City & Borough of Sitka
Electric Department
105 Jarvis Street, Sitka AK. 99835
Telephone: 907-747-4000 Fax: 907-747-3208

Memorandum

May 7, 2014

To: Mark Gorman, Municipal Administrator
From: Christopher Brewton, Utility Director
Subject: **Bulk Fuel Oil Purchase – Petro Marine Services**

Request:
In accordance with SGC § 3.16.060(I.), this is to request Assembly approval to authorize the Municipal Administrator to award a fuel oil supply contract (Appendix A) to Petro Marine Services to provide bulk fuel for testing and commissioning the *Solar* Titan 130 diesel turbine and to provide bulk fuel storage and supply for the planned Blue Lake Generation Outage. Fuel contract will be for one year at a not to exceed (NTE) cost of $1,260,000.

Objective:
The purpose of this fuel oil procurement is to address three distinct but related issues:

1. Provide 70,000 gallons of fuel that meets *Solar* specifications for testing and commissioning of the Solar Titan 130 turbine generator.

2. Provide bulk fuel deliveries, as needed, for supplemental diesel generation during the planned Blue Lake Generation Outage.

3. Provide off-site storage of 50,000 gallons of bulk fuel while the Jarvis Bulk tank T-103 is out of service for an API-653 inspection.

Each of these objectives is discussed in greater detail in Appendix (B).

Background:
As noted in previous correspondence to the Assembly[1,2,3], fuel oil quality is paramount in ensuring successful long term operation of the new turbine generator. To that end the Electric Department, in conjunction with Mr. Doug Moore, a *Solar* Engineering Representative; have been engaged in extensive planning, evaluation, and assessment of the fuel oil supply chain to ensure fuel meets *Solar* Technical Specification ES 9-98; Fuel, Air, Water, (Or Steam) & Compressor Cleaning Fluids for *Solar* Gas Turbine Engines (Appendix C).

As noted in Appendix (D), *Solar* Liquid Fuel Quality Sampling Report dated April 10, 2013, *Solar* field representatives have completed an on-site inspection and laboratory analysis of the City's fuel system and Petro Marine's Bulk Fuel facility and included recommendations to ensure fuel quality and compliance with *Solar* fuel oil specifications.

---

[1] February 26, 2013 Assembly Meeting approving purchase of Titan Solar 130 turbine excluding fuel oil centrifuge.
[2] Municipal Administrator's December 19, 2013 approval of Solar PCN# 004Rev1 replacing fuel oil centrifuge with fuel filtration skid.
[3] April 8 2014 Assembly Meeting approving transfer of funds from CIP#90647 – Jarvis Tank Inspection to CIP# 90646 - Jarvis Street Diesel Capacity Increase.

cc: Robin Koutchak, Municipal Attorney
Jay Sweeney, Finance Director

As previously noted in Assembly correspondence, the Department elected to pursue a static fuel treatment facility in lieu of an expensive and maintenance intensive fuel oil centrifuge. Enclosed as Appendix (E) is the operations manual developed for the liquid fuel skid designed by Mr. Moore. The unit will provide the Department with redundant fuel filtering capabilities to ensure reliable diesel operations. This one-of-a-kind fuel filtering skid also provides a new capability to perform continuous maintenance and conditioning of the bulk fuel. Again, this document provides clear information on the criticality of good fuel to ensure acceptable turbine performance.

In addition to stringent fuel oil specifications, the Titan 130 turbine requires a dedicated fuel purge system that injects pure water into the turbine during shutdown sequences to prevent coke formation in the fuel injectors. This requirement will be met by the installation of a small membrane water system that will provide adequate water supply for turbine operations. Additional information on this fuel related system is attached as Appendix (F).

Funding:
Funding in the amount of $1,260,000 is programmed in the Blue Lake Hydroelectric Expansion Project, CIP # 90594 for supplemental diesel generation.

Conclusion:
Technical documentation included with this memorandum clearly supports the need for a reliable fuel supply that meets all *Solar* specifications. The proposed vendor has worked closely with the Department and *Solar* representatives to ensure adequate fuel will be available for commissioning the new diesel turbine and for the Blue Lake Generation Outage. Future fuel contracts will be competitively bid and prospective vendor's locations evaluated to ensure compliance with *Solar* fuel specifications.

Recommended Motion:
I MOVE to authorize the Municipal Administrator to award a bulk fuel oil contract to Petro Marine Services for in a NTE amount of $1,260,000 and execute the Agreement on behalf of the Assembly of the City & Borough of Sitka.

Solar® Turbines
A Caterpillar Company

SPECIFICATION

FUEL, AIR, WATER (OR STEAM) & COMPRESSOR CLEANING FLUIDS FOR *SOLAR*® GAS TURBINE ENGINES

Data Control Level
1

SPECIFICATION NO. ES 9-98

ISSUED: 10/29/82; ERL5670-1
(Date and PRD No.)

REVISION:
(Letter, Date and PRD/CR No.)

A; 03/29/85; ERL8646-1
B; 01/29/87; ERL9338-1
C; 02/20/90; ERL0210-1
D; 05/24/93; ERL10900-1
E; 08/05/93; ERL11071-1
F; 08/10/03; PRD14724-1
G; 03/22/04; CR09269
H; 07/09/04; CR09270
J; 10/14/04; CR10321
K; 01/18/05; CR10788
L; 08/28/06; CR14043
M; 12/12/06, CR15195
N; 01/30/08; CR18878
P; 06/27/08; CR20704
R; 01/06/09; CR22506
T; 02/23/09; CR22863
U; 07/14/09; CR24384
V; 12/16/09; CR24042
W; 02/17/10; CR26201
Y; 05/25/10; CR26924
AA; 03/14/11; CR29413

Release Stamp
CDM

Rev. Ltr.	CR #	Signature & Title	Date
AB	37814	Prepared By: **Abdul Ahmed** Approved By: **Jose Aurrechoechea**	12-01-11

Caterpillar: Green

CONTENTS

CONTENTS (Continued)

CONTENTS (Continued)

TABLES

FIGURES

1.0 SCOPE - This specification establishes the quality requirements for the fuel, air, water (or steam) and compressor cleaning solutions to be used in *Solar* gas turbine engines.

This specification supersedes all previous Solar fuel, air, or water specifications, including fuel specification ES 1211, ES 9-247, and ES 9-251, for use in *Solar* gas turbine operation.

1.1 RESPONSIBILITY/DEVIATIONS - It is the responsibility of the end user to ensure that where required by this specification, Solar Turbines' approval has been sought for use of the fluids cited. It is also the responsibility of the end user to ensure on a continuing basis that all fluids entering the gas turbines are compliant with this specification. Deviations from the limits and requirements herein shall not be considered without consultation and specific written approval from Solar Engineering. These approvals can be attained through the Special Engine Request Process.

2.0 APPLICABLE DOCUMENTS - The following documents, of issue in effect on the date of this specification, shall be a part of this specification to the extent specified herein.

SPECIFICATIONS

Solar

ES 9-62	Ingestive Cleaning Solar Turbine Engines
ES 2069	Set-up, Installation, and Operating Instructions for Evaporative Coolers
FORM 2594	Liquid Fuel Suitability Inquiry
FORM 2595	Gaseous Fuel Suitability Inquiry
FORM 3091	Total Site Contamination Worksheet

American Society for Testing and Materials

ASTM D86	Method of Test for Distillation of Petroleum Products
ASTM D93	Method of Test for Flash Point by Pensky - Martens Closed Tester
ASTM D97	Method of Test for Pour Points
ASTM D129	Method of Test for Sulfur in Petroleum Products by the Bomb Method
ASTM D130	Method of Test for Copper Corrosion by Petroleum Products, Copper Strip Test
ASTM D240	Method of Test for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter
ASTM D323	Method of Test for Vapor Pressure of Petroleum Products (Reid Method)
ASTM D445	Method of Test for Viscosity of Transparent and Opaque Liquids (Kinematic and Dynamic Viscosities)
ASTM D482	Method of Test for Ash from Petroleum Products
ASTM D511	Tests for Calcium and Magnesium in Water
ASTM D512	Standard Test Method for Chloride Ion in Water
ASTM D524	Method of Test for Ramsbottom Carbon Residue of Petroleum Products
ASTM D808	Tests for Chlorine in New and Used Petroleum Products (Bomb Method)
ASTM D859	Tests for Silica in Water
ASTM D1072	Test for Total Sulfur in Fuel Gases
ASTM D1179	Standard Test Methods for Fluoride Ion in Water
ASTM D1253	Tests for Residual Chlorine in Water
ASTM D1266	Sulfur in Petroleum Products and liquefied Petroleum Gases (Lamp Method)
ASTM D1267	Vapor Pressure of Liquefied Petroleum Gases
ASTM D1293	Tests for pH of Water
ASTM D1298	Density, Specific Gravity or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
ASTM D1319	Method of Test for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Absorption

ASTM D1657	Test Method for Density or Relative Density of Light Hydrocarbons by Pressure Thermohydrometer
ASTM D1838	Copper Strip Corrosion by Liquefied Petroleum Gases
ASTM D1945	Standard Test Method for Analysis of Natural Gas By Gas Chromatography
ASTM D2163	Analysis of Liquefied Petroleum Gases by Gas Chromatography
ASTM D2500	Method of Test for Cloud Point
ASTM D2598	Calculation of Physical Characteristics of Liquefied Petroleum Gases From Compositional Analysis
ASTM D3605	Trace Metals in Gas Turbine Fuels by Atomic Absorption and Flame Emission Spectroscopy
ASTM D3373	Tests for Vanadium in Water
ASTM D3559	Tests for Lead in Water
ASTM D3588	Standard Practice for Calculating Heat Value, Compressibility Factor, and Relative Density (Specific Gravity) of Gaseous Fuels
ASTM D3868	Standard Test Methods for Fluoride Ion in Brackish Water, Seawater, and Brines
ASTM D3919	Standard Practice for Measuring Trace Elements in Water By Graphite Furnace Atomic Absorption Spectrophotometry
ASTM D4052	Standard Test Method for Density and Relative Density by Digital Density Meter
ASTM D4192	Standard Test Method for Potassium in Water By Atomic Spectrophotometry
ASTM D4418	Standard Practice for Receipt, Storage, and Handling of Fuels for Gas Turbines
ASTM D4629	Standard Test Method for Trace Nitrogen in Liquid Petroleum Hydrocarbons by Syringe/Inlet Oxidative Combustion and Chemiluminescence Detection
ASTM D5186	Test Method for Determination of Aromatic Content of Diesel Fuels by Supercritical Fluid Chromatography
ASTM D5453	Determination of Total Sulfur in Light Hydrocarbons
ASTM D5673	Standard Test Method for Elements in Water By Inductively Coupled Plasma Spectrometry
ASTM D5762	Standard Test method for Nitrogen in Petroleum and Petroleum Products by Boat-Inlet Chemiluminescence
ASTM D5907	Standard Test Method for Filterable and non-Filterable Matter in Water
ASTM D6079	Evaluating Lubricity of Diesel Fuels by High-Frequency Reciprocating Rig (HFRR)
ASTM D6217	Standard Test Method for Particulate Contamination in Middle Distillate Fuels
ASTM D6304	Standard Test Method for Determination of Water in Petroleum Products
ASTM F25	Standard Test Method for Sizing and Counting Airborne Particulate

Natural Gas Processors Association

NGP 2140-70 Liquefied Petroleum Gas Specifications and Test Methods

Deutches Institute Fur Normung (DIN)

DIN 51850 Gross and Net Calorific Value of Pure Gaseous Fuels

US Bureau of Mines

Bulletin 627 Flammability Characteristics of Combustible Gases and Vapors

3.0 GENERAL REQUIREMENTS - The requirements stated herein govern the quality of air, fuel, and water (steam) entering the engine. Failure to meet the requirements in this specification can result in a negative impact on the performance and life expectations of the engine and package.

