SCIENTIFIC CONTRIBUTIONS OIL AND GAS
Vol. 40, Number 1, April 2017: 5 of 5
RESEARCH AND DEVELOPMENT CENTRE FOR OIL & GAS TECHNOLOGY LEMIGAS
Journal Homepage:http://www.journal.lemigas.esdm.go.id
ISSN: 2089-3361 (Print) e-ISSN: 2541-0520 (Online)

TECHNOLOGY DEVELOPMENT ON THE USE OF DIMETHYL ETHER AS FUEL: A REVIEW

REVIEW PERKEMBANGAN TEKNOLOGI PEMANFAATAN DIMETHYL ETHER SEBAGAI BAHAN BAKAR

Riesta Anggarani[1,2], **I Made K. Dhiputra**[1], **Cahyo S. Wibowo**[2], and **Dimitri Rulianto**[2]
[1] Flame and Combustion Lab.
Mechanical Engineering Department of Universitas Indonesia
Depok, Indonesia
[2] "LEMIGAS" R&D Center for Oil and Gas Technology
Jl. Ciledug Raya, Kav. 109, Cipulir, Kebayoran Lama, P.O. Box 1089/JKT, Jakarta Selatan 12230 INDONESIA
Tromol Pos: 6022/KBYB-Jakarta 12120, Telephone: 62-21-7394422, Faxsimile: 62-21-7246150
E-mail: riesta@lemigas.esdm.go.id; E-mail: cahyow@lemigas.esdm.go.id; E-mail: dimitri@lemigas.esdm.go.id;

First Registered on January 10th 2017; Received after Correction on April 19th 2017
Publication Approval on: April 28th 2017

ABSTRAK

Penelitian mengenai bahan bakar alternatif menjadi fokus para peneliti di seluruh dunia. Dalam dua dekade ini, Dimethyl Ether (DME) muncul sebagai bahan bakar baru yang potensial untuk menggantikan bahan bakar minyak dan turunannya. Bahan baku DME yang bervariasi dari batubara, biomassa, gas alam dan juga minyak bumi menjadikannya menarik untuk dikembangkan sebagai sumber energi. Teknologi produksi DME dari beberapa bahan baku sudah tersedia secara matang, namun teknologi aplikasi DME untuk berbagai pemanfaatan masih terbatas. Pemanfaatan DME telah dilakukan pada berbagai sektor; otomotif, industri, aplikasi pada rumah tangga, dan bahkan juga penelitian fundamental untuk menggali pengetahuan yang lebih dalam tentang keselamatan penggunaan DME dan pertimbangan teknis lainnya dilakukan secara intensif di universitas serta lembaga –lembaga penelitian. Paper ini meringkas progress kegiatan penelitian yang telah dilakukan untuk mengembangkan teknologi aplikasi DME. Beberapa peluang untuk menemukan aplikasi baru didiskusikan dalam tulisan ini.

Kata Kunci: *DME, proses, teknologi aplikasi.*

ABSTRACT

Researchers have started focusing their research on alternative fuels. During the last two decades, Dimethyl Ether (DME) has emerged as a new potential fuel to substitute for oil and its derivatives. Raw materials for DME from sources such as coal, biomass, natural gas and also crude oil are spread all over the world so the interest is growing for using it as an energy source. While the technology for processing raw materials into DME is well established, the technology for DME applications for a wide range of usages is still being developed. The range of DME usage includes for automotive purposes, in industrial sectors, for household applications, and there is even fundamental research to discover more knowledge about DME safety and another technical considerations. Many research activities are now intensively being conducted in R&D centers and universities. This paper reviews progress in research activities that been used to develop the technology for DME application. Some opportunities for discovering more applications are also discussed in this paper..

Keywords: DME, process, application technology.

I. INTRODUCTION

DME is already been used at the industrial level especially for aerosol, propellant, refrigerant, solvent, and it is currently in a developing stage as a fuel. While is not comprised of newly known chemicals, its use as a fuel has really only just been investigated in the last 15 years or so. The first country known to develop the use of DME as a fuel in an extensive quantity was China. (Larson and Yang 2004) stated in 2005 there were 2 DME plants completed: the Sichuan plant with total capacity of 110,000 ton/year from feedstock natural gas; and a plant in Ningxia with a bigger capacity of up to 630,000 ton per year which will use coal as feedstock. Both of the plants use the final DME products for household purposes as a substitute for Liquified Petroleum Gas (LPG).

The potentiality of DME to be a substitute for LPG as a household fuel for cooking is an option to accelerate the transition from traditional fuels used in households such as firewood, coal briquette, and kerosene. The traditional fuels currently used in developing countries are gradually being transformed to modern fuels in the form of gaseous fuels. The transformation is required in line with the establishment of the Millenium Development Goal (MDG), where one of the aims is to develop the health and welfare of the poor in communities, especially women and children. In relation to the energy used in households, traditional fuels come from biomass and coal significantly impact on women's health by causing indoor air pollution (Foell et al. 2011). In order to improve both efficiency and the health issue, gaseous fuels are considered as the best option to replace the biomass and coal-based traditional fuels.

