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Application of Dimethyl Ether as LPG Substitution for Household Stove

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Abstract

Dimethyl Ether (DME) has potency for substituting LPG for household. Indonesia is rich of the sources of DME so DME usage becomes very attractive. The experiments performed in Research and Development Center for Oil and Gas Technology LEMIGAS aimed to assess application of DME for gas cooking stoves. We tested the mixture of LPG - DME at concentrations of DME: 5%, 10%, 15%, 20%, 25%, 30%, 50% and compare with LPG as reference at 6 stoves. The parameters observed are heat consumption, fuel efficiency, and flame stability. The result is the higher DME concentration increasing heat consumption and lowering fuel efficiency.

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Keywords: Dimethyl Ether; cooking fuel; performance test; heat consumption; fuel efficiency

Nomenclature

DME	Dimethyl Ether
LPG	Liquefied Petroleum Gas
SNI	National Standard of Indonesia
LEMIGAS	Research and Development Center for Oil and Gas Technology of Indonesia

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1. Introduction

The successful implementation of the Indonesian mega project of kerosene conversion to Liquefied Petroleum Gas (LPG) for household sector in 2008 had reduced the kerosene subsidy significantly [1]. The large volume of subsidized kerosene withdrawn and replaced with LPG provided state's subsidy saving by more than 2.9 billion US dollars in May 2010. As a result, the increasing needs for LPG supply follows by the first year of the mega project's implementation.

Figure 1 describes the supply of LPG in Indonesia during period 2004-2011. The data were taken from Handbook of Energy and Economic Statistics of Indonesia [2]. We can observe from Figure 1 that supply of LPG coming from domestic production is relatively stable in the last 3 years (2009-2011). As the kerosene conversion program started in 2008, the amount of imported LPG was increasing significantly in order to fulfill domestic demand especially household sector. Without any strategy to meet the increasing demand of LPG, the saving of state's subsidy for kerosene conversion will be meaningless.

As a response to this situation, LEMIGAS conducted a study to investigate a new alternative energy that emerged as a promising source to substitute LPG. This new energy is DME, an ether compound with molecule structure of CH_3OCH_3. The study was conducted in 2011, with the aim of getting technical data on the application of DME with various blending concentration with LPG as a fuel for existing LPG stove.

The physical of DME is similar with those of LPG, so DME has been recently considered as one promising candidate for LPG substitution. Traditionally DME has been produced in two step process, where syngas is first converted to methanol, followed by methanol dehydration to DME. Resources to generate syngas are natural gas, coal and biomass; hence DME is not limited to one feedstock. A study conducted by Marchionna *et al.* [3] reports that mixture of LPG-DME (DME 15-20%) brings significant improvement compared to pure DME.

An advance application of using DME as fuel for household stove had been conducted in China, the first country to build a pilot scale plant of DME for household purpose. In 1995, they already built a 500 t/y DME plant for substituting LPG using methanol as feedstock aimed to feed around 3000 families in Xi'an, Shaanxi province [4].

Not only been used for LPG substitution, DME attacked the interest of researchers to study its potency as automotive fuel. For spark-ignition engine commonly fed with gasoline, the thermal efficiency, NO_x and HC emissions are improved with DME addition level [5]. DME was also blended with LPG for spark-ignition engine at DME concentration at 20% with the result that the differences between emission level and fuel economy were not significant according to the blend of *n*-butane, propane, and DME [6]. The emission and combustion characteristic of a diesel engine fuelled with DME mixed with biodiesel was studied by Wang *et al.* [7].

Various applications of DME proved its potentiality to be used as alternative fuels in the future. For Indonesia, application of DME will be one of the national energy security strategies due to the fact that Indonesia is rich of coal, natural gas and biomass, the raw materials of DME.

This paper resumes the result of performance test of various mixtures of DME with LPG (or LPG Mixed DME); 5%, 10%, 15%, 20%, 25%, 30% and 50% on the 6 different brands of cooking stoves commonly fed with LPG. The result of this study could be used as a base for further improvement on the application of DME as household cooking fuel.

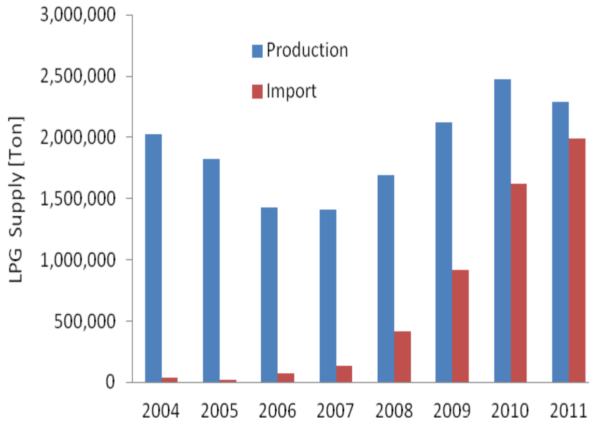

Fig. 1. LPG supply of Indonesia in 2004-2011.