3.1 UNDESIRABLE CONTAMINANTS - The contaminants listed here are known to be harmful to engine components and must be controlled to within the maximum allowable limits specified for each contaminant in order to attain maximum engine life. The total quantity of each contaminant ingested by the engine must be limited regardless of whether it enters through the air, fuel, injected water (steam), or as liquid water carryover from evaporative cooling.

The limits for each of the several critical contaminants from all possible sources are provided in Table 1.

Table 1. Maximum Allowable Contaminant Concentrations

Contaminant	Limit(Note 1) in Fuel Equivalent Concentrations	Test Method
Sulfur (see Notes 2, 3, & 4)	**10,000 ppmw FEC (See note 5A & 5B). Additional restrictions apply for *SoLoNOx* liquid operation (See note 6)**	ASTM D129, D1072, D1266 or ASTM D5453
Sodium + Potassium	0.5 ppmw FEC	ASTM D3605 or D1428
Vanadium	0.5 ppmw FEC	ASTM D3605, D3373
Lead	1 ppmw FEC	ASTM D3605, D3559
Calcium + Magnesium	2 ppmw FEC	ASTM D3605, D511
Fluorine	1 ppmw FEC	ASTM D1179, D3868
Chlorine	0.15 weight percent or 1,500 ppmw FEC	ASTM D512, D808, D1253,
Others (See Notes 7 &8)	0.5 ppmw FEC	

Notes:

(1) The limits given are FUEL EQUIVALENT CONCENTRATIONS (FEC), i.e., the maximum allowable concentration of each contaminant as if each contaminant is found solely in a fuel with LHV - 18,380 Btu/lb. (such as diesel #2). Instructions for performing calculations are provided in Appendix A, Form 3091, Total Site Contamination Worksheet.

(2) For installations with exhaust heat recovery equipment, it is important to maintain sulfur levels at below the SO_3 dewpoint. Because conversion from SO_2, to SO_3 in the combustor is a function of several factors that are not readily definable, it is recommended that fuel sulfur is limited to less than 0.5% weight FEC. This value is based on 60:1 air-to-fuel ratio at up to 17% conversion for an acid dewpoint of 240°F.

(3) If sulfur is present in the form of hydrogen sulfide, appropriate precautions must be taken to detect leaks because of the highly toxic nature of this gas even in trace quantities. High sulfur fuels (exceeding limits) may be used with special provisions; however, such fuels must be reviewed and approved in writing by Engineering prior to use.

(4) U.S. Federal and local Air Pollution control districts may require lower limits for sulfur.

(5A) Harsh environment protection hardware and ancillary equipment is required for gas fuel with H_2S concentration greater than 3000 ppmw FEC or liquid fuel with sulfur concentration more than 2000 ppmw FEC..

(5B) Higher sulfur levels (> 10,000 ppmw FEC) can be considered for a specific application and must be approved in writing by engineering.

(6) Liquid fuel sulfur content limits and specific fuel handling and storage requirements are required for *SoLoNOx* liquid fuel operation. See section 8 and appendix C.

(7) The following contaminants are unlikely to be present except in unusual or accidental contamination of air, fuel or water supplies. However, if detected at levels greater than 0.5 ppmw FEC fuel equivalent, special treatment and precautions are required.

Mercury – Cadmium – Bismuth – Arsenic – Indium – Antimony – Phosphorous – Boron - Gallium

(8) Any other trace element with concentrations over 0.5 ppmw FEC fuel equivalent should be discussed with, and reviewed, by Engineering.

3.2 SOURCES OF CONTAMINATION – There are four major potential sources of contamination - air, fuel (gas, liquid, or solid), injected water/steam (for continuous NO_x control) and liquid water carryover from the evaporative cooler (if used). Minor sources of contamination include water for compressor cleaning, water for dual fuel injector purging, and compressor cleaning fluids have also been identified.

In order to effectively control the quality of air, fuel, and water entering the engine as defined in this Specification, Solar's Package Engineering Department shall be consulted in specifying treatment and cleanup systems for the major sources, while the minor sources must meet the quality specified in Tables 3 and 4 of this document.

3.3 DETERMINATION OF TOTAL CONTAMINANTS - The total concentration of each of the major potential sources of contaminants entering the engine can be determined by using the equations provided here.

For direct fired applications:

$$\text{Total Contaminant} = \frac{18{,}380}{\text{LHV}} \times [(\text{AFR})A + F + (\text{WFR})W + (\text{CFR})C]$$

For indirect fired applications:

$$\text{Total Contaminant} = 65 \times [A + (\text{WAR})W + (\text{CAR})C]$$

Where:

Total Contaminant	=	total concentration of that particular contaminant, ppmw fuel equivalent (for indirect fired applications, total contaminant is expressed as ppmw air equivalent concentration, normalized to 65 air-to-fuel ratio.
LHV	=	lower heating value of fuel, Btu/lb
AFR*	=	air-to-fuel mass ratio
A	=	concentration of that particular contaminant in air entering the engine, ppmw in air
F	=	concentration of that particular contaminant in fuel, ppmw in fuel
WFR*	=	water-to-fuel mass ratio
W	=	concentration of that particular contaminant in injected water, ppmw in water
CFR*	=	carryover water-to-fuel mass ratio
C	=	concentration of that particular contaminant in evaporative cooler water (or feedwater), ppmw in water
WAR	=	water-to-air mass ratio
CAR	=	carryover water-to-air mass ratio

* Fuel ratios are based on <u>actual</u> fuel rather than combustible fuel

A worksheet (Form 3091) with instructions for performing the above calculation is provided in Appendix A. (Derivation of the above equation for directly fired applications and the functional equation used in Form 3091 are included in Appendix B.)

3.4 ADDITIVES - Chemicals can be added to fuel and water treatment systems for specific purposes, e.g., softening, settling out of particulates, inhibition of organic growths, etc. Caution should be exercised to ascertain that the additives are not comprised of critical elements listed in Table 1 and that the maximum allowable limits specified are complied with.

3.5 CUSTOMER SITE DATA REQUIREMENTS - Information as to the condition and quality of the air, water (including steam), and fuel to be ingested by the engine, and other environmentally influenced conditions such as ambient temperature and humidity ranges is required by Solar to adequately define the necessary combustion system configuration, engine controls, settings, protective coatings, devices and operating procedures.

3.5.1 SAMPLING - Sampling and analyses of air, fuel, and water must be performed by Solar approved laboratories. In certain critical applications, either Solar or the customer may specify a particular facility. Unless specifically instructed otherwise, all sampling should be performed at locations just up stream of the engine.

3.5.2 ADDITIONAL SITE DATA - The following information, if available, is required for all installations:

- Ambient temperature range
- Ambient humidity range
- Altitude
- Type of environment (rural, agricultural, residential, arctic, industrial, offshore, marine, coastal, desert, semi-arid, or tropical)
- Fuel conditions (fuel temperature and pressure ranges)

4.0 AIR

4.1 AIR QUALITY - Air borne constituents such as gases, liquid droplets and solid particles, can contain undesirable contaminants that are considered harmful. Adequate air filtration must be used to remove the bulk of such air borne constituents including water carryover from evaporative cooler applications. The combined concentration of contaminants from air, fuel and water (steam) shall meet the requirements of paragraph 3.1 and the maximum limits specified in Table 1.

4.1.1 ADDITIONAL LIMITS - In addition, quality of air entering the air inlet shall also meet the following requirements.

Maximum particle size	≤10 microns	ASTM F25, ISO 8573
Total particulates	≤500 ppmw	
Total combustibles	≤5 ppmw	ASTM D1945, D3588

4.2 CONCENTRATION OF AIR BORNE CONTAMINANTS - Air borne contaminants constitute only one of several means by which contaminants enter the turbine engine. The minimum air quality allowed depends on the quality of the other fluids, such as injected water, fuel, and water carryover (if applicable). In order to assess the impact of air borne contaminant(s) on the total concentration present in the engine, the fuel equivalent concentration (FEC) of each air borne contaminant can be calculated using the following function.

$$\text{Concentration in air, ppmw FEC} = AFR \times \frac{18380}{LHV} \times A\,(1-N)$$

Where:
- AFR = air-to-fuel ratio
- LHV = lower heating value, Btu/lb.
- A = concentration in ambient air, ppmw
- N = air cleaner efficiency, expressed as value <1.0

4.2.1 CONCENTRATION GUIDELINES FOR AIR BORNE CONTAMINANTS - In general, air borne contaminants are expected to contribute less than 20% of the total concentration allowed except when air and fuel are the two fluids present. Depending on the type of application involved and the potential for system upsets, Table 2 serves as an approximate guideline for air borne contaminants, recognizing that variations in fluid quality can significantly change the balance implied in this guideline.

Table 2. Guidelines for Contaminant Concentrations
(for nominal operating conditions with natural gas fuel)

Available Sources	Air Borne Contaminants (% of Total)	Fuel Borne Contaminants (% of Total)	(Inj.) Water Borne Contaminants (% of Total)	Contaminants From E/C Carryover (% of Total)
Air + Fuel	<70	<10	0	0
Air + Fuel + Inj. Water	<20	<10	<50	0
Air + Fuel + Inj. Water + E/C	<20	<10	<20	<30
Air + Fuel + E/C	<20	<10	0	<50
Note: These values are provided only as guidelines and they are based on experience at Solar. Because of the inexactness of some of the values involved in the calculations, a 20% margin is built in to the numbers provided here.				

4.3 SITE SPECIFIC CONTAMINANTS IN AIR - If ambient air at a particular site is known to be of poor quality, based on prior experience or influence of industries and/or activities in the vicinity, consult with Package Engineering to ascertain compliance with all the requirements of this specification.

5.0 INJECTED WATER (OR STEAM)

5.1 WATER QUALITY FOR WATER INJECTION TO REDUCE NO_x - The quality of water injected into the combustor for NO_x control must meet the general requirements defined in Section 3.1 as well as the specific requirements described here.

	Limit	Test Method
pH	5.5 to 8.5	ASTM D1293
Suspended solids	$\leq$2.6 mg/l	ASTM D5907; ISO 11923
Maximum particle size	10 microns	
90% of particles	$\leq$5 microns	
Dissolved Silica	$\leq$0.1 ppmw SiO_2 ($\leq$0.1 mg/l)	ASTM D859
Electrical Conductivity	5 µS/cm	ASTM D5391

5.2 CONCENTRATION OF (INJECTED) WATER BORNE CONTAMINANTS - Water borne contaminants from injected water/steam constitute only one of several means by which contaminants enter the turbine engine. The minimum water quality allowed depends on the quality of the other fluids, such as air, fuel, and water carryover (if applicable). In order to assess the impact of water borne contaminant(s) from injected water/steam on the total concentration present in the engine, the fuel equivalent concentration (FEC) of each water borne contaminant can be calculated using the following function.

$$\text{Concentration in water, ppmw FEC} = WFR \times \frac{18380}{LHV} \times W$$

Where:

WFR	=	water-to-fuel ratio
LHV	=	lower heating value, Btu/lb
W	=	concentration of contaminant in injected water, ppmw

5.2.1 CONCENTRATION GUIDELINES FOR (INJECTED) WATER BORNE CONTAMINANTS - In general, water borne contaminants from injected water are expected to contribute less than 50% of the total concentration allowed. Depending on the type of application involved and the potential for system upsets, Table 2 serves as an approximate guideline for injected water (steam) borne contaminants, recognizing that variations in fluid quality can significantly change the balance implied in this guideline.

5.3 BOILER FEEDWATER - In general, boiler feedwater is not suitable for use in water injection; additional treatment to remove dissolved and suspended contaminants is usually required to satisfy all the requirements of this specification.

5.4 OPERATION - It is recommended that Package Engineering is consulted in selecting appropriate equipment for treatment water. Continuous monitoring of water quality is strongly recommended with an alarm or automatic shut down device installed between the final stage of treatment and the fuel injector manifold. The trip point shall be set to ensure that water entering the combustor is within the allowable limits of this specification.

