Emission Estimates at Start-up, Shutdown, and Commissioning for SoLoNOx™ Combustion Products

Leslie Witherspoon

PURPOSE

The purpose of this Product Information Letter (PIL) is to provide emission estimates for start-up and shutdown events for Solar® gas turbines with SoLoNOx™ dry low emissions combustion systems.[1] For start-up and shutdown emissions estimates for conventional combustion turbines, landfill gas, digester gas, or other alternative fuel applications, contact Solar's Environmental Programs team.

INTRODUCTION

The information presented in this document is representative for both generator set (GS) and compressor set/mechanical drive (CS/MD) SoLoNOx combustion turbine applications. Operation of duct burners and/or any add-on control equipment is not accounted for in the emissions estimates. Emissions estimates related to the start-up, shutdown, and commissioning of combustion turbines will not be warranted. The estimates in this document are based on limited engine testing and analysis. The engine testing was conducted at idle and other non-SoLoNOx mode load points. An actual start-up/shutdown event was not measured.

The start-up and shutdown estimates are most commonly used for potential to emit calculations to determine air permitting status. **Solar discourages customers from accepting the estimates in this document as permit limits, with or without source testing requirements.** Accurately measuring emissions during a – non-steady state – start-up or shutdown event with steady state source test methods may prove to be very challenging. In the event customers take permit limits and accept compliance testing permit conditions, Solar recommends adding significant margin to the estimates in this document.

START-UP PROCESS

The duration of a nominal start-up is the same for a cold start, warm start, or hot start (e.g., a Solar Turbine is programmed to start-up in "x" minutes whether it's a cold, warm, or hot start).

The start-up and shutdown time for a Solar turbine in a simple-cycle or combine heat and power application is the same. Heat recovery steam generator (HRSG) steam pressure is usually 250 psig or less. At 250 psig or less, thermal stress within the HRSG is minimized and, therefore, firing ramp-up/ramp-down is not limited. However, some combined heat and power plant applications will desire or dictate longer start-up/shutdown times due to external requirements.

The start-up sequence and attaining SoLoNOx combustion mode takes three steps:

1. Purge-crank
2. Ignition and acceleration to idle
3. Loading/thermal stabilization

[1]Start-up and shutdown emissions for the Mercury™50 engine are found in PIL 205

During the "purge-crank" step, rotation of the turbine shaft is accomplished with a starter motor to remove any residual fuel gas in the engine flow path and exhaust. During "ignition and acceleration to idle," fuel is introduced into the combustor and ignited in a diffusion flame mode and the engine rotor is accelerated to idle speed.

The third step consists of applying up to 50% load[2] while allowing the combustion flame to transition and stabilize. Once 50% load is achieved, the turbine transitions to SoLoNOx combustion mode and the engine control system begins to maintain the combustion primary zone temperature and limit pilot fuel to achieve the targeted nitrogen oxides (NOx), carbon monoxide (CO), and unburned hydrocarbons (UHC) emission levels.

SHUTDOWN PROCESS

Normal, planned cool down/shutdown duration varies by engine model. Once the shutdown process starts the engine unloads and moves into a cooldown mode.

START-UP AND SHUTDOWN EMISSIONS ESTIMATES

Tables 1 through 5 summarize the estimated pounds of emissions per start-up and shutdown event for SoLoNOx products. The mass emissions estimates are calculated using exhaust characteristics at ISO conditions in conjunction with ppm emissions estimates at various load points. The estimates in Tables 1 and 2 are representative of new production units ordered from 2006 up until the implementation of Enhanced Emissions Control (EEC). Tables 3 and 4 summarize emissions estimates for turbine models and ratings equipped with EEC. Enhanced Emission Control is a control regime that will result in lower CO and UHC values at lower loads thus reducing the estimated emissions per start-up and shutdown sequence. The Titan™ 250 and the Titan 130 23001/23502 (and 22401/22402) ratings have always been equipped with EEC. As testing is completed and other models/ratings are qualified and able to be equipped with the updated controls PIL170 will be updated. Reference PIL 220, specifically pages 7 and 8, for additional information about Enhanced Emission Control. Table 5 summarizes start-up and shutdown emissions estimates for liquid fuel applications.

Please contact Solar Environmental Programs, Leslie Witherspoon (858.694.6609) or Anthony Pocengal (858.505.8554) for support.

