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THE SYNTHESIS OF DIMETHYL ETHER (DME) FROM NATURAL GAS AND COAL

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ABSTRACT

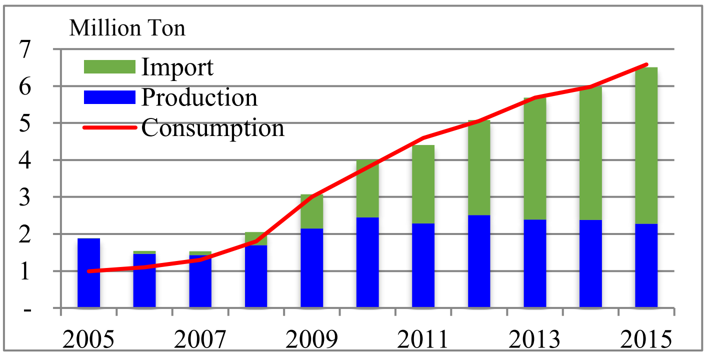
The need to substitute LPG with alternative fuels for supplying domestic energy demand in the households is very urgent in Indonesia as there has been a significant increase of LPG imports due to limited domestic production and higher subsidy for LPG. Dimethyl Ether (DME) is one of fuel candidates that can be used to substitute LPG due to the similarity of physical properties of DME with LPG. While LPG has to be imported from other countries, DME can be synthesized from natural gas and/or coal, in which the coal used for DME synthesis can be low-rank quality. Although low-rank coal with the lowest price can be processed to produce DME, however, it seems that natural gas still more economically viable for producing DME. For 10 years of project life, the economic analysis shows that the production investment of DME from natural gas almost half compare to that production from coal, with the payback period and IRR only 4.1 years and 25.1% while DME production from coal needs 5.4 years and 16.8%. This paper presents the techno-economic feasibility for both, natural gas and coal. The discussion of this paper is focused on the selection of technology processes to synthesis DME based on technical as well as economic feasibility and its sensitivity analysis.

Keywords: Coal, DME, Natural Gas, Direct Indirect Synthesis, Process Synthesis, Reforming, Shift Converter, Technical and Economic Feasibility

INTRODUCTION

Currently, the consumption of Liquefied Petroleum Gas (LPG) in Indonesia is increasing significantly while the domestic production cannot fulfill the demand. Therefore, import of LPG is unavoidable. Figure 1 presents the production, consumption, and import of LPG. It can be seen that the demand increased significantly during 2008-2015 (31%/year), which is in lined with the success of Kerosene to LPG substitution program in Indonesia.

Figure 1: Domestic production, consumption, and import of LPG, 2005-2015 (MEMR, 2016 & MEMR, 2017)



Refer to (MEMR, 2016 & MEMR, 2017), the major LPG consumer in Indonesia is households (86.3%), followed by industry (7.2%) and commercial (6.5%). Based on modeling analyses by (APERC Analysis, 2012 & BPPT, 2012) , this demand is expected to continue increasing at 4.9%/year, as a consequence import of LPG will also increase since the domestic production is still low. These analyses also estimate that the demand from households will increase 9.26%/year and from commercials 4.35%/year. Therefore, the need to substitute LPG with alternative fuels for supplying household and commercial is very urgent.

Dimethyl Ether (DME) is a colorless mono-structure gas at ambient temperature (stable condition). DME can be one of candidates to substitute LPG due to its similarity with LPG in physical properties (see Table 1). Refer to this table, it can be expected that DME can be used directly in LPG stove without any stove modification. In addition, DME can also reduce 80% CO_2 emission and 15% N_2O if it is blending with LPG.

