Di-Methyl Ether (DME) Prospective in Terms of Conventional Fuels in Pakistan from Gasification of Aboriginal Coal

Aziza Aftab Memon[1], Shaheen Sheikh[1], Mohammad Siddique[2], Shagufta Ishtiyaque[3], Abdul Sattar Jatoi[4], Faisal Mushtaq[2]

[1]Department of Chemical Engineering, Mehran University of Engineering and Technology, Jamshoro, Pakistan, [2]Department of Chemical Engineering, Balochistan University of Information Technology, Engineering and Management Sciences, Quetta, Pakistan, [3]Department of Chemical Engineering, University of Karachi, Pakistan, [4]Department of Chemical Engineering, Dawood University of Engineering and Technology, Karachi, Pakistan

Abstract

The whole world is facing increment in the stipulation of energy and for this purpose fossil fuels are burning readily to achieve the demand of energy. The world strives for pollution free environment and to maintain the equilibrium in energy demand and supply, focus of the world is diverting towards clean, cheap, renewable and efficient fuel that can withstand with other conventional fuel. Coal potential of Pakistan is 185.5 billion tons and is about more than the reserves of oil and gas in Arabian countries. Energy Crises and Environmental dilemma of Pakistan can be overcome by the production of DME fuel from gasification of aboriginal coal. It is estimated by the Bureau of Energy Pakistan that Diesel consumption by the transport sector and industries are 8 million tons. Pakistan spends 5.37 billion dollars extra on importing diesel of 4.8 million tons and 58,613 million tons of LPG. It is estimated that Pakistan consumes 8 million tons of diesel yearly with the rapid increment of 5%. Pakistan bears the expenditure of 5.37 billion dollars for importing the 4.8 million tons of diesel. This burden on the budget can be reduced by producing the DME from aboriginal sources as a substitute to conventional fuels. In terms of cost comparison, DME costs 40% less than diesel. Pakistan is a rich country in terms of aboriginal reserves 185 billion tons coal can produce 92 billion tons of DME. By the end of 2020, Pakistan will import diesel costing 9.18 billion dollars according to country requirement and cost of DME production 3.67 billion dollars. The fuel importing burden of budget in Pakistan till 2020 can be reduced to 5.51 billion dollars. DME can be used as an alternative to crude oil derived fuels in the boilers, combustion engines and domestic fuel.

Keywords: Fossil fuel; Energy crises; Liquefied Petroleum Gas; Di Methyl Ether; Crude

Corresponding author's email: *aziza.bano@faculty.muet.edu.pk*

INTRODUCTION

The equilibrium of energy must be maintained by flawless framework of energy utilization and production (Jatoi et al., 2016b; Mahar et al., 2017). The energy demand of the world is extensively increasing rapidly due to urbanization and industrialization along with enhancement in the living standards Jatoi et al., 2016aSeveral fuels are available worldwide but their stipulation depends upon the regional basis along with vehicle requirements with value of money. Fossil fuels takes place an important factor in the evolution of world. On combustion, fuels like coal, gas and oil emits a huge amount of CO_2, NO_x, SO_x and water vapours. The whole globe extensively facing the environmental problems due to burning of fossil fuels and increasing fuel prices (Varışlı and Doğu, 2008; Yuanyuan et al., 2009). The major progression is to convert these polluting fuels into less emission and economical fuel. This disturbance in equilibrium of demand and supply will cause more problems in future. The pollution of world is increasing day by day with the burning of conventional fuels like coal, Natural gas, petroleum (Kim et al., 2012). It is now mandatory to overcome environmental problems by searching for some substitutes of conventional fuels. Dimethyl ether (DME) can be withstand as an alternative of diesel and LPG because of emission potency is much less and efficiency is comparatively similar to those fuels (Namasivayam et al., 2010). DME shows the great potential for the available alternate fuel because DME is the versatile characteristics and can be produced through variety of sources such as coal, Natural gas, bio mass and organic waste etc. coal is the major source of producing DME and it can be produced at large scale from coal at low cost (Chen et al., 2013). Properties of LPG and DME are very much similar to each other, due to similarities in properties DME can be used as a substitute of LPG, in china DME used as a substitute