5.5 WATER FOR INJECTOR PURGE AND COMPRESSOR CLEANING – Water is used in small quantities from time to time (not continuous operation), to either aid cleaning the compressor or to purge liquid fuel passages in dual fuel injectors during fuel transfers and liquid fuel shutdown. It has been determined that the contaminant limits for the water can be higher for these duties because the consumption is small and Table 3 shows the limits for the particular application.

6.0 EVAPORATIVE COOLER WATER

6.1 GENERAL - For operation in hot and dry environments, evaporative cooling is commonly employed for power augmentation. The design/selection, installation and maintenance of evaporative cooler equipment is critical to engine operation and longevity and also effects the extent of water carryover into the airstream. Appropriate treatment of feedwater must be specified in order to comply with the total requirements of this specification.

6.1.1 EVAPORATIVE COOLER EQUIPMENT - Instructions for set-up, installation and operation of evaporative coolers are provided in Engineering specification ES 2069.

Table 3. Contaminant Limits For Short Duration Water Ingestion Duties

	Test Method	Max. Limits for On-Crank Cleaning	Max. Limits for On-Line Cleaning	Max. Limits for Dual Fuel Injector Water Purge
Sodium + Potassium	ASTM D1428	105 ppmw	1.9 ppmw	1.9 ppmw
Fluorine	ASTM; D1179	100 ppmw	1.9 ppmw	1.9 ppmw
Chlorine	ASTM D512	100 ppmw	40 ppmw	40 ppmw
Lead	ASTM D3559	2 ppmw	0.70 ppmw	0.70 ppmw
Vanadium	ASTM D3373	2 ppmw	0.35 ppmw	0.35 ppmw
Iron, Tin, Silicon, Aluminum, Copper, Manganese, Phosphorus	ASTM D857, D858, D1068, D1688	10 ppmw	3.8 ppmw	3.8 ppmw
Calcium + Magnesium	ASTM D3605, D511	100 ppmw	3.8 ppmw	3.8 ppmw
Total Dissolved Solids	ASTM D1888	350 ppmw	5 ppmw	30 ppmw
Suspended solids	ASTM D5907	2.6 mg/l	2.6 mg/l	2.6 mg/l
Maximum particle size		10 microns	10 microns	10 microns
90% of particles		5 microns	5 microns	5 microns
Dissolved Silica		0.1 mg/l SiO_2	0.1 mg/l SiO_2	0.1 mg/l SiO_2
PH	ASTM D1293	6 - 9	6 - 9	6 - 9
Electrical Conductivity		540 μS/cm	8 μS/cm	50 μS/cm

6.1.2 DEIONIZED WATER - Do not use deionized water unless the evaporative cooler has been specially designed for it. The use of deionized water will require the use of stainless steel construction and binder reinforced media.

6.1.3 SOFT WATER - Soft water is usually high in sodium salts and low in calcium and magnesium salts. Therefore, soft water <u>cannot</u> be used for evaporative cooling unless it can be proven that sodium + potassium (and any other dissolved salts present) are in compliance with the requirements of Section 3.1.

6.2 CONCENTRATION OF CONTAMINANTS IN WATER CARRYOVER - Contaminants from evaporative cooler water carryover constitute only one of several means by which contaminants enter the turbine engine. The minimum evaporative cooler water quality allowed depends on the quality of the other fluids, such as air, fuel, and injected water. In order to assess the impact of contaminant(s) from evaporative cooler water carryover on the total concentration present in the engine, the fuel equivalent concentration (FEC) of each contaminant can be calculated using the following function.

$$\text{Concentration in water carryover, ppmw FEC} = C \times R \times \frac{(1 - E)}{f} \times 9.2$$

Where: C	=	concentration in water delivered to header of evaporative cooler, ppmw (for recirculating system, C = concentration in reservoir; for non-recirculating system, C = concentration of feedwater)
R	=	carryover rate, gallons per minute (see Section 6.2.2)
E	=	mist eliminator efficiency, expressed as <1.0
f	=	fuel flow rate, MBtu/hour (10^6 Btu/hour)

6.2.1 CONCENTRATION GUIDELINES FOR CONTAMINATION IN EVAPORATIVE COOLER WATER - In general, contaminants from evaporative cooler carryover are expected to contribute less than 50% of the total concentration allowed. Depending on the type of application involved and the potential for system upsets, Table 2 serves as an approximate guideline for water carryover contaminants, recognizing that variations in fluid quality can significantly change the balance implied in this guideline. (Refer to ES 2069 for details on evaporative cooler installation and operation.)

6.2.2 CARRYOVER RATE - In the absence of actual measurements, the following estimated carryover rates could be used.

2.8 GPM for *Titan* 130
1.7 GPM for *Mars*
1.5 GPM for *Taurus* 70
1.3 GPM for *Taurus* 60
0.9 GPM for *Centaur* 40 and 50, *Mercury* 50
0.5 GPM for *Saturn*

6.3 WATER CARRYOVER - While water carryover can be effectively reduced or eliminated with correct equipment specification and installation/operation, it is also recognized that system upsets can be expected to occur during the life cycle of the engine when water from the evaporative cooler can accidentally enter the compressor as liquid water droplets of varying size. Vane type mist eliminators are required for evaporative cooler applications as a means of further reducing or eliminating water carryover. Nevertheless, the general requirements in paragraph 3.1 include evaporative cooler water carryover as a potential source of contamination.

6.4 ADDITIONAL LIMITS FOR EVAPORATIVE COOLER WATER

	Limits
pH	6-9
Turbidity	≤5,000 turbidity units (also know as Jackson units)
Hardness	160 ppmw $CaCO_3$

6.5 OTHER CONTAMINANTS - Algae, aromatic hydrocarbons, oils, grease and wetting/ dispersing agents such as phosphates can be harmful to the evaporative cooler media pad. Precautions must be exercised to prevent the formation or introduction of these contaminants into the feedwater.

7.0 COMPRESSOR CLEANING FLUIDS

7.1 COMPRESSOR CLEANING PRODUCT QUALITY – Composition and physical properties of cleaning products must comply with the limits defined in Table 4. Failure to comply with these limits can cause corrosive attack and/or other harmful effects resulting in rapid engine deterioration. When the cleaning product consists of a mixture of cleaning solution concentrate and water, the limits in Table 4 apply to the resulting cleaning product.

Table 4. Requirements for Cleaning Product Used in Ingestive Cleaning of *Solar* Engines

	Test Method	Max. Limits for On-Crank Solutions	Max. Limits for On-Line Solutions
Sodium + Potassium	ASTM D1428	105 ppmw	1.9 ppmw
Fluorine	ASTM D1179	100 ppmw	1.9 ppmw
Chlorine	ASTM D512	100 ppmw	40 ppmw
Lead	ASTM D3559	2 ppmw	0.70 ppmw
Vanadium	ASTM D3373	2 ppmw	0.35 ppmw
Iron, Tin, Silicon, Aluminum, Copper, Manganese, Phosphorus	ASTM D857, D858, D1068, D1688	10 ppmw	3.8 ppmw
Calcium + Magnesium	ASTM D3605 ASTM D511	100 ppmw	3.8 ppmw
Ash	ASTM D482	0.25 wt. %	0.01 wt. %
Flash Point	ASTM D93	>140°F	>140°F
PH	ASTM D 1293	6 - 9	6 - 9

8.0 FUEL

8.1 GASEOUS FUELS - Gaseous fuels, which meet the limits in Table 5, can be used in the standard fuel systems. The fuels must be free from condensed hydrocarbons, oils or water. Fuels, which do not meet these limits, must be reviewed by Solar. If judged suitable for use, control and/or combustor modifications will generally be required.

8.1.1 GASEOUS FUEL SUITABILITY - The Solar Gaseous Fuel Suitability Inquiry Form 2595 must be completed. In addition, any entrained solid contaminants should be identified, along with their concentrations and size. For gaseous fuels, if water is known to be present, even in minute quantities, the concentration of salts dissolved in this water must be included when calculating the amount of contaminants contributed by the water portion of this fuel to the total system. It is also required that a gas analysis including all heavy hydrocarbons beyond C_6 be provided during the proposal stage of the project.

8.1.2 COKE OVEN GAS – Coke Oven Gas (COG) is the gas released in the process that converts coal into coke. COG is a medium heating value fuel containing mainly hydrogen, methane, water, oxygen, carbon monoxide, nitrogen and carbon dioxide. However, COG also has extreme levels of harmful contaminants including:

- Tar
- Light oil vapors (aromatics), mainly Benzene, Toluene and Xylene (BTX)
- Naphthalene vapor
- Ammonia gas
- Hydrogen sulfide gas
- Hydrogen cyanide gas
- Calcium carbonate from direct water cooling of COG
- Trace metals

The contaminants found in COG must be controlled to levels listed in Tables 1 and 5. Contact Solar for recommendations on Balance of Plant equipment to remove or reduce the contaminants to levels acceptable for gas turbine operation.

The superheat level specified in Table 5 is also required for COG to ensure remaining naphthalene and heavy hydrocarbons do not precipitate out in the fuel system.

Table 5. Requirements for Gaseous Fuels

Fuel Volume Ratio (1220/WOBBE Index*)	0.9 to 1.1
Fuel Mass ratio (21550/LHV Btu/lb)	<5
Hydrogen Content	<4% by volume
Carbon Monoxide Content**	<12.5% by volume
Hydrogen Sulfide**	10,000 ppmw Max. (See Table 1)
Ratio of Flammability Limits Upper flammability limit *** / Lower flammability limit	 >2.2 for Saturn >2.8 for Centaur and Mars
Stoichiometric Flame Temperature with Air Temperature Equal to Compressor Discharge Temperature at Design Point	>3600°F (1980°C)
Total Particulates	<30 ppmw x (LHV/21500)
Maximum Particle Size	10 micron
Gas Supply Temperature (at inlet flange of package) to ensure no liquid condensation:	The higher of dew point temp + 50°F for natural gas liquids and dew point temp + 20 °F for water up to a limit of 200°F at the fuel skid edge supply pressure. and no lower than -40°F.

*WOBBE Index = Lower Heat Value (use ASTM 3588 or DIN 51850 for individual component heating values) in Btu/Scf divided by the square root of the relative density (specific gravity).

**If carbon monoxide or hydrogen sulfide are present in the fuel gas, precautions must be taken to detect leaks.

***Flammability limits at 1 atm and 25°C as defined by M.G. Zabetakis, US Bureau of Mines Bulletin 627.

Note:

If the required fuel temperature is above ambient air temperature, adequate thermal insulation and heat tracing of fuel lines and fuel control system is required to avoid condensation. If condensates form during shutdown or are otherwise introduced, provisions should be made to drain fuel lines just before start up to ensure that gas fuel condensation is completely eliminated.

8.1.3 GASEOUS FUEL SUPPLY PRESSURE - Fuel supply pressure should be maintained at constant level to minimize wear damage to the fuel control system caused by fluctuating and unstable fuel pressures.

8.2 DISTILLATE FUELS - Distillate fuel shall be a homogeneous mixture of hydrocarbon compounds. The fuel, when received, shall be clear, bright, and free of any haze, as viewed in ordinary light through a clear vessel. Technical requirements shall be as specified in Tables 6and7.

8.2.1 DISTILLATE FUEL SUPPLY TEMPERATURE - Distillate fuel supply temperature at turbine package fuel inlet shall be no lower than the temperature at which the viscosity is 12 centistokes or cloud point temperature plus 10°F, whichever is higher. The fuel supply temperature shall not be lower than -65°F, nor higher than +140°F.