The gaseous fuels produce cleaner combustion, lower pollutant levels, and are more convenient to be stored and distributed because they can be compressed to form a liquid phase (Lee 2015). The gaseous fuels that been used extensively are LPG, natural gas, city gas, and the future fuels ready for mass utilization are DME, ethanol, biogas, and producer gas (produced from biomass gasification). There are a number of countries which have conducted special programs to manage the transformation of firewood, charcoal, and also kerosene for household purpose into LPG nationally. Brazil started to introduce LPG earlier than any other country, at 1937 by chance that a discontinuation of transcontinental propane transportation made the government distribute the cylinder to 166 household (Coelho and Goldemberg 2013). In 1996 the share of LPG users was 50% while the remainder were firewood users, and its percentage has risen since then. In India, the use of LPG that been subsidized by the Government accelerated on replacing the biomass-based energy in rural areas and it is already the first choice for cooking energy in urban areas (Pachauri and Jiang 2008). Another country that has achieved success with a conversion program from conventional fuel to LPG is Indonesia (Budya and Yasir Arofat 2011). The main reasons were revealed in a survey conducted (Andadari et al. 2014) about using LPG. They found it is clean, fast and cost-effective for household purposes.

Along with the escalation of LPG demand as an energy source in many countries, there is increasing concern about the sustainability of LPG, especially in LPG importing countries. Among the alternative options, DME has attracted more attention from researchers. The similarity between DME and LPG makes the focus on DME applications increasingly significant.. As we discussed earlier, the concern about the increasing quantity of LPG used for cooking fuel directly attack the interest to study DME on substituting LPG. (Marchionna et al.) conducted a combustion test using three burner types that are the most common type in Europe using a set of variation of DME mixture with Propane and Butane as the main components of LPG. The result showed that the mixture of 15-20% of DME in LPG produce thermal input slightly lower than normal LPG but still in the tolerance value.

The attention on DME application is not just centering on the LPG substitution for cooking energy. Many research activities have also been conducted on the use of DME as automotive fuel. Cetane number property of DME as high as 55 – 60 made it attractive to be used in diesel engines. In 2008, (Kim et al. 2008) reported the use of DME in a Compression Ignition (CI) engine with variation on the injection strategy; the Premixed Charge Compression Ignition (PCCI) and the Partial Premixed Charge Compression Ignition (PPCCI) to produce ultra-low NO_x emission.

Other researchers have also investigated the use of DME in Spark Ignition (SI) engines. The idea comes from the previous studies using LPG for fueling SI engines, so the similarity between DME and LPG has attracted attention on the study of DME performance in an SI engine. (Ji et al. 2011) conducted an experiment on mixing of DME and gasoline by injecting both fuels synchronously on the intake ports at particular DME and gasoline ratios. The result on a test bench of 1.6 L port fuel injection with 4 cylinders showed a decrease on fuel energy flow rate in line with the increase in the DME fraction at stoichiometric condition. Reduction of Hydrocarbons (HC) emission level was also reported along with the increase in the DME fraction.

Some review papers were published to help the researcher manage and collect knowledge on certain topics. From the perspective of the production process, a review had collected the most updated process technology relating to reactors, catalysts, and the factors affecting the conversion to DME (Azizi et al. 2014). The potentiality of DME as alternative fuels had been well-discussed (Semelsberger et al. 2006). To know how viable DME is as a substitute for petroleum-based fuels, Semelsberger compared the DME with the conventional diesel fuel and gasoline, and with the promising alternative fuel candidates namely hydrogen, methane, methanol, ethanol, biofuels, and Fischer-Trops fuels. One of the interesting points concluded in that paper is that DME can address the issue of energy security and energy concerns, while at the same time achieve better emission level of DME which can preserve the environment. The review of the DME related works on diesel engine (Arcoumanis et al. 2008) explored the potentiality of DME for CI engine. Within this paper, some key factors related to the production and properties of DME, spray characteristics, fuel injection system and emission level were emphasized. Intensive research on the application for diesel engines then lead the updated review (Park and Lee 2014) to guide the progress achieved in optimum conditions for DME-fuelled CI engine.

As DME is considered more for its use as fuel in many applications, this paper compiles the recent progress on DME research activities. The results achieved in the application field ranging from automotive to industrial purposes and also for household apparatus is discussed with some potential for improvement in capturing opportunities. At the end of this review, we highlight the fundamental research that is considered critical on accelerating the use of DME as fuel. This field covers discussion about jet diffusion flame for the enrichment of DME combustion knowledge, the use of DME blends with other fuels, and also updated research on the material compatibility that is suitable for DME.

II. PHYSICAL CHARACTERISTICS OF DME

As we are focusing our discussion in this paper on the use of DME for fuel, then in this section only physical and chemical characteristics relating to combustion are discussed. DME is not a new chemical, so its properties are relatively settled

Table 1
Combustion characteristics of DME, propane & butane

Parameter	DME	Propane	Butane
Chemical structure	CH_3OCH_3	C_3H_8	C_4H_{10}
Boiling point [^{0}C]	-25.1	-42.0	-0.5
Liquid density [g/cm^3, @20^{0}C]	0.67	0.49	0.57
Relative gas density (air=1)	1.59	1.52	2.07
Vapor pressure [MPa, @25^{0}C]	0.61	0.93	0.24
Max. burning velocity [m/s]	50	43	41
Explosion limit [%]	3.4 - 17	2.1– 9.4	1.9-8.4
Ignition temperature [^{0}C]	350	470	405
Lower heating value [MJ/kg]	28.9	46.6	48.0
Higher heating value [MJ/kg]	31.7	50.3	49.5
Adiabatic flame temp. [^{0}C]	1954	1977	1982
AFR (stoichiometric)	9	15.7	15.5

and will only be completed when the field being studied need the new characteristic of DME. Here we summarise the critical combustion characteristics of DME compared to Propane and Butane from the DME Handbook (Forum 2006) in Table 1.