of LPG for cooking purpose. DME is portable, clean; efficient convenient and accessible like LPG. DME and LPG have very similar handling conditions and physicochemical properties (Kabir et al., 2013). LPG and DME can be blended. DME an alternative to diesel because of their matching properties like Cetane number, self-ignition temperature, hydrogen content and calorific value closely related to each other. The difference in terms of emission is that diesel is not an oxygenated fuel while the DME is, so diesel soot on burning while DME behave like a smokeless fuel (Namasivayam et al., 2010). Due to Cetane similarity in both fuels, DME can also be used in diesel engine with a moderate modification of Fuel injection system. DME is a versatile alternative fuel that can be used in many sectors such as transport, cooking, power generation etc. DME is the best option to use an alternate of Diesel in Pakistan (Kim et al., 2012). Toxic NOx Emissions of DME are also less than standardized levels of emission according to regulations of EPA. Wheel to wheel emissions of DME is less than conventional fuels. Manufacturing process of DME is the most important, for economical production of DME, it is important to produce DME at large scale for competitive price with other fuels (Marchionna et al., 2008). Direct synthesis of DME must be used instead of indirect synthesis for economical purpose because indirect synthesis is more costly process than direct synthesis (Kabir et al., 2013).

MATERIALS AND METHODS

Material used for current work is coal which is mainly available different region of Pakistan.

Current work related with coal via gasification. Pakistan has huge resources of coal so there is need to explore the technology for treating and generating energy from fossil fuel. Two step methods were utilized for current work.

- DME synthesis by indirect utilization of coal
- DME synthesis by direct utilization of coal

Figure 1, 2 and 3 shows process step for DME synthesis. DME is multi source fuel it can be produced from many sources such as Natural gas, Biomass, organic waste etc. but the coal is the major source of producing DME. Gasification is the best technology available for producing DME from coal, still research is undergoing for improving the efficiency of gasification. Underground gasification is the latest technology used in the world. Basically, DME production process consists of 2 units one is gasification and other is methanol dehydration. There are different technologies are used for methanol dehydration but the important one is methanol syntheses and DME syntheses. Syntheses gas ($CO+H_2$) is produced from gasification then syngas is synthesized to produce methanol than methanol synthesized to produced DME, this is called methanol dehydration, this is called indirect syntheses but DME can be produced directly from syngas without producing methanol that is called direct syntheses of DME.

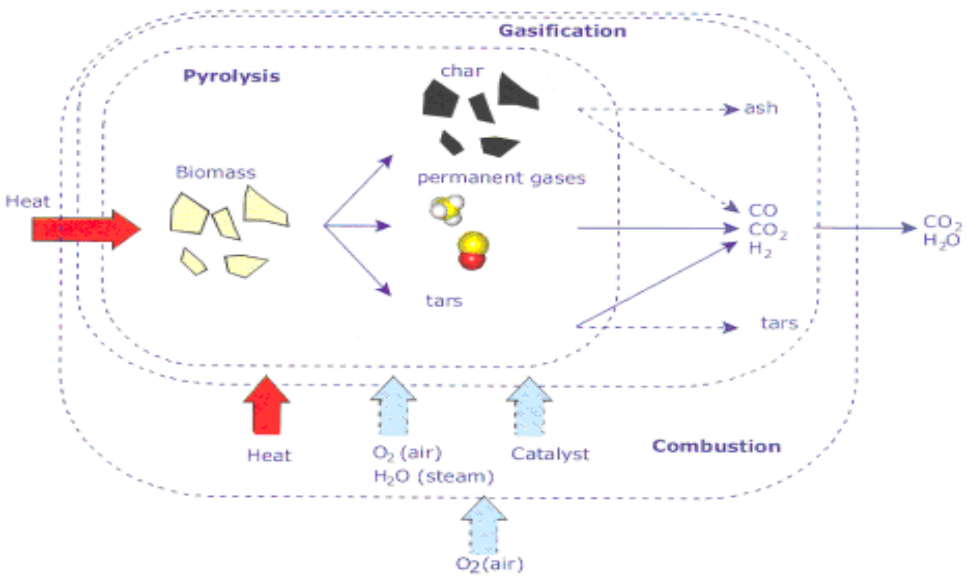

Figure 1: Process setup for gasification for DME production

Process Synthesis Route for DME Production

Several methods are available for the production of DME from indigenous coal but the most feasible process is the conversion of synthetic gas into DME. Two methods are discovered for this conversion. First is the direct method that involves the conversion of aboriginal coal into synthetic gas and then this gas undergoes the process of DME synthesis. Second is the indirect method in which conversion of coal by gasification in synthetic gas takes place further this gas undergoes the process of methanol dehydration for transformation of synthetic gas into methanol and then methanol endure the process of DME synthesis for production of DME.