8.2.2 DISTILLATE FUELS – The Solar Fuel Suitability Inquiry Form in Appendix D must be completed.

Table 6. Distillate Fuels - Physical Requirements

		Test Method
a.	Contaminants <u>Solid</u> - The fuel shall contain less than 2.6 mg per liter of sediment, solid or hard contaminants, 90% of the 2.6 mg shall be less than 5 microns in size. Maximum allowable particle size shall be 10 microns. <u>Liquid</u> - The fuel shall contain less than 0.25 cc free water per liter (0.025 % by volume) at an ambient temperature of 80°F.	 ASTM D6217 or by use of Millipore microscan contamination detector ASTM D6304
b.	Kinematic Viscosity* The kinematic viscosity of the fuel shall be within the following limits: Maximum: 12 centistokes Minimum: 1 centistoke, at 100°F	 ASTM D445 ASTM D445
c.	Relative Density (Specific Gravity) Relative Density shall be between 0.775 and 0.875.	 ASTM D1298 or ASTM D4052
d.	Reid Vapor Pressure* The vapor pressure of the fuel shall be less than 3 psia.	 ASTM D323
e.	Cloud Point The cloud point shall be at least 10°F below the expected minimum ambient temperature.	 ASTM D2500
f.	Pour Point Pour point shall be at least 10°F below the cloud point Temperature	 ASTM D97
g.	Lubricity The lubricity of the liquid fuel shall meet an HFRR at 60°C 520 micron maximum.	 ASTM D6079
*EXCEPTIONS:	Naphtha fuels, which have a viscosity of 0.5 to 1.0 centistokes, relative density below 0.775, and vapor pressure above 3 psia will be considered. Use of these fuels will require modification to the standard fuel system.	

Table 7. Distillate Fuels - Chemical Requirements

		Test Method
a.	Flash Point	
	100°F minimum or legal limit	ASTM D93
b.	Distillation	
	90% evaporated 640°F maximum. End point 690°F maximum	ASTM D86
c.	Aromatics	
	35% by volume maximum	ASTM D1319*
d.	Olefins and Diolefins	
	5% by volume maximum	ASTM D1319
e.	Lower Heating Value	
	18,000 Btu/lb. minimum	ASTM D240
f.	Carbon Residue on 10% Distillation Residue	
	0.35% maximum	ASTM D524
g.	Ash	
	0.005% by weight maximum	ASTM D482
h.	Copper Strip Corrosion	
	No. 3 (3 hr at 122°F)	ASTM D130
i.	Fuel Bound Nitrogen	ASTM D4629 or ASTM D5762

Measurement required for liquid emissions guarantees

*Use ASTM D5186 for fuels having final boiling points over 600°F.

8.3 NATURAL GAS LIQUID FUELS - Natural gas liquid fuels shall consist primarily of saturated paraffinic hydrocarbons such as ethane, propane, butane, pentane, hexane and heptane either individually or mixtures of some or all of the above. Technical requirements shall be as specified in Table 8.

8.3.1 NATURAL GAS LIQUID SUPPLY TEMPERATURE - Liquid gas supply temperature at the fuel inlet to the package shall be between -65°F and +90°F and shall be in a liquid phase only.

8.3.2 NATURAL GAS LIQUID FUELS - The following information is required to determine the suitability of natural gas liquids:

- Composition on volumetric gases
- Relative density at 60°F
- Vapor pressure at 100°F
- Viscosity at 100°F

8.4 MULTIPLE FUEL SOURCES - If more than 1 fuel source is available, individual fuel analyses of all fuel sources must be submitted to review to ensure proper fuel handling.

8.5 CONCENTRATION OF FUEL BORNE CONTAMINANTS - Fuel borne contaminants constitute only one of several means by which contaminants enter the turbine engine. The minimum fuel quality allowed depends on the quality of the other fluids, such as air, injected water and water carryover (if applicable). In order to assess the impact of fuel borne contaminants on the total concentration present in the engine, the fuel equivalent concentration (FEC) of each fuel borne contaminant can be calculated using the following function.

$$\text{Concentration in fuel, ppmw FEC} = \frac{18380}{LHV} \times (1-K) \times F$$

Where: LHV = lower heating value, Btu/lb

K = fuel cleanup (if applicable), expressed as value <1.0
F = concentration in fuel entering combustor, ppmw

8.4.1 CONCENTRATION GUIDELINES FOR FUEL BORNE CONTAMINANTS - In general, contaminants from fuel are expected to contribute less than 10% of the total concentration allowed. Depending on the fuel of application involved and the potential for system upsets, Table 2 serves as an approximate guideline for fuel borne contaminants, recognizing that variations in fluid quality can significantly change the balance implied in this guideline.

9.0 HANDLING AND STORAGE OF DISTILLATE FUELS

9.1 FUEL TEMPERATURE - Fuel should not be stored permanently at ambient temperature above 100°F.

9.2 MAINTENANCE - Fuel should be changed completely or refiltered at least once a year or more frequently, depending on ambient temperatures and contamination experience. Fuel under continuous storage should be cleaned periodically to maintain the contaminant levels below that specified in Table 6a.

9.3 CLEANING - Fuel tanks should be drained, cleaned, flushed, and scoured whenever necessary to control contamination problems.

9.4 STORAGE AND HANDLING EQUIPMENT – The selection of equipment for storage and handling is a crucial part of ensuring that fuel generally conforms to ES 9-98 when it reaches the engine. Cleanup devices will always be required because contamination frequently occurs during transportation. Solar has identified the types of equipment that are required to ensure that liquid fuel being supplied to an engine will be cleaned up to specification. Appendix C lays out the requirements for various liquid fuel applications.

9.5 ADDITIONAL INFORMATION - Refer to ASTM D4418 for more information on handling and storage of fuels.

10.0 NOTES

10.1 SIGNIFICANCE OF LIMITS - Total contaminants should comply with Table 1. The following subparagraphs explain the significance of limits in the specification.

Table 8. Natural Gas Liquid Fuels - Physical and Chemical Requirements

Property	Allowable Limits	Test Method
Composition percent by volume	Report	ASTM D2163
Vapor pressure at 100°F (38°C)	780 psia maximum	ASTM D1267 or ASTM D2598
Relative density at 60°F/60°F (15°C/15°C)	0.37 to 0.68	ASTM D1657 or ASTM D1298
Copper strip	No. 1 maximum	ASTM D1838
Moisture content for fuels with relative density 0.37 to 0.51	Pass	Use one of the methods for moisture content as described in the Commercial Propane Dryness Test, Cobalt Bromide Method or Dew Point Method of the Natural Gas Processors Association Publication 2140
Free water content for fuels with relative density of 0.51 to 0.68	None	ASTM D1657 - The presence or absence of water shall be determined by inspection of the sample on which the relative density is determined
Solid contaminants	Less than 2.6 mg of sediment per liter of fuel 90% of sediment shall be less than 5 microns in size Maximum size of any solid sediment particle shall be less than 10 microns	ASTM D6217
Lower Heating Value	18,000 Btu/lb. Minimum	ASTM D240

10.1.1 SULFUR – Sulfur and sulfur compounds can have an impact on the fuel system life and maintenance, turbine hot section life, exhaust system life and a pollutant emissions signature. The presence of sulfur in the combustor will burn or oxidize to form sulfur dioxide. In the presence of even minute quantities of sodium and potassium in the combustor environment (excess oxygen and high thermal load), sodium and potassium sulfates are readily formed. These salts if condensed onto turbine airfoil surfaces will react with the base metal, resulting in hot corrosion degradation. Gas turbines with waste heat recovery equipment must operate above the sulfuric acid dewpoint, which may require additional sulfur control to prevent cold end corrosion. Additionally, US Federal and certain local air pollution regulations require more restrictive limits on sulfur. Fuel bound sulfur in liquid fuel has been found to promote carbon deposition on hot surfaces of lean premix *SoLoNOx*® injectors leading to the blockage of liquid fuel passages over time. As a result the sulfur content is being limited for *SoLoNOx* liquid fuel operation and is a function of the frequency and duration of liquid operation. See Appendix C for details.

10.1.1.1 HYDROGEN SULFIDE - Hydrogen sulfide can occur both in natural gas, process and manufactured gases. It is corrosive to some materials such as bronze and brass used in fuel gas systems, the corrosiveness being more severe in the presence of water and at high pressure. If the sulfur exceeds the limit then the fuel system materials must be upgraded. Hydrogen sulfide burns to sulfur dioxide and sulfur trioxide, which results in the corrosion described above. Some manufactured gases also contain organic sulfur compounds, which are corrosive to some control system materials. Since hydrogen sulfide is toxic, if it is present in the gas, precautions must be taken to detect leaks.

10.1.1.2 ELEMENTAL SULFUR DEPOSITION - Aside from H2S, natural gas may contain other sulfur compounds or sulfur vapor that even in very low concentrations (ppbw) can form solid elemental sulfur. In sufficient quantities elemental sulfur can impede operation of fuel valves and gas flow measurement devices on the gas turbine package. However, there are no reliable and practical methods for knowing how much elemental sulfur is contained in a gas, and if and where elemental sulfur deposition will occur. If deposition takes place, the solution is to heat the gas fuel prior to the skid edge. The temperature that the gas must be heated to will depend on the concentration of the sulfur in the gas supply. For standard pipeline gas with low concentrations of total sulfur, fuel heating in the range of 120 to 160°F (50 to 70°C) has proven effective at preventing sulfur deposition.

10.1.2 SODIUM AND POTASSIUM - Sodium and potassium can combine with vanadium to form eutectic, which melts at temperatures as low as 1050°F (566°C) and can combine with sulfur in the fuel to yield sulfates with melting points in the operating range of the gas turbine. These compounds produce severe corrosion in the turbine hot section. Accordingly, the sodium plus potassium level must be limited, but each element must be measured separately. These elements can be removed by water washing and subsequent removal with a centrifuge or electrostatic precipitator.

10.1.3 VANADIUM - Vanadium can form low melting compounds such as vanadium pentoxide which melts at 1275°F (691°C), and alkali metal vanadates which melt as low as 1050°F (566°C) which can cause severe corrosive attack on all of the high temperature alloys in the gas turbine hot section.

10.1.4 MERCURY - Mercury compounds are corrosive to aluminum, copper, lead, and silver; therefore, these materials are to be avoided if mercury is present. Mercury compounds are not known to be corrosive to the hot section of a gas turbine. Mercury in the exhaust of the turbine must be limited to comply with local regulations.

10.1.5 LEAD - Lead can cause corrosion and in addition, it can spoil the beneficial effect of magnesium additives on vanadium corrosion. Since lead is rarely found in significant quantities in crude oils, its appearance in fuel oils is primarily the result of contamination during processing or transportation.

10.1.6 FLUORINE AND CHLORINE - Halides such as fluorine and chlorine as well as alkali/mixed halides and alkali sulfates can attack the protective oxide scale on hot turbine components, thus accelerating the rate of oxidation.

10.1.7 CALCIUM AND MAGNESIUM - Calcium and magnesium are not harmful from a corrosion standpoint; in fact, it serves to inhibit the corrosive action of vanadium. However, calcium can produce hard bonded deposits that are not self-spalling when the gas turbine is shut down. These hard bonded deposits are not readily removed by water washing of the turbine (Ref. ES 9-62). The fuel washing systems used to reduce the sodium and potassium levels will also reduce calcium levels.

10.1.8 SILICON - Siloxanes in fuel gas is known to result in silicon-based deposition in the gas turbine flow path that can cause damage, high rates of performance degradation, and higher overhaul costs. The rate of deposition is a function of the type and quantity of silicon-based material contained in the fuel, and is thus produced from the combustion process. As such damage and performance loss is preventable only by control of siloxane levels in the fuel, such damage is not covered by Solar's warranty. It is, therefore, the customer's responsibility to monitor and minimize as appropriate siloxane content through the use of a reliable siloxane removal system.

