

Title : LPG Burning Gas Turbine Technology

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1. ABSTRACT

LPG (Liquefied Petroleum Gas) is well known as fuel for home or office use and for automobile fueling. However, superiority as fuel for gas turbine power generation is not well known. Because of recent excess LPG production, inquiries regarding LPG burning gas turbine power plant are increasing. In this paper, LPG market trend, experiences of LPG Burning gas turbines, its characteristics, design know-how and also requirement to LPG supply system are introduced. From the point of view of LPG supply system chain, economy, environment and easiness of handling, LPG is expected as a most suitable fuel in Caribbean islands.

2. KEY WORDS

LPG, Gas Turbine, LNG, Natural Gas, Dual Fuel Combustor, Emission, NOx, Dry Low NOx, Multi-Cluster Combustor

3. INTRODUCTION

Fig.1⁽¹⁾ shows LPG worldwide consumption and its breakdown. Almost half (45.5 %) is home and office use. It is mainly due to easiness in handling, transportation and competitive price. Fig 2^(1,2) shows trend of LPG production. It is found that production is rapidly increasing, especially in North America (Mainly USA). It is due to increasing shale gas/oil associated gas. As a result, excess LPG is seeking for new area of consumption.

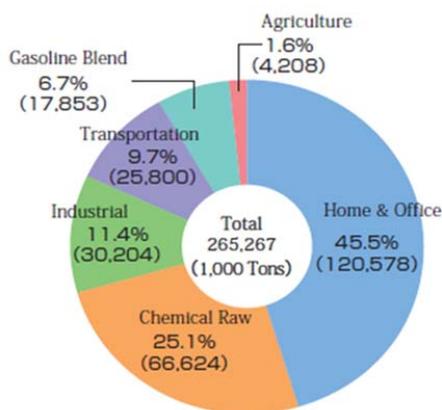


Fig.1 LPG applications (2013)

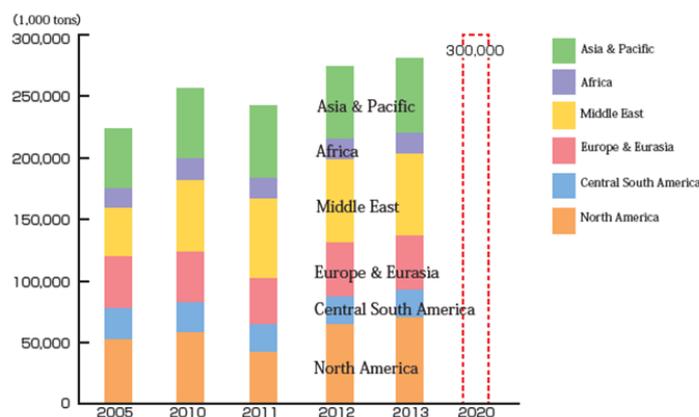


Fig.2 LPG world production

The purpose of this paper is to introduce LPG burning gas turbine power plant as a solution, which is environmentally friendly, economical and superior in performance and maintenance ability compared with Diesel oil.

4. DESCRIPTION / DISCUSSION

4.1 History of LPG Burning Gas Turbine Power Plant

Fig.3⁽³⁾ shows that more than 121 units of LPG burning gas turbines were installed worldwide since 1964. LPG burning gas turbine itself is not a new technology but a “proven technology” even though special attention must be paid due to the unique characteristic of LPG. From the figure, it is found that more than 70 % is small power plants less than 40 MW with a fact that most of these units are with dual fuel or triple fuel configuration, and LPG is a back up fuel. It means LPG was burned during the maintenance period of main fuel system. It is supposed mainly LPG cost and supply chain uncertainty in the past. The country where most LPG burning GT were installed is USA with 47 units. Next is turkey with 19 units and Japan with 11 units. It maybe the results of LPG production and country policy.

4.2 MHPS LPG Burning Experience

MHPS has enough and unique experience of LPG burning gas turbines as shown in Table 1. Total 7 units of H-25 (Fig.4) gas turbine were installed with dual fuel, but I-Refinery where LPG is main fuel was continuously operated and accumulated operation hour reached approx. 200,000 hours.