2. Material and method

In this study we conduct a performance test on 6 different brands of existing 2-burners cooking stove commonly fed with LPG. As tested fuels, we prepared LPG as reference fuel and 7 concentrations of LPG Mixed DME (with DME concentration: 5%, 10%, 15%, 20%, 25%, 30% and 50% volume). The LPG used in this research was obtained from PT Pertamina, and the DME was obtained from PT Bumi Tangerang Gas Industri.

2.1. Material preparation

Preparation of the tested fuels was done at Combustion Laboratory of Fuel Research Group of LEMIGAS. First, we analyze the physical and chemical characteristics of the pure LPG and DME. The parameters observed are referred to the LPG specification established by Directorate of Oil and Gas of Government of Indonesia. The physical and chemical characteristic of LPG and DME used in this research is listed in Table 1.

After collecting the physical and chemical characteristic data, we conduct the blending of LPG and DME to get the desirable DME concentration. Blending process of LPG and DME was done using our blending unit designed for 5 kg blend per batch. Figure 2 shows the blending unit used for this experiment.

Table 1. Physical and chemical characteristic of LPG and DME.

	Parameter	Unit	Limit		LPG	DME	Test Method	
			Min	Max			ASTM	Others
1	Specific Gravity	-	To be reported		0,537	0.74	D-1657	
2	Vapour Pressure	Psig	-	120	100	110	D-1267	
3	Weathering Test	% v	95	-	99,8	99.95	D-1837	
4	Copper Corrosion		-	No.1	1b	1a	D-1838	
5	Water Content		No free water		-	No free water	-	Visual
6	Comp. :						D-2163	
	DME	% v			0	99.95		
	C_2	% v		0,8	0,16	-		
	C_3 and C_4	% v	97,5		99.4	-		
	C_{5+} (C_5 and heavier)	% v		2,0	0,4	-		

Fig. 2. LPG & DME blending unit (injector & manifold).

2.2. Performance test method

Performance test covers the measurement of heat input, fuel efficiency, and flame stability referred to the test method of Indonesian National Standard (SNI) 7368:2007 used for one-burner LPG stove with mechanical ignition system.

3. Result and discussion

The resulting blend of LPG and DME with DME concentration 5%, 10%, 15%, 20%, 25%, 30% and 50% were tested for its physical and chemical characteristic refer to LPG specification of Indonesia. Table 3 showed us the physical and chemical characteristic of the fuel blends. We can observe that the resulted LPG Mixed DME with concentration of DME vary from 5%, 10%, 15%, 20%, 25%, 30% and 50% are in accordance with LPG specification limit range, except for the limit of LPG composition. The limit range showed in Table 2 is in accordance with LPG specification designated by Directorate General of Oil and Gas of Indonesia.

Table 2. Physical and chemical characteristic of LPG mixed DME.

			Limit		DME Concentration							Test Method	
No	Parameter	Unit	Min	Max	5%	10%	15%	20%	25%	30%	50%	ASTM	Other
1	Specific Gravity	-	To be reported		0.5419	0.5468	0.5551	0.5602	0.5682	0.5703	0.5976	D-1657	
2	Vapour Pressure	psig	-	120	103	105	110	110	110	110	113	D-1267	
3	Weathering Test	% vol.	95	-	99.5	99.7	99.5	99.8	99.7	99.6	99.6	D-1837	
4	Copper Corr.		-	no.1	1b	1b	1b	1b	1b	1b	1b	D-1838	
5	Water Content		No free water		-	-	-	-	-	-	-	-	Visual
6	Composition											D-2163	
	DME	%vol.	-	-	6.116	11.41	17.3	22.73	28.45	32.23	55.84		
	C_2	%vol.	-	0.8	0.17	0.15	0.12	0.11	0.09	0.09	0.06		
	C_3-C_4	%vol.	97.5	-	93.44	88.17	82.27	76.9	70.99	67.35	43.97		
	C_6+	%vol.	-	2	0.27	0.27	0.31	0.26	0.47	0.33	0.13		

We may observe that actual DME concentration in each blended fuel is slightly differ from the designed value. The difference comes from the blending method that using the mass fraction of LPG and DME for technical consideration, while the actual DME concentration inside the blended fuel was quantified in % volume using Gas Chromatography. After analyzing the physical and chemical characteristics of all LPG Mixed DME samples, we continue to show the result of performance test on 6 brands of cooking stove.