Based on engine operating experience to date, Solar considers that limiting the amount of silicon, as measured by the Jet-Care SiTest method, to no more than 5 mg Si/nm^3 CH_4 for the Mercury 50^{TM} and 10 mg Si/nm^3 CH_4 for all other turbines should result in target time between overhaul with normal performance degradation.

Contact Solar Turbines for recommendations on Balance of Plant equipment to remove or reduce the contaminants to tolerable levels for gas turbine operation.

10.1.9 OTHER TRACE METALS - Oxides of other trace metals with or without other impurities can be deposited on blades and vanes forming extremely hard and difficult-to-remove deposits. The presence of these oxides will also increase the rate of oxidation of blade and vane alloys at high temperatures.

10.1.10 PARTICULATES IN AIR - Inert particulates in the turbine inlet air cause erosion and/or fouling of the compressor section. By limiting the size of the particulates, erosion is minimized. Contamination of the compressor blading is caused by smaller particulates. Factors such as humidity, presence of oil or soot and dust particle composition affects the rate of fouling.

10.1.11 SOLIDS IN WATER - Inert solid particles in water can cause wear and plugging of control components and fuel injectors. Malfunctions of the control system and damage to the combustor and turbine section would be the result.

10.1.12 pH OF WATER - The pH of water is limited from slightly acidic to slightly basic. Strong bases or acids would attack various components in the water control and injection system.

10.1.13 FUEL GAS VOLUME RATIO - The fuel gas volume ratio is an indication of the capability of the fuel control to properly schedule the fuel flow. If this ratio is within the specified limits, the standard system without modifications can be used. Ratios with values up to 2 can be handled with minor modifications to the fuel injection system. If the ratio is between 2 and 4, the modifications are substantial and if the ratio is above 4, a redesign of the combustor is required.

10.1.14 FUEL GAS MASS RATIO - The fuel gas mass ratio is an indication of the effects of the fuel mass flow on the performance and matching of the turbine. Ratios up to 5 are acceptable without modification. If the ratio is between 5 and 10 then a fuel meeting the standard requirements must be used for start and acceleration to avoid compressor surge. If the ratio is above 10, extensive turbine redesign is required to accommodate larger turbine mass flow.

10.1.15 HYDROGEN AND CARBON MONOXIDE IN GAS - The presence of hydrogen and/or carbon monoxide in the fuel gas above the specified levels can cause safety and materials problems. If hydrogen level is above 4% by volume, a review of the fuel system materials for hydrogen embrittlement is required. If hydrogen level is between 4 and 9% or carbon monoxide level is between 12.5 and 18%, then a specially sequenced start and purge system must be used. At hydrogen levels above 9% or carbon monoxide level is between 12.5 and 18%, then a specially sequenced start and purge system must be used. At hydrogen levels above 9% or carbon monoxide levels above 18%, starts and accelerations must be made on a standard fuel with transfer to the hydrogen or carbon monoxide bearing fuel at idle or above. If hydrogen level is above 4% or carbon monoxide is above 12.5%, special safety provisions must be taken such as detectors in the package, separation of the engine and generator compartments, and leak-free piping joints. Since carbon monoxide is toxic, if it is present in the fuel gas, precautions must be taken to detect leaks.

10.1.16 FLAMMABILITY - The ratio of the upper-to-lower flammability limits is an indication of whether the gas will allow engine starting and adequate range of operation, in particular on single shaft generator sets.

10.1.17 FLAME TEMPERATURE - The adiabatic flame temperature of gas fuels is used to determine its suitability. If the value is below the limit, major combustion system modifications and/or changes to operating procedures may be required.

10.1.18 PARTICULATES IN GAS - Solid particles in gas can cause wear and plugging of control components and fuel injectors. Malfunctions of the control system and damage to the combustor and turbine section would be the result.

10.1.19 FUEL SUPPLY TEMPERATURE - For gas fuels there are two considerations: one is the dew point. The fuel must be supplied at the inlet flange to the package, 50°F above the dew point to ensure that no liquids can enter the fuel control and injection system. Liquids in a gas system cause malfunction and serious thermal damage to the engine if liquid is injected with the gas into the engine. The other consideration is the thermal capability of the materials in the control system.

For distillate fuels, the temperature must be above the cloud point to prevent plugging of the filters and control components. It must also be above the temperature that corresponds to a viscosity of 12 centistokes to ensure satisfactory atomization required for starting performance. The range of allowable temperatures is determined by the thermal capabilities of the materials in the control system.

For natural gas liquid fuels, the allowable temperature range is determined by the control system materials and the critical point of the lightest fuel. This latter constraint is to limit the vapor pressure on the fuel.

10.1.20 VISCOSITY - Viscosity of a fluid is a measure of its resistance to flow. In distillate fuel it is highly significant since it indicates both the relative ease with which the fuel will flow or may be pumped and a measure of atomization by the fuel injectors. Minimum viscosity is limited because standard fuel pumps will not perform satisfactorily if viscosity reaches too low a value. Maximum viscosity is limited since too high a viscosity can cause excessive pressure losses in the piping system and poor fuel atomization.

10.1.21 RELATIVE DENSITY OF DISTILLATE - Relative density alone is of no significance as an indication of the burning characteristics of fuel oil. However, when used in conjunction with other properties, it is of value in weight-volume relationships and in calculating the heating value of the fuel.

10.1.22 REID VAPOR PRESSURE - The Reid vapor pressure is a criterion of freedom from foaming and fuel slugging due to vaporization of the fuel. Special fuel systems are required if the Reid vapor pressure is above the specified level.

10.1.23 CLOUD AND POUR POINTS - Cloud point is the temperature at which a cloud or haze of wax crystals appears. Operation at temperatures below the cloud point causes plugging of filters. Pour point is an indication of the lowest temperature at which a fuel can be stored and still be capable of flowing under gravitational forces. The cloud and pour points are prescribed in accordance with the conditions of storage and use. Heated tanks and lines may be required where ambient temperature is below the cloud and pour points of the proposed fuels.

10.1.24 FLASH POINT - Flash point is an indication of the maximum temperature at which a fuel can be stored and handled without serious fire hazard. The minimum permissible flash point is usually regulated by Federal, State, or Municipal laws and is based on accepted practices in handling and use.

10.1.25 DISTILLATION - The distillation test indicates the volatility of a fuel and the ease with which it can be vaporized and burned. It also indicates the possibility of carbon deposition and smoke formation.

10.1.26 AROMATICS AND OLEFINS - Combustion of highly aromatic fuels can result in increased smoke. Carbon or soot deposition and increased combustor metal temperature resulting in exhaust particulate emissions, opacity violations, and reduced engine life.

Use of fuels with excessive olefin content can result in decomposition of the fuel, which causes plugging of fuel system components including the fuel injectors.

10.1.27 LOWER HEATING VALUE (LHV) - The lower heating value is used to calculate actual fuel consumption. Also, if the value for distillate fuels is below the limit, it is an indication of a heavy fuel, which may have other properties exceed in the limits.

10.1.28 CARBON RESIDUE - Carbon residue is a measure of the carbonaceous material left in a fuel after all the volatile components are vaporized in the absence of air. It is a rough approximation of the tendency of a fuel to form carbon deposits in the combustion system of the gas turbine.

10.1.29 ASH - Ash is the noncombustible material in a fuel. Ash-forming materials may be present in fuel in two forms: (1) solid inert particles and (2) oil or water-soluble metallic compounds. The solid particles are for the most part the same material that is designated as sediment in the water and sediment test. Depending on their size, these particles contribute to wear in the fuel system and to plugging of fuel filter and fuel injectors. The soluble metallic compounds have little or no effect on wear or plugging, but may contain elements that produce hot section corrosion and deposits as described above.

10.1.30 COPPER STRIP CORROSION - This test provides an indication of possible corrosive attack of non-ferrous metals such as copper, brass, and bronze.

10.1.31 WATER AND SEDIMENT IN DISTILLATES - Appreciable amounts of water and sediment in fuel tend to cause fouling of the fuel-handling facilities and to give trouble in the fuel system of the turbine. An accumulation of sediment in storage tanks and on filter screens may obstruct the flow of fuel from the tank to the package. Water in distillate fuels may cause corrosion of tanks and equipment. Water in the fuel also provides a place for microbiological growths to occur. These growths can plug filters and screens and can promote corrosion of fuel tanks.

10.1.32 COMBUSTIBLES IN AIR - If combustibles are ingested into the engine inlet, the hydrocarbon and carbon monoxide levels in the exhaust will be increased assuming none of the combustibles complete combustion.

10.1.33 FUEL BOUND NITROGEN - Fuel Bound Nitrogen (FBN) found in distillate fuels causes NOx in the exhaust to increase. In order to offer liquid emissions guarantee, FBN must be determined by fuel analysis.

10.1.34 LUBRICITY - Low sulfur diesels tend to have a reduced lubricity and that could affect the life and reliability of the fuel pumps. The processes used to remove the sulfur from fuel also remove the natural occurring lubricity compounds in the fuel. Special fuel pumps are required when fuels do not meet the requirement listed in Table 6.

APPENDIX A

TOTAL SITE CONTAMINATION WORKSHEET
FORM 3091

(Blank form and Sample Calculation)

Solar Turbines
A Caterpillar Company

Specification No. ES 9-98AB

TOTAL SITE CONTAMINATION WORKSHEET

TOTAL SITE CONTAMINATION WORKSHEET		INQUIRY NO.	Q.R. NO./S.O. NO.
CUSTOMER		DATE ISSUED	DATE REQUIRED
ENGINE MODEL	FUEL	FREQUENCY OF STARTS	RUNNING TIME PER START
EQUIPMENT LOCATION		LOAD CONDITIONS ☐HIGH ☐LOW ☐STEADY ☐CYCLIC	
ALTITUDE FEET	AMBIENT TEMPERATURE RANGE °F MAXIMUM; °F MINIMUM		AVERAGE HUMIDITY %

INSTRUCTIONS - Enter best known values. Explanations and helpful information are provided on the reverse side. Perform calculations as indicated to obtain total site contamination for each (or all) species of interest.

EVAPORATIVE COOLER ☐YES ☐NO WATER INJECTION ☐YES ☐NO

		Concentrations, ppmw	Na + K	S	F	V	Pb	Ca + Mg
	1	Ambient Air, ppmw						
	2	Fuel, ppmw						
	3	Injected Water, ppmw						
	4	Evaporative cooling water, ppmw						
	5	LHV, Btu/#						
	6	Compute: 18,380/[5]						
Air	7	Air-to-Fuel Ratio						
Air	8	1 - N (Correction Factor)						
Air	9	Compute: [1] x [6] x [7] x [8], ppmw FEC						
Fuel	10	1 - K (Fuel Factor)						
Fuel	11	Compute: [2] x [6] x [10], ppmw FEC						
Water	12	Water-to-fuel Ratio						
Water	13	Compute: [3] x [6] x [12], ppmw FEC						
Evaporative Cooling	14	E.C. Carryover Rate, GPM						
Evaporative Cooling	15	1 - E (Mist eliminator Factor)						
Evaporative Cooling	16	Fuel Flow rate, million Btu/hr						
Evaporative Cooling	17	Compute: $\frac{[4]x[5]x[6]x[14]x[15]x5x10^{-4}}{[16]}$ ppmw FEC						
	18	Total Contaminants, ppmw FEC [9] + [11] + [13] + [17]						
	19	Max. Allowable Limits, ppmw FEC per ES 9-98	0.5	10,000	1	0.5	1	2

COMMENTS:

PREPARED BY: ______________________ DATE:__________

Row #	Term Explanation	Typical Values
1	Concentration of contaminant in ambient air, expressed as ppmw in air	Unless available for site of interest, select most appropriate value for S and Na+K from ranges given below. All other contaminants are assumed to be zero unless specifically known to be present.