Table 1 : Physical property of DME, Propane, Butane (BPPT, 2012)

Property	DME (CH_3OCH_3)	Propane (C_3H_8)	n-Butane (C_4H_{10})
Boiling point (°C)	-24.9	-42.1	-0.5
Vapor pressure at 20°C (bar)	5.1	8.4	2.1
Liquid density at 20°C (kg/m^3)	668	501	610
Specific density (gas)	1.59	1.52	2.01
Lower heating value (MJ/kg)	28.43	46.36	45.74
T auto ignition at 1 atm (° C)	235-350	470	365
Flammability limits in air, %-v	3.4-17	2.1-9.4	1.9-8.4

In addition, while LPG has to be imported from other countries, DME can be synthesized from domestic natural gas and/or coal, in which the coal used for DME synthesis can be low-rank quality. In addition, DME can also be produced from biomass and/or fuel oil (Ogawa, 2003). There are many routes of DME syntheses from these various sources, i.e. indirect or direct processes. In indirect processes, DME is synthesized from methanol, where the methanol is produced from syngas generated from natural gas, coal or biomass. In direct process, the synthesis needs one stage reaction, which is synthesizing DME from the syngas.

The indirect process has been commercially produced the DME. In China, the first DME production was operated in August 2003 with the production capacity of 10,000 ton/year. The plant is built by Lituanhua Group, which used license from Toyo Engineering Japan (Washimi, 2012). After the success of this plant, the development of DME plant continues with higher capacity (110,000 ton/year) that is operated in end of 2005 (International DME Association, 2007 & Gray et al, 2001). At December of 2006, China signd a join contract between Lituanhua Group and Toyo Engineering Japan for the development of DME plant with 1,000,000 ton/year in Mongolia, which will be the largest DME plant in the world. For the direct process, the DME plant technology is developed by JFE Corporation. Most of direct processes are still under pilot project.

This paper presents results of a research on the development of methodology to evaluate techno-economic feasibility each of processes to synthesis DME from natural gas and coal and its sensitivity. Based on this feasibility, the research carries out the selection of process technology to synthesis DME.

PROBLEM STATEMENT

While LPG has to be imported from other countries, DME can be synthesized from natural gas, coal, and biomass. The coal used for DME synthesis can be low-rank quality. Although low-rank coal with the lowest price can be processed to produce DME, however, it seems that natural gas still more economically viable for producing DME. Based on research (Ogawa, 2003; Washimi, 2012; Toyo Engineering, 2007; Ohno et al, 2005; Japan DME Forum, 2007; JFE R&D, 2011; Ogawa, 2002), the natural gas gives the highest conversion to DME (see Table 2). The biomass gives the longest road of making DME than coal and natural gas, therefore, it will need more cost than coal or natural gas.

Table 2: **Percent Conversion and Process of DME Synthesis (Ogawa, 2003; Washimi, 2012; Toyo Engineering, 2007; Ohno et al, 2005; Japan DME Forum, 2007; JFE R&D, 2011; Ogawa, 2002)**

Feedstock	% Conversion	Process
Natural Gas	70.2	Reformer - DME Synthesis - Separation - DME Product
Coal	66.3	Coal Gasifier - Shift Converter - Desulfurization/CO_2 removal - DME synthesis - Purification - DME product
Biomass	53.3	Drying - Gasifier - Desulfurization/ CO_2 Removal - DME Synthesis - Purification - DME Product

As discussed previously, there are two ways in making DME, i.e. direct and indirect processes. In indirect process, the synthesis needs two stage reactions, i.e. conversion of syngas to methanol and methanol to DME. In direct process, the synthesis needs only one stage reaction, which is synthesizing DME directly from the syngas. In both synthesis routes, the syngas can be generated from the reforming of natural gas and the gasification of coal or biomass. There are many parameters that can be important factors in selecting the synthesis route for the DME production, whether from natural gas or from coal. Table 3 presents a brief conclusion of the comparison of indirect process than direct process for synthesizing DME.

