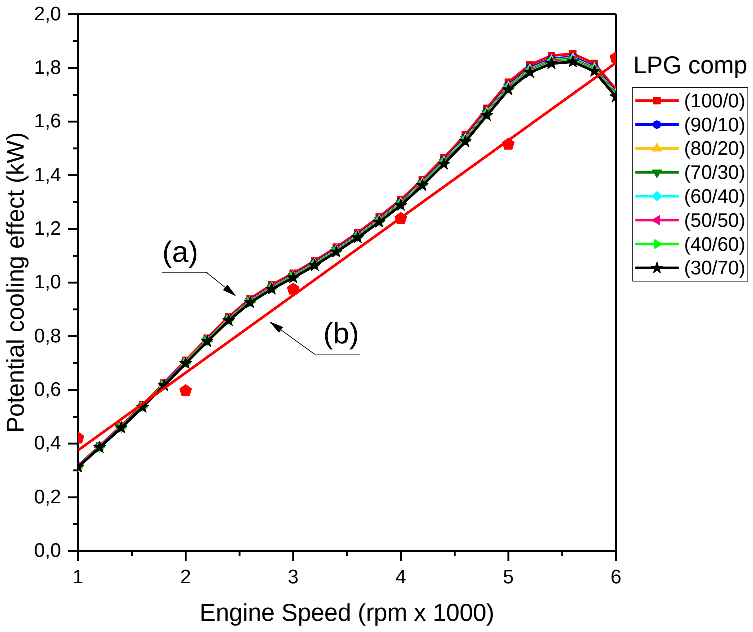


Fig. 8. The total potential cooling effect from LPG vaporizer at various LPG composition (a) and comparison with Masi study (b).

The curve designated with the notation (a) is a group of total cooling effect (q_{ev}) generated from this study. The results of calculations based on thermodynamic properties show that the composition of LPG does not affect significantly on the total cooling effect generated. While the curve (b) is the actual heat transfer of LPG to the engine coolant calculated from Masi et al. in the percentage of propane is 53% by mass. At low engine speed (<1800 rpm), the experimental results by Masi generate heat absorption greater than this study. While in medium to high engine speed (> 1800 rpm), this study resulted in the greater potential heat absorption. This condition occurs because the volumetric efficiency of the engine used by Masi tends to be larger, above 80% for all engine speed. While in this study, almost the entire value of the volumetric efficiency is below 80% for all engine speed.

In general, the cooling effect is influenced by the engine speed, in this case by the mass flow rate of fuel. A 1998 cm^3 engine at 1000 rpm (LPG flow rate of 0.9 g/s) provides potential cooling effect of less than 0.4 kW for all composition. However, at the engine speed of 3000 rpm, the vaporizer is able to provide potential cooling effect of more than 1.0 kW (LPG flow rate of 2.9 g/s). The highest potential cooling effect occurs at the engine speed of 5600 rpm but this condition is rare in normal driving conditions.

4.2. Contribution to A/C load

In accordance with the objectives of this study, the potential cooling effect produced is to reduce the load of air-conditioning systems. As it is known, the cooling capacity of the automobile A/C system was determined to be 1 TR (about 3.5 kW) [1]. Recently, Abdulsalam [30] reported of a thermal load of a passenger's car A/C systems that operated in Indonesia during the day (representing tropical country). The A/C load to achieve a comfortable temperature was reported up to 3.5 kW in the harshest conditions (at 1.00 pm). Referring to the Abdulsalam study, the potential cooling capacity from the LPG vehicle to A/C load present in Fig. 9 as follow.

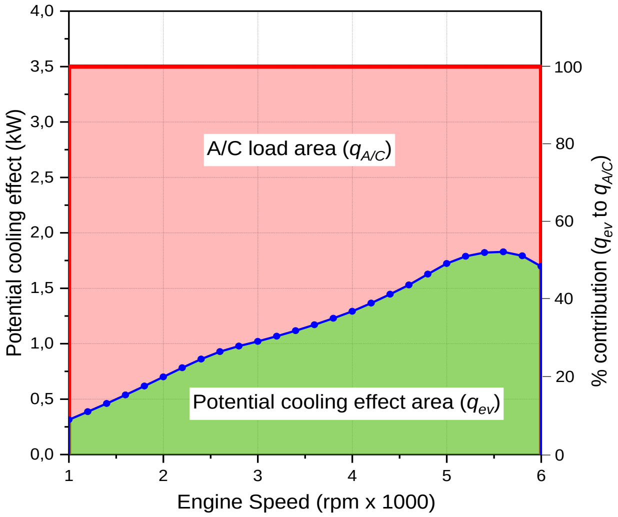


Fig. 9. Contribution of potential cooling from LPG vaporizer to A/C load.