S(ppmw)		Na+K(ppmw)	
.0.001	Moderately clean	>0.001	Arctic
0.050-0.007	City	>0.010	Agricultural/Residential
.0.100	Industrial	0.003-0.010	Industrial
>0.100	Processing/Chemical Plant	0.007-0.260	Coastal (less than 1 mile)
		0.010-0.136	Desert
		0.010-3.600	Offshore platform

Row #	Term Explanation	Typical Values
2	Concentration of contaminant in fuel supply expressed as ppmw in fuel	For gas fuels, and residual liquid water from processing can be very high in dissolved salts. If possible, analyses of trace water present in gas fuel is the best method for obtaining reliable data. For liquid fuels, direct measurement for contaminants is recommended. Some APPROXIMATE values for S and Na+K are provided here:

S(ppmw)	Na+K(ppmw)	
1,000	.0.1	pipeline gas
>10,000	>3.0	process gas
>10,000	>3.0	biomass gas
>10,000	>1.0	distillate liquid fuel

Row #	Term Explanation	Typical Values
3	Concentration of contaminant in injected water, expressed as ppmw in water	Contaminants in treated water at entry into combustor should be known, either based on actual water analyses or equipment specifications (auto shut down limit).
4	Concentration of contaminant in water delivered to header of evaporative cooler, expressed as ppmw	Contaminants in reservoir (for recirculating systems) or feedwater (for non-recirculating systems) should be known, either based on actual water analyses or equipment specifications.
5	Lower heating value, expressed as 10^6 But/hr	Available from fuel analysis report.
6	FUEL LHV ADJUSTMENT FACTOR USING 18,380 BTU/# AS REFERENCE FUEL PER ES 9-98.	
7	Air-to-fuel ratio	Use actual value -generated by FASTE run at site specific conditions with project fuel. Otherwise: Multiply by LHV Btu/pound / 20,000 60.04 for *Mars* 100 60.05 64.08 for *Mars* 90 71.58 for *Centaur* 40 58.07 for *Centaur* 50 62.94 for *Saturn* 20 60.61 for *Mercury* 50 57.21 for *Taurus* 60 57.21 for *Taurus* 70 57.74 for *Titan* 130
8	Correction factor for air cleanup system, N	Use N = 0.99
9	CONTAMINANTS FOUND IN AIR ENTERING ENGINE, [1] x [6] x [7] x [8], PPMW, FUEL EQUIVALENT CONCENTRATION	
10	Fuel factor to account for fuel cleanup system, K	Use K = 0.95 unless instructed otherwise. If no fuel treatment is applicable between supply and engine, use 0 here.
11	CONTAMINANTS FOUND IN FUEL ENTERING ENGINE, [2] x [6] x [10], PPMW, FUEL EQUIVALENT CONCENTRATION	
12	Water-to-fuel ratio	Use actual value. Range is typically from 0.5 to 1.0.
13	CONTAMINANTS FOUND IN INJECTED WATER, [3] X [6] X [12], PPMW, FUEL EQUIVALENT CONCENTRATION	

Row #	Term Explanation	Typical Values
14	Rate of liquid water carried off the evaporation cooler (carryover) into air steam, expressed as gallons per minute	It is expected that during the duty cycle of the engine, liquid water can accidentally enter the air steam. Use the following values unless otherwise instructed by Package Engineering. 2.8 GPM for *Titan*130 1.7 GPM for *Mars* 1.5 GPM for *Taurus* 70 1.3 GPM for *Taurus* 60 0.9 GPM for Centaur 40 and 50, *Mercury* 50 0.5 GPM for *Saturn*
15	Adjustment factor for mist eliminator if applicable, E	Mist eliminators are required for evaporative cooler installations. Use the following values unless otherwise instructed. No mist eliminator: E = 0 All non-vane type mist eliminators: As indicated by manufacturer of mist eliminator. Vane type mist eliminator: E > 0.95
16	Fuel flow rate expressed in million Btu per hour	Conversion from million Btu/hour to pounds per sec of fuel flow is included in the expression in the final expression in [17].

17 CONTAMINANT FOUND IN WATER CARRYOVER FROM EVAPORATIVE COOLER, IF USED

$$\frac{[4] \times [5] \times [6] \times [14] \times [15] \times 5 \times 10^{-4}}{[16]}$$ PPMW, FUEL EQUIVALENT CONCENTRATION.

18 TOTAL CONTAMINANT FROM ALL SOURCES, [9] + [11] + [13] + [17], PPMW, FUEL EQUIVALENT CONCENTRATION.

19 MAXIMUM ALLOWABLE LIMITS FOR EACH CONTAMINANT PER ES 9-98, PPMW, FUEL EQUIVALENT CONCENTRATION

Solar Turbines
A Caterpillar Company

Specification No. ES 9-98AB

TOTAL SITE CONTAMINATION WORKSHEET		INQUIRY NO.	Q.R. NO./S.O. NO.
CUSTOMER EXAMPLE		DATE ISSUED	DATE REQUIRED
ENGINE MODEL CENTAUR T4000	FUEL Diesel	FREQUENCY OF STARTS Monthly	RUNNING TIME PER START 500 hours
EQUIPMENT LOCATION San Diego, California	LOAD CONDITIONS ☐HIGH	☐LOW ☐STEADY	☐CYCLIC
ALTITUDE 100 FEET	AMBIENT TEMPERATURE RANGE 90°F MAXIMUM;	40°F MINIMUM	AVERAGE HUMIDITY 50% RH

INSTRUCTIONS - Enter best known values. Explanations and helpful information are provided on the reverse side. Perform calculations as indicated to obtain total site contamination for each (or all) species of interest.

EVAPORATIVE COOLER ☐NO   WATER INJECTION ☐YES ☐NO

		Concentrations, ppmw	Na + K	S	V	Pb	F	Ca + Mg
	1	Ambient Air, ppmw	0.03	20	0	0	0	0
	2	Fuel, ppmw	0.1	500	0.05	0	0	0
	3	Injected Water, ppmw	0.2	0.1	0	0	0	0
	4	Evaporative cooling water, ppmw	10	100	0	0	0	0
	5	LHV, Btu/#	20,100					
	6	Compute: 18,380/[5]	0.914					
Air	7	Air-to-Fuel Ratio	68					
Air	8	1 - N (Correction Factor)	0.01					
Air	9	Compute: [1] x [6] x [7] x [8], ppmw FEC	0.019	12.4	0	0	0	0
Fuel	10	1 - K (Fuel Factor)	1.0	1.0	1.0	1.0	1.0	1.0
Fuel	11	Compute: [2] x [6] x [10], ppmw FEC	0.09	457	0.04	0	0	0
Water	12	Water-to-fuel Ratio	0.8					
Water	13	Compute: [3] x [6] x [12], ppmw FEC	0.15	0.08	0	0	0	0
Evaporative Cooling	14	E.C. Carryover Rate, GPM	0.9					
Evaporative Cooling	15	1 - E (Mist eliminator Factor)	0.05					
Evaporative Cooling	16	Fuel Flow rate, million Btu/hr	40					
Evaporative Cooling	17	Compute: $\frac{[4]x[5]x[6]x[14]x[15]x5x10^{-4}}{[16]}$ ppmw FEC	0.10	1.4	0	0	0	0
	18	Total Contaminants, ppmw FEC [9] + [11] + [13] + [17]	0.36	471	0.04	0	0	0
	19	Max. Allowable Limits, ppmw FEC, per ES 9-98	0.5	10,000	0.5	1	1	2

COMMENTS

PREPARED BY: ______________________ DATE:__________

APPENDIX B

DERIVATION OF TOTAL FUEL EQUIVALENT CONCENTRATION EQUATION FOR UNDESIRABLE CONTAMINANTS

The expression given in paragraph 3.1.3 for directly fired applications is derived from first principles in section 1. Section 2 explains the incorporation of system efficiencies into this fundamental expression and its use in the Total Site Contamination Worksheet, Form, 3091, with the appropriate unit conversions.

B1.0 Derivation of Fundamental Expression for Total Fuel Equivalent Concentration (For Directly Fired Applications Only)

Solar's air, fuel, and water specification is based on FUEL EQUIVALENT CONCENTRATIONS, i.e., the concentration of a given contaminant as if that given contaminant were present in the fuel alone, with the fuel having a LHV of 18,380 Btu/lb or 10,212 kcal/kg.

Nomenclature used in the derivation is given in Table B-1.

Table B-1. Nomenclature for Fuel Equivalent Derivation

Input Steam to Gas Turbine	Mass Flow Rate	Concentration of i^{th} Contaminant	Mass Flow Ratios of Each Steam or Fuel
Reference Fuel	r	R_i	1
Fuel	f	F_i	1
Air	a	A_i	a/f or (AFR)
Water	w	W_i	w/f or (WFR)
Steam	s	S_i	s/f or (SFR)
Carryover	c	C_i	c/f or (CFR)

(LHV) = lower heating of a given fuel, Btu/lb
i = Na, K, V, Pb, etc.
T_i = Fuel equivalent for the reference fuel which has a lower heating value of 18,380 Btu/lb (10,212 kcal/kg)

The mass flow of the i^{th} contaminant in the combustion products burning the reference fuel is:

$$rR_i + aA_i + wW_i + sS_i + cC_i \quad (1)$$

The total mass flow of the combustion product is:

$$r + a + w + s + c \quad (2)$$

The concentration of the i^{th} contaminant in the combustion products is:

$$\frac{rR_i + aA_i + wW_i + sS_i + cC_i}{r + a + w + s + c} \quad (3)$$

Next suppose that the total mass flow of the i^{th} contaminant in the combustion products came from the reference fuel alone. Let T_i equal the reference fuel equivalent concentration of the i^{th} contaminant. Then, the concentration of the i^{th} contaminant in the combustion products, the environment of the hot section components, would be:

$$\frac{rT_i}{r + a + w + s + c} \tag{4}$$

Equating Eq. (3) with Eq. (4) and dividing through r gives:

$$T_i = R_i + (a/r)\,A_i + (w/r)\,W_i + (s/r)\,S_i + (c/r)\,C_i \tag{5}$$

In order to have an expression that gives the Fuel Equivalent, T_i, for the cases where a fuel, f, of any heating value (LHV) are used, Eq. (5) must be modified. It is required that, regardless of the LHV of either fuel, the flow of each fuel be such that the same thermal input is provided to the engine. Therefore,

$$r\,(18{,}380 \text{ Btu/lb}) = f\,(LHV) \tag{6}$$

or

$$r = \frac{f\,(LHV)}{18{,}380 \text{ Btu/lb}}$$

In addition, it is required for the same T_i that the contribution of the contaminant to the total from either fuel r of fuel f be the same.

$$rR_i = fF_i \tag{7}$$

Combining Eq. (6) and Eq. (7) gives:

$$R_i = \frac{18{,}380}{(LHV)}\ F_i \tag{8}$$

Substituting Eq. (6) and Eq. (8) into Eq. (5) gives:

$$T_i = \frac{18{,}380}{(LHV)}\,F_i + \frac{a}{f(LHV/18{,}380)}\,A_i + \frac{w}{f(LHV/18{,}380)}\,W_i + \frac{s}{f(LHV/18{,}380)}\,S_i + \frac{c}{f(LHV/18{,}380)}\,C_i \tag{9}$$

Finally, rearranging and substituting the nomenclature in the fourth column of Table B-1 gives:

$$T_i = \frac{18{,}380}{(LHV)}\,[F_i + (AFR)A_i + (WFR)W_i + (SFR)S_i + (CFR)C_i] \tag{10}$$

B2.0 Derivation of Expression Used in Form 3091

Taking Eq. (10) and assigning units to the variables result in the following definition of terms. (The steam term is dropped from the basic expression because it is currently not applicable to *Solar* engines.)