Table 3: Comparison of factors for selecting DME Synthesis

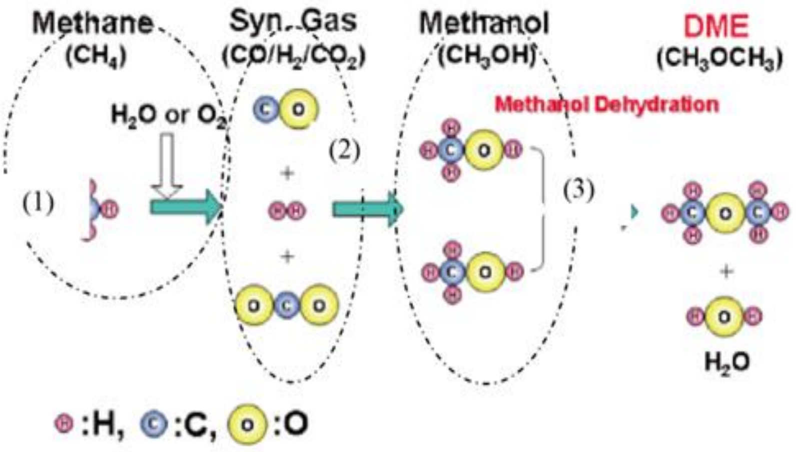
Parameter	Indirect Process	Direct Process
Reactor used		√
Reaction time		√
By Product	√	
Safety	√	
Pressure	√	
Temperature	√	
Application	√	

The decision for selecting direct or indirect, natural gas or coal needs a comprehensive assessment on techno-economic feasibility of each of process to synthesis DME from natural gas and coal and its sensitivity is needed, therefore, the selection of process technology to synthesis DME can be carried out.

DME SYNTHESIS

There are two ways in making of DME based on natural gas or coal as feedstock, i.e. indirect and direct processes. The indirect process is developed by Toyo Engineering. The process is divided into two stages, where in the first stage methanol is produced from syngas and in the second stage the methanol is covert through the dehydration of methanol into DME. This indirect process is illustrated in Figure 2.

Figure 2: Indirect Process of DME Illustration (Toyo Engineering, 2007)



As explained before, there are two reactors needed in indirect process. The operating condition of each process of indirect DME synthesis is shown in Table 4 (Toyo Eng., 2007; Ohno, 2005). The reactions involved in the indirect process are shown as below:

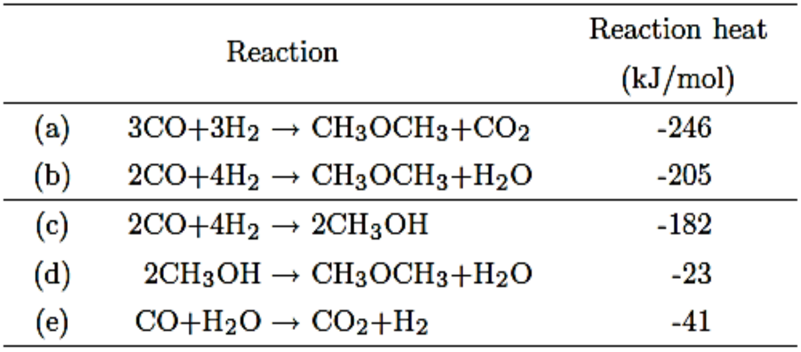
Methanol synthesis-1:
$CO + 2\,H_2 \rightarrow CH_3OH$ $\Delta H = +90.7$ kJ/mol ……………………..(1)
Methanol synthesis-2:
$CO_2 + 3\,H_2 \rightarrow CH_3OH + H_2O$ $\Delta H = +49.4$ kJ/mol……………………(2)
Methanol dehydration:
$2CH_3OH \rightarrow CH_3OCH_3 + H_2O$ $\Delta H = +23.4$ kJ/mol………………….. (3)

Table 4: Operating Process for DME Synthesis Indirect Process

Process	*Indirect Proses*	
	Methanol	**Dehydration**
Reaction Pressure (MPa)	8-10	1-2
Reaction Temperature (°C)	180-270	300-340
One Through Conversion (%)	38	70
Reaction By Product	-	*Water*
Reactor	*Phase Fixed*	*Fixed Bed*
Cold Gas efficiency (%)	57	57
Theoretical cold gas efficiency (%)	66	87

The other process of DME synthesis is direct process. The direct process of DME synthesis is developed by JFE Co. The reaction needs only one stage reaction, which is synthesizing DME from syngas based on reaction paths shown in Table 5 (Japan DME Forum, 2007).