COMMISSIONING EMISSIONS

Commissioning generally takes place over a two-week period. Static testing, where no combustion occurs, usually requires one week and no emissions are expected. Dynamic testing, where combustion will occur, typically includes a number of engine start and shutdown cycles and a variety of loads will be placed on the system. It is impossible to predict how long the turbine will run and in what combustion/emissions mode it will be running. The dynamic testing period is generally followed by one to two days of final commissioning during which the turbine is running at various loads.

[2]40% load for the Titan 250 Engine on natural gas. 65% load for all engines on liquid fuel (except 80% load for the Centaur™ 40).

Table 1: Estimation of Start-up and Shutdown Emissions (lbs/event) for SoLoNOx Generator Set Applications

Nominal Start-up and Shutdown, Natural Gas Fuel

Production Units from 2006 and without Enhanced Emissions Control

Emissions estimates will NOT be warranted.

Engine	Total Emissions Per Start (lbs)					Total Emissions Per Shutdown (lbs)				
	NOx	CO	UHC	VOC	CO2	NOx	CO	UHC	VOC	CO2
Centaur 40 4701S	1	66	62	12	247	1	67	67	13	228
Centaur 50 6201S	1	67	84	17	333	1	67	88	18	316
Taurus™ 60 7901S	1	86	110	22	338	1	89	119	24	311
Taurus 65 8701S	1	74	67	13	376	1	75	74	15	347
Taurus 70 10801S	1	78	67	13	544	1	58	52	10	411
Mars™ 90 13000S GSC	1	84	41	8	640	1	80	44	9	605
Mars 100 15000S/16000S GSC	1	81	39	8	669	1	76	42	8	616
Titan 130 20501S	3	172	138	28	832	3	174	151	30	768

Assumes ISO conditions: 59°F, 60% RH, sea level, no losses.

Assumes unit is operating at >50% load prior to shutdown.

Assumes natural gas fuel; ES 9-98 (Fuel Air and Water or Steam for Solar Gas Turbine Engines) compliant.

Table 2: Estimation of Start-up and Shutdown Emissions (lbs/event) for SoLoNOx CS/MD Applications

Nominal Start-up and Shutdown, Natural Gas Fuel

Production Units from 2006 and without Enhanced Emissions Control

Emissions estimates will NOT be warranted.

Engine	Total Emissions Per Start (lbs)					Total Emissions Per Shutdown (lbs)				
	NOx	CO	UHC	VOC	CO2	NOx	CO	UHC	VOC	CO2
Centaur 40 4702S	1	21	17	3	188	1	19	18	4	194
Centaur 50 6102S	1	21	17	3	184	1	20	19	4	169
Taurus 60 7802S	1	22	17	3	180	1	20	18	4	161
Taurus 70 10802S	1	88	88	18	381	1	78	83	17	295
Mars 90 13000S CS/MD	1	45	20	4	437	1	56	28	6	590
Mars 100 15000S/16000S CS/MD	1	46	20	4	385	1	58	28	6	490
Titan 130 20502S	1	55	37	7	662	1	61	43	9	751

Assumes ISO conditions: 59°F, 60% RH, sea level, no losses.

Assumes unit is operating at >50% load prior to shutdown.

Assumes natural gas fuel; ES 9-98 (Fuel Air and Water or Steam for Solar Gas Turbine Engines) compliant.

Table 3: Estimation of Start-up and Shutdown Emissions (lbs/event) for SoLoNOx Generator Set Applications

Nominal Start-up and Shutdown, Natural Gas Fuel

Production Units with Enhanced Emissions Control

Emissions estimates will NOT be warranted.

