Effect of Fuel Viscosity on Combustion Performance of Heavy Fuel Oil (Hfo) Fired Gas Turbines

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Abstract: **Fuel flexibility in thermal power generation plays a vital role in energy security in the present context because of the scarcity of petroleum resources. Among them, gas turbines play a key role since its ability to operate in multiple fuels and switch fuels during the operation. Especially in countries like Sri Lanka where the petroleum reserves are not available, burning HFO (Heavy Fuel Oil) in a Combined Cycle Power Plant with gas turbines will be an added advantage for the countries power system and the economy. The HFO is produced as a byproduct in the local refineries could also be utilized in an efficient and eco-friendly manner for Gas Turbine operation rather than using it for conventional boilers for small scale industry as done at present. This too would accrue a considerable benefit to the country environmentally and economically.**

Yugadanavi 300 MW Combined Cycle Power Plant was a landmark project in Sri Lanka which started its commercial operation on 2008 as a Simple Cycle power plant while converted into Combined Cycle in 2010. It consists of two GE frame 9E gas turbines and one GE SC5 steam turbine. The gas turbines are continuing its 10th year of commercial operation being one of the critical power stations to the Sri Lankan grid by playing an anchor role in reliability. Being the first Combined Cycle power plant operated in HFO in the region, Yugadanavi was a remarkable achievement by local engineering talent of LTL HOLDINGS which is one of the leading engineering companies in Sri Lanka.

Fuel is the lifeblood of the combustion and hence proper characteristics of fuel need to be maintained. Typically, in a gas turbine, liquid fuels are atomized to break into small droplets to have a better combustion. Viscosity is one of the most significant factors which directly affect characteristics of atomization. Controlling the viscosity of fuel oil is an important aspect of an efficient combustion. A high viscosity fuel oil tends to degrade atomization which in turn leads to incomplete combustion. Meanwhile low viscosity can lead to insufficient lubrication of the wear parts of the fuel circuit and can lead to premature failures.

This paper sets out the 1st phase of field verification and the preliminary test carried out in gas turbine by varying the viscosity of the HFO and controlling the fuel temperature.

I. INTRODUCTION

Heavy duty gas turbines (GT) boast several significant assets as power production tools. Indeed, they offer a high level of reliability and maintainability as well as short installation lead times and versatility of operation in all electrical applications: peaking; cogeneration; base/half-base power production.

The primary energy of choice for gas turbines is gas in most cases, but due to the increasing price volatility of this conventional fuel, energy stakeholders are led to actively explore alternative options. This has been the case in Sri Lanka where LTL Holdings (LTL) has adopted heavy fuel oil as primary fuel with distillate oil (DO) as startup/shutdown fuel.

Burning HFO in a GT combined cycle implies developing an integral policy in the fields of power system design, fuel procurement, operation procedures and environmental aspects, with a special attention to be paid to SOx, NOx, and particulate matter (PM) emissions as well as on aqueous effluents.

Since 2008, LTL Holdings operates 2 Frame 9E units at their Yugadanavi 300 MW Combined Cycle power plant. This power plant has been converted to combined cycle in 2010 and both gas turbines together has exceeded 60,000 hours of successful operation on HFO as of May 2017.

After reviewing the main milestones and achievements of the Yugadanavi project, this paper covers the preliminary study of fuel viscosity in combustion performance and the financial impact on fuel heating with new viscosity requirements.

II. BRIEF OF YUGADANAVI

Figure 1 shows a general picture of the Yugadanavi power plant which is located in Kerawalapitiya, Wattala. Yugadanavi power plant, a 300 MW E-class Combined Cycle Gas Turbine (CCGT) plant featuring 2 Frame 9E GTs, 2 heat recovery steam generators (HRSG) and 1 steam turbine (ST), a plant structure denoted as a “2-2-1 configuration”.

Figure 1: General view of the Yugadanavi 300 MW CCPP

III. BRIEF PORTRAIT OF YUGADANAVI

Fuel sourcing was a difficult task from the outset and CPC (Ceylon Petroleum Cooperation) took the responsibility of supplying the fuel as per the OEM guidelines and as well as to cater the environmental regulations given by CEA. Both CPC and the power plant agreed on a Fuel Supply Agreement (FSA) and fuel was supplied in accordance with that agreement. Table 1 shows the typical fuel specification for the power plant.

