Feasibility Study of Alternative Gas Turbine Fuel for Offshore Power Generation

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Abstract

Offshore platform power generation is an essential part of oil and gas operations. Due to the strict fuel requirements set by gas turbine manufacturers, power generation can be quite a costly business for operators. This cost increases drastically when there is insufficient gas fuel to power the turbines and expensive refined diesel is required to keep the operations running. Although it is also possible to run the turbine on alternative fuel sources such as the crude oil produced from the operation, the higher level of contaminants can have a detrimental effect on both the reliability and the operation life of the turbine. This paper looks at the alternative fuel sources available for offshore platforms, experiences with the running of alternative fuels, and discusses their feasibility.

1.0 Introduction

In modern offshore platform applications, gas turbines are essential to the daily operation and the production capacity of a Floating Production, Storage and Offloading (FPSO) vessel. Most gas turbines are designed with dual-fuel capacity, having the ability to run on both liquid and gas fuels. Due to the harshness of its operating conditions, fuel selection is an important factor that determines a gas turbine's reliability and operating lifespan. The only fuels recommended by manufacturers such as Solar Turbines are gas fuel and diesel, and all other fuels must be assessed and pre-approved by the manufacturer before use (ES9-98K).

In offshore installations, after the oil/water mixture is processed through the separator, crude oil and natural gas are separated. Due to the difficulty of its storage and its cleanness, natural gas is the ideal fuel for the turbine. Compared to the refined diesel fuel that has to be purchased and shipped from far away, running on the gas fuel is much cheaper and much more convenient. This is why gas fuel is the preferred fuel used in offshore power generation.

However, there are situations in the FPSO operation that there is not enough gas to run all turbines. One example of gas depletion situation is that when the reduction in production happens. In such a situation, refined diesel becomes the only alternative fuel specified by the turbine manufacturers. Due to the fact that this is a very expensive alternative, it will significantly increase the operation cost. Operators are forced to consider alternative fuels other than diesel for the gas turbine, in order to reduce the running costs and make operations more viable.

In some regions of the world, the crude oil produced is relatively clean and meets most of criteria specified by turbine manufacturers. The running costs will be significantly reduced if the crude oil can be used directly to drive gas turbines with little or no treatment. There have already been many attempts in this application around the world. This research is to study outcomes and experiences of these experiments and applications, and examine the feasibility of using this alternative fuel.

2.0 Background

2.1 Gas turbine background

Gas turbines are ideal for offshore platforms due to their lower set-up and running costs, their compactness and low weight, and their multi-fuel applications (Boyce, 2002). Another reason why gas turbines have become increasingly popular is their increasing efficiency due to the development of newer technologies, especially in the areas of materials, coatings and newer cooling schemes. These technologies enable the turbine to withstand tougher operating environment such as higher temperatures and greater compressor pressure ratio. They also increase the turbine life by reducing damages on the vital turbine parts due to erosion and corrosion. With the continuing development of these technologies in the past 20 years, gas turbine thermal efficiency has increased from about 15% to over 45%.

A typical gas turbine package used for offshore platforms is Solar Mars 100 Turbine, which has a power rating of 11.2 MW at 34% thermal efficiency. The structure of this turbine can be seen in Fig. 1. The typical operation lifespan of this turbine package is rated at 30,000 hours, which is equivalent to 3.5 years non-stop running. The specified fuel is limited to fuel gas (wobbe 1126) or standard diesel (DF2).

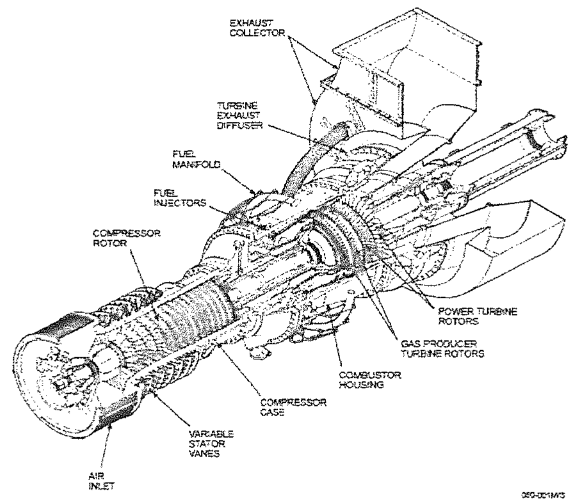

Figure 1. Mars Gas Turbine Cutaway

Figure 1. Solar Mars 100 Turbine (Courtesy of Solar Turbines Inc.)