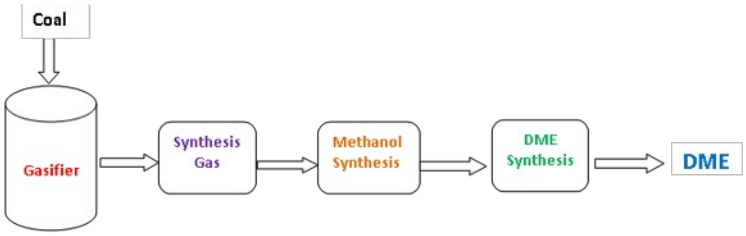

Figure 2: DME synthesis by indirect utilization of coal

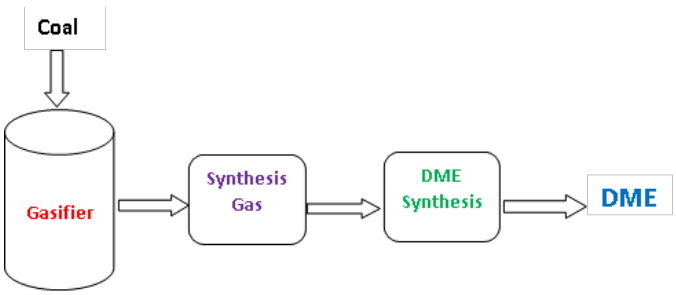

Figure 3: DME synthesis by direct utilization of coal

Several methods are available for the production of DME from indigenous coal but the most feasible process is the transformation of synthetic gas into DME. Two methods are discovered for this conversion. First is the direct method that involves the conversion of aboriginal coal into synthetic gas and then this gas undergoes the process of DME synthesis (Hayer et al., 2011). Second is the indirect method in which conversion of coal by gasification in synthetic gas takes place further this gas undergoes the process of methanol dehydration for transformation of synthetic gas into methanol and then methanol endure the process of DME synthesis for production of DME.

DME as substitute of diesel

Di-methyl ether (DME) an alternative to diesel because of their matching properties like Cetane number, self-ignition temperature, hydrogen content and calorific value closely related to each other (Larson and Yang, 2004).. The difference in terms of emission is that diesel is not an oxygenated fuel while the DME is, so diesel soot on burning while DME behave like a smokeless fuel. Due to Cetane similarity in both fuels, DME can also be used in diesel engine with a moderate modification of Fuel injection system. Properties of DME and Diesel fuel can be seen in Table.

Table 1: Characteristics of DME and diesel fuel

Characteristics	Units	DME	Diesel
Chemical formula		$(CH_3)_2O$	$C_nH_{1.87n}$
Molar mass	g/mole	46.069	170
Boiling temperature	^0C	- 24.8	180/370
Self-ignition	^0C	235	250
Heat of vaporization	kJ/kg	467	300
Cetane number		>55	57.8
Stoichiometric A/F	kJ/kg	09	14.6
Liquid density at 20 ^0C	kg/m^3	668	829.3
Lower heating value	kJ/kg	28430	43200
Carbon contents	mass%	52.5	86
Hydrogen contents	mass%	13	14
Oxygen contents	mass%	34.8	0
Sulfur	mass%	0	0.14
Critical temperature	^0C	52.4	
Critical pressure	Atm	126.95	
Enthalpy of vaporization	kJ/kg	467.13	300
Kinematics viscosity of liquid	cSt	< .1	3
Surface tension at298K	N/m	0.012	0.027
Gaseous specific heat capacity		2.99	1.7
Ignition limit	kJ/kg K	3.4/18.6	0.6/6.5

DME as a Substitute of Lpg

Properties of LPG and DME are very much similar to each other, due to similarities in properties (Hayer et al., 2011) DME can be used as a substitute of LPG. In China, DME used as a substitute of LPG for cooking purpose and is portable, clean, efficient convenient and accessible like LPG. DME and LPG have very similar handling conditions and physicochemical properties. LPG and DME can be blended (Yuanyuan et al., 2009). The requirement for the storage of DME requires mild pressurization as compared to the LPG that stored as liquid. DME possesses volumetric energy density as a liquid that estimated to be the 80% of that propane, component of LPG (Larson and Yang, 2004) Similarity of properties of DME and LPG can be seen the table.

