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SGT-700 DLE COMBUSTION SYSTEM EXTENDING THE FUEL FLEXIBILITY

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Abstract

Siemens Industrial Turbomachinery AB in Finspång, Sweden, manufactures gas turbines in the load range from 19 to 50.5 MW. The SGT-700 (33 MW) gas turbine has experience from more than one million hours of field operation using the 3rd generation DLE (dry low emissions) system. The same DLE burner is also used as standard in the SGT-800 (50.5 MW) engine and is an available option for the SGT-600 (25 MW) engine.

Highly reactive gas fuels containing components such as hydrogen, ethane, propane or heavier hydrocarbons have traditionally been used in gas turbines with non-DLE combustion systems, resulting in high NOx emissions. The DLE systems have commonly only operated on natural gas fuels. Stricter environmental legislation pushes for the use of DLE engines also for the more reactive fuel types, thus potentially introducing combustion related problems such as flashback or instability. The stability and fuel flexibility of the 3rd generation DLE system has been systematically verified on both unreactive fuels containing nitrogen and reactive fuels containing hydrogen, ethane and pentane. Some recent data from continued tests with hydrogen is presented in this work.

Propane was successfully used in the SGT-600 with DLE combustion system already in the 90´s, where an engine accumulated around 10 000 hours of operation. NOx emissions below 20 ppm were achievable at full load. Recently, ethane and propane has gained an increased interest as turbine fuels. An important example is the shale gas industry which has created an oversupply of low priced ethane and propane to the market. Other chemical industries, such as PDH (propane dehydrogenation) plants could also produce off-gases rich in ethane and or/propane. Propane or ethane could also be suitable as backup fuels to natural gas as they have many advantages compared to distillate fuels, which is commonly used as backup fuel for gas turbine installations.

Commercial operation on propane has been verified in a SGT-700 in mechanical drive application for a PDH (propane dehydrogenation) plant in China. The gas turbine also uses another fuel source of variable composition predominantly consisting of ethane. The SGT-700 with DLE combustion system shows stable operation on both fuels in any combination. The current work describes the operation on ethane and propane rich fuels in the SGT-700.

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The SGT-700 and the 3rd generation DLE system

Siemens manufactures gas turbines from 5 to 400MW output, in many locations around the world. Siemens Industrial Turbomachinery AB (SIT AB) in Sweden manufactures industrial gas turbines in the medium load range from 19 to 53 MW. The industrial gas turbine models are listed in Table 1.

Table 1. Overview of the SIT AB medium sized industrial gas turbines

Turbine	Power (MW)	Combustion system
SGT-500	19	2nd Generation DLE Non-DLE
SGT-600	25	2nd Generation DLE 3rd Generation DLE Non-DLE
SGT-700	33	3rd Generation DLE
SGT-750	37	4th Generation DLE
SGT-800	53	3rd Generation DLE

The older machines (SGT-500 and SGT-600) are available both in Dry Low Emission (DLE) version as well as non-DLE (conventional, diffusion flame). The SGT-700 and SGT-800 only comes in DLE-version since this unique, design allows reliable and fuel flexible operation at a lower investment cost than the non-DLE-design.

The 2nd generation DLE burner (see Figure 1) was developed to meet the increased emissions requirements for the on-shore market. It was introduced in the SGT-600 gas turbine in 1991. The SGT-600 combustion system is capable of NOx emission levels below 25 ppm NOx using gas fuel. The DLE burner is a split cone with two main fuel pipes. The combustion air enters in the two slots where also main fuel (stage 2) is injected. The injection of pilot gas fuel (stage 1) as well as main liquid fuel is positioned in the center of the burner. This design allows for operation across the full load range without any staging of the combustion

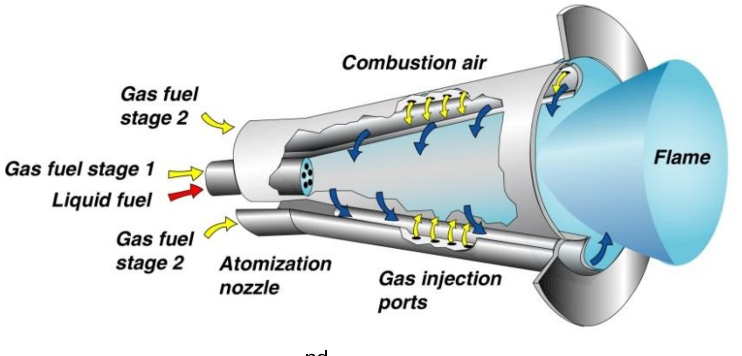

Figure 1. The 2nd generation DLE burner

During the development of the SGT-700 and the SGT-800, the DLE technology was brought one step further when the 3rd generation DLE burner was introduced. By using the experience from the 2nd generation technology, the NOx emissions were decreased with natural gas fuel and the burner also delivered dry low emissions with distillate fuel.