$$T_i = \frac{18{,}380}{(LHV)} [F_i + (AFR)A_i + (WFR)W_i + (SFR)S_i + (CFR)C_i]$$

where

T_i = fuel equivalent concentration of contaminant i, in ppmw

LHV = lower heating value of fuel, in Btu/lb

F_i = concentration of contaminant i in fuel entering combustor, in ppmw

AFR = air-to-fuel mass ratio

A_i = concentration of contaminant i in air entering compressor, in ppmw

WFR = water-to-fuel mass ratio

W_i = concentration of contaminant i in water injected into combustor, in ppmw

CFR = carryover water-to-fuel mass ratio

C_i = concentration of contaminant i in carryover water (same as evaporation cooler feedwater), in ppmw

Examining each term in greater detail:

Fuel Term: F_i

Let K = overall efficiency rating for fuel cleanup system

Adjusted fuel term = $F_i (1 - K)$ (11)

Air Term: $(AFR)A_i$

A_i is concentration air entering compressor

$$A_i = (1 - N)A_i^{amb}$$

where N = efficiency of air filter

A_i^{amb} = concentration of contaminant i in ambient air, in ppmw

Adjusted air term = $(AFR)(1 - N)A_i^{amb}$ (12)

Water Term: $(WFR)W_i$

W_i is concentration in water injected into combustor, ALSO THE SET POINT FOR AUTOMATIC SHUTDOWN

Carryover Term: $(CFR)C_i$

Let water carryover rate = R gal/min x 8.337 lb/gal

$$= 8.337\ R\ \text{lb/min}$$

Let fuel flow rate $= f$ MBtu/hr

$$\frac{f\ \text{MBtu}}{\text{hr}} \times \frac{1\ \text{hr}}{60\ \text{min.}} \times \frac{\text{lb}}{\text{LHV Btu}} \times \frac{10^6\ \text{Btu}}{\text{MBtu}} = \frac{16{,}700f\ \text{lb/min}}{\text{LHV}}$$

Let E = efficiency of mist eliminator

Carryover rate = (1 - E) (8.337R) lb/min

$$\text{CFR} = \frac{8.337R\ (\text{LHV})\ (1 - E)}{16{,}700f}$$

$$= 4.99 \times 10^4 R\ (\text{LHV})\ (1 - E)/f \qquad (13)$$

Substitute in Equation (10),

$$T_i = \frac{18{,}380}{\text{LHV}} \Big[F_i\ (1 - K) + (\text{AFR})\ (1 - N)A_i^{amb} + (\text{WFR})W_i$$

$$+ \frac{[4.99 \times 10^{-4} R\ (\text{LHV})\ (1 - E)]}{f}\ C_i\Big] \qquad (14)$$

or

$$T_i = \frac{(18{,}380)}{\text{LHV}}\ (1 - K)F_i + \frac{(18{,}380)}{\text{LHV}}\ (\text{AFR})\ (1 - N)A_i^{amb}$$

$$+ \frac{(18{,}380)}{\text{LHV}}\ (\text{WFR})W_i + \frac{(18{,}380)}{\text{LHV}}\ (5 \times 10^{-4})R\ (\text{LHV})\ (1 - E)\ \frac{C_i}{f} \qquad (15)$$

where $\frac{(18{,}380)}{\text{LHV}}\ (1 - K)F_i$ = fuel equivalent concentration of i^{th} contaminant in fuel, ppmw

$\frac{(18{,}380)}{\text{LHV}}\ (\text{AFR})\ (1 - N)A_i^{amb}$ = fuel equivalent concentration of i^{th} contaminant in air, ppmw

$\frac{(18{,}380)}{\text{LHV}}\ (\text{WFR})W_i$ = fuel equivalent concentration of i^{th} contaminant in injected water, ppmw

$\frac{(18{,}380)}{\text{LHV}}\ (5 \times 10^{-4})R\ (\text{LHV})\ (1 - E)\ \frac{C_i}{f}$ = fuel equivalent concentration of i^{th} contaminant in evaporation cooler feedwater, ppmw

T_i = sum of fuel equivalent concentration of i^{th} contaminant from all sources, ppmw

Equation (15) is used in Form 3091.

APPENDIX C

LIQUID FUEL HANDLING AND STORAGE REQUIREMENTS

C.1 LIQUID FUEL STORAGE AND HANDLING SYSTEM SELECTION

The following section details the configuration required for liquid fuel handling and storage systems for Solar gas turbines operating in Dual Fuel or Liquid Fuel only configurations. Refined quality liquid fuel may be contaminated during transportation or storage and it is important to provide auxiliary fuel cleaning systems to maintain or restore fuel quality prior to delivery to the gas turbine package.

A complete fuel composition analysis for the liquid fuel should be submitted at time of equipment quotation so that verification of compliance can be confirmed and requirements or recommendations for package modifications to ensure proper operation and turbine durability. This verification also applies to liquid fuel that is to be used at a preliminary package pre-commissioning phase, typically at a shipyard or fabrication yard. Even temporary operation with non-compliant fuel can be detrimental to the durability of a gas turbine.

The selection of liquid fuel storage, handling and treatment systems is a function of the site location and expected liquid fuel operation per year with site qualification as follows:

Inland	10 miles (16 km) away from an ocean or body of salt water. Fuel supply, transportation and handling systems are generally of high quality.
Coastal	Near shore of body of salt water where salt air is present. Fuel supply is not barged or transported by sea, otherwise treat as Marine.
Marine/ Offshore	Offshore fixed or floating platforms as well as land based installations near a body of salt water. Fuel supply is delivered via sea transport or where fuel quality is a concern.

Table C.1 Liquid Fuel Handling, Storage and Treatment Requirements

Liquid or Dual Fuel - Conventional or SoLoNOx (Hours of Operation on Liquid Fuel)			
Installation	**Inland**	**Coastal**	**Marine / Offshore**
Fuel Storage Tank with Central Sump and Floating Suction **See C.2.1**	Required	Required	Required
Dual in-line Filter/Coalescer System **See C.2.2**	Recommended Operation Up to 1,000 hrs/yr	Required Operation Up to 1,000 hrs/yr	Option Not Available
Buffer Tank and Centrifuge System **See C.2.3**	Required Operation 1,000 – 4,000 hrs/yr	Required Operation 1,000 – 4,000 hrs/yr	Required Operation Up to 1,000 hrs/yr
Buffer Tank and Dual Centrifuge System **See C.2.4**	Required Operation over 4,000 hrs/yr	Required Operation over 4,000 hrs/yr	Required Operation Over 1,000 hrs/yr
Monitoring System Comprised of a Duplex Filter for Detecting Solid Contamination **See C.2.5**	Required (Unless C.2.2 is Selected)	Required (Unless C.2.2 is Selected)	Required
Exceptions to these requirements are subject to review and approval by Solar Turbines engineering departments.			

C.2 FUEL STORAGE AND HANDLING REQUIREMENTS

This section describes the fuel handling and treatment equipment specified in Table C.1, along with critical procedures that need to be followed. Three basic fuel handling and storage systems options with varying levels of complexity to meet the requirements defined in Table C1.

C.2.1 FUEL STORAGE TANK WITH CENTRAL SUMP AND FLOATING SUCTION PIPE

Fuel storage facilities must consist of one or several main storage tanks and/or holding tanks with floating suction pipes, sloping bottoms with a drain at the low point to remove water and sediment, and special inlet distributors, such as a velocity diffuser, to minimize sediment disturbance (Figure C.1). Copper-bearing steel or black iron are acceptable for storage tanks and interconnect pipes. Coatings should be insoluble in and non-reactive with the fuel. Galvanized or cadmium plated fittings or other components must be avoided.

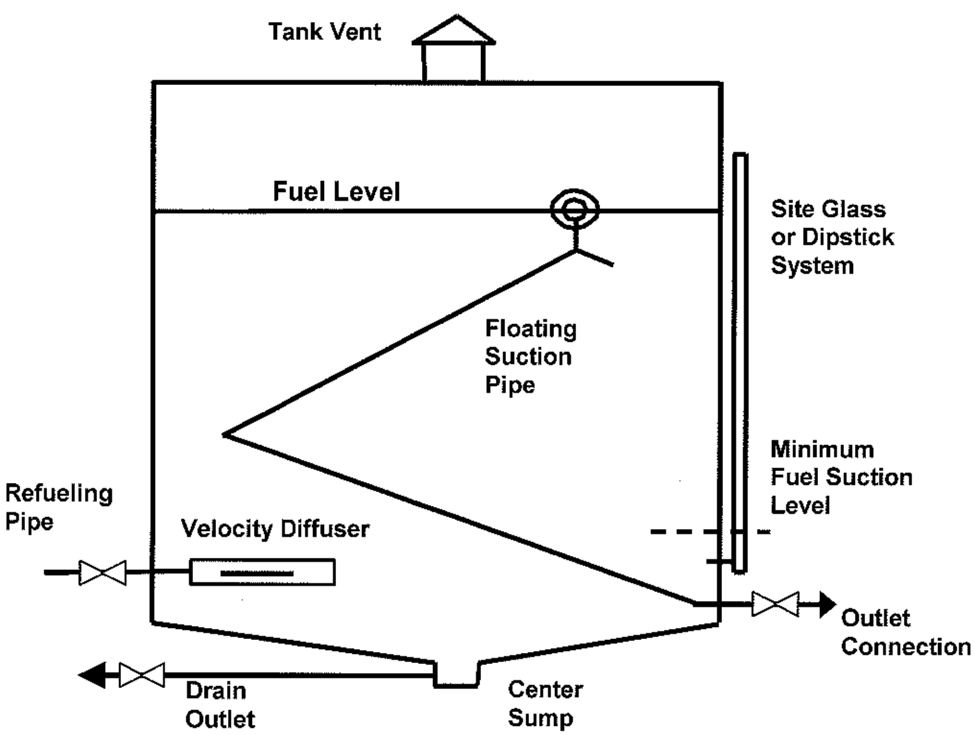


Figure C.1 Schematic of Main Gas Turbine Liquid Fuel Storage Tank

C.2.1.1 FUEL STORAGE TANK HANDLING PROCEDURES

1. Fuel should be clean and conform to Solar's fuel specification, ES 9-98, when the fuel arrives at the site. Gas turbine liquid fuels are often contaminated with leaded gasoline or salty ballast water in the shipping tanks during transportation. Simple tests can be carried out to check for such contamination.
2. Clean truck or barge unloading equipment and hoses from road dust and water before each use. Always keep unloading equipment covered and shipping tanks closed when not in use.
3. Fuel delivery must be monitored by the operator to ensure that contaminants are not introduced in to the tank(s).
4. The fuel cloud point must be suitable for the conditions under which the fuel is to be stored. This may require a heated tank or lines.
5. Frequently drain storage tanks to remove sediment and water.
6. Fuel in the main storage tanks must not be sent directly to the gas turbine package without centrifuging or filtering first.

C.2.2 TWIN FILTER/WATER COALESCER SYSTEM - WHEN CENTRIFUGE IS NOT REQUIRED

Figure C.2 shows a twin filter / water coalescer system. This will typically be specified on such projects where a centrifuge system is not required. The Filter / Coalescer systems are designed to remove water and solids from liquid fuels and positioned in the fuel supply line to the gas turbine package. Water can be automatically drained but solids filters may have to be changed on a regular basis. Two suitably sized units set up in parallel will allow the filters to be changed out without shutting down the engine when the ΔP across the filter becomes too high. Each unit will require a 5-micron filter for solid particles. A ΔP monitor with alarm and shutdown limits should be included to ensure that the filter does not collapse in the event of upstream system failure. A water level gauge will also be required to activate the automatic drain and actuate alarms in the event of drain malfunction.