3.1. Heat consumption

Heat consumption produced by each stove depends on the fuel used for combustion process. Based on the test method of SNI 7368:2007, heat consumption is obtained by measuring amount of the fuel used for heating process in maximum operation without any load in 1 hour period. During this experiment, the gas flow was kept constant by the gas regulator. Fuel consumption was calculated by subtracting the end weight of the fuel from the initial weight, and then calculates the fuel flow rate in kg/hour. The heat consumption is calculated using the equation (1).

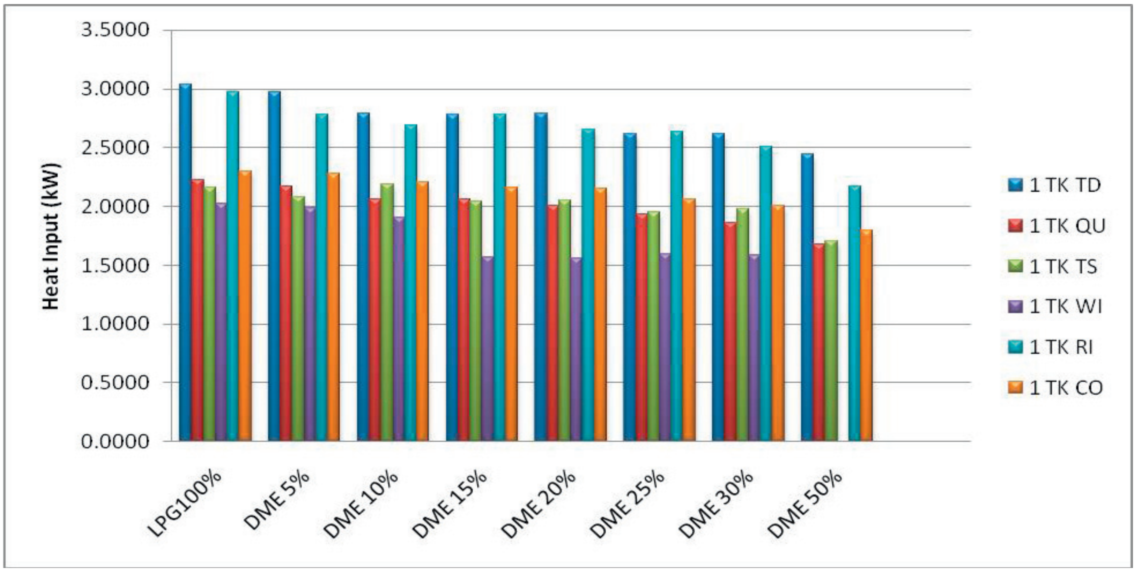

Fig. 3. Heat consumption of 6 different brands of gas cooking stove using tested fuels.

$$Q_n = \frac{1000 x M_n x H_s}{3600} \quad (1)$$

where, Q_n is heat consumption (kW)
M_n is fuel flow rate (kg/hr)
H_s is the fuel calorific value (MJ/kg)

Figure 3 shows us the heat input result for 6 different stoves fuelled by LPG Mixed DME at all concentration variation. We can observe that the heat input vary based on stove's design. From 6 stoves, two stoves show higher heat input than others. Figure 3 also reveals that increasing DME concentration caused decreasing on the heat input on each stove. This phenomenon can be explained by using the fact that calorific value of DME with the value of 6790 kcal/kg is almost half of LPG calorific value with the value of 11960kcal/kg.

3.2. Fuel efficiency

Fuel efficiency measurement was done by heating 6.1 kg water using 26 cm diameter pan from 20^0 C to 90^0 C. Calculation of the fuel efficiency use the formula (2) that referred to SNI 7368:2007 :

$$\eta = \frac{4.186x10^{-3} xM_e x(t-t_1)x100}{(M_c xH_s)} \tag{2}$$

where:
M_e is total mass of pan and water (kg)
t is final temperatur of heated water (°C)
t_1 is water temperature before heating (°C)
M_c is mass of the gas needed for heating (kg)
H_s is gas calorific value (MJ/kg)

Figure 4 shows us the trend of fuel efficiency with the addition of DME into LPG. By observing Figure 4 we can understand that increasing of DME concentration makes effect on the decreasing of fuel efficiency. Design of the stove is the major influencing aspect on the fuel efficiency. However, the lower calorific value of DME than LPG also affected the decreasing of fuel efficiency. In Table 3 we can observe the decreasing calorific value along with the increasing of DME concentration.