2.2 Power requirement

A typical FPSO consists of topsides process equipments, utilities, power generation, and living quarters for crews on board. The typical power requirement for all these operations is around 10-12MW, which is enough for a small residential town. This can vary due to the change in production and the installation of other operations, such as fuel centrifuge system discussed in later sections.

2.3 Fuel Requirement

The fuel that can be used in a turbine has to meet certain criteria specified by its manufacturer, such as minimum flash points, a range of kinematic viscosity, and maximum trace contaminants (ES9-98K Specification). Some of these criteria must be met, in order for a fuel to be used in a turbine. For gaseous fuels, it is required that the fuel must be between 0.9-1.1 fuel volume ratio and have a fuel mass ratio of less than 5. Other restrictions for hydrogen, carbon monoxide and silicon content and firing conditions also apply. For distillate fuels, the kinematic viscosity must be between 1–12 centistokes at 100°F (38°C) with a specific gravity between 0.775 and 0.875. Other restrictions to firing and storage conditions and maximum water content (0.25cc at 80°F (27°C)) also apply.

2.4 Running scheme

The power of the offshore platform operation is purely from gas turbines. Thus the availability and reliability of the gas turbine are essential for daily production. A typically running scheme is to run n+1 turbines, where n is the number of turbines required to provide the power for the entire operation. This scheme ensures that if there is an unexpected trip from one of the turbines, the other turbines can provide enough power so that the operation will not be affected. It is also essential to run an additional turbine to drive the gas lift and compressor. Due to its critical nature, reliability of the gas lift gas turbine needs to be ensured or production targets may be compromised.

3.0 Problems with Alternative Crude Oil Fuel

3.1 Availability and Reliability Issues

Availability and Reliability, along with cost, are the most important factors for the industry. Although savings from the usage of alternative fuel of crude oil can be huge, the cost associated with reliability and availability issues could just be as great. Overhaul of the turbines may disable the production capability of the facilities, cause lost production and incur additional maintenance expenditure. Therefore these factors need to be evaluated before the gas turbines can switch to alternative crude fuel.

3.2 Basic Firing Requirements

In order for the crude oil to be used, the basic firing requirement such as viscosity, heating value, fuel volume and fuel mass ratios must be met. In addition to these factors, fuel temperature and pressure must be maintained to ensure the safety of handling and the stable combustion. Additional equipments and modifications maybe required to satisfy these conditions, such as the manifold modification required for crude oil firing and valve modification required for LPG firing.

3.3 Contaminants

Even when the basic requirements are met, the performance and maintenance of a gas turbine are strongly influenced by the level of trace metal contaminants in the fuel. The five most concerned trace metals are vanadium, sodium, potassium, lead and calcium (Foster). The first four of the five contaminants cause severe corrosion while all five create deposits. Although the presence of these contaminants is only in the term of parts-per-million, it can be noted that for the operation of every 50 hours, one-part-per-million is equivalent to one pound of contaminant entering the turbine. Thus, even with the presence of a few part-per-million of these contaminants can have a detrimental effect on both performance and operating lifetime of a gas turbine.

Although all five trace-metals are critical, sodium and vanadium are generally the most frequent found in fuels. Only a small amount of these metals can be tolerated before there is danger of corrosion and deposits at elevated temperature. Compounds such as sodium sulphate, vanadium pentoxide and sodium vanadates are formed in the operating temperature range of the gas turbine. These compounds are semi-molten and will cause accelerated oxidation especially on the turbine blades. Currently from the Solar Turbine Specification, the combined level of sodium and potassium is limited to 1.0ppm, while the level of vanadium is limited to 0.5ppm. (ES9-98K)

4.0 Practical Considerations

4.1 Problems of Gas Turbine Running on Lower Grades of Fuel

Throughout the years, a small yet significant number of turbines have been experimented by General Electrics (GE) running on lower grade of turbine fuels. In the period from 1950 to 1960, 78 gas turbines were operated on heavy fuels in various industries. Additional 88 gas turbines were run on heavy fuels during the period of 1961 and 1983. The concentration levels of sodium and vanadium of those raw fuels are as high as 100ppm (Foster, GE internal paper).