The 3rd generation DLE burner utlizises the same design principle as the previous version, but now the cone has been split in to four pieces, an additional mixing tube has been introduced downstream the cone, the pilot fuel is now entering on the burner tip. This design is used both in the SGT-700 and SGT-800 ; it is only the number of burners that differs. The SGT-700 combustion system consists of 18 removable burners in an annular combustor (where the SGT-800 comes with 30 burners).

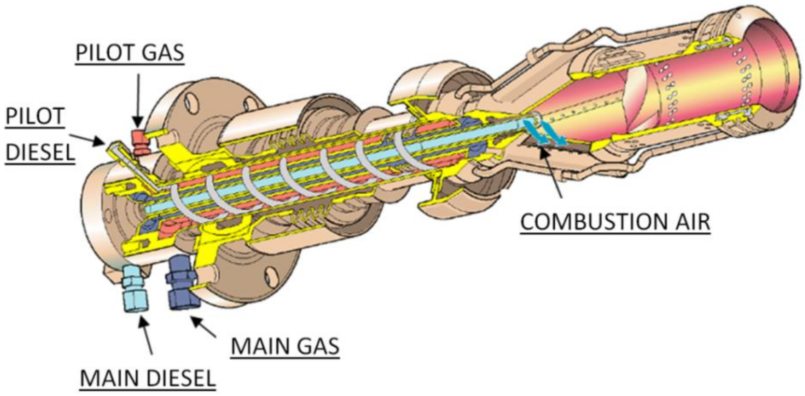

Figure 2. The 3rd generation DLE burner

The 3rd generation DLE system emits below 15 ppm NOx emissions on natural gas and 42 ppm NOx on liquid fuel [1]. With the latest development efforts [2] it is possible to transfer the low NOx and CO emissions with a turn-down to 50% load, without any staging.

72 units of SGT-700 engines have been sold from where the split is approximately 50/50 between Power Generation and Mechanical Drive. The fleet leader has accumulated 80 000 hours of operation and the fleet in total has accumulated more than one million hours of field operation, all of them with DLE and with a reliability of >99.3%.

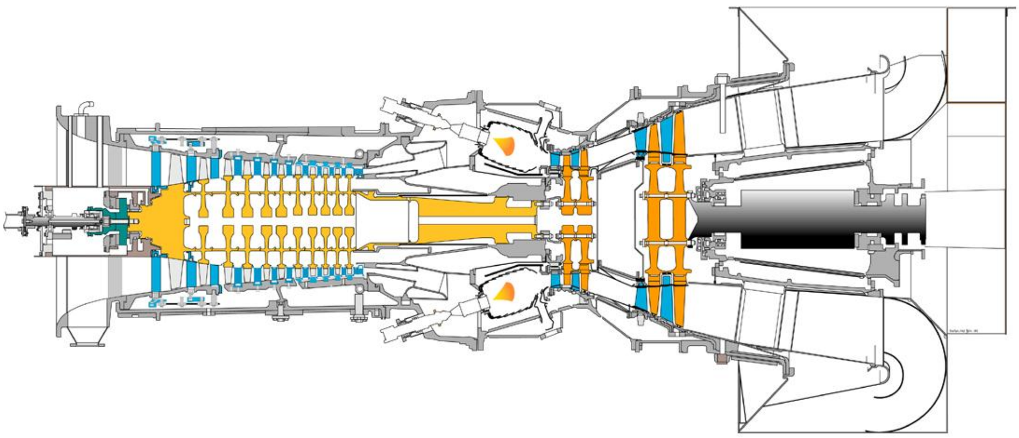

Figure 3. SGT-700 (33 MW) engine, with dual fuel capability, available for MD and PG applications

Fuel flexibility of the SGT-700

Fluctuations in market prices and availability of different fuels offers an advantage to have the ability to operate on opportunity fuels thus giving the customer flexibility and in the end improved profitability. Operation on non-standard fuels could also be important for chemical or petrochemical plants when fuel streams with no or little commercial value are created in their process. The use of these fuels in gas turbines could significantly improve overall efficiency and economy of the plant as well as improving the environmental footprint by reducing emissions.

Another reason for fuel flexibility could be the possibility to use hydrogen rich, H2fuels, which may become an important source of fuel if electrical over-production of renewables may be stored via H_2-conversion.