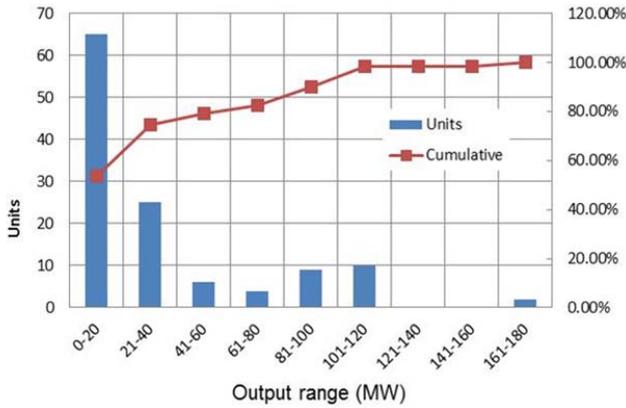


Fig.3 LPG burning GT records

4.3 LPG Characteristics

LNG (Liquefied Natural Gas) which mainly consists of CH₄ is the most popular fuel for gas turbine. However, there are difficulties to build a LNG supply system in islands or small countries. Large LNG ship normally does not stop to the small consumption area. The cost to build LNG receiving facility is too expensive to cool -196 deg.C. This is a background that distillate oil is still used in islands.

LPG consists of Propane (C₃H₈) or Butane (C₄H₁₀) and easily liquefied. It is a big merit for transportation and handling. In addition, LPG is clean fuel compared with Diesel oil. Price is also an important factor as gas turbine fuel. Fig. 5⁽⁴⁾ shows fuel price trend of Diesel Oil, LPG, LNG and Natural Gas since Jan. 2008. Recently oil price changes drastically, however, price ratio of NG, LPG, LNG to Diesel Oil is not significantly changed.

Fuel Price : Diesel > LPG > LNG > NG.

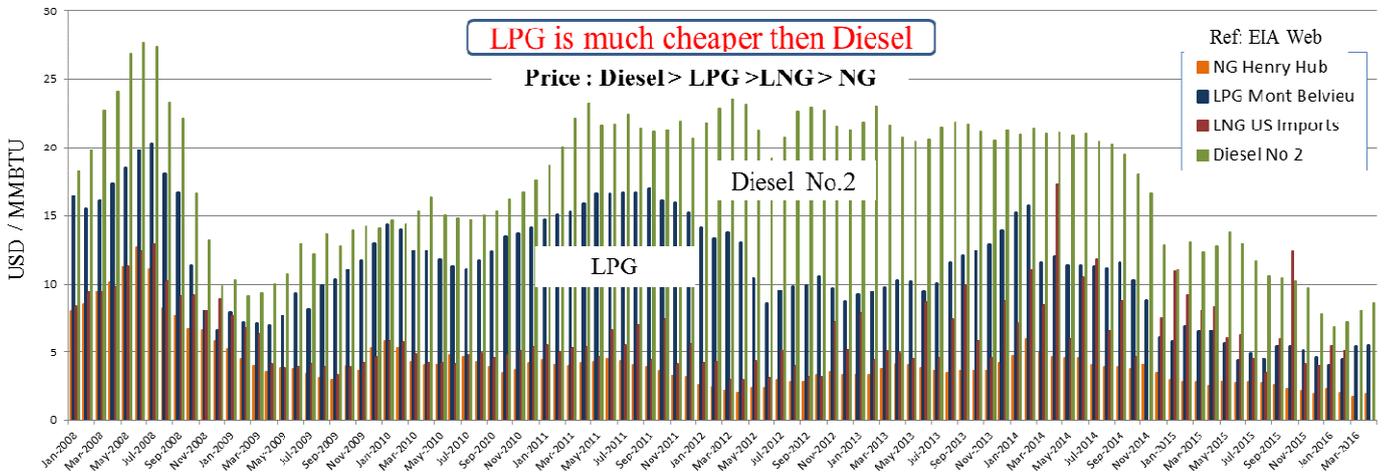


Fig.5 Fuel price trends

4.4 LPG Burning Gas Turbine Characteristics

The merits of LPG compared with LNG or Diesel oil are summarized in Tab. 2. From this table, it is found that LPG is much superior to Diesel Oil in cost, performance, maintenance, reliability and emission. This is the reason why LPG is recommended to Caribbean islands. Actually, the big merit of fuel change from Diesel Oil to LPG in Virgin Islands was reported⁽⁵⁾.