Although it has been demonstrated that lower grade turbine fuel with higher contaminant level can be used as the alternative fuel for gas turbine, there are experiences indicating that this alternative fuel has a detrimental effect on the turbine life. A study conducted by Hussey *et al.* (1973) revealed that when using a lower grade of marine turbine fuel with a sodium level of 10ppm and vanadium level of 4ppm, the turbine was overhauled after only 6,375 hours of operation. The inspection found that the corrosion had become extensive. Similar results were also experienced by Woodside Energy Pty. Ltd. (Woodside) in an incident when its diesel fuel was contaminated by seawater. As a result, sodium level reached as high as 6ppm, and the turbines were overhauled at only around 5,000 hours due to the excessive amount of hot corrosion to the turbine blades and vanes. Extensive laboratory studies of the safe operation limit for the use of different grades of fuel concluded that at a surface temperature of 1500°F (816°C), excessive corrosion would occur for a fuel with 5ppm sodium and 2ppm vanadium (Hussey, 1973). Winkler (1973) has suggested that vanadium should be limited to as low as 0.2ppm for a dependable and long gas turbine life, as the corrosion rate is low at these concentrations. It should be noted that most turbines are rated to tolerate corrosion from vanadium levels of 0.5ppm and sodium and potassium levels of 0.5ppm (ASTM D2880-03). Figure 2 shows how the operating lifespan of a gas turbine changes with sodium and potassium levels (Boyce, 2002). It can be shown that a turbine's operating lifespan can be reduced by 90% when either 6ppm of sodium and potassium or 11.5ppm of vanadium is present in the fuel.

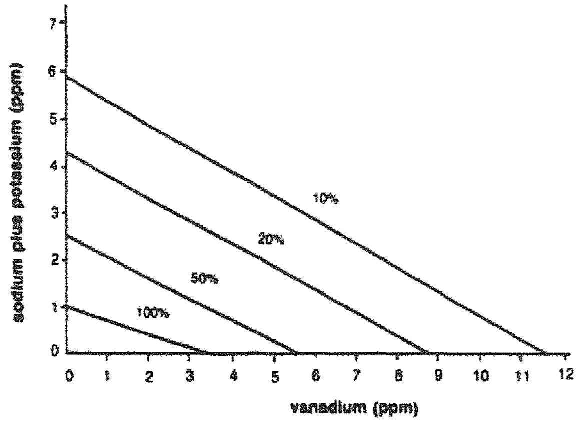

Figure 2. Effect of Sodium, potassium and vanadium on combustor life (Gas Turbine Handbook 2nd Edition)

4.2 Treatment of Low Grade Turbine Fuel

As mentioned above, the effect of sodium and vanadium is detrimental to the turbine life. Reduction of both sodium and vanadium levels in the fuel will significantly increase the lifespan of a turbine. It has been proven that centrifuge systems and magnesium inhibitors are able to dramatically bring sodium and potassium levels down. These treatments are so effective that sodium and vanadium with level as high as 100ppm can be reduced to an acceptable level (Hussey, 1973).

4.2.1 Centrifuge System for Sodium and Potassium Removal

For distillate fuels and light crude oils to meet the requirements of modern high temperature gas turbines, sodium and potassium, the two common alkali metals that cause damages to the turbines, must be reduced to a combined level of 0.5 – 1.0ppm, as specified by the turbine manufacturer. With the combination of very high centrifugal forces (4,000–8,000g) and short settling distance (0.5mm), the heavier particles such as water droplets and trace metals will be accelerated in settling. A typical Westfalia separator system is able to reduce 17ppm of sodium and potassium to 0.5ppm in less than 5 seconds (Schwicking, Westfalia internal paper).

In addition to the separation of salt contents to acceptable levels, centrifuge can also get rid of free water and other contaminants such as sand and rust in the fuel. Due to the relatively inexpensive set-up and operating costs, centrifuge systems can be implemented easily should crude or distillate oils are used for gas turbine operations.