The variety of gas fuels that gas turbine manufacturers are requested to operate on is expanding. Figure 4 gives an overview of the wide range of fuel enquiries that SIT AB have received during recent years, as illustrated by Wobbe index[1] and heating value.

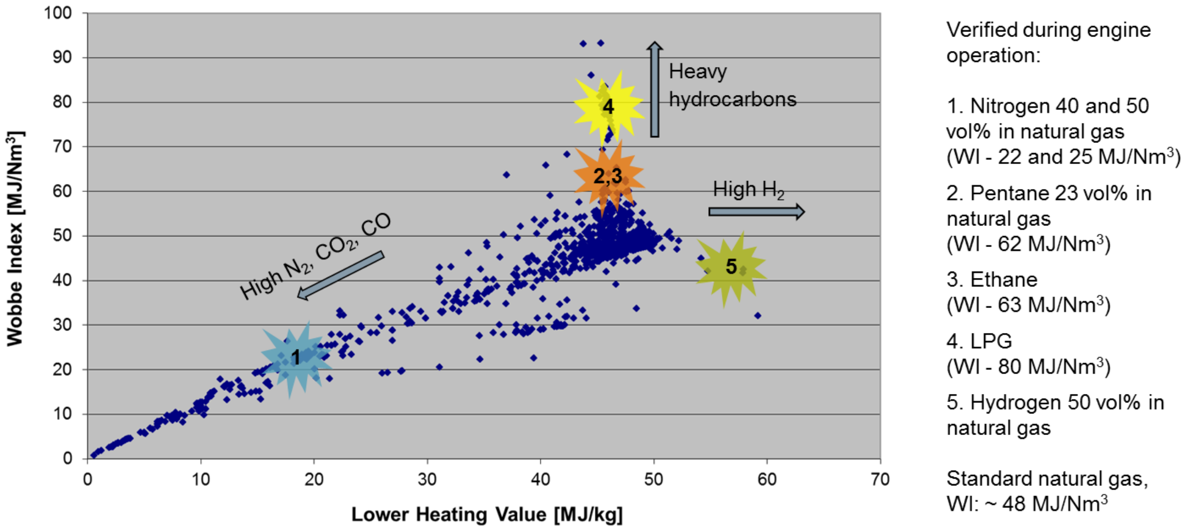

Figure 4. Gas fuel enquiries (blue dots) for SIT AB during the years 2011-2012

From such requests follows an increased need for testing and development of more fuel flexible engines in general and combustion systems in particular. Older technologies relying on diffusion combustion and injection of massive amounts of water/steam are often no longer acceptable alternatives, hence pushing for modern flexible DLE solutions also for the more exotic fuel types. Estimations on expected emissions and risks for combustion related problems such as flashback and flameout must often be evaluated on

[1] The fuel gas Wobbe index, WI, is defined as the lower heating value, LHV (volumetric) divided by the square root of the relative density.

$$WI = \frac{LHV}{\sqrt{\rho_{rel}}} \qquad (\rho_{rel} = \frac{\rho_{gas}}{\rho_{air}})$$

Nm^3 (normal cubic meter) at 101.325 kPa and 273 K (0°C).

a case by case basis. The wide spread in fuel qualities gives a clear need for combustion testing as it may influence:

- Flame stability and combustion dynamics
- Flameout/flashback
- Hardware temperatures
- Emissions of NOx, CO and unburned hydrocarbons

During the last years, Siemens medium sized industrial gas turbines and their DLE systems have been extensively tested and verified on both lean and rich gas fuel. On the lean side this includes full engine operation on nitrogen rich fuel containing up to 40-50% by volume of nitrogen [4] in the SGT-700 and SGT-800. The Wobbe index for these gas compositions is around 22-25 MJ/Nm^3 (Figure 4). Variations in Wobbe index and composition were also possible without affecting the stability of the combustion system. Figure 5 illustrates an instant stop of nitrogen supply to the natural gas/nitrogen mix, resulting in Wobbe index variation rates exceeding 0.6 MJ/m^3/s. It can be noted that engine power is kept constant and unaffected by the fuel change. However, NO_x emissions increase when nitrogen flow is reduced. This is an effect of “nitrogen dilution” of the pilot fuel and after the fuel change is completed, the pilot fuel flow can be adjusted to reach low NO_x emissions also on natural gas. In practice, this means there is a need for some type of fuel related emission control system when running on varying fuel composition and emission legislation is stringent.