Table 5: Reaction mechanisms involved in 'direct' process



	Reaction	Reaction heat (kJ/mol)
(a)	$3CO+3H_2 \rightarrow CH_3OCH_3+CO_2$	-246
(b)	$2CO+4H_2 \rightarrow CH_3OCH_3+H_2O$	-205
(c)	$2CO+4H_2 \rightarrow 2CH_3OH$	-182
(d)	$2CH_3OH \rightarrow CH_3OCH_3+H_2O$	-23
(e)	$CO+H_2O \rightarrow CO_2+H_2$	-41

As shown in Table 5, reaction (a) and (b) can be considered as direct process if combining the methanol synthesis (c), methanol dehydration (d), and water-gas shift reaction (e). The operating condition for direct process of DME synthesis is shown in Table 6.

Table 6: Operating Condition of Direct Process

Process	Reaction Condition
Temperature (^{0}C)	260
Pressure (MPa)	5.0
Feed Syngas (H_2/CO ratio)	1.0
Ratio catalyst to flow rate (kg/(kgmol/h)	4.0

Source: JFEE R&D Forum, 2007; Ogawa, 2002

METHODOLOGY FOR ASSESSING OPTIMAL ROUTE OF DME SYNTHESIS

This study uses Aspen HYSYS 8.8 software for model simulation, in which the model is developed to design process flow diagram of DME Synthesis. The model also uses for developing mass and energy balance system. Before the development of the process model, a preliminary selection is to be carried out to reduce the number of routes for simplifying the model simulation, in which direct process is excluded due to this technology has not been matured (still under pilot) and has not economically viable. In this study, the model evaluation and simulation will be carried out for the DME from natural gas and coal using indirect process. The characteristics of natural gas and coal from an Indonesian mining, i.e. physical - chemical properties, are given in Table 7 and 8. Before simulation, the model is validated using data from process licensed by Toyo Engineering 2007 (Toyo engineering, 2007).

Table 7: Characteristics of natural gas (Total E&P Indonesie, 2016) and coal (Bukit Asam Tanjung Enim, 2016) from an Indonesian mining

Natural Gas Composition	Mol Fraction
CH4	0.854
C2H6	0.042
C3H8	0.029
n-C4H10	0.007
i-C4H10	0.006
n-C5H12	0.002
i-C5H12	0.003
C6H14	0.003
CO2	0.055
N2	0.0004
C7H16	0.00004
Total	1.0

Ultimate Analysis of Coal	Mass Fraction
C	0,376
H	0.039
O	0.092
S	0.004
N	0.009
H_2O	0,164
Ash	0.078
Total	1.0

Table 8: Proximate analysis of an Indonesian coal (Bukit Asam Tanjung Enim, 2016)

Coal Characteristics	Value
Total Moisture (% as received)	28
Ash (% as dry basis)	7
Inherent Moisture (% as dry basis)	14
Volatiles (% as dry basis)	39
Sulfur (% as dry basis)	0,8 max
Gross Calorific (as received)	5000 (Kcal/kg)

Based on those characteristics data of feedstock for DME production, the simulation are made using Aspen Hysys 8.8. The production capacity of the DME production system is set at 360 KTA based on the projection of 2020 (Gray, 2001). After simulation (with the accumulation of near zero) then evaluate the economic analysis and its sensitivity analysis based on the year of 2025 using Excel with assumptions data shown in Table 9.

Table 9: Economic analysis assumptions data

Component	**Amount**
Natural Gas Price	$ 7 / MMBTU
Coal Price	$ 24 / ton
DME Price	$ 625 / ton
Inflation	6%
Interest Rate	12%
Ratio of Equity to Loan	20% Equity and 80% Loan
Project Life	10 years
Operation	330 days/year

Source: Peters, et al 2003 [20]

RESULTS AND DISCUSSION

This section will be divided into two parts of discussion, which are technical and economic feasibility and sensitivity analysis. The first section is technical and economic analysis. For this analysis, the consumption of feedstock to produce the same volume of DME is around 364 KTA for natural gas and 394 KTPA for coal. Process flow diagram for synthesizing DME from natural gas is presented in Figure 3 while synthesizing DME from coal is presented in Figure 4. The conversion factor of 82.94% is used in this study, in which the number is taken based on the most license data, i.e. 80-85% [Peters, et al 2003; Kidnay, et al 2006; and Poling, et al 2001).