The combustion characteristics listed in Table 1 compare DME with Propane and Butane as the main components in LPG. Some points should be highlighted from Table 1. The first one is the calorific value that is the most critical point in combustion, which relates directly with the lower cylinder pressure impacting on the output of a diesel engine (Sezer 2011). The other characteristic to be noted is air fuel ratio (AFR) or its Equivalence Ratio (ER). The ER of DME and H_2 blends was studied (Pan et al. 2014), where the result showed that the dependency of ignition delay to ER depends on the H_2 fraction. The ratio of air to fuel in DME combustion is lower than Propane and Butane because DME has an O_2 molecule in its structure.

Because of its distinctive characteristics, to reach cleaner emission levels while at the same time to minimize fuel consumption, the optimization of the engine operation conditions is needed. (Kim and Park 2016) apply a Genetic Algorithm (GA) optimization method to get optimum operation conditions of a diesel engine when fueled by DME. The various parameters were start of injection, injection pressure, injection angle and equivalence ratio. Relates with the combustion characteristic, autoignition temperature and detonation development of DME and air mixtures been investigated by considering the effect of initial temperature (Dai and Z. Chen 2017).

Another study related to the physical characteristics of DME involved measuring the compressed liquid density and saturated liquid density on 8 isotherm points up to 35 MPa using vibrating tube density meter (Yin et al. 2011). Similar with the density that changes along the change of temperature and pressure, the measurements were done to build a correlation of viscosity covering the liquid and vapor region (Meng et al. 2012). This successfully developed a multiparameter equation with uncertainty of 2% for liquid phase and 3% for gas phase.

An updated measurement of the explosion characteristics was done (Zhang and Ng 2016). They performed a set of experiments to measure the explosion characteristics of DME, its including Flammability limit, maximum rate of pressure rise $(dp/dt)_{max}$, laminar burning velocity and evolution of flame radius. By understanding the physical and also chemical characteristic of DME well, the development of applications may use the collected data to support the improvement of both apparatus and operation conditions.

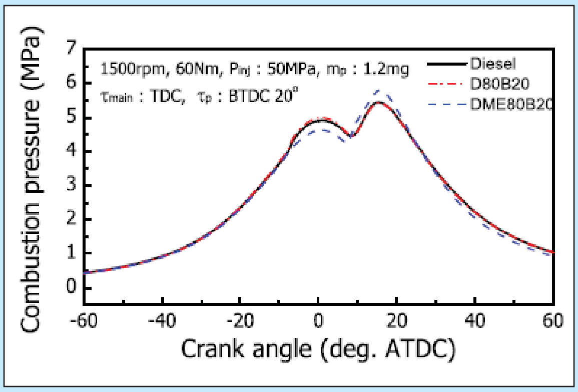

Figure 1
Comparison of combustion pressure of diesel, D80B20 and DME80B20 (Roh et al. 2015).

III. DME APPLICATION FOR AUTOMOTIVE

Currently, the most intensive research activities on DME application is in the automotive field. Many publications focus on DME performance both in diesel and gasoline engines, the optimization of engine setting, the strategy on injection of the DME, and also the improvement of emissions. The position of DME as a alternative fuel to substitute for diesel fuel is considered. In an experiment (Roh et al. 2015) compare the performance of DME-biodiesel blend (DME80B20), biodiesel-diesel fuel blend (B80D20) and diesel fuel on a 4-cylinder common rail diesel passenger car. Figure 1 below describes the results showing that near the Top Dead Center (TDC) the pressure rise of DME80B20 is lower than diesel and B80D20 because the DME has lower LHV than both fuels.

The discussion made in this section is divided into the utilization of DME in diesel (CI) engines, gasoline (SI) engines, and the impact of both on emission levels.

A. Substitution of Diesel Fuel in Compression Ignition (CI) Engine

In the early stage of DME utilization as fuel, researchers recognized that DME has a high cetane number, similar with the cetane number of diesel fuel. This fuel also known for having an ability to reduce pollutant emissions such as soot, CO, and HC (Park 2012). Although the cetane number is similar with those of diesel fuel, many of other physical characteristics of DME are different and so require further study when it will be applied for diesel or CI engines. Vapor pressure of DME is greater than that of diesel fuel, and DME vaporized more quickly than diesel fuel. For the injector performance, DME lubricity is lower than diesel fuel, which focuses attention on improving injection strategy or even the design of the injection pump on DME-fueled CI engine, both of which are crucial (Wang et al. 2012).

As a result of differences between characteristics of DME and diesel fuel, the research activities are focusing on the crucial points into injection strategy and operation optimization to lower the emission levels. In an numerical simulation performed (Mohan et al. 2017), there was focus on investigating the cavitation characteristic of ether fuels (Dimethyl Ether and Diethyl Ether). The cavitation phenomenon happens inside the injector nozzle and significantly affects the fuel spray and atomization. The results showed that ether fuels produce higher cavitation effect than diesel fuel because they have lower viscosity as depicted in Figure 2.

Another injection strategy was proposed (Yoon and Bae 2013) that is a multiple injection strategy which consists of pilot, main, and post injection. In their experiment, the post-injection, which improves air entrainment with split fuel injection, was used to reduce soot emission. Although DME is almost soot-free combustion, this strategy showed a decrease of HC and CO emissions. A quite different approach was proposed to be used in a Homogenous Charge Compression Ignition (HCCI) engine, where direct injection and Exhaust Gas Recirculation (EGR) applied (Jang et al. 2013). Direct injection is considered as one of the options to improve DME combustion because the fuel stratification can vary the injection timing. For all variations on the direct injection timing and EGR setting they found an optimum condition. A similar strategy was also adopted (Zhao et al. 2014), which use a Premixed Charge Compression Ignition (PCCI) engine type with EGR and vary the premixed ratio of DME-air. In a PCCI, lower smoke and NO_x will be produced meanwhile the CO and HC will increase. It is the main reasons why the researchers adopted EGR for PCCI engine.