Table 2: Characteristics of DME and diesel fuel

Properties	**Unit**	**LPG**		**DME**
		Butane	Propane	
Chemical structure		C_4H_{10}	C_3H_8	C_2H_6O
Molecular weight	g/mole	58	44.09	46.079
Carbon contents	mass%		89	52.05
Hydrogen contents	mass%		18	13
Boiling point	^0C	- 2	- 45	- 25 C
Net calorific value	Kcal/kg	11800	11900	6900
Net calorific value	Kcal/l	6840	5950	5110
Cetane number			5	55
octane number			100	13
saturated pressure			9.3	6.1
Liquid density at 20ºC	(kg/m^3)	610	501	668
lower heating value	MJ/kg	45.74	46.36	28.43
Auto ignition temp:	^0C	365	470	235-350
Flammability limits in air	vol %	1.9-8.4	2.1-9.4	3.4-17

RESULTS AND DISCUSSION

DME is a versatile alternative fuel that can be used in many sectors such as transport, cooking, power generation etc. DME is the best option to use an alternate of Diesel in Pakistan. Pakistan has the large indigenous coal reservoirs and coal gasification can be utilized for the production of DME. Pakistan has 185 billion tons of coal in different provinces and can be converted into 92 billion ton of DME from our aboriginal coal much enough for the next 200 years. DME is eco-friendly substitute fuel it release zero sulphur emissions. Toxic NOx Emissions of DME are also less than standardized levels of emission according to regulations of EPA (Kabir et al., 2013).

Diesel Costs in Imports in Pakistan

The total diesel requirement of Pakistan in year 2009 is 8 MT through which 4.8 MT was imported; cost for importing Diesel is 360 Billion rupees. Pakistan is a third world country and the heavy importing cost may impose burden on economy so why not use the abundant coal in Pakistan to conversion into DME that costs 40% less than that of diesel. From the data given in tables it is estimated that the cost for the 1 gallon of diesel equal the cost of 1.8 gallon s of DME.

By the data in the given table it is concluded that Pakistan can use this feasible versatile fuel as cheap alternative of domestic fuels like LPG and Diesel.

Table 3: Diesel Import Cost in Pakistan

Year	Total Diesel MT	Import MT	Cost on Import Rs Billion	Cost on Import $ Billion
2009	8	4.8	360	5.37
2010	8.4	5.04	378	5.63
2011	8.82	5.29	396.9	5.92
2012	9.26	5.55	416.74	6.21
2013	9.72	5.83	437.58	6.52
2014	10.21	6.12	459.46	6.85
2015	10.72	6.43	482.43	7.19
2016	11.25	6.75	506.55	7.55
2017	11.81	7.09	531.88	7.93
2018	12.41	7.44	558.47	8.33
2019	13.03	7.81	586.40	8.74
2020	13.68	8.20	615.72	9.18

Table 4: DME Production and Cost Saving in Pakistan

Year	DME MT	Cost of DME Rs Billion	Cost of DME $ billion	Saving cost in Rs	Saving cost in $
2009	4.8	144	2.14	216	3.22
2010	5.04	151.2	2.25	226.8	3.38
2011	5.29	158.76	2.36	238.14	3.55
2012	5.55	166.69	2.48	250.04	3.73
2013	5.83	175.03	2.61	262.54	3.91
2014	6.12	183.78	2.74	275.67	4.11
2015	6.43	192.97	2.87	289.46	4.31
2016	6.75	202.62	3.02	303.93	4.53
2017	7.09	212.75	3.17	319.13	4.76
2018	7.44	223.39	3.33	335.08	4.99
2019	7.81	234.56	3.49	351.84	5.24
2020	8.20	246.28	3.67	369.43	5.51