Figure 3: Process flow diagram for DME synthesis using natural gas

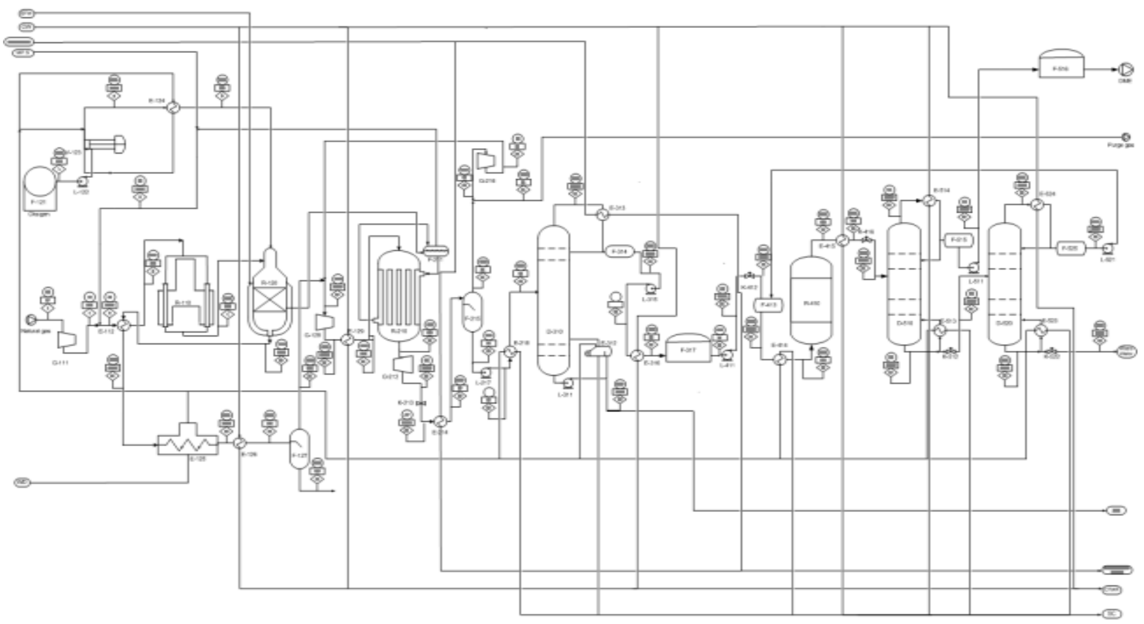
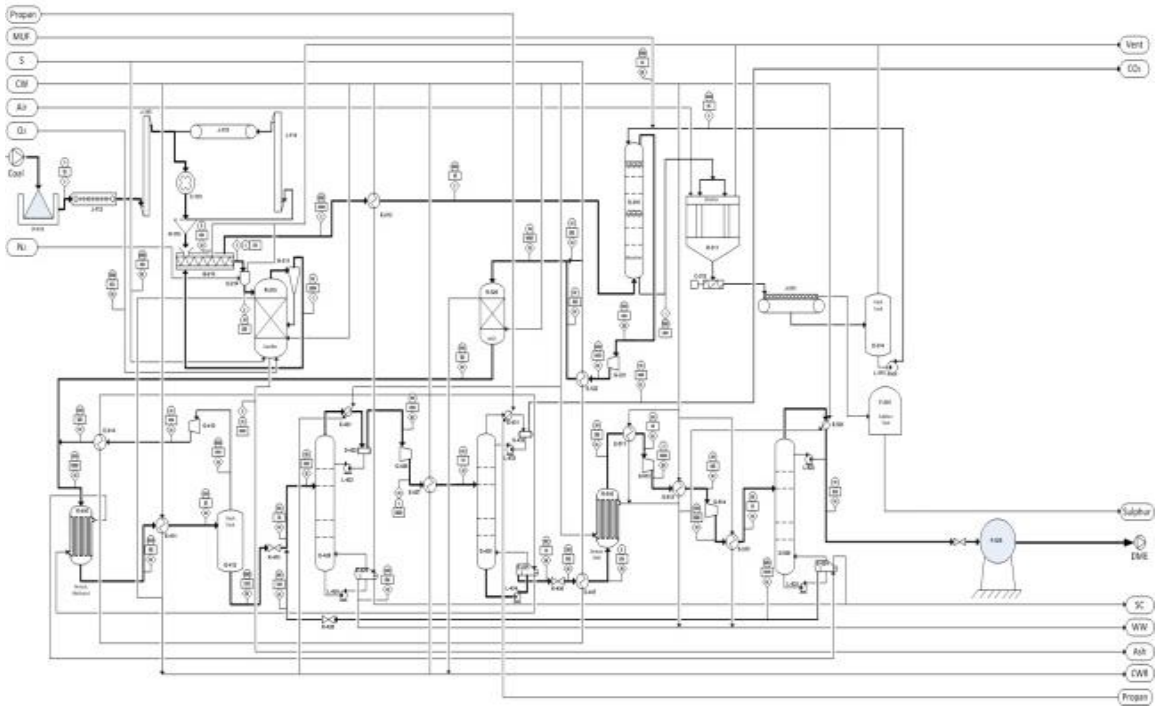