Despite the potential cooling of LPG vaporizer reaches 1.8 kW but it was achieved at the mass flow rate of LPG was great, about 6 g/s (5600 rpm). In fact, people tend to drive a car at low speed to obtain eco-driving. Berry [31] states in order to get eco-driving, the vehicle should not be driven more than 2500 rpm. This means the potential cooling effect of LPG vaporizer contributes up to 26% of the thermal load of air conditioning.

In view of LPG properties showed at Table 2 and result of numerical study, it provides an opportunity to replace the engine coolant with air driven by a special fan. If the ambient air flowed through the evaporator cavities and the LPG took the heat from the air for a phase changing, this process will generate the air with lower temperatures. The simplest utilization is to help cooling the car's cabin as well as to reduce the workload of automobile A/C systems.

5. Conclusions

LPG absorbs heat to change from liquid phase to vapor phase. Replacing the evaporator fluid from engine coolant to the ambient air is promising to produce a cooling effect. The potential cooling effect available depends on mass flow rate of fuel. The result shows that the 1998 cm^3 engine capable of generating the potential cooling effect of about 1.0 kW at 1000 rpm and a maximum of up to 1.8 kW at 5600 rpm. The potential cooling effects from the LPG vaporizer contributes about 26% to the A/C system works on eco-driving condition. The result of calculation also indicated the greater the butane in LPG composition, the greater the potential cooling effect on the absorption of latent heat. On the other hand, the greater the butane in the LPG, the smaller its sensible heat transfers. However, the composition of LPG does not affect the total cooling effect generated. In conclusion, the potential cooling effect from LPG evaporator device is very promising for being use in tropical countries such as Indonesia, Malaysia, and other tropical countries that have no winter experience.

This study will be continued with an experimental study to investigate the actual cooling effect that can be harvested. To optimize heat transfer process, an auxiliary evaporator was installed between LPG tank and the original vaporizer. Thus, the absorption process will switch from the original vaporizer to the auxiliary evaporator. In this case, LPG vaporizer functions as a flow rate regulator.

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Appendix A
Data of potential cooling effect (q_{ev})

Potential cooling effect from 1998 cm^3 LPG-fueled vehicle at evaporation pressure of 0.15 MPa