4.2.2 Magnesium Inhibitors

Vanadium, an ash-forming compound, is highly corrosive. It is oil soluble and thus hard to be removed from the fuel. Magnesium inhibitor has been found very effective in reducing the corrosive effect of vanadium by forming a high melting point compounds that may even form a beneficial coating for the turbine blades (Hussey, 1973). It is recommended that for vanadium levels exceeding the 0.5ppm, a 3:1 to maximum of 3.5:1 weight ratio of magnesium to vanadium is required (ASTM 2880-03). For cases when there are high level of sodium to vanadium ratio and high level of interactions between the two metals, this ratio sometimes needs to be increased. The weight ratio of magnesium to vanadium is increased to about 5:1 when the sodium to vanadium ratio is 1/15, and to as high as 10:1 when the sodium to vanadium ratio is 1/5. This is to limit the formation of the compound that is especially damaging to the lifespan of the turbine.

4.3 Materials and Coatings

Other than reducing the contaminants in fuel, the development of better corrosion resistant materials and coatings is also a viable option for gas turbines. Materials such as chromium and nickel are found to contribute to corrosion resistance. It has been demonstrated that when chromium level is greater than 20%, the material is very effective in resisting oxidation, especially in the grain boundaries (Boyce, 2002). The addition of cobalt also raises the temperature for corrosion attack to occur. However, replacing the turbine material with those with corrosion resistance would compromise strength and other factors such as metallurgical stability. A coating applied on the material surfaces, such as platinum alumide (PtAl), would improve the corrosion resistance of the turbine without compromising other factors. The development of the coating has improved throughout the years. The current GE heavy-duty coatings can last 10 to 20 times more than their first generation (Kaufman, GE internal paper). The combination of better corrosion resistant materials and coatings has permitted ten-fold increase in bucket corrosion life (Foster). With the development of newer technology in this field, it will provide turbines with higher tolerance of contaminants in fuels and make more low-grade fuels usable.

4.4 Previous Experiences

Results from some previous experiences suggest that contaminants may not need to be restricted to levels specified by standards or manufactures' specifications. Hussey et al. (1973) demonstrated that turbines running on crude oil of 0.5ppm sodium and 2ppm vanadium had no problem reaching its service life. Axelsson (1975) suggested that the corrosion mechanism of vanadium was mainly from the oxidation due to the decomposition of sodium vanadic vanadate. The corrosiveness was reduced when sodium was removed. These claims were supported by a Solar Training Presentation, where some of its PNG turbines running on Naphtha with slightly higher levels of vanadium and sodium had reached the service life of 28,000 hours, with the package rate at 30,000 hours. Another example was the MS7000 package sold to Indonesia-PLN, which was rated at 40,000 hours on crude fuel with sodium level of 2ppm and vanadium level of 1ppm untreated at 1730°F (943°C) running temperature (Foster).

Another important effect due to vanadium levels was is identified by Lai (1990) and de Blas (1998). According to their studies, vanadium pentoxide does not easily form and it is only very damaging when combined with sodium or potassium in the fuel. In accordance to Boyce's graph, turbine life should be close to the specified lifespan if sodium and potassium can be reduced to less than 0.5ppm by centrifuge, and vanadium will not reduce turbine life if its level is less than 1ppm. It has also suggested that the availability of turbines running on crude oil will be reduced due to the need of water cleaning shutdowns to remove blade deposit, as the deposit can contribute to up to 15% derating of turbines (World Bank 1991). Most manufacturers suggest that the turbines are to operate at lower firing temperature to reduce this problem.

Currently, Woodside has some of their power generation equipments running on crude fuel. The crude oil produced from those FPSOs is relatively clean and light that meets most of the criteria specified by the manufacturer. While its vanadium level is only slightly above the specified level, its sodium content is reduced by a centrifuge treatment system to the level much lower than 1.0ppm. With such a simple treatment, the crude oil is used to run the turbines. The past several years' experience of this operation indicates that apart from some initial commissioning problems, there has been no additional maintenance induced. The obvious cost advantage suggests that this running scheme should be continued in Woodside.

4.5 Cost Consideration

To enable the use of crude or distillate oil, there will be an initial set-up cost for system modification and centrifuge system. There will also be an operation cost associated with the centrifuge system and the inhibitor. Extra maintenance costs are also possible due to initial commissioning problems and unforseen problems. Costs due to the reduction of turbines' lifespan will also be considered.