Figure 4: Process flow diagram for DME synthesis using coal



The number of equipment used in each simulation model (Figure 3 and 4) is almost the same, 53 for coal and 50 for natural gas. The consumption of natural gas and coal for producing the same volume of DME is about 82,803.6 ton/year for natural gas and 620,453 ton/year for coal. It can be seen from this simulation results, the natural gas consumption is less than coal due to the length of processes in coal to DME synthesis. Longer process needs more feedstock. The coal simulation needs to gasify into syngas, which needs much feedstock because of low conversion rate of gasification processes.

In the economic feasibility section, four parameters are used in the economic analysis, i.e. Total Investment Cost, Payback Period, Internal Rate of Ratio, and Net Present Value (Higman, 2008). The first parameter is total investment cost. Using Least Square Index, the total investment cost for natural gas based DME production system is $ 256,365,552 while for the coal base is $ 506,188,834. Natural gas has less total investment cost than coal because of the length of the process. The high cost of DME production from coal is due to the high cost of desulfurization and gasification processes. The second parameter of the economic analysis is payback period. It can be seen that coal base technology gives longer time of payback period, i.e. 5.36 years while the natural gas base only 4.11 years. The longer time of payback period of coal base technology is related to the higher total investment cost that will also affect the amount of loan from the bank.

The third parameter in economic analysis is internal rate of return (IRR). This parameter is crucial for economic analysis because it will make the investor to make a choice between investing in the project or investing the money in a bank. The analysis shows that the IRR of natural base DME synthesis is 25.13% while the IRR of coal base DME Synthesis is 16.76%. The economic analysis shows that the IRR of both are higher than bank interest, therefore, it can be concluded that both routes are economic attractive where natural gas base route gives better IRR than coal.