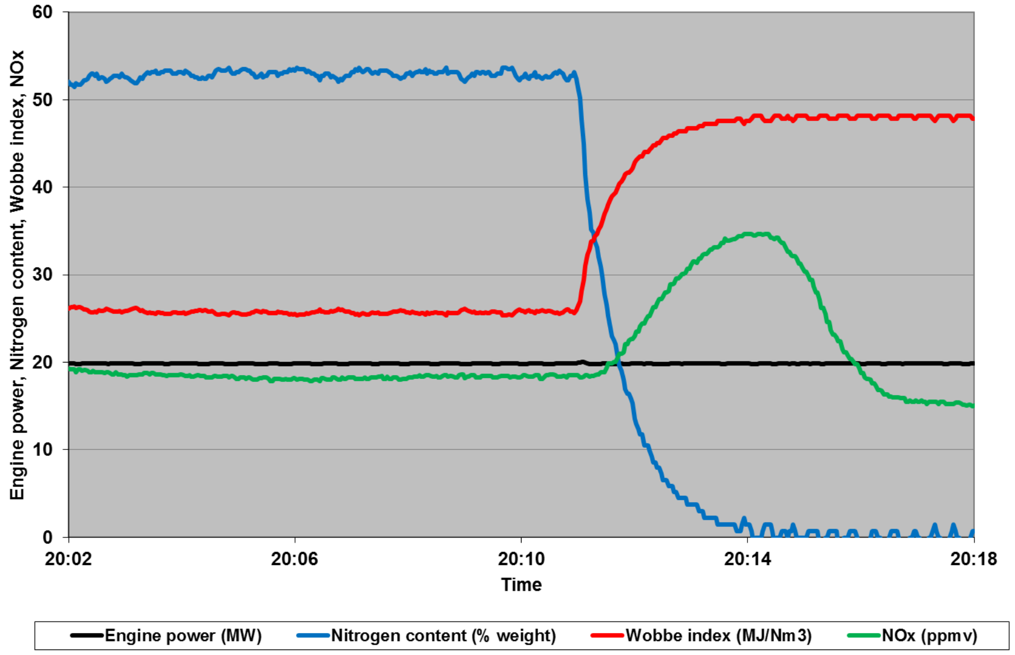

Figure 5. Stopping nitrogen supply (40 vol%) at 20 MW in SGT-700.

For the richer or more reactive fuels containing components such as hydrogen, ethane, propane or heavier hydrocarbons, the 3rd generation DLE system has also been thoroughly verified. Pentane (C_5H_{12}) enriched natural gas has been successfully tested [3, 5] as well as 100% ethane (C_2H_6) [6]. The ethane test was completed in order to qualify the SGT-700 DLE engine for operating on ethane rich process gas for a customer in China. The commercial operation of the SGT-700 in this project is described in the next section.

Hydrogen enriched natural gas was verified during engine operation in 2012 [6, 7]. Stable operation could be achieved using hydrogen fractions around 30-40% by volume, resulting in the release of up to 15% for the 3rd generation DLE system, with a possibility to accept higher fractions on a case by case basis. Further analysis of these hydrogen tests indicated that minor modifications to the standard burner could improve the hydrogen capability. Changes were implemented and new tests with modified burners were performed during 2014. A criterion for acceptable burner modifications was that natural gas capability should be kept with acceptable emissions.

Customer enquiries containing hydrogen rich fuels often come from a need for disposal of a waste stream from a chemical plant or a refinery. The plant often also has a need for mechanical or electrical power. Two types of operating situations can then be envisaged with either a constant hydrogen flow and the engine power is varying or a constant engine power with a varying hydrogen flow. An example of a test addressing the first situation is shown in Figure 6 . The gas turbine is varied in load with standard ramp between 27 and 10 MW with a constant flow of hydrogen corresponding to approximately 0.5 ton/h for an SGT-700. It can be seen that the hydrogen content in the fuel varies between 50% and 75% as a consequence of the varying load. The high load case is run with 50% to 60% hydrogen in the fuel. NOx emissions variation is a consequence of the variation of pilot depending on load. Lower load needs higher pilot for stability, which gives higher NO_x.