Tab. 3 is an example of emission calculation for both typical Diesel Oil and LPG, which is summarized as LPG is

- 15 % reduction in greenhouse gas
- Over 80 % reduction in VOC, PM and SOx
- 15 % reduction in NOx

Tab. 1 H-25 LPG burning units

No.	Customer	Place	Output	GT Type	Units	NOx Reduction	Fuel (Main / B.Up)	COD
1	I-Refinery	Japan	26.25 MW	H-25 (28)	1	Steam Injection	LPG / "A" Heavy Oil ⁽²⁾	1988
2	Y-Refinery	Japan	25.0 MW	H-25 (28)	2	Steam Injection	Off Gas / LPG	1996
3	O-Refinery	Japan	32.92 MW	H-25 (32C)	1	Steam Injection	Off Gas / LPG	2005
4	A-Refinery	Japan	33.99 MW	H-25 (32C)	2	Steam Injection	Off Gas / LPG	2007
5	O-Plant	Korea	31.38 MW	H-25 (32C)	1	Water Injection	Off Gas (C1/C3 Gas)	2008

Type	Heavy Duty
Output	28.1~42 MW
Efficiency	34.2~37.2 %

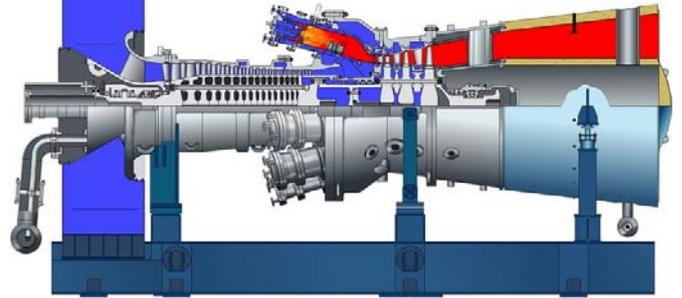


Fig.4 H-25 gas turbine

Tab. 2 Merits of LPG burning GT

	Items	Merits of LPG
A	Compared with LNG	
1	Capex	Lower than LNG burning facility
2	Handling	Easier storage and transportation
B	Compare with Diesel Oil	
1	Fuel cost	Cheaper than Diesel Oil Typical value (2016 Average) LPG : 0.457 USD/ Gallon, 5.49 USD/ MMBTU Diesel : 1.2 USD/ Gallon, 8.6 USD/MMBTU
2	Maintenance	Maintenance interval for a given operational profile is 20-30 % lower
3	Performance	Output : Approx. + 0.7 % Efficiency : Approx. +1.3 % (Relative)
4	Reliability	Rotational equipment (fuel pimp) and precision equipment (flow divider) are not required. Reliability of the auxiliary system increases.
5	Emissions	Emission decreases greatly. See Tab.3.

Tab. 3 Emission comparison

	NOx	VOC ^(*)	CO	PM10 ^(*)	SO ₂	CO ₂
Diesel Oil	1,205	36	63	40	110	175,969
LPG	1,024	7	12	2	0	148,392
% Reduction	15.03	80.97	80.97	95.06	100	15.67

^(*) Volatile Organic Compounds ^(*) Particulate Matter

Assumptions:

1) Fuels : Diesel Oil : Includes S (0.1 wt. %) and N (0.05 wt. %)
LPG : C3H8 100 %

2) Operation : 213,440 MWh/year (Equivalent to Diesel unit 8,000 hrs operation)

Fig.6 shows a trial calculation results of fuel cost saving when 15 years old Diesel burning 25 MW class GT (14,835 Btu/kWh) is replaced with new LPG burning H-25 (26.54 MW, 10,189 Btu/kWh). Of course, the cost saving depend on fuel price. As a maximum price case, medium and lowest cases, Jan.2013, Jul. 2008 and Mar. 2016 fuel price in Fig. 5 were used respectively. Even in the current cheapest case, 15.2 MUSD of fuel cost saving is expected by one unit

replacement. If fuel price rebound to the level in 2013, saving of 55.8 MUSD /year is expected. In case of 80 MW class plant (3 units replace), it will reach 167 MUSD. Investment cost for the replacement will be recovered soon.

4.5 Design of LPG Burning Gas Turbine

LPG is superior fuel for gas turbine especially for island applications. However, when LPG is used as a gas turbine fuel, special attentions must be paid. Tab. 4 shows summary of key points to design LPG burning gas turbine. High dew point is a merit for handling and transportation. However, liquefaction in gas turbine fuel system must be avoided to results in severe damage to combustor. Piping and equipment downstream of vaporizer must also be suitably heat traced.