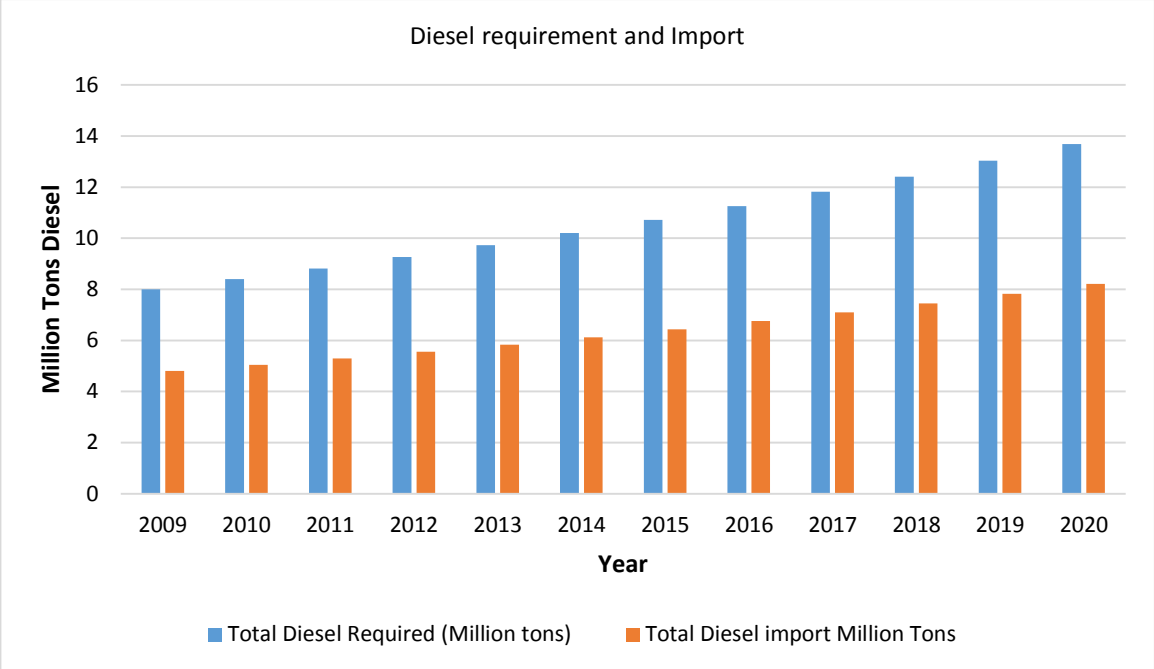

Figure 4: Diesel Requirement and import in Million Tons

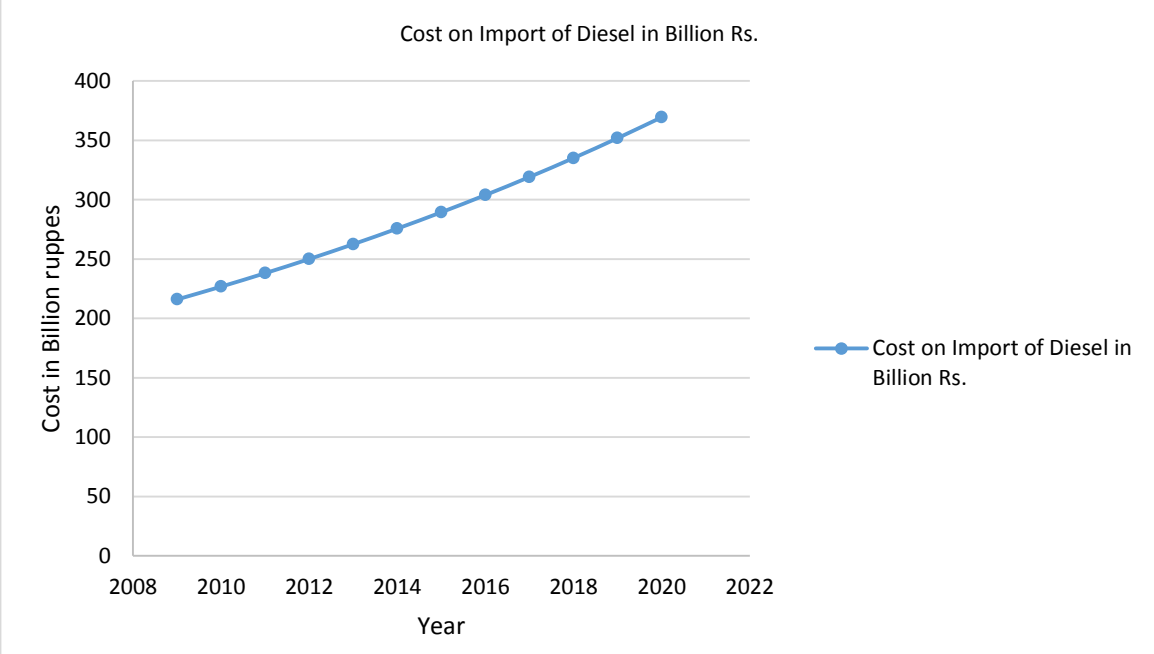

Figure 5: Cost on import of diesel in billion rupees

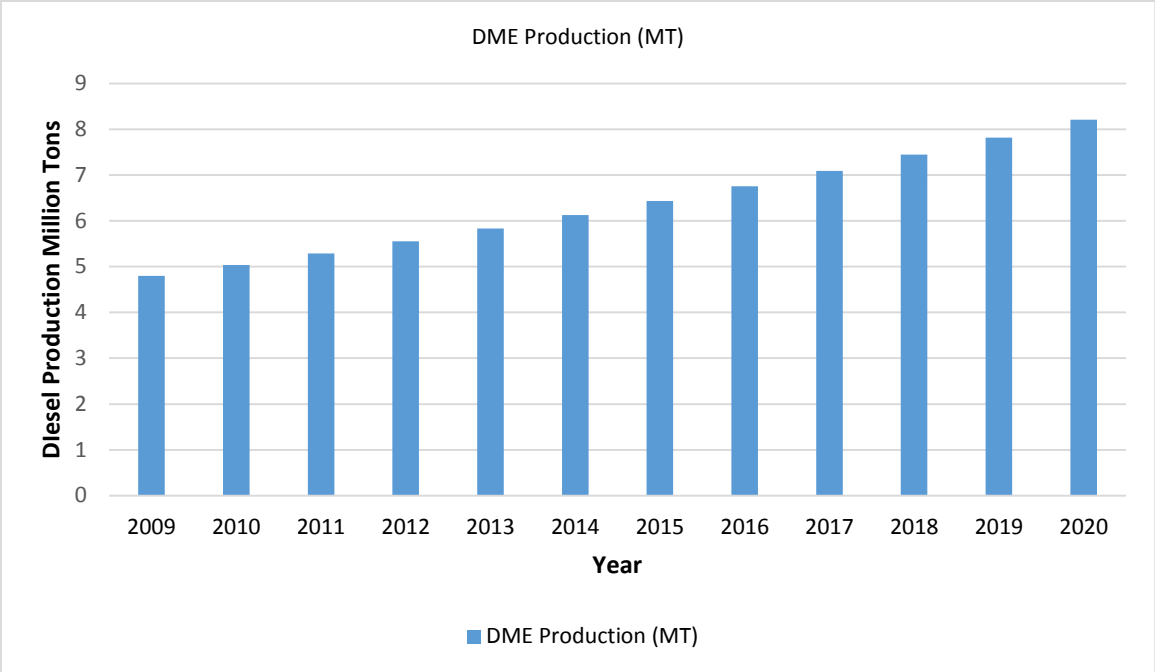

Figure 6: DME production in Metric Tons

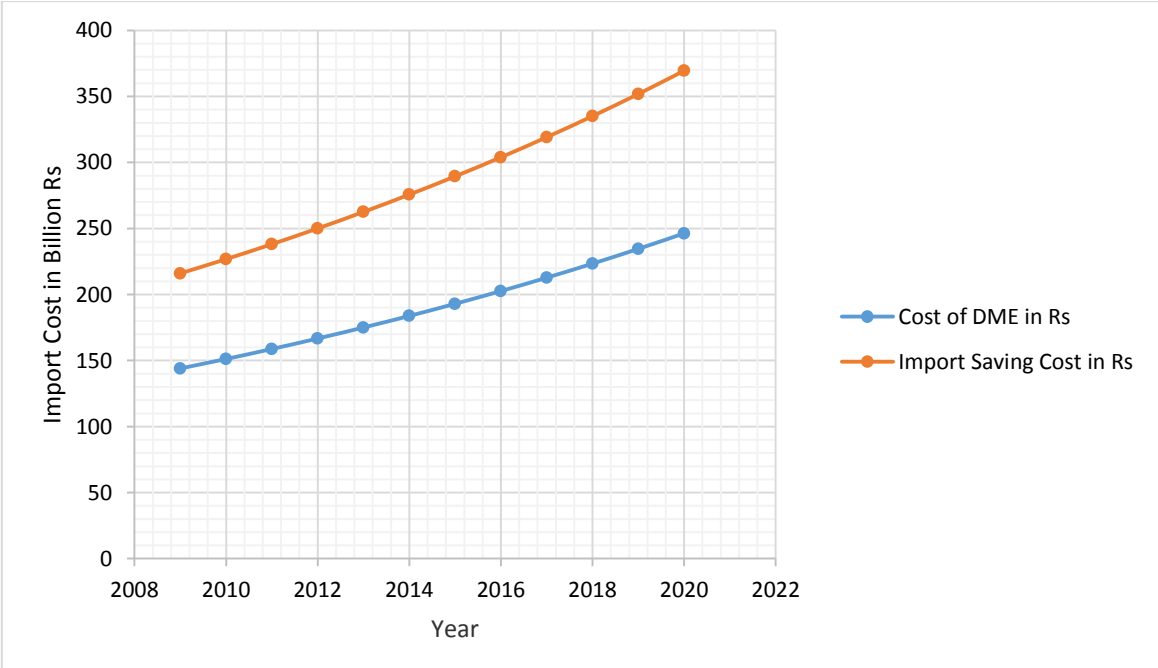

Figure 7: Import Cost in Billion rupees

Potential of DME as a Substitute for LPG in Pakistan

In Pakistan there is large consumption of LPG in transportation as well as in household cooking fuel. LPG consumed 1.4% of total energy consumption of Pakistan and per year LPG consumed