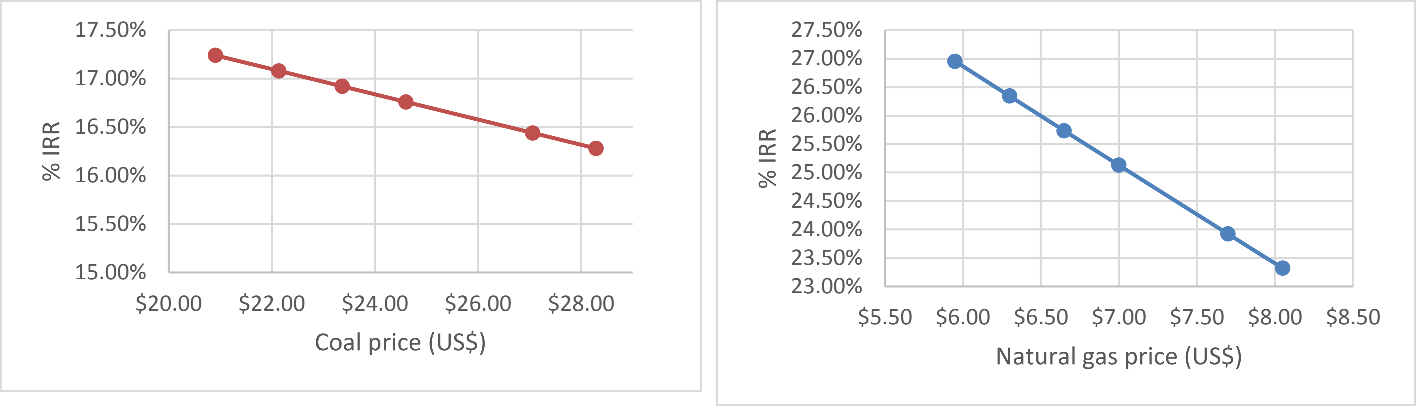
The last parameter in economic analysis is net present value (NPV). This parameter will indicate how much the amount of the asset of the simulation based on year of company's projected life. Higher NPV shows better economic feasibility. The analysis results shows that NPV of coal base is $ 170,894,997 and natural gas base is $ 249,825,952. NPV of natural gas is higher than coal due to the natural gas consumption for feedstock is lower than coal. In addition, the investment cost will also affect the NPV (see Table 10).

Table 10: Parameters of Economic Analysis in 10 Years of Project Life

Parameters	**DME from Natural Gas**	**DME from Coal**
Total Investment Cost	$ 256.365.552	$ 506.188.834
Payback Period	4.11 years	5.36 years
Internal Rate of Return	25.13%	16.76%
Net Present Value	$ 249.825.952	$ 170.894.997

The second part of this discussion section is sensitivity analysis. This part discusses the effect of the changes of the level of some parameters to the IRR. There are 3 parameters observed in this analysis, i.e. feedstock price, DME price, and total investment cost. As shown in Figure 5, increasing price of feedstock will result to the low IRR that means low feasibility. Feedstock price affects significantly the IRR of natural gas base system while in the coal base system the coal price does not significantly affect the IRR. Therefore, IRR or economic feasibility of coal base system is more stable and it is not much affected by feedstock price. It should be noted that the IRR of coal base system is very low compare.

Figure 5: Sensitivity analysis of various natural gas and coal price to the IRR



The effect of DME price to the IRR is presented in Figure 6. It can be seen in Figure 6 that DME price is significantly affect the economic feasibility of DME production, particularly in the natural gas base system. The increment for the worst case into the best case for coal base system is only 15.64% while for natural gas system is 20.60%.

In addition, the sensitivity of total investment cost to the IRR is also analyzed in this study, as presented in Figure 7. It can be seen that in the coal base system, the effect of increasing investment cost to IRR is not significant compare to those in the natural gas base system. The decreasing of the best case into the worst case for coal base system is 0.96% while for the natural gas base system is 3.37%. It shows that decreasing factor for the IRR in coal base system is better compare to those in natural gas base system. The decreasing IRR level for coal base system is 8.63% and for natural gas base system is 10.13%.

Compare to sensitivity analysis of these parameters (see Figure 5 to 7), it can be seen that the IRR of DME production system is significantly affected by the DME price.