Vent and flare system may be required for LPG supply system to warm up it to permissible condition before start-up of the gas turbine

NOx reduction is an important technology for LPG. Even though LPG is a clean energy, NOx level is expected more than 250 ppm @ 15 % O₂ in diffusion combustor without dilution (steam/water) injection, even though NOx emission changes depends on firing temperature.

There are two types of low NOx technology, wet and dry (Tab.5). One of key technology of low NOx is to avoid local

Tab. 4 Key Points of LPG burning GT Design

	LPG characteristics	Design considerations for LPG
1	High dew point	Easily liquefied by compression to 24-30 barg • Heating (above 100 deg.C) is required • Steam tracing is required for LPG line.
2	Heavier specific gravity than air	Suitable ventilation is required to avoid explosion.
3	Combustion characteristics • High combustion speed • Rich "C" content	Countermeasure may be required depending on environmental regulation.
4	Impurity	In order to keep high reliability, fuel must strictly satisfy GT supplier's fuel specifications, not only physical conditions but also chemical compositions. This is not limited to LPG and common to all fuels

and NOx level decreases. However, Pre-Mixed low NOx combustor intrinsically has potential of flashback to the nozzle because both fuel and air exist. MHPS is now developing a unique Dry Low NOx combustor so called Multi-Cluster Combustor.

4.6 MHPS Multi-Cluster Combustor (MCC)

Multi-Cluster Combustor has been developed as a dry low NOx Combustor for a fuel-flexible gas turbine. Initially, the capability to burn H₂ rich syngas was verified in Eagle IGCC pilot plant⁽⁶⁾. Then, Multi-Cluster Combustor is now installed into H-100 gas turbine (100 MW class gas turbine) and subject to commissioning at OSAKI CoolGen oxygen-blown IGCC plant⁽⁷⁾ in Japan. Fig.7 shows Multi-Cluster Combustor structure. It consists of multiple pairs of air hole and a fuel nozzle that

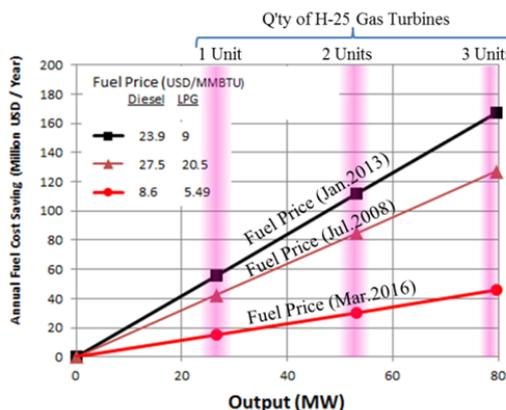
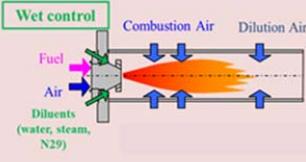
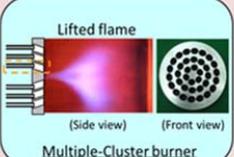


Fig.6 Fuel cost saving by replace

high temperature spots. NOx increases exponentially with temperature. Even if total average temperature is same, if high spot exists, NOx increases. Wet type combustor reduces NOx by injecting water or steam into high spot and reducing temperature. It is well known and established technology because diffusion combustor is stable.

On the other hand, well known dry low NOx technology is Pre-Mix method. Pre-mixed fuel and air make homogeneously flame. As a result, high spots are eliminated

Tab.5 Low NOx Combustion technology

Low NOx Technology		Combustor Structure
W E T	Diffusion combustor + Steam injection or Water injection	
D R Y	Multi-Cluster Burner (Neither Steam Injection nor Water Injection)	