Table 1: Typical properties of HFO

Density @ 15°C	970 kg/m3
Flash point PMCC	70 °C
Pour point	< 24°C
Total sulfur content	1.69 % w
Kinematic viscosity at 50°C	170 cSt
Water content	0.24 %
Ash content	0.02 % w
Conradson carbon residue	10.61 % w
Lower Heating Value	43 MJ/kg
Vanadium	34 ppm w
Nickel	21 ppm w
Lead	< 1 ppm w
Sodium + potassium	7 ppm w
Calcium	4 ppm w

IV. INITIATION OF THE DEVELOPMENT

Initially, the HFO specification for the power plant was driven by the category "RME 180" in ISO 8217 with some adjustments to Sulfur, Sodium & Vanadium content. Therefore, CPC supplied special fuel to the power plant and parameters were almost at a constant level. Initially, the HFO heating temperature was pre-configured at 130 °C to meet the viscosity limit given by GE (10 cSt at GT fuel nozzle inlet) as per GEI 41047.
Progressively, CPC upgraded their refinery process as well as the source of crude; they were able to produce suitable HFO for Yugadanavi. Also with the competitiveness of the fuel supply in the world and fuel blending, some parameters started to vary significantly. Viscosity became one critical of them and plays a vital role in fuel combustion.
An efficient atomization is the basic need for an adequate mixing of fuel and heated air, without which, an efficient combustion cannot be obtained. Thus, it is very important to set the viscosity value in the right range. Viscosity of heavy fuel oils can be reduced by raising its temperature with a dedicated fuel oil heater. This can be done by using either; automatically regulated heaters to maintain a constant temperature or by using a manual control which can be adjusted according to the requirement.

V. PRELIMINARY FIELD TEST

A viscosity meter, which operates by measuring the damping of an oscillating electromechanical resonator immersed in a fluid whose viscosity is to be determined, was installed down-stream of the HFO heater. Basically, temperature measuring probes (24 devices) which were installed on GT exhaust was used to measure the combustion efficiency. On the other hand, installed temperature sensors in hot gas path and measurements recorded by the emission monitoring system on HRSG (Heat Recovery Steam Generator) were used as a secondary measurement. Figure 2 shows a schematic diagram of the existing system with new installation.

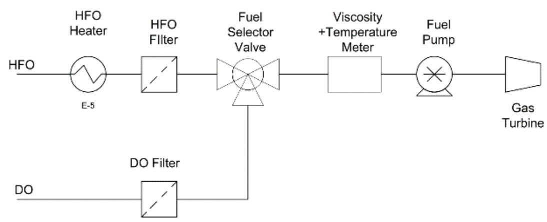

Figure 2: Schematic diagram of the existing system with new Viscometer

Four temperature settings (130 °C, 125 °C, 120 °C & 117.5 °C) were tested initially with two load cases which are 100 % and 75 % of GT load. Temperature and the mass flow measurements installed on the both side of the HFO heater were used to do the financial saving calculations. In order to investigate the long-term effects, borescope inspection technique was used in GT combustors.

VI. TEST RESULTS

Fuel sourced from Singapore is used for this test and Table 2 shows the parameters of the fuel used.

Table 2: Parameters of the fuel used for the test

Density @ 15 °C	970.7 kg/m^3
Viscosity @ 50 °C	96.3 mm^2/s
Sulfur content	1.53 m/m
Flash point	> 70 °C

Pour point	21 °C
Water content	0.1 % V/V
Ash content	0.03 % m/m
Vanadium	22 mg/kg
Sodium	6 mg/kg

Table 3 & 4 shows the variation of viscosity, density and fuel temperature at tested temperature set point of the heater when the unit was running at 100 % & 75 % load.