Figure 6: Sensitivity analysis of the DME price to the IRR

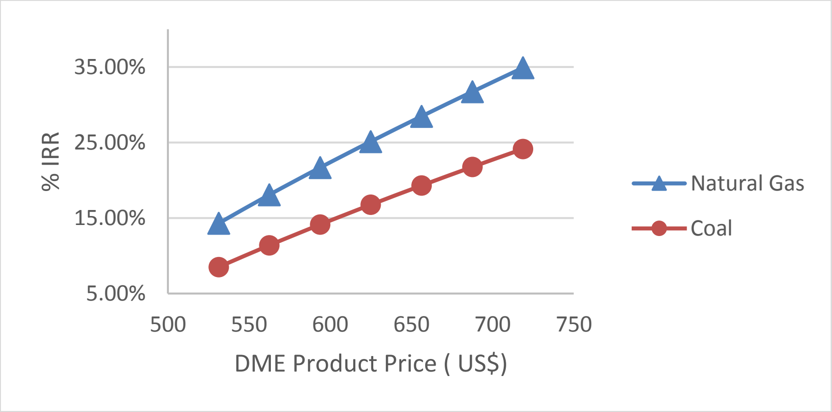
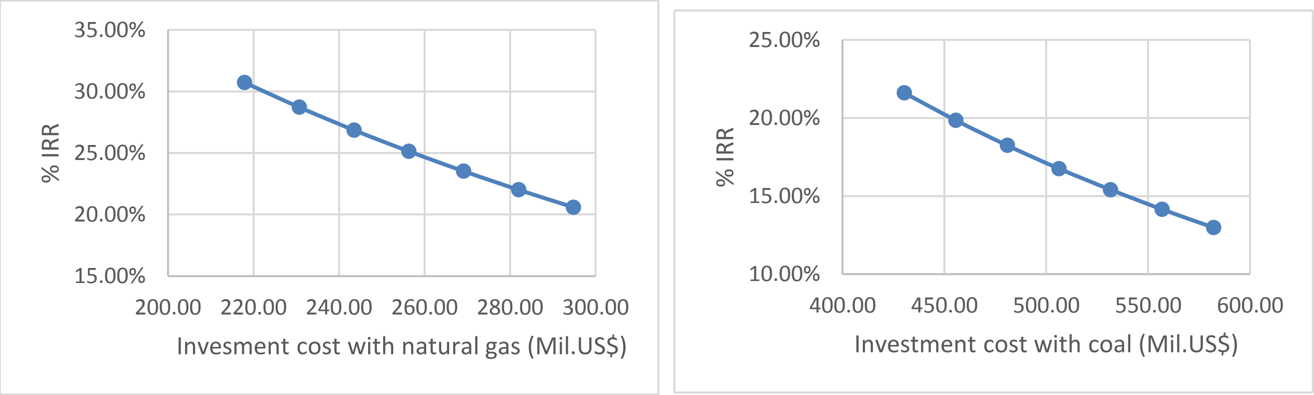


Figure 7: Sensitivity analysis of the investment cost to the IRR



CONCLUSION

Based on previous discussions, it can be concluded that indirect process is selected due to the mature of production process technology and economically viable of the system. The capacity of natural gas and coal base DME synthesis for indirect processes can be designed up to around 360 KTA, where this size is world economic size of DME production.

For the same production capacity of the DME, the consumption of feedstock to produce is around 364 KTA for natural gas and 394 KTPA for coal. It can be seen that consumption of feedstock is higher in the coal base system compare to the natural base system. High feedstock consumption in coal base system is due to low conversion of coal to the DME. As the implication, the operation and the investment costs will be higher and will affect the economic feasibility of the system and its sensitivity.

The techno-economic assessment of each synthesis routes of the DME production shows that although low-rank coal with low price can be processed to produce DME, it seems that natural gas still more economically viable for producing DME. For 10 years of project life, the economic analysis shows that the investment of DME production from natural gas almost half compare to those from coal, with the payback period and IRR only 4.1 years and 25.1% while DME production from coal needs 5.4 years and 16.8%.

The sensitivity analysis shows that DME price gives the most effect to the IRR, however as the IRR of coal base system is lower than natural gas base therefore in overall the changes of feedstock price will not significantly affect to the changes of IRR of coal base system. Although the coal base system gives the low IRR compare to the natural gas base system, however the IRR or economic feasibility of coal base system is more stable and it is not much affected by the changes feedstock price, investment cost, and DME prices.

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