Engine	Total Emissions Per Start (lbs)					Total Emissions Per Shutdown (lbs)				
	NOx	CO	UHC	VOC	CO2	NOx	CO	UHC	VOC	CO2
Taurus 60 7901S GSC (Post 9/2020 Orders)	1	42	24	5	368	1	50	28	6	345
Taurus 70 10801S GSC (Post 2/2018 Orders)	1	21	26	5	552	1	16	21	4	419
Taurus 70 11101S GSC (Post 2/2018 Orders)	1	21	27	5	563	1	17	22	4	427
Mars 90 13000S GSC (Post 9/2020 Orders)	1	23	20	4	727	1	25	20	4	682
Mars 100 15000S GSC (Post 9/2020 Orders)	1	40	34	7	760	1	44	36	7	710
Mars 100 16000S GSC (Post 8/2017 Orders)	1	32	26	5	789	1	35	27	5	733
Titan 130 19501S (Post 9/2020 Orders)	1	15	17	3	842	1	15	17	3	795
Titan 130 20501S (Post 2/2018 Orders)	1	18	21	4	839	1	19	22	4	782
Titan 130 23001S (All Units)	1	24	28	6	943	1	26	30	6	885
Titan 250 30000S GSC (All Units)	2	42	22	4	1502	2	33	17	3	1159
Titan 250 31900S GSC (All Units)	2	32	18	4	1280	2	26	14	3	975

Assumes ISO conditions: 59°F, 60% RH, sea level, no losses.

Assumes unit is operating at >50% load prior to shutdown.

Assumes natural gas fuel; ES 9-98 (Fuel Air and Water or Steam for Solar Gas Turbine Engines) compliant.

Table 4: Estimation of Start-up and Shutdown Emissions (lbs/event) for SoLoNOx CS/MD Applications

Nominal Start-up and Shutdown, Natural Gas Fuel

Production Units with Enhanced Emissions Control

Emissions estimates will NOT be warranted.

Engine	Total Emissions Per Start (lbs)					Total Emissions Per Shutdown (lbs)				
	NOx	CO	UHC	VOC	CO2	NOx	CO	UHC	VOC	CO2
Taurus 60 7802S (Post 9/2020 Orders)	1	6	5	1	247	1	7	6	1	235
Taurus 70 10802S (Post 2/2018 Orders)	1	20	28	6	381	1	19	27	5	295
Mars 90 13000S CS/MD (Post 9/2020 Orders)	1	17	12	2	437	1	24	18	4	564
Mars 100 15000S CS/MD (Post 9/2020 Orders)	1	20	13	3	474	1	30	18	4	612
Mars 100 16000S CS/MD (Post 8/2017 Orders)	1	19	13	3	496	1	28	19	4	642
Titan 130 20502S (Post 9/2020 Orders)	1	11	6	1	682	1	14	8	2	762
Titan 130 22402S (All Units)	1	13	15	3	690	1	15	17	3	775
Titan 130 23502S (All Units)	1	17	19	4	767	1	20	23	5	869
Titan 250 30000S CS/MD (All Units)	2	33	13	3	1172	2	28	11	2	1036
Titan 250 31900S CS/MD (All Units)	1	21	8	2	987	1	18	7	1	880

Assumes ISO conditions: 59°F, 60% RH, sea level, no losses.

Assumes unit is operating at >50% load prior to shutdown.

Assumes natural gas fuel; ES 9-98 (Fuel Air and Water or Steam for Solar Gas Turbine Engines) compliant.

Table 5: Estimation of Start-up and Shutdown Emissions (lbs/event) for SoLoNOx Generator Set Applications

Nominal Start-up and Shutdown, Liquid Fuel (Diesel #2)

Emissions estimates will NOT be warranted.

Engine	Total Emissions per Start (lbs)					Total Emissions per Shutdown (lbs)				
	NOx	CO	UHC	VOC	CO2	NOx	CO	UHC	VOC	CO2
Centaur 40 4701S	1	11	1	1	420	1	12	1	1	388
Centaur 50 6201S	1	15	1	1	471	1	17	1	1	439
Taurus 60 7901S	1	14	1	1	510	1	16	1	1	467
Taurus 70 10801S	2	27	2	2	754	1	22	1	1	568
Mars 100 16000S GSC	2	19	1	1	821	2	25	2	2	804
Titan 130 20501S	2	32	2	2	1189	2	35	2	2	1106
Titan 130 23001S	2	27	2	2	1231	2	29	2	2	1132
Titan 250 30000S GSC	5	7	1	1	2188	4	6	1	1	1656
Titan 250 31900S GSC	4	5	1	1	2172	3	4	1	0	1643

Assumes ISO conditions: 59°F, 60% RH, sea level, no losses.

Assumes unit is operating at >50% load prior to shutdown.

Assumes natural gas fuel; ES 9-98 (Fuel Air and Water or Steam for Solar Gas Turbine Engines) compliant.