Table 3: Variation of parameters at 100 % load

Temperature set point	130 °C	125 °C	120 °C	117.5 °C
Fuel viscosity mm^2/s	7.527	8.171	9.378	9.928
Fuel density kg/m^3	946.40	950.88	953.23	954.51
Fuel temperature °C	128.31	123.26	118.39	115.66
Fuel flow kg/s	7.835	7.6158	7.641	7.667

Table 4: Variation of parameters at 75 % load

Temperature set point	130 °C	125 °C	120 °C	117.5 °C
Fuel viscosity mm^2/s	7.577	8.295	9.145	9.638
Fuel density kg/m^3	949.18	951.63	954.03	955.07
Fuel temperature °C	128.44	123.67	118.58	116.04
Fuel flow kg/s	6.832	6.837	6.813	6.818

Main combustion patterns were monitored using the installed thermocouples for the gas turbine exhaust temperature variation, and all 3-exhaust spread values the (difference between highest and lowest exhaust temperature readings) in order to verify even combustion in all 14 combustion chambers. Intensity values of the all 4 flame detectors, temperature distribution in between hot gas path were also used to monitor combustion dynamics and patterns. HRSG stack emissions were also measured and variation was studied to analyze improper combustion.

Figure 03 shows the variation of exhaust temperature sensor 1 (out of 24) with time at 100 % load on the gas turbine. Graph clearly shows the variation in all the temperature set points for the fuel is in same range and it elaborates there is no significant exhaust temperature change with the fuel viscosity variation.

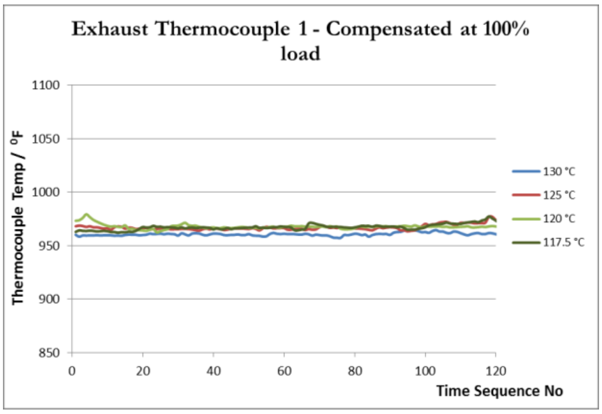

Figure 3: Variation of exhaust thermocouple 1 as a function of time at 100 % load

Figure 04 shows the variation of combustion spread 1 which will be the maximum one (out of 3) with time at 100 % load on the gas turbine. Exhaust spread indicated the difference between maximum recorded exhaust temperature and the minimum recorded exhaust temperature at a given time. Graph shows there are no significant spread change with the fuel viscosity and hence conclude the proper combustion.

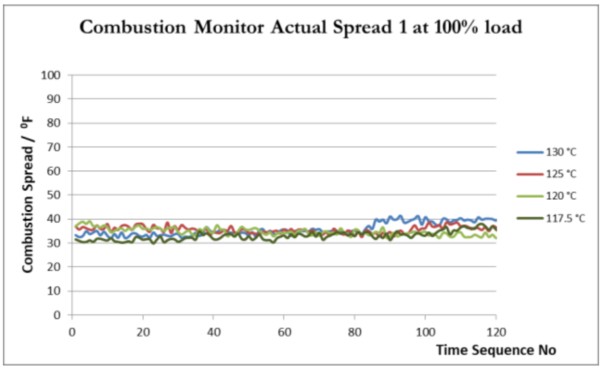

Figure 4: Variation of exhaust spread 1 as a function of time at 100 % load

Figure 05 shows the variation of first turbine temperature at the exhaust gas flow at 100 % load on the gas turbine. This will give an indication where the combustion is happening in combustion chamber. Since all the readings related to all viscosity points are at same level, it can argue that the proper fuel atomization is happening at all viscosity levels and fuel combustion is equivalent to initial set point given by GE as 130 ^{0}C.