is 578,419 million tons in the year of 2005-06 and 24,779.2 were imported (Kim et al., 2012). Detailed consumption of LPG region wise and import of LPG is given in following table. LPG demand is increased every day in Pakistan; 30-40% demand of LPG is increased per year in Pakistan.

The demand of LPG is fulfilled by indigenous production as well as by importing LPG from other countries. DME is the suitable substitute for LPG in Pakistan because DME can produce at large scale from our indigenous coal at low cost. Blended LPG-DME mixture can be used in LPG engines because the properties of both fuels are very similar as shown in Table 2.

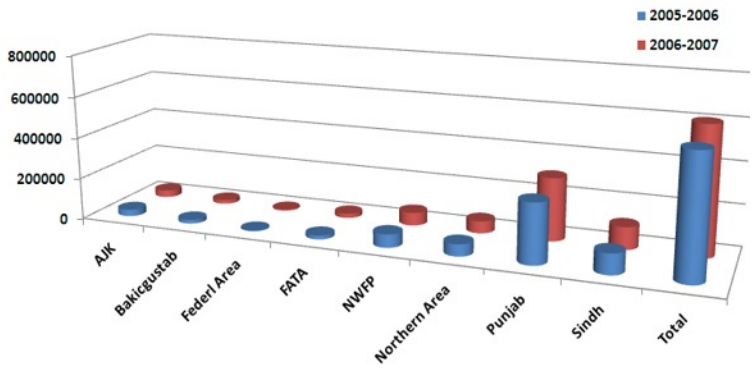

Figure 8: Comparison of LPG consumption in Pakistan for year 2005-2006-2007

Table 5: Regional wise LPG consumption in Pakistan (Unit: Million tons)

Region	2004-05	2005-06	2006-07
Sindh	74,433	98,225	10,7749
Punjab	19,6171	28,6562	30,1366
NWFP	44,786	63,829	62,461
Baluchistan	98,35	17,890	18,794
AJK	26,614	31,627	33,579
Federal area	39,00	44,65	56,35
Fata	15,595	18,513	21,454
Northern areas	44,950	57,308	58,191
Total	41,6284	57,8419	60,9229

Table 6: LPG imports yearly basis in Pakistan (Unit: Million Tons)