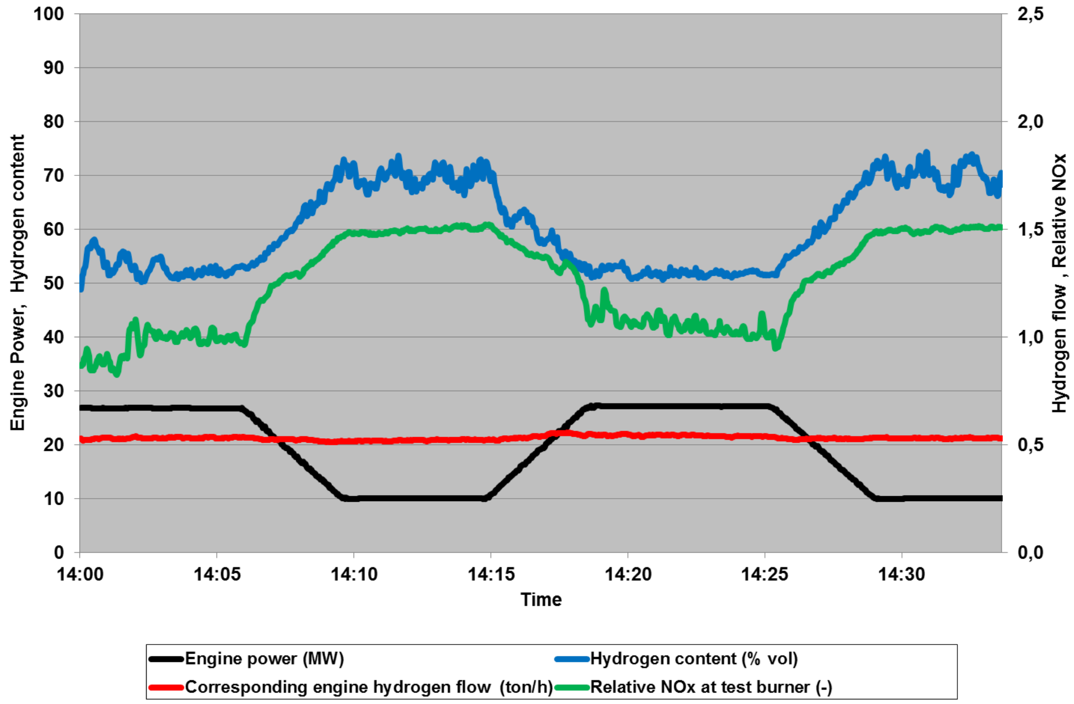

Figure 6. SGT-700 test with constant hydrogen consumption at variable engine power.

The influence of hydrogen content on NO_x emissions is shown in Figure 7 where relative NOx value is shown at full load without pilot. A small increase of NO_x can be seen as hydrogen content increases, but the increase is only significant above 45% hydrogen.

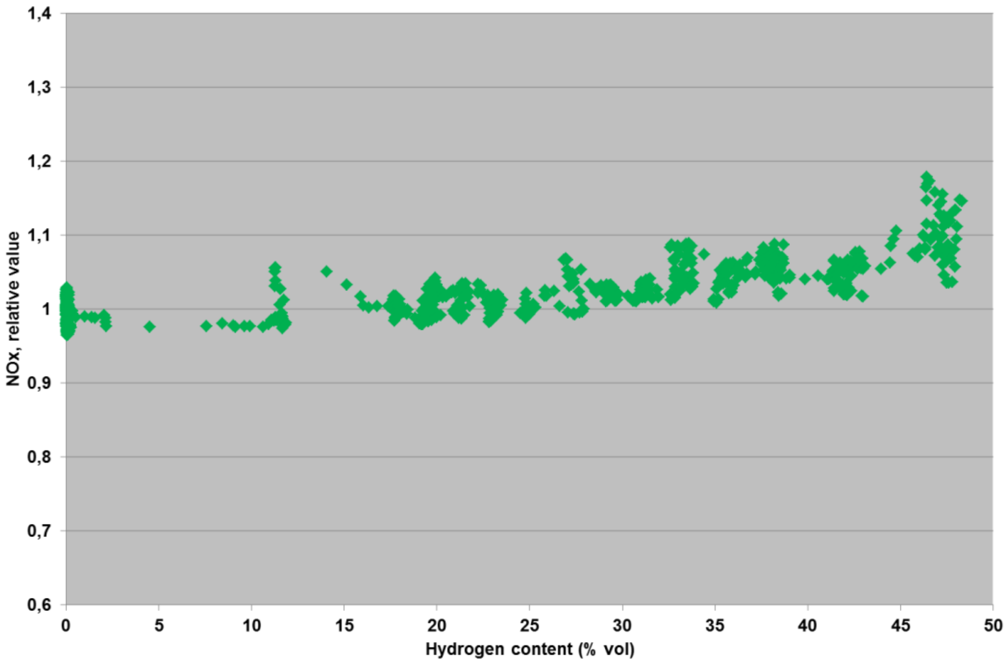

Figure 7. NO_x vs hydrogen content during the SGT-700 test. Full load and no pilot fuel.