The latest update on DME combustion is again conducted using a HCCI engine. Being known to be limited by excessive pressure-rise rate (PRR) on high-load operation, one strategy to reduce PRR is to retard the combustion phase after TDC. To control combustion phasing in an HCCI engine researchers widely use EGR. Jung and Iida (Jung and Iida 2017) designed an experiment using a single cylinder HCCI research engine with external rebreathed EGR to examine the effect of cycle-to-cycle combustion and the mechanism responsible for the unstable operation. Figure 3 illustrates the valve opening during the stages of exhaust, intake and rebreathing.

Based on the latest publications of DME-fueled engine applied on an HCCI engine, it is without doubt that in the future this type of engine will be a center of interest. The HCCI operates in Low Temperature Combustion (LTC) to reduce the losses on heat transfer and the combustion ignition spontaneously takes place in whole cylinder without diffusion flame (Bendu and Murugan 2014). One of the benefits is the very low NO_x and soot emissions. This new technology has some limitations, where the most critical is about preparing the homogeneous mixture and combustion phase staging. Starting from

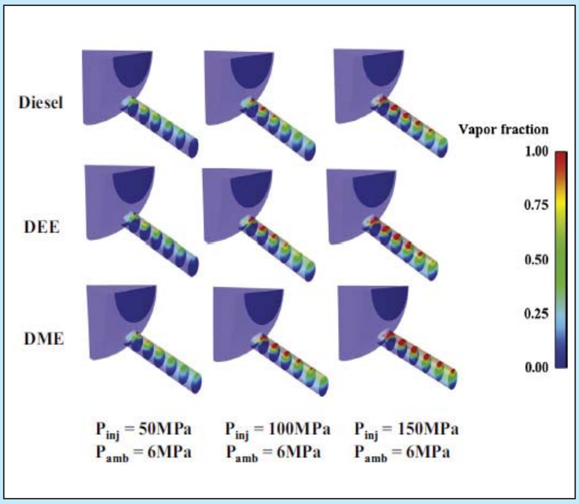

Figure 2
Comparison of cavitation inception with different fuels at different pressure (Mohan et al. 2017).

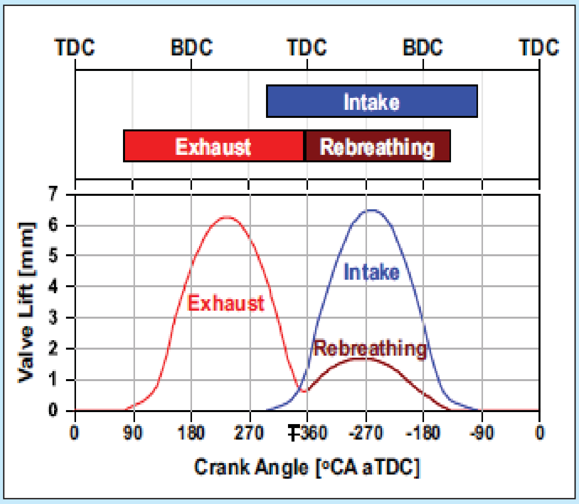

Figure 3
Illustration of valve opening during exhaust, intake and rebreathing stage on HCCI research engine (Jung and Iida 2017).

the main concept that HCCI gain a higher efficiency from faster reaction between homogeneous mixture of fuel, oxidizer and excess air, (Bahng et al. 2016) proposed a new technology by adopting 2 alternatives; (1) to employ a Water Electrolysis Gas (WEG) to enhance heating potential of fuel mixture and (2) skipping the evaporation process of gasoline in the cylinder for rapid homogeneous mixing.

By understanding these latest publications on development of high efficient engine and the fuel condition required, we suggest that DME will attract more attention to be employed as an alternative fuel replacing diesel fuel. There is no need to vaporize because the physical properties of DME clearly show that it has similar properties as LPG, which means that DME changes its phase to gaseous form faster than conventional fuel as gasoline and diesel fuel.

B. Utilization in Spark Ignition (SI) Engine

From the previous section, utilization of DME in a CI engine is basically based on the properties of DME having a high cetane number. In this section, we focus on the use of DME as fuel in an SI engine, either as a blend with gasoline or fully fueled by DME. At an early stage of DME utilization in an SI engine, it is used by blending into various fraction with LPG. An experiment was conducted in a 2.7 L SI engine equipped with a Liquid Phase injection (LPi) system to use LPG and a series of LPG-DME blends (10% DME, 20% DME, and 30% DME) The results showed that the increased DME content in the blend decreased the engine torque, increased the Break Specific Fuel Consumption (BSFC), increased the exhaust gas temperature, and increased the knocking occurrence.

Another experiment was conducted in an SI ethanol engine, where DME was used as enrichment for ethanol in a volume fraction of 1% and 2% with a consideration that ethanol having high octane number will strengthened when enriched with DME that having high cetane number (Lee and Choi 2008). The result showed that DME enrichment improved burning condition, decreased HC emission, but the CO and NO_x was slightly increased.

Blending DME with other fuel seems was applied in a current SI engine. The blends in variation of 5% to 20% DME in Liquefied Gas Vehicle (LGV) were used in a 2.0 L 4 cylinder SI engine to investigate the Brake Horse Power (BHP), fuel consumption and the CO and HC emission level (Anggarani et al. 2015). The results showed that the higher DME content led to a decreasein the BHP produced by the fuel blend. To overcome the limitation of DME-LPG blends for an SI engine, (Lee et al. 2011) investigated the effect of n-butane and propane, 2 main components in LPG on the combustion performance and emission level. They varied the composition of n-butane and propane with the result that propane showed better knocking resistance than n-butane due to its high octane number.