Table 3. Physical and chemical characteristic of LPG mixed DME.

Fuel	Calorific Value (Kcal/kg)
LPG	11.964,44
DME	6.790,60
LPG Mixed DME 5%	10.753,47
LPG Mixed DME 10%	10.536,71
LPG Mixed DME 15%	10.289,98
LPG Mixed DME 20%	10.136,09
LPG Mixed DME 25%	9.830,04
LPG Mixed DME 30%	9.678,42
LPG Mixed DME 50%	9.098,30

3.3. Flame stability

Flame stability is the ability of a flame to stand on wind disturbance that be blown at 3 m/s. Table 4 describes the flame stability of the tested fuels. We may observe that only 1 stove getting its flame off when disturbed by 3 m/s wind. From this result we can conclude that 6 existing stoves being tested produce good flame stability when fuelled with both LPG and LPG Mixed DME.

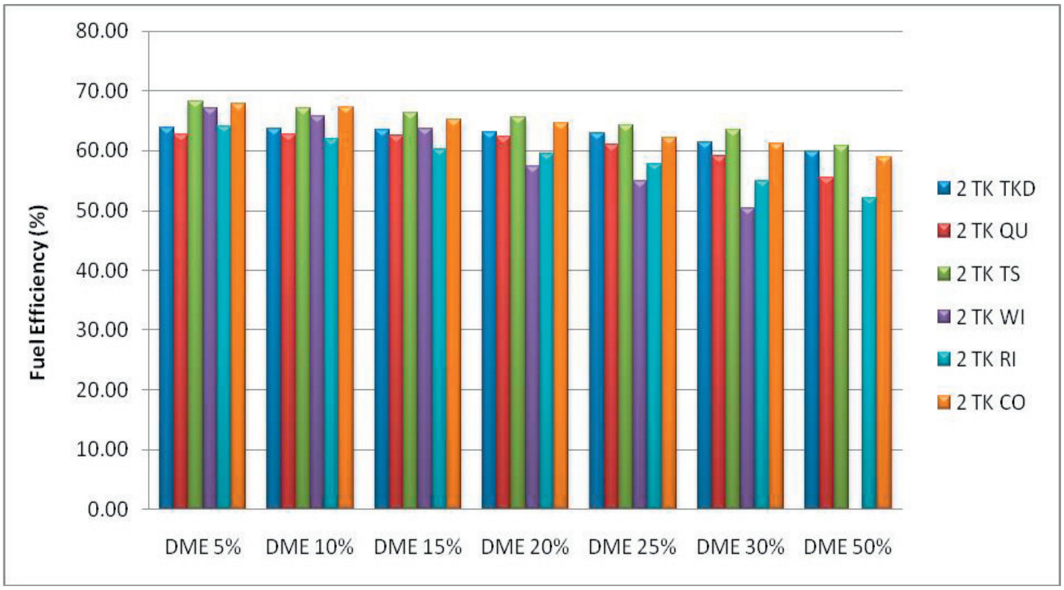

Fig. 4. Fuel efficiency of 6 stoves using tested fuel.

Table 4. Flame stability of tested fuels.

No.	Stove's Code	Tested Fuels							
		LPG100%	DME 5%	DME 10%	DME 15%	DME 20%	DME 25%	DME 30%	DME 50%
1	2 TK TD	Flame on	Flame on	Flame on	Flame on	Flame on	Flame on	Flame on	Flame on
2	2 TK QU	Flame off	Flame off	Flame off	Flame off	Flame off	Flame off	Flame off	Flame off
3	2 TK TS	Flame on	Flame on	Flame on	Flame on	Flame on	Flame on	Flame on	Flame on
4	2 TK WI	Flame on	Flame on	Flame on	Flame on	Flame on	Flame on	Flame on	Flame on
5	2 TK RI	Flame on	Flame on	Flame on	Flame on	Flame on	Flame on	Flame on	Flame on
6	2 TK CO	Flame on	Flame on	Flame on	Flame on	Flame on	Flame on	Flame on	Flame on

4. Conclusions

The performance test result of LPG Mixed DME used for existing LPG stove had demonstrated the potentiality of DME mixed with LPG within the range concentration of DME 5%, 10%, 15%, 20%, 25%, 30% and 50% to be used for household purpose. Even though the test reveals that heat consumption and fuel efficiency of the gas stove decreased with the increasing DME concentration, but this fact lead us to face the challenge to improve the design of the current gas stove. Improving current gas stove design and makes it appropriate to LPG Mixed DME and even for pure DME will accelerate the diversification of energy used.

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