The 2014 tests confirmed the possibility to run the SGT-700 on high hydrogen fuels with results indicating 40-50% H_2 is possible at high loads. At lower loads, higher hydrogen content is possible as can be seen in Figure 6. At 10 MW load, 100% H_2 was satisfactorily demonstrated, but the hydrogen flow had to be doubled and NOx emissions were about 60% higher than the high load emissions.

Due to these development efforts and recent experience gained, SIT AB can expand the acceptable fuel characteristics used in its gas turbines. Table 2 shows a general specification for natural gas fuels suitable for the SGT-700, but now allows for extending to 100% propane and/or ethane as well as hydrogen fractions up to 40-50% by volume. The acceptable Wobbe indices range from approximately 25 to 80 MJ/Nm^3 without modifications to the burner hardware.

Table 2. Fuel specification for gas fuels, SGT-700

Gas Fuel Constituent		Max, New	Max, Previous
Methane, CH_4	mole %	100	100
Ethane, C_2H_6	mole %	100	50
Propane, C_3H_8	mole %	100	50
Butanes and heavier alkanes, C_4+	mole %	15	15
Hydrogen and carbon monoxide, H_2 + CO	mole %	50	15
Inerts, N_2/CO_2	mole %	40/30	40/30
Hydrogen sulfide, H_2S	mole %	3	3

Commercial operation on propane and ethane fuels

Natural gas liquids such as ethane and propane are produced by extraction and separation from natural gas production streams via gas processing facilities and fractionation. Propane and other types of liquefied petroleum gas are also produced as a by-product of oil refineries. Associated gases used as gas turbine fuels could also contain significant fraction of ethane and heavier hydrocarbons.

The requests for propane and ethane have not been very frequent until the last few years, when they have gained an increased interest as gas turbine fuels. Apart from off-gases from refineries there has also been an increased utilization of associated gases containing heavy components. The main reason for almost pure ethane or propane being relevant as gas turbine fuels is the low prices due to oversupply created from extraction of natural gas liquids from the shale gas industry. Chemical industries, such as PDH (propane dehydrogenation) plants could also produce off-gases rich in ethane, propane and/or hydrogen. For PDH plants, propane could also be a suitable backup fuel as this is available as the raw material in their process.

Followed by the acceptance test on ethane [6], one SGT-700 was sold to a PDH plant in China for operation on ethane rich off-gas. A general picture of the PDH process is shown in Figure 6. Propane is vaporized, heated and then dehydrogenated to propylene in the catalytic reactor section. The reactor catalyst is regenerated with hot compressed air. The reactor products pass through the purification section where compression, refrigeration and distillation steps are used to separate the hydrocarbons into fuel gas and products.

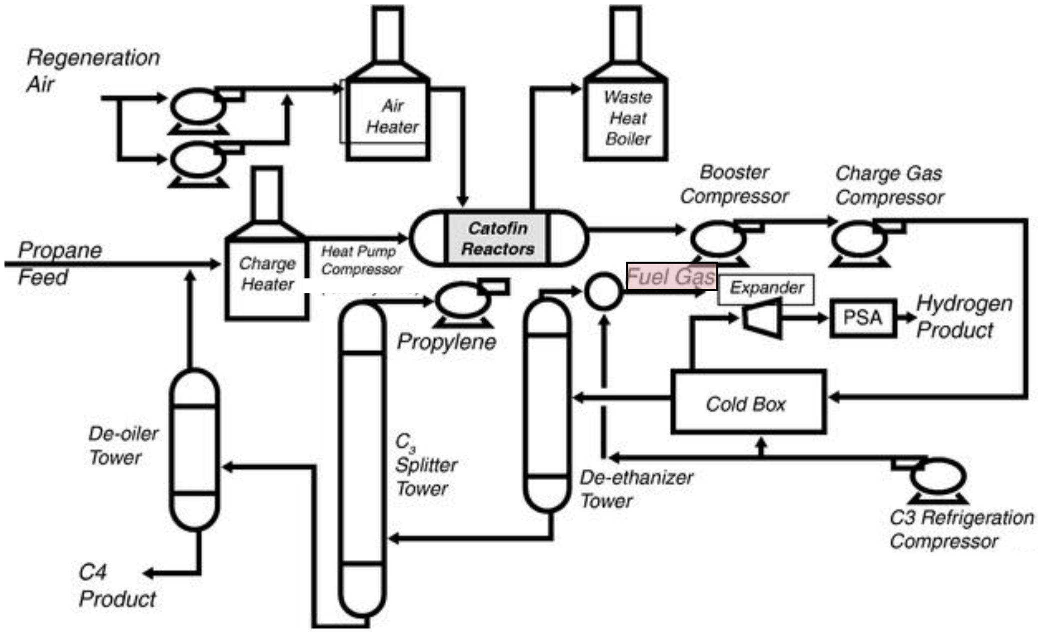

Figure 8. Schematic of a PDH process (Source: PetroLogistics LP). The main fuel is entering in the marked position ("Fuel Gas") but is also blended with other sources