Fewer publications are available for DME application in SI engines. The published papers involved experiments mostly with blends of DME with gasoline, LPG, or ethanol, some fuels that have been proven through their use in SI engines. More experiments were still conducted in the fundamental stage to investigate the characteristics of DME combustion. The application in an SI engine will be a potential field of study on DME for fuel research activities.

IV. APPROACH OF USAGE IN INDUSTRIAL SECTOR

The discussion in the previous section focused on the DME application for automotive purposes. In this section we discuss the utilization of DME as fuel to be used in industrial sectors. It covers power generation equipment and for boiler and furnace instruments.

A. Power Generation Equipment

In a power generation system, a gas turbine is one of the most used pieces of equipment. Gas turbines convert the heat release by burning fuel into mechanical energy that in the next stage will be converted into electrical power. The efficiency of the gas turbine then relies on the combustion process which includes the thermodynamic properties of the fuel used in it. One of the gas turbine types proposed to increase the performance is Chemically Recuperated Gas Turbine (CRGT). Currently CRGT is using the methane from steam reforming, but it is limited by high reforming temperature. So in a work proposed (Cocco et al. 2006), DME was used to fuel a CRGT as it has a lower reforming temperature. The result showed that the increase in the water/DME molar ratio increased the CRGT efficiency as shown in Figure 4.

The use of DME was performed on an established 60 kW gas turbine combustion test facility in Pyong-tak Korea. In this experiment, the DME combustion performance was compared to Methane as the main component of natural gas (Lee et al. 2009). Flame comparison of DME and Methane at the fuel nozzle is shown in Figure 5. It is observed that DME burned near the fuel nozzle and produced higher pressure fluctuations than methane.

Considering that existing gas turbine equipment is not suitable to be dedicated for DME fuel, researchers have tried to develop a new combustor system for gas turbine. (Jiang et al. 2011) developed a plat-flame micro combustor for burning DME in a thermoelectric power generation system. In this experiment, a rectangular centimeter magnitude plat-flame micro combustor was integrated with a micro Thermoelectric (TE) power generation system. Using this designed apparatus, a stable flame of DME/air can be reached in a lean combustion situation. It was validated that using a porous chamber wall as mixture inlet in micro combustor can reduce wall temperature and heat loss.

Drawing on a previous study, Lee and Yoon proposed a new design for a gas turbine fuel nozzle dedicated for DME (Lee and Yoon 2012). In the design process, they considered natural gas for the original fuel nozzle and DME for the new design. As the first step, the Wobbe Index (WI) that indicates energy of the heat input to the combustor was calculated. Then using the WI basis, the minimum cross-section sum of the fuel injection ports was calculated.

Further study on the application of DME for power generation systems is still required. Many operation consideration on the gas turbine, combustor, and the fuel injection system should be noticed and studied more to get optimum condition.

B. Boiler and Furnace Fuelled DME

In the industrial sector, DME utilization is still limited. The reported research publications involving industrial equipment is not as many as for automotive applications. One study was conducted (Kang et al. 2014) using a medium-scale gas combustion test platform. It was assembled from a three section components, which all are a commonly-used component for an industrial boiler. Five excess air ratios were applied and observed to investigate the NO_x and CO emission behavior of DME/air premixed flame. The results indicated that the NO and CO decreased with the increment of excess air ratio.

A more fundamental study specifically intended to be applied in a ceramic kiln or furnace is designed by simulating the condition required for a ceramic kiln such as specified kiln wall and kiln crown material (Chen Wang and Wang 2012). The DME and air mixture is varied at different oxygen levels of 10%, 20%, 30%, 40% and 90% using fluent software. They compare the performance of DME with LPG. The results showed that the lower burning temperature of DME than LPG is observed at the same oxygen level.

The other fundamental study specifically investigated the jet diffusion flames behavior of DME, methane and LPG to extend the knowledge of flame properties required for industrial boilers and kiln furnaces (Kang et al. 2015). It is critical to have knowledge of jet flame, because the pilot flame in the furnace involves fuel which is introduced into the oxidizing environment in the form of a jet.

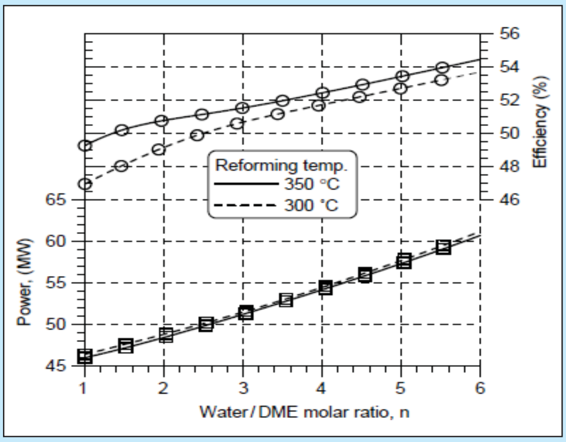

Figure 4
Power and efficiency of CRGT power plant vs water/DME molar ratio (Cocco et al. 2006).