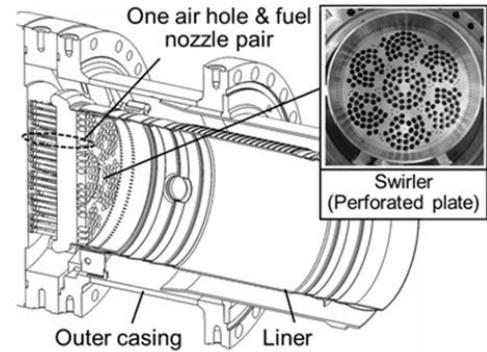


Fig.7 Multi-Cluster Combustor

are installed coaxially. This structure makes a rapid mixing and as a result flashback-resistant combustion available. Following H₂ rich syngas, MHPS recently performed the tests using Natural Gas and LPG to show the capability of fuel flexibility. Fig.8 shows test result of fuel staging and its flame conditions. Fuel staging consists of four distinct modes: pilot mode, partial mode (1), partial mode (2) and final mode. Ignition and initial load are performed by pilot burner. Then, with increasing load, inner part of main burner (F2), outer burner (F23-1) and finally remaining outer burner (F23-2) are burned in order. The figure shows stable flame in each stage. Multi-Cluster Combustor had no experience of flash back through the tests. Fig. 9 shows the results of NO_x characteristic. The ordinate is relative NO_x value normalized by the minimum NO_x for Natural Gas within the stable range. The tests were examined changing “inner fuel ratio: Rin” without changing combustor outlet gas temperature. From the figure, it is found that NO_x decreases with decreasing “inner fuel ratio” in both fuels. LPG shows relatively higher NO_x and narrower stable range compared with Natural Gas. It is thought due to LPG’s higher stoichiometric flame temperature and higher combustion speed and calorific values. Detail of Multi Cluster dual fuel burning test results will be presented at the International Gas Turbine Conference held at Brussels on October 2016.

These test results shows that Multi-Cluster Combustor has capability of dry low NO_x dual fuel (LPG / LNG) combustion. It will give a big incentive for the island countries. The plant can start operation with LPG until LNG becomes available, then, if it becomes available, the unit can be operated by LNG.

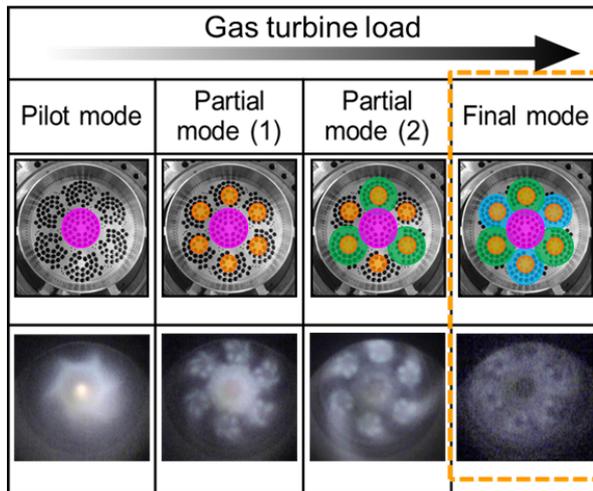


Fig.8 LPG flames at each stage

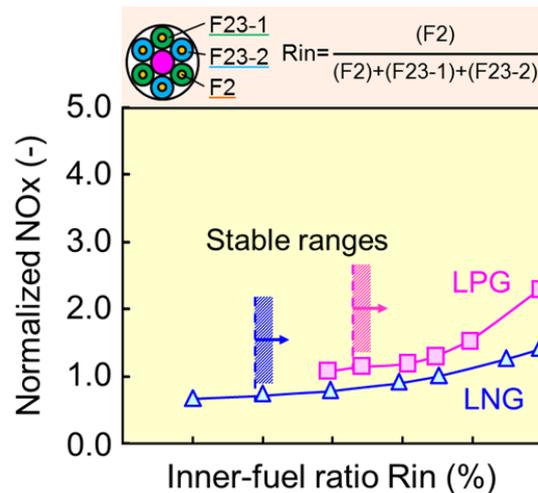


Fig.9 NOx emissions (final mode)

5. CONCLUSIONS

This paper introduced LPG trends in the world and a benefit of LPG as a gas turbine fuel especially for island countries. The latest LPG burning GT technology is also introduced.

- 1) With increasing LPG production, LPG worldwide trade becomes more active.
- 2) LPG is superior to LNG in handling and transportation capability. It does not require costly receiving facility such as LNG.

- 3) LPG is superior to Diesel oil in operational cost, performance, emission and maintenance ability.
- 4) As a result, LPG is the best near-term solution for Caribbean island countries until LNG becomes available.
- 5) MHPS is now developing Multi-Cluster dry low NOx combustor which can burn both LNG and LPG. It will give a big incentive to the plant owners in the island countries. Not only dilutions (water/steam) are not required but also the unit can be operated with LPG and LNG.

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