This SGT-700 engine in this case operates in compressor drive application for compressing the reactor product. Gas turbines could also be used for compression of the regeneration air for the catalyst. This is the case for two other SGT-700 engines in another PDH plant in China. These engines currently operate on natural gas but are sold with propane as backup fuel.

During commissioning of the gas turbine (for gas compression application), propane was mainly used as fuel as this is the raw material in the PDH process. This fuel source is also used during start-up of the plant. During normal operation the gas turbine also uses the de-ethanizer off-gas. This gas has been variable in composition and has often been used in combination with propane or even heavier fuel streams. See example fuel compositions in Table 3.

Table 3. Example of fuel compositions for a SGT-700 in a PDH plant. (Note: Commercial operation, after commissioning, starts at Day 1).

	Component (mol %)											
	Hydrogen H2	Nitrogen N2	Methane CH4	Ethane C2H6	Ethylene C2H4	Propane C3H8	Propylene C3H6	Butanes C4H10	Butenes C4H8	Pentanes C5H12	Pentenes C5H10	Others*
Day -21	-	-	0.1	0.6	-	99.2	-	0.1	-	-	-	-
Day -9	5.7	0.2	21.3	13.3	0.7	57.6	0.8	1.1	0.0	0.0	-	-
Day 9	-	-	0.0	0.9	-	79.9	0.0	18.9	0.2	0.0	0.1	0.1
Day 13	-	0.4	0.0	0.9	-	90.5	0.0	6.1	0.3	0.0	0.1	1.7
Day 14	-	0.1	-	0.6	-	65.6	0.0	13.8	1.0	0.3	0.2	18.4
Day 15	-	-	0.0	1.0	-	93.7	0.0	4.9	0.2	0.0	0.1	-
Day 15	-	0.1	0.0	0.4	-	62.3	0.0	15.3	1.1	0.3	0.2	20.3
Day 34	-	-	8.6	56.6	2.6	13.5	0.0	10.7	0.6	0.1	0.1	7.3
Day 38	-	0.4	1.3	50.3	1.6	23.3	0.0	20.9	1.1	0.1	0.1	1.0
Day 44	-	0.1	12.9	67.0	3.8	13.8	0.0	1.8	0.2	0.0	0.0	0.5
Day 49	-	0.0	0.8	16.8	0.5	37.9	1.1	23.3	2.9	0.4	0.6	15.8
Day 52	-	0.1	10.7	65.8	3.4	14.9	0.0	3.9	0.4	0.0	0.0	0.8
Day 155	9.5	0.0	18.6	51.7	5.7	14.4	0.0	0.1	0.0	-	-	0.0
Day 157	0.1	0.0	1.5	32.7	1.4	58.9	0.0	3.8	0.2	0.0	0.0	0.4
Day 162	4.3	0.2	13.8	56.3	3.5	19.9	0.0	1.1	0.1	0.0	0.0	0.6
Day 165	0.6	0.0	16.5	66.7	4.0	11.1	0.0	0.5	0.0	0.0	0.0	0.5
Day 173	0.3	0.1	12.1	48.7	2.4	34.3	0.0	1.7	0.1	0.2	0.0	0.2
Day 178	-	0.0	0.0	0.6	-	95.0	0.0	2.2	0.1	0.0	0.1	2.0
Day 181	-	0.0	0.1	0.5	-	79.9	0.0	14.3	1.0	0.2	0.2	3.8
Day 183	0.9	0.0	16.9	46.9	3.1	29.1	0.0	1.5	0.2	0.0	0.1	1.2
Day 186	0.2	-	15.7	63.1	4.8	10.3	0.0	3.9	0.6	0.0	0.1	1.3
Day 189	0.1	-	10.2	83.5	5.5	0.1	0.0	0.1	0.0	0.0	0.0	0.4
Day 199	0.1	0.0	14.2	77.2	6.8	0.7	0.0	0.4	0.1	0.0	0.0	0.3

* C6+, Dienes, Propyne, Acetylene, etc

As can be seen, the analyzed content of ethane plus ethylene varies between 0 and almost 90%. Propane content varies between 0 and 99%. Often there are also a lot of butanes present in the fuel gas. On occasion there has also been hydrogen fraction around 10% in the gas as well as 20% of heavier hydrocarbon such as hexanes. The fuel supply temperature is usually around 120-140°C to ensure that condensation will not occur. The SGT-700 with DLE combustion system shows stable operation on these variable fuel compositions and the transitions between them. So far, the engine has accumulated around 7000 hours of operation. An example of 150 days of continuous operation is shown in Figure 9. Four of the compositions from Table 3 are also marked in the graph.