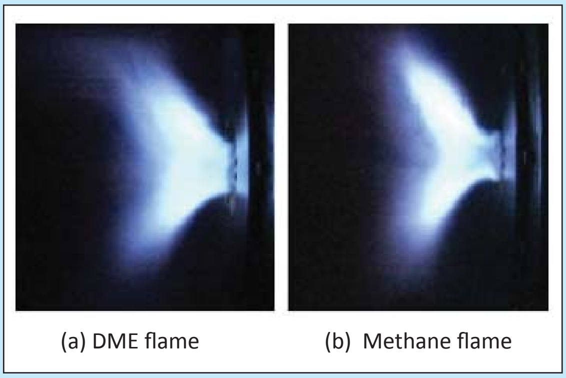

Figure 5
Comparison of DME and methane flame in gas turbine combustor (Lee et al. 2009).

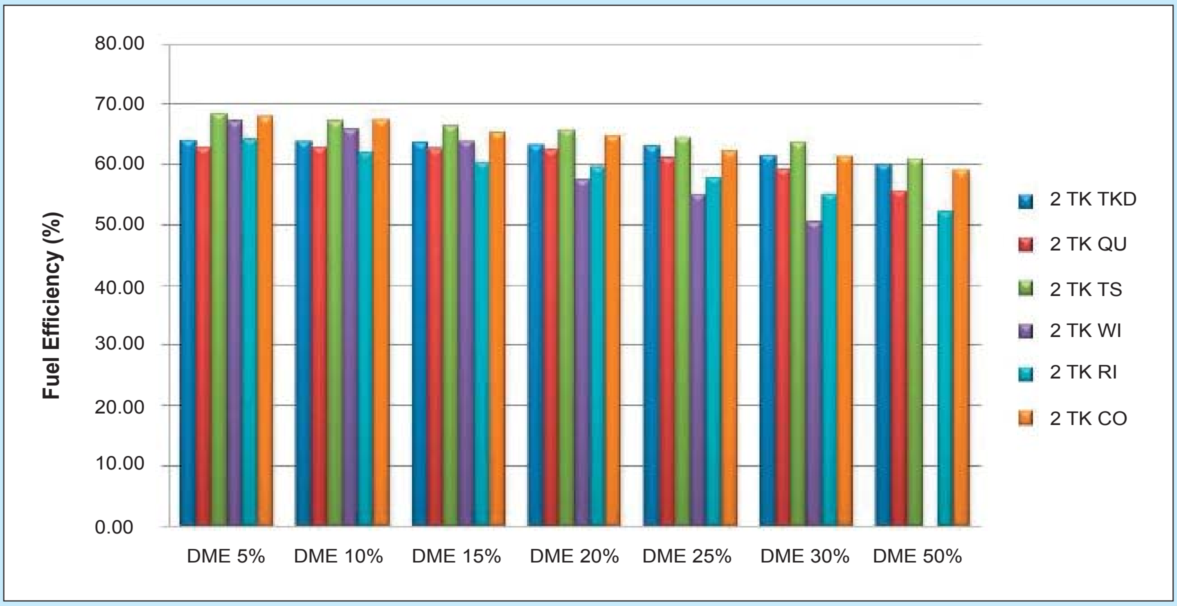

Figure 6
Fuel efficiency of DME-LPG fuel blends on the tested gas stoves (Anggarani et al. 2014).

V. SUBSTITUTION OF LPG FOR HOUSEHOLD PURPOSE

Similarity between DME and LPG physical characteristics has led to research activities into domestic appliances, especially the gas stove for cooking purposes. Currently, the use of gaseous fuel for household purposes is showing an increasing trend. In many developing countries, the use of traditional fuels such as firewood, coal bricquette, and kerosene are gradually being replaced by the use of gaseous fuels such as LPG, city gas and also methane-biogas(Rahut Behera and Ali 2016; Puzzolo et al. 2016; Duan et al. 2014; Baiyegunhi and Hassan 2014; Zhang and Wang 2017).

The depletion of fossil fuels has also served to enhance the utilization of alternative fuels. DME, being produced from various raw materials such as coal and biomass, had attracted the attention of countries that have coal resources. India for example, is considering biomass-based DME to substitute LPG in the form of blends with LPG (Arya et al. 2016). Thailand, is also interested in using DME as an alternative fuel by assessing the rice straw potency to produce DME (Silalertruksa et al. 2013). In the context of household purposes, China is already known as the leader in DME production and use, with more than 90% of DME produced in China being blended with LPG for residential cooking and heating purposes (Fleisch Basu and Sills 2012).

In Indonesia, an experiment was conducted in 2011 using a blends of DME-LPG with DME vary from 5% v/v to 50% v/v into 6 gas stoves available in Indonesian market and then comparing the performance with LPG in terms of heat consumption, fuel consumption and flame stability. Figure 6 below shows a comparison between fuel efficiency of the DME-LPG fuel blends on 6 gas stoves.

The area with more published research papers related to stove appliances or LPG substitution is in the field of fundamental combustion research. One of the main areas of focus is flame stabilization, as we know that in gas stoves the combustion is a diffusion reaction between air and the fuel. Stabilization of laminar non-premixed DME-air coflow flames was investigated (Deng et al. 2015). Various coflow temperatures with different inlet velocities to know their influences on stabilization mechanism.

VI. CONCLUSION

Utilization of DME for fuel has generated enormous interest. Research activities are growing with respect to developing suitable technology to use DME. The automotive field is the biggest sector developing DME for fuel, although until now the mass production engines dedicated for DME are not available yet. The industrial and domestic sectors have also raised their awareness on applying DME, either to blend DME with conventional fuel or adopt it in fully dedicated equipment. There is still further useful research activities to collect more knowledge about DME behavior. We still need to consider supporting appliances or conditions on DME-related operation such as; the effect of DME to materials, safety and hazard prevention, the DME infrastructure, and also the stability of DME for storage facilities.