5.0 Cost Analysis

Costs associated with running turbines are fuel cost, maintenance cost, costs for machine replacement and fuel treatment. The cost analysis is to estimate how much money is saved in operation should alternative fuels be used. This analysis applies to the scenario that there is gas deficiency, and diesel and crude oil are the only alternative fuels. Cost saving is estimated by comparing the turbine running cost with crude oil and diesel. The analysis is based on the current operating cost of the Woodside crude oil scheme. For simplification, the following figures are used for the analysis:

5.1 Cost Parameters

- *Cost of the crude oil*
  The crude oil price in the current world market. The May 2006 price from PetroCanada of $ 94.90 Australian dollar per barrel is used for the calculation.
- *Cost of diesel*
  The current diesel price in Australian Market, which is about A$1.00 per litre, excluding possible tax benefits and shipping costs.
- *Extra maintenance and operation costs*
  Aside from Woodside's recent experience, there is no sufficient data and evidence to make a conclusion that there is definitely no additional maintenance cost associated with the crude oil scheme. As such, a conservative estimation is required that assumes the lifespan of turbines is reduced so significantly that one additional new turbine engine is needed

annually, costing around one million Australian dollars. The extra operation cost is mainly the cost of running the fuel treatment system, which is no more than one million Australian dollars a year.

5.2 Fuel volume requirements

Courtesy of Woodside, the following table shows the correlation of the fuel heating value in megawatts to the fuel volume in tons.

Table 1. Heating efficiency of fuels.

	Gas Fuel	Diesel	Crude Oil
Fuel Heating Value (MW)	63.2	26.7	54.7
Fuel Volume (T/day)	145	55	107.5

Assuming the total amount of power required is 11MW, and the turbine is running at the lowest efficiency of 25.2%. It can be calculated that the fuel energy needed is 43.7MW, which equals to 90.0 tons of diesel or 85.8 tons of crude oil. This is equivalent to around 105,905.83 litres of diesel or 720.12 barrels of crude oil a day.

5.3 Costs Comparison

Use the current diesel price of A$1.00 per litre and the crude oil price of A$94.9 per barrel, the daily and annual costs of running a typical FPSO in Australian dollars can be calculated and listed in Table 2.

Table 2. Running costs of a FPSO on diesel and crude oil.

	Daily fuel cost	Annual fuel cost	Annual extra cost	Total Annual cost
Diesel	105,905.83	38,655,627.95	-	38,655,627.95
Crude Oil	68,339.39	24,943,877.35	2,000,000	26,943,877.35

It is very clear that the cost saving by running crude oil in place of diesel is more than $10 million dollars a year.

5.4 Further Discussion

5.4.1 True Crude Fuel Cost

The assumption made in the above calculations is that the cost of the crude fuel is the crude oil price in the current world market. In reality, the crude fuel cost is much lower. This is because companies need to pay a substantial amount of money as royalties to governments that, together with costs associated with processing and transportation, will be added up to the selling price in the market. Thus the true cost of crude oil cost in this analysis is only around 20-30% of the crude oil price in the market. Therefore the true cost saving by using crude oil can be tripled. The cost saving calculated in Section 5.3 should be going up to $30 million dollars a year.

5.4.2 Rising Oil Prices

World oil price has risen drastically in the past few years, and the trend suggests that the rise will continue. This may further increase price gap between the diesel and the crude oil, and then the operating cost of offshore platforms. It will be even more viable to run turbines using the crude oil in a FPSO that is produced from its own operation.

5.5 Cost Analysis Conclusion

Comparing the cost of running the gas turbines on crude oil to the cost of running on diesel suggests the cost saving far outweigh the additional maintenance and operation cost (around $2 million/year in this analysis). Judging purely from the cost point of view, it is definitely recommended to run the machines on crude oil instead of diesel fuel.

6.0 Conclusions

Alternative fuels for gas turbines, such as crude oil, have been experimented by industries since the 1950s due to the obvious cost advantages and availability. Experiences so far suggest that as long as the basic requirements such as viscosity and specific gravity are fulfilled, the alternative fuel can be used to run the turbine. However, due to the high level of contaminants presented in some of these alternative fuels, the extra maintenance and reliability issues may induce extra costs, making their applications infeasible. There are contaminants treatment technologies that have been proven very effective to reduce the trace metals down to the safe levels, such as the centrifuge system and magnesium inhibitors. With these treatments, most crude oils can be used as alternative turbine fuels. The cost-efficiency compared with the use of diesel is significant.

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