Engine speed	m_{LPG}	Qev latent (kW) at LPG composition of :								Qev sensible (kW) at LPG composition of :								Qtotal (kW) at LPG composition of :							
rev/min	*(g/s)*	*(100/0)*	*(90/10)*	*(80/20)*	*(70/30)*	*(60/40)*	*(50/50)*	*(40/60)*	*(30/70)*	*(100/0)*	*(90/10)*	*(80/20)*	*(70/30)*	*(60/40)*	*(50/50)*	*(40/60)*	*(30/70)*	*(100/0)*	*(90/10)*	*(80/20)*	*(70/30)*	*(60/40)*	*(50/50)*	*(40/60)*	*(30/70)*
1000	0.92	0.237	0.247	0.255	0.262	0.268	0.274	0.279	0.283	0.081	0.069	0.060	0.052	0.046	0.040	0.034	0.029	0.318	0.316	0.315	0.314	0.314	0.313	0.313	0.312
1200	1.13	0.292	0.304	0.314	0.323	0.331	0.337	0.344	0.349	0.100	0.085	0.074	0.065	0.056	0.049	0.042	0.036	0.392	0.389	0.388	0.388	0.387	0.387	0.386	0.385
1400	1.35	0.348	0.362	0.374	0.384	0.393	0.402	0.409	0.416	0.119	0.101	0.088	0.077	0.067	0.058	0.050	0.043	0.466	0.463	0.462	0.461	0.461	0.460	0.460	0.459
1600	1.57	0.406	0.422	0.437	0.449	0.459	0.469	0.478	0.485	0.138	0.118	0.103	0.090	0.078	0.068	0.059	0.050	0.544	0.541	0.539	0.538	0.538	0.537	0.536	0.535
1800	1.81	0.467	0.486	0.503	0.516	0.529	0.540	0.550	0.559	0.159	0.136	0.118	0.104	0.090	0.078	0.068	0.058	0.626	0.622	0.621	0.620	0.619	0.618	0.617	0.616
2000	2.05	0.529	0.551	0.570	0.585	0.599	0.612	0.623	0.633	0.181	0.154	0.134	0.117	0.102	0.089	0.077	0.065	0.710	0.706	0.704	0.703	0.702	0.701	0.700	0.699
2200	2.29	0.591	0.616	0.636	0.654	0.669	0.683	0.696	0.707	0.202	0.172	0.150	0.131	0.114	0.099	0.086	0.073	0.793	0.788	0.786	0.785	0.783	0.782	0.781	0.780
2400	2.52	0.650	0.677	0.700	0.719	0.736	0.751	0.766	0.778	0.222	0.190	0.165	0.144	0.126	0.109	0.094	0.080	0.872	0.867	0.865	0.863	0.862	0.861	0.860	0.858
2600	2.71	0.701	0.730	0.755	0.775	0.794	0.810	0.825	0.839	0.239	0.204	0.178	0.155	0.135	0.118	0.101	0.087	0.940	0.934	0.932	0.931	0.929	0.928	0.927	0.925
2800	2.86	0.739	0.770	0.796	0.817	0.837	0.854	0.870	0.884	0.252	0.216	0.187	0.164	0.143	0.124	0.107	0.091	0.992	0.985	0.983	0.981	0.980	0.979	0.977	0.976
3000	2.99	0.771	0.803	0.830	0.853	0.873	0.891	0.908	0.923	0.263	0.225	0.195	0.171	0.149	0.130	0.112	0.095	1.035	1.028	1.026	1.024	1.022	1.021	1.020	1.018
3200	3.12	0.806	0.839	0.868	0.891	0.912	0.931	0.949	0.964	0.275	0.235	0.204	0.179	0.156	0.135	0.117	0.100	1.081	1.074	1.072	1.070	1.068	1.067	1.066	1.064
3400	3.27	0.844	0.879	0.908	0.933	0.956	0.975	0.994	1.010	0.288	0.246	0.214	0.187	0.163	0.142	0.122	0.104	1.132	1.125	1.122	1.120	1.119	1.117	1.116	1.114
3600	3.42	0.884	0.921	0.952	0.978	1.001	1.022	1.041	1.058	0.302	0.258	0.224	0.196	0.171	0.149	0.128	0.109	1.186	1.179	1.176	1.174	1.172	1.170	1.169	1.167
3800	3.59	0.928	0.967	0.999	1.027	1.051	1.073	1.093	1.111	0.317	0.271	0.235	0.206	0.179	0.156	0.134	0.115	1.245	1.238	1.234	1.232	1.230	1.229	1.227	1.225
4000	3.78	0.976	1.016	1.050	1.079	1.105	1.128	1.149	1.168	0.333	0.284	0.247	0.216	0.189	0.164	0.141	0.120	1.309	1.301	1.298	1.295	1.293	1.292	1.290	1.288
4200	3.99	1.032	1.074	1.110	1.141	1.168	1.192	1.215	1.234	0.352	0.301	0.261	0.229	0.199	0.173	0.149	0.127	1.384	1.375	1.372	1.369	1.367	1.366	1.364	1.361
4400	4.23	1.092	1.138	1.176	1.208	1.237	1.262	1.286	1.307	0.373	0.318	0.277	0.242	0.211	0.184	0.158	0.135	1.465	1.456	1.452	1.450	1.448	1.446	1.444	1.442
4600	4.47	1.156	1.204	1.244	1.278	1.308	1.335	1.361	1.382	0.394	0.337	0.293	0.256	0.223	0.194	0.167	0.143	1.550	1.540	1.537	1.534	1.532	1.530	1.528	1.525
4800	4.76	1.230	1.281	1.323	1.360	1.392	1.421	1.448	1.471	0.420	0.358	0.312	0.273	0.238	0.207	0.178	0.152	1.649	1.639	1.635	1.632	1.629	1.628	1.626	1.623
5000	5.04	1.302	1.356	1.401	1.440	1.474	1.505	1.533	1.558	0.444	0.380	0.330	0.289	0.252	0.219	0.189	0.161	1.747	1.736	1.731	1.728	1.726	1.724	1.722	1.718
5200	5.23	1.351	1.407	1.454	1.494	1.529	1.561	1.590	1.616	0.461	0.394	0.342	0.299	0.261	0.227	0.196	0.167	1.812	1.801	1.796	1.793	1.790	1.788	1.786	1.783
5400	5.33	1.376	1.433	1.481	1.522	1.558	1.590	1.620	1.646	0.470	0.401	0.349	0.305	0.266	0.231	0.199	0.170	1.846	1.834	1.830	1.827	1.824	1.822	1.819	1.816
5600	5.34	1.381	1.438	1.486	1.527	1.563	1.596	1.626	1.652	0.471	0.403	0.350	0.306	0.267	0.232	0.200	0.170	1.852	1.841	1.836	1.833	1.830	1.828	1.826	1.823
5800	5.24	1.354	1.410	1.457	1.497	1.533	1.565	1.594	1.620	0.462	0.395	0.343	0.300	0.262	0.228	0.196	0.167	1.816	1.805	1.800	1.797	1.795	1.792	1.790	1.787
6000	4.96	1.282	1.336	1.380	1.418	1.452	1.482	1.510	1.534	0.438	0.374	0.325	0.284	0.248	0.216	0.186	0.158	1.720	1.709	1.705	1.702	1.700	1.698	1.695	1.692