ACKNOWLEDGMENT

The authors are grateful for the support of the Ministry of Energy and Mineral Resources of the Republic of Indonesia for financing the study and the research activities on DME burner design in the University of Indonesia in conjunction with center of research and development for oil and gas technology "LEMIGAS".

REFERENCES

Andadari, R.K., P. Mulder, and **P. Rietveld,** 2014, *Energy poverty reduction by fuel switching. Impact evaluation of the LPG conversion program in Indonesia.* Energy Policy, 66: pp. 436-449.

Anggarani, R., et al. 2015, *Performance and Emission Characteristics of Dimethyl Ether (DME) Mixed Liquefied Gas for Vehicle (LGV) as Alternative Fuel for Spark Ignition Engine.* Energy Procedia, 65: pp. 274-281.

Anggarani, R., C.S. Wibowo, and **D. Rulianto,** 2014 *Application of Dimethyl Ether as LPG Substitution for Household Stove.* Energy Procedia, 2014. 47: pp. 227-234.

Arcoumanis, C., et al. 2008, *The potential of di-methyl ether (DME) as an alternative fuel for compression-ignition engines: A review.* Fuel, 87 (7): pp. 1014-1030.

Arya, P.K., et al. 2016, *DME blended LPG as a cooking fuel option for Indian household: A review.* Renewable and Sustainable Energy Reviews, 53: pp. 1591-1601.

Azizi, Z., et al. 2014, *Dimethyl ether: A review of technologies and production challenges.* Chemical Engineering and Processing: Process Intensification, 82: pp. 150-172.

Bahng, G., et al. 2016, *A new technology to overcome the limits of HCCI engine through fuel modification.* Applied Thermal Engineering, 98: pp. 810-815.

Jang, J., et al. 2013, *Improvement of DME HCCI engine combustion by direct injection and EGR.* Fuel, 113: pp. 617-624.

Baiyegunhi, L.J.S. and **M.B. Hassan,** 2014, *Rural household fuel energy transition: Evidence from Giwa LGA Kaduna State, Nigeria.* Energy for Sustainable Development, 20: pp. 30-35.

Bendu, H. and **S. Murugan,** 2014, *Homogeneous charge compression ignition (HCCI) combustion: Mixture preparation and control strategies in diesel engines.* Renewable and Sustainable Energy Reviews, 38: pp. 732-746.

Budya, H. and **M. Yasir Arofat,** 2011, *Providing cleaner energy access in Indonesia through the megaproject of kerosene conversion to LPG.* Energy Policy, 39(12): pp. 7575-7586.

Chen, R., H.-t. Wang, and **H. Wang,** 2012, *Different Oxygen Levels of Dimethyl Ether Combustion Influence Numerical Simulation.* Procedia Engineering, 31: pp. 934-940.

Cocco, D., V. Tola, and **G. Cau,** 2006, *Performance evaluation of chemically recuperated gas turbine (CRGT) power plants fuelled by di-methyl-ether (DME).* Energy, 31(10–11): pp. 1446-1458.

Coelho, S.T. and **J. Goldemberg**, 2013, *Energy access: Lessons learned in Brazil and perspectives for replication in other developing countries.* Energy Policy, 61:pp. 1088-1096.

Dai, P., C. Qi, and **Z. Chen,** 2017, *Effects of initial temperature on autoignition and detonation development in dimethyl ether/air mixtures with temperature gradient.* Proceedings of the Combustion Institute, 36(3): pp. 3643-3650.

Deng, S., et al. 2015, *Stabilization of laminar nonpremixed DME/air coflow flames at elevated temperatures and pressures.* Combustion and Flame, 162(12): pp. 4471-4478.

Duan, X., et al. 2014, *Household fuel use for cooking and heating in China: Results from the first Chinese Environmental Exposure-Related Human Activity Patterns Survey (CEERHAPS).* Applied Energy, 136: pp. 692-703.

Fleisch, T.H., A. Basu, and **R.A. Sills,** 2012, *Introduction and advancement of a new clean global fuel: The status of DME devel*opments in China and beyond. Journal of Natural Gas Science and Engineering, 9: pp. 94-107.

Foell, W., et al., 2011, *Household cooking fuels and technologies in developing economies.* Energy Policy, 39 (12): pp. 7487-7496.

Forum, J.D., DME Handbook. 2006, Japan: Japan DME Forum. 605.

Ji, C., C. Liang, and **S. Wang,** 2011, *Investigation on combustion and emissions of DME/gasoline mixtures in a spark-ignition engine.* Fuel, **90**(3): pp. 1133-1138.

Jiang, L.Q., et al., 2011, *Experimental study of a* *plat-flame micro combustor burning DME for thermoelectric power generation.* Energy Conversion and Management, 52(1): pp. 596-602.

Jung, D. and **N. Iida,** 2017, *Thermal and chemical effects of the in-cylinder* charge at IVC on cycle-to-cycle variations of DME HCCI combustion with combustion-phasing retard by external and rebreathed EGR. Applied Thermal Engineering, 113: pp. 132-149.

Kang, Y., et al. 2014, *An experimental and modeling study of NOx and CO emission behaviors of dimethyl ether (DME) in a boiler furnace*. Fuel Processing Technology, 122: pp. 129-140.

Kang, Y.-H., et al. 2015, E*xperimental and theoretical study on the flow, mixing, and combustion characteristics of dimethyl ether, methane, and LPG jet diffusion flames.* Fuel Processing Technology, 129: pp. 98-112.