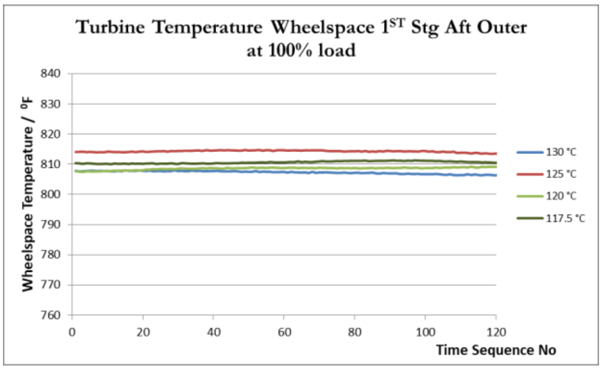

Figure 5: Variation of hot gas path temperature 1 as a function of time at 100 % load

Figure 06 & 07 shows the variation of NO_x emission and Opacity (indication of the amount of particulate matter) of the exhaust gas, with time at 100 % load on the gas turbine. Similar readings elaborate the complete combustion with same characteristics at all 4 given viscosity values.

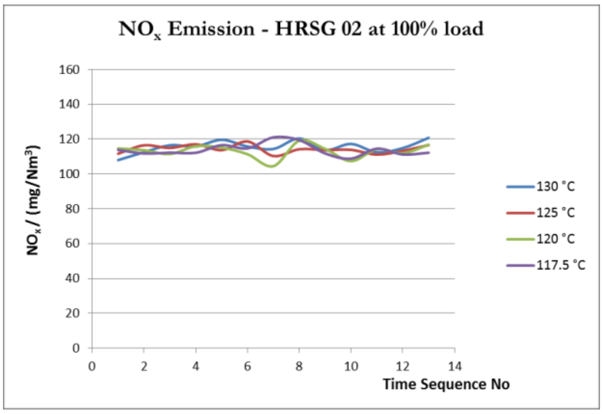

Figure 6: Variation of NOx as a function of time at 100 % load

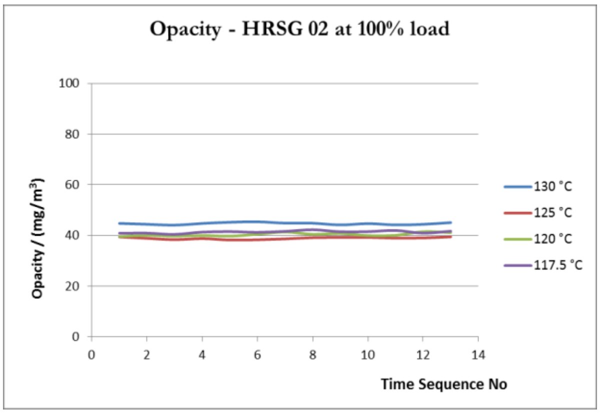

Figure 7: Variation of opacity (particulate matter) as a function of time at 100 % load

VII. FINANCIAL EVALUATION

Based on the field data collected at 100 % and 75 % load, it was clearly identified that there is an opportunity to reduce the fuel temperature at fuel nozzle inlet while keeping good combustion & emission patterns. Financial gains were evaluated after a month of operation at reduced fuel temperature. A considerable financial saving is observed during in the window of field test and detail calculations will be done during the second phase of this test.

VIII. FUTURE DEVELOPMENT AND 2ND PHASE

This experiment should be conducted over an extended period in order to pursue the evaluation of main combustion patterns. So, following steps should be considered for future testing:

1. Increase of fuel viscosity up to 12 cSt and carry out the same evaluation
2. Operate the power plant at a certain fuel temperature level over an extended period and evaluate the effects on the unit efficiency (determine best conditions for operation)
3. Operate the power plant during one cycle (combustion inspection) with fixed viscosity and evaluate/compare the parts status with the one related to baseline operating conditions

Once the above listed steps are complete, closed-loop control logic could be implemented in order to allow the GT User to set a fuel viscosity/temperature level for an improved control of the HFO heater.

IX. CONCLUSION

The expected vigorous development of the Sri Lankan economy during the forthcoming decades requires an energy efficient operating system burning petroleum products for power generation. In this context, an online viscometer for HFO operation in units such as gas turbines and boilers can provide significant financial benefits and fuel savings.

This technique can be used for any type of combustion installation burning heavy fuel oil since online viscometers are available on the market and are relatively cheap as compared with the energy savings on the fuel reheating system.

This development work has been carried out as part of a fruitful LTL-GE collaboration. This paper has summarized two outstanding initiatives aiming at improving fuel economics by using new viscosity requirements for the combustion system and reducing fuel consumption for the HFO heater.

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