Sector	2004-05	2005-06	2006-07
LPG Imports	40,492	24,779	58,613

CONCLUSION

Pakistan can become the big market of DME, annually 8 million tons of Diesel is consumed in Pakistan and demand of diesel is increased every year (Rao et al., 2016). Pakistan import 60% diesel and cost of imported diesel is too high, Pakistan is the developing country and cannot afford that high imported cost of diesel. Pakistan annually pay 360 billion rupees on importing diesel from other countries such as Saudi Arabia, Iran, Qatar, Bahrain etc. as the result of annual consumption of diesel cost of import bill is also increased. After 10 years the cost of diesel is increased up to 600 billion rupees and after 20 years cost on import of diesel is reached to 1000 billion rupees. Pakistan can save over 200 billion rupees by using DME

as substitute of diesel. In 10 years Pakistan can save over 20 billion rupees and reduce the import cost of crude oil.

The potency of 185.5 billion tons of Thar coal is enough for the production of DME that can fulfil energy demands of Pakistan. Economic feasibility of DME Production is based on the crude oil prices if it crosses the barrier of $70 per barrel. DME can only with stand with other fuels by considering cost factor, for economically production of DME from Thar coal reserves.

REFERENCES

- Chen HJ, Fan CW, Yu CS. (2013). Analysis, synthesis, and design of a one-step dimethyl ether production via a thermodynamic approach. Applied energy 101:449-456.
- Hayer F, Bakhtiary-Davijany H, Myrstad R, Holmen A, Pfeifer P, Venvik HJ. (2011). Synthesis of dimethyl ether from syngas in a microchannel reactor—simulation and experimental study. Chemical Engineering Journal 167(2-3):610-615.
- Jatoi AS, Aziz S, Mahar H, Shah SF, Hussain S, Unar I, Shahzad K. (2016). Numerical Simulation of ethanol production from molasses using thermos tolerant kluyeromyces Marxian's. Journal of the Pakistan Institute of Chemical Engineers 44(1):92-99.
- Jatoi AS, Parkash A, Aziz S, Soomro SA, Shah SF. (2016). Mathematical modeling for ethanol production from molasses using thermotolerant kluyeromyces marxians. Science International 28(1):319-322.
- Kabir KB, Hein K, Bhattacharya S. (2013). Process modelling of dimethyl ether production from Victorian brown coal—Integrating coal drying, gasification and synthesis processes. Computers & Chemical Engineering 48:96-104.
- Kim IH, Kim S, Cho W, Yoon ES. (2010). Simulation of commercial dimethyl ether production plant Computer aided chemical engineering. Elsevier 28: 799-804.
- Kim S, Kim J, Yoon ES. (2012). Evaluation of coal-based dimethyl ether production system using life cycle assessment in South Korea Computer Aided Chemical Engineering. Elsevier 31:1387-1391.
- Larson ED, Yang H. (2004). Dimethyl ether (DME) from coal as a household cooking fuel in China. Energy for sustainable development, 8(3):115-126.
- Mahar H, Jatoi AS, Gopang IA, Jalbani NB, Hussain S, Kumar D. (2017). Parametric Effect On Ethanol Production Though Use Of Monod Model. Journal Of Faculty Of Engineering & Technology, 24(1): 99-105.
- Marchionna, M., Patrini, R., Sanfilippo, D., & Migliavacca, G. (2008). Fundamental investigations on di-methyl ether (DME) as LPG substitute or make-up for domestic uses. Fuel Processing Technology, 89(12), 1255-1261.
- Namasivayam A, Korakianitis T, Crookes R, Bob-Manuel K, Olsen J. (2010). Biodiesel, emulsified biodiesel and dimethyl ether as pilot fuels for natural gas fuelled engines. Applied Energy, 87(3):769-778.
- Rao S, Sahito AR, Panhwar I. (2016). 169. Environmental Impacts of Thar Coal Mining.
- Varısli D, Dogu T. (2008). Production of clean transportation fuel dimethylether by dehydration of methanol over nafion catalyst. Gazi University Journal of Science, 21(2):37-41.
- Yuanyuan H, Zhang H, Weiyong Y, Dingye F. (2009). Modeling and simulation of production process on dimethyl ether synthesized from coal-based syngas by one-step method. Chinese Journal of Chemical Engineering, 17(1):108-112.