Kim, H.J. and **S.H. Park,** 2016, *Optimization study on exhaust emissions and fuel consumption in a dimethyl ether (DME) fueled diesel engine*. Fuel, 182: pp. 5**41-549.**

Kim, M.Y., J.H. Lee, and **C.S. Lee,** 2008, *Combustion Characteristics and NOx Emissions of a Dimethyl-Ether-Fueled Premixed Charge Compression Ignition Engine*. Energy & Fuels, 22 (6): pp. 4206-4212.

Larson, E.D. and **H. Yang,** 2004, Dimethyl ether (DME) from coal as a household cooking fuel in China. Energy for Sustainable Development, 8 (3): pp. 115-126.

Lee, S., et al. 2011, Effect of n-Butane and propane on performance and emission characteristics of an SI engine operated with DME-blended LPG fuel. Fuel, 90(4): pp. 1674-1680.

Lee, J.S., et al. 2015, Combustion and NO Emission Characteristics of Liquefied Petroleum Gas/Dimethyl Ether Blended Fuel in Counterflow Non-Premixed Flame. Combustion Science and Technology, 187(9): pp. 1468-1484.

Lee, S., S. Oh, and **Y. Choi,** 2009, *Performance and emission characteristics of an SI engine operated with DME blended LPG fuel*. Fuel,88(6): pp. 1009-1015.

Lee, M.C., et al. 2009, I*ndustrial gas turbine combustion performance test of DME to use as an alternative fuel for power generation. Fuel,* 88(4): pp. 657-662.

Lee, M.C. and **Y. Yoon,** 2012, *Development of a gas turbine fuel nozzle for DME and a design method thereof. Fuel,* 102: pp. 823-830.

Liang, C., C. Ji, and B. Gao, 2013, *Load characteristics of a spark-ignited ethanol engine with DME enrichment. Applied Energy, . 112: pp. 500-506.*

Marchionna, M., et al. 2008, *Fundamental investigations on di-methyl ether (DME) as LPG substitute or make-up for domestic uses.* Fuel Processing Technology,89 (12): pp. 1255-1261.

Meng, X., et al. 2012, *Experimental Measurement and Modeling of the Viscosity of Dimethyl Ether.* Journal of Chemical & Engineering Data, 57 (3): pp. 988-993.

Mohan, B., et al. 2017, *Numerical analysis of spray characteristics of dimethyl ether and diethyl ether fuel.* Applied Energy, 185, Part 2: pp. 1403-1410.

Pachauri, S. and **L. Jiang,** 2008, *The household energy transition in India and China.* Energy Policy, 36 (11): pp. 4022-4035.

Pan, L., et al. 2014, *Effect of pressure and equivalence ratio on the ignition characteristics of dimethyl ether-hydrogen mixtures.* International Journal of Hydrogen Energy, 39 (33): pp. 19212-19223.

Park, S., 2012, *Optimization of combustion chamber geometry and engine operating conditions for compression ignition engines fueled with dimethyl ether.* Fuel, 97: pp. 61-71.

Park, S.H. and **C.S. Lee,** 2014. *Applicability of dimethyl ether (DME) in a compression ignition engine as an alternative fuel.* Energy Conversion and Management, 86: pp. 848-863.

Puzzolo, E., et al. 2016, Clean fuels for resource-poor settings: A systematic review of barriers and enablers to adoption and sustained use. Environmental Research, 146: pp. 218-234.

Rahut, D.B., B. Behera, and **A. Ali**, 2016, *Patterns and determinants of household use of fuels for cooking: Empirical evidence from sub-Saharan Africa.* Energy, 117, Part 1: pp. 93-104.

Roh, H.G., D. Lee, and **C.S. Lee,** 2015, *Impact of DME-biodiesel, diesel-biodiesel and diesel fuels on the combustion and emission reduction characteristics of a CI engine according to pilot and single injection strategies.* Journal of the Energy Institute, 88 (4): pp. 376-385.

Semelsberger, T.A., R.L. Borup, and **H.L.** 2006, *Greene, Dimethyl ether (DME) as an alternative fuel.* Journal of Power Sources, 156(2): pp. 497-511.

Sezer, İ., 2011, *Thermodynamic, performance and emission investigation of a diesel engine running on dimethyl ether and diethyl ether*. International Journal of Thermal Sciences, 50(8): pp. 1594-1603.

Silalertruksa, T., et al. 2013, *Life cycle GHG analysis of rice straw bio-DME production and application in Thailand.* Applied Energy, 112: pp. 560-567.

Wang, Y., et al. 2014, *Combustion and emission* *characteristics of a diesel engine with DME as port premixing fuel under different injection timing*. Energy Conversion and Management, 77: pp. 52-60.

Yin, J., et al. 2011, *Compressed liquid density measurements of dimethyl ether with a vibrating tube densimeter.* The Journal of Chemical Thermodynamics, 43(9): pp. 1371-1374.

Yoon, H. and **C. Bae,** 2013, *Post injection in a compression ignition engine fueled with dimethyl-ether.* Fuel, 103: pp. 1123-1131.

Zhang, B. and H.D. Ng, 2016, *An experimental investigation of the explosion characteristics of dimethyl ether-air mixtures.* Energy, 107: pp. 1-8.

Zhang, X. and Y. Wang, 2017, *How to reduce household carbon emissions: A review of experience and policy design considerations.* Energy Policy, . 102: pp. 116-124.

Zhao, Y., et al. 2014, Combustion and emission characteristics of a DME (dimethyl ether)-diesel dual fuel premixed charge compression ignition engine with EGR (exhaust gas recirculation). Energy, 72: pp. 608-617.