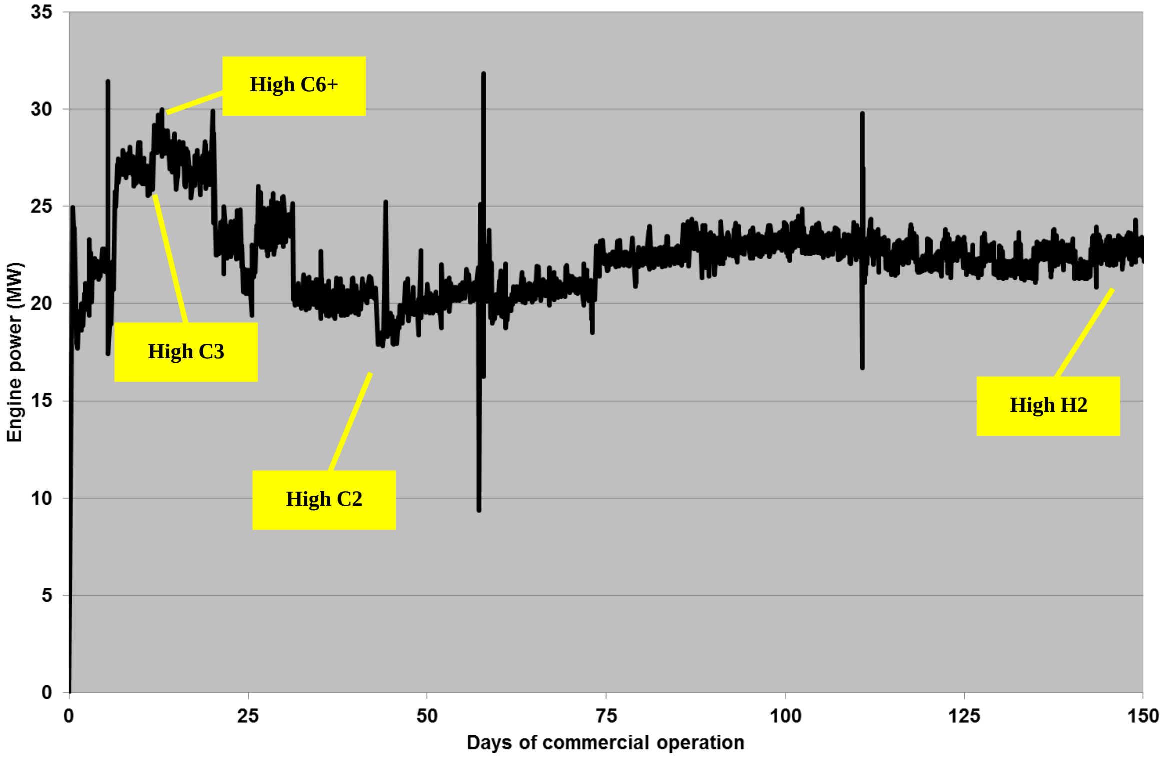

Figure 9. SGT-700 MD power output during 150 days of continuous operation

There is no continuous emission measurement of the exhaust gas, but a few measurements done with a temporary system indicate NO_x emissions well below 25 ppmv were achieved during these measurements. For full flexibility and simple control, the engine is usually running with higher pilot fuel flow, resulting in emissions around 30-35 ppmv. Emissions of carbon monoxide, CO, are negligible.

Conclusions

The SGT-700 gas turbine with DLE combustion system has proven its fuel flexibility by operation on a wide range of both lean and rich gas fuels. Recent development testing shows the ability to operate on hydrogen rich fuels. Also, commercial operation in a PDH plant show an extreme variability in fuel compositions delivered to the gas turbine. These fuels include high levels of ethane, propane, hydrogen, butanes, unsaturated hydrocarbons and also heavier hydrocarbons. The SGT-700 shows stable operation and low emissions on these variable fuel streams.

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