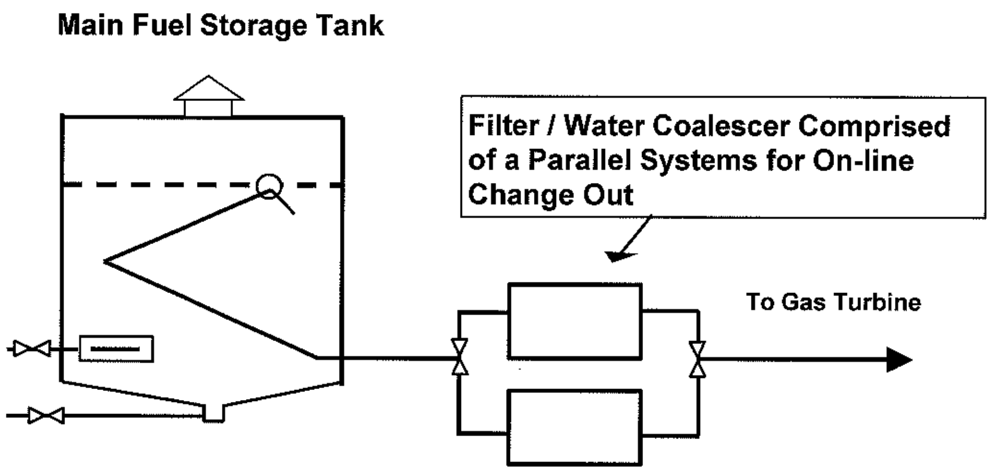


Figure C.2 **On line Filter/Coalescer System for Applications not Requiring a Centrifuge Cleaning System**

C.2.3 SINGLE CENTRIFUGE AND STORAGE TANK SYSTEM

Figure C.3 shows a single centrifuge and tank storage system for applications where the buffer tank contents are sufficient to cover a complete liquid running period without refilling. The storage tank should be sized to cover the longest single period of liquid operation anticipated. Filling can be from another storage tank, road tanker, or barge.

In this scenario, the centrifuge would be used to clean the fuel after delivery has been made, and then periodically thereafter on a regular basis to remove accumulating moisture and sediment dropping out of the fuel as it sits.

Centrifuges with water scrubbing capability are essential on sites (typically coastal or offshore), where significant contamination is expected.

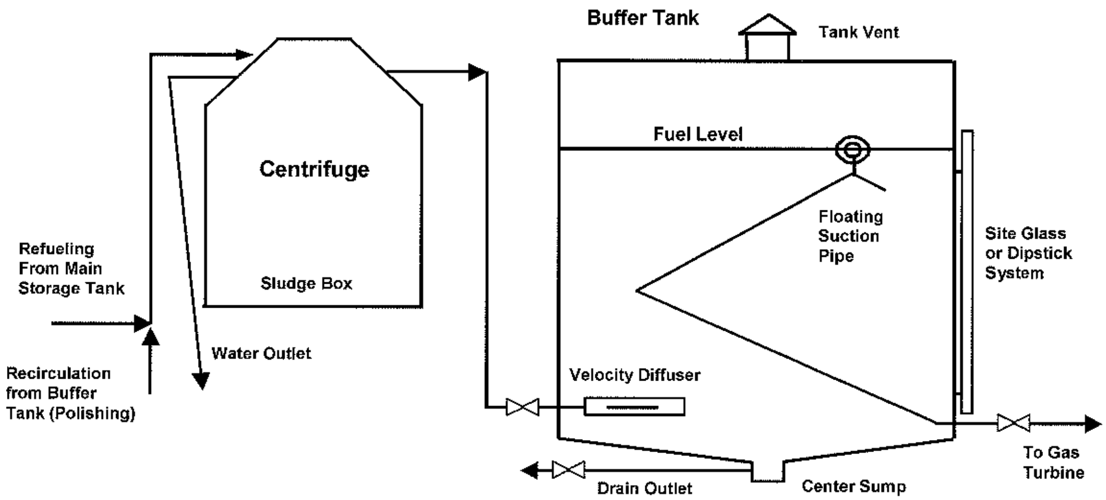


Figure C.3 Single Centrifuge and Storage Tank

C.2.3.1 FUEL BUFFER TANK AND CENTRIFUGE HANDLING PROCEDURES

1. Never "agitate" the fuel. Fuel in a buffer tank should be allowed to settle without being disturbed for at least eight hours before being used as turbine fuel.
2. Tank filling and fuel recirculation through the centrifuge should not be done when the tank is being used to supply a turbine.
3. Periodically remove fuel from the lower end of the holding tank and clean tanks by returning this fuel to the main storage tank(s) via centrifuges. This recirculation minimizes the accumulation of dirt and contaminants in the clean tanks.
4. Centrifuges should be cleaned out per manufacturers recommendations.
5. If sodium and/or potassium are present in the fuel, the centrifuge must also incorporate a water scrubbing system.
6. Frequently drain tanks to remove accumulated sediment and water.

C.2.4 DUAL CENTRIFUGE AND STORAGE SYSTEM

For applications where turbines will be operating continuously on liquid fuel for long periods, there should be at least two fuel conditioning systems feeding into a correctly non-metallic or fully lined buffer tank for final fuel settling and supply.

Figure C.4 shows the most comprehensive system for liquid operation per requirements specified in Table C.1.

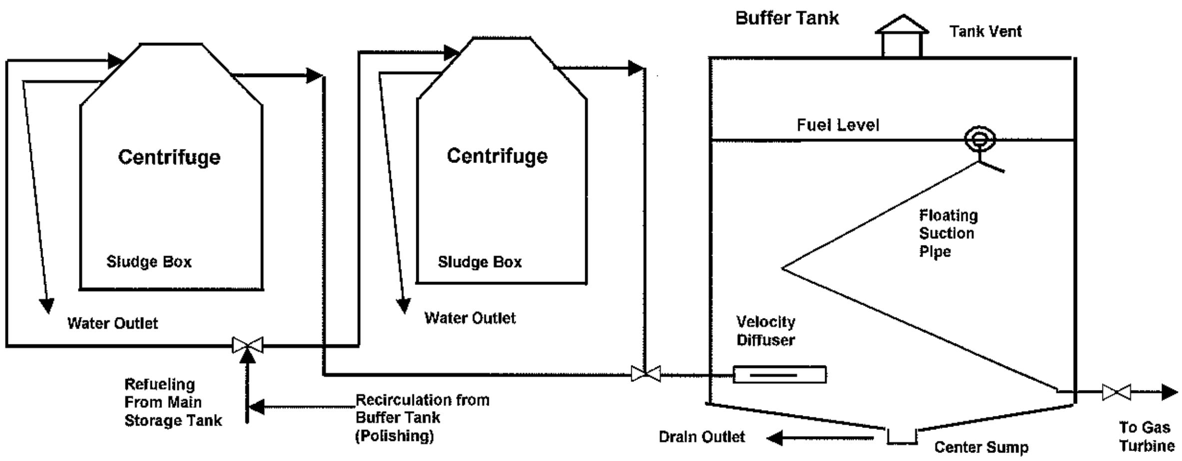


Figure C.4 Dual Centrifuge System

C.2.4.1 FUEL BUFFER TANK AND CENTRIFUGE HANDLING PROCEDURES

1. Never "agitate" the fuel. Fuel in a "buffer tank" should be allowed to settle without being disturbed for at least eight hours before being used as turbine fuel.
2. Tank filling and fuel recirculation through the centrifuge should not be done when the tank is being used to supply a turbine.
3. Periodically remove fuel from the lower end of the holding tank and clean tanks by returning this fuel to the main storage tank(s) via centrifuges. This recirculation minimizes the accumulation of dirt and contaminants in the clean tanks.
4. Centrifuges should be maintained and cleaned per manufacturers recommendations.
5. If sodium and/or potassium are present in the fuel, the centrifuge must also incorporate a water scrubbing system.
6. Frequently drain tanks to remove sediment and water.

C.2.5 Monitoring System – Duplex Filter

The off-skid Filter Monitor System provides monitoring of the fuel quality just prior to delivery to the turbine package. The system detects water or solid contamination and provides an alarm when the delta-p increases above a set point. This system is not a fuel filter system as its primary function is to monitor the liquid fuel in case the primary filtration or centrifuge systems are not able to clean the fuel as required.

C.3 FUEL MONITORING AND MAINTENANCE

C.3.1 FUEL QUALITY MONITORING

A process is required to monitor the quality of the fuel that is being delivered to the engine and to compile a log of physical and chemical properties of the fuel consumed.

Fuel parameters logged must include:

- Water content
- Sediment content
- Sulfur content
- Analysis of metallic elements
- Sodium and potassium content

C.3.1.1 PROCEDURES

Fuel samples must be taken and analyzed on a regular basis while operating on liquid fuel to ensure that the fuel contaminants do not exceed fuel specification. This can be accomplished via an automated system or by taking a sample from the liquid supply line to the engine and sending to a qualified laboratory. The frequency should be sufficient to ensure that every batch of fuel delivered is analyzed at least once. The log should be made available for examination during routine package maintenance and engine inspections.

If specification limits are exceeded the problems must be remedied or prevailing equipment warranties may be affected.

C.3.2 ANNUAL INJECTOR FLOW TESTS AND INSPECTION

An annual inspection measuring the injector flow area is required to determine if the unmonitored main and pilot liquid passages are plugging. Please contact the local Solar District Office for assistance.

Solar's SoLoNOx combustion – liquid fuel systems need additional consideration for successful operation. It has been found that excessive fuel bound sulfur, solids, water, sodium and potassium makes internal passages prone to plugging and operators need to provide the right level of treatment commensurate with the frequency and duration of liquid fuel operation and the quality of fuel being supplied to minimize the effects on the fuel system.

C.3.3 SPARE FUEL INJECTORS

To minimize downtime, spare fuel injectors located near installation are recommended for sites where it has been determined that injectors will require frequent cleaning.

APPENDIX D

LIQUID FUEL SUITABILITY FORM

The table below contains the allowable limits for liquid fuel characteristics and contaminants. Solar's Liquid Fuel System Assessment form should be filled out with the Solar Sales Engineer to specify project information that will identify liquid fuel filtration requirements.

Liquid Fuel Suitability Form

Project			
Characteristics	**ES 9-98**	**Project**	**Comments**
Solids	≤2.6 mg/liter of sediment, solid or hard contaminants, 90% of the 2.6 mg shall be less than 5 micron in size. Max allowable size ≤ 10 micron		
Liquid	≤ 0.25 cc free water per liter at an ambient temp of 80 °F (27 °C)		
Sulfur	**10,000 ppmw. (See Table 1). Additional restrictions apply for *SoLoNOx* liquid operation**		
Fuel Bound Nitrogen	Measurement required for liquid emissions guarantees		
Sodium & Potassium	≤ 0.5ppmw		
Vanadium	≤ 0.5 ppmw		
Lead	≤ 1 ppmw		
Ca & Mg	≤ 2 ppmw		
Fluorine	≤ 1 ppmw		
Chlorine	≤ 0.15 % wt		
Others – Mercury, Cadmium, Bismuth, Arsenic, Antimony, Phosphorous, Boron, Gallium, Indium.	≤ 0.5 ppmw		
Kinematic Viscosity	12 centistokes max 1 centistoke min at 100 °F (38 °C)		
Specific Gravity	0.775 min 0.875 max		
Reid vapor pressure	< 3 psia < 20.6 kPa		
Cloud point	At least 10 °F (6 °C) below expected min ambient temp.		
Pour point	At least 10 °F (6 °C) below cloud point		
Flash point	≥ 100 °F (38 °C) or ≥ legal limit		
Distillation	90% evaporated at 640 °F (338 °C) maximum. End point at 690 °F (366 °C) maximum		
Aromatics	35% by volume maximum		
Olefins and Diolefins	5% by volume maximum		
LHV	>18,000 Btu/lb >41838 kJ/kg		
Carbon residue on 10% distillation residue	≤ 0.35 %		
Ash	≤ 0.005 % max		
Copper strip corrosion	No 3 (3hr at 122 °F (50 °C)) in ASTM D130		
Expected annual liquid operating hours			
Lubricity, HFRR @ 60°C	520 micron maximum. by ASTM D6079 or equivalent.		

Fuel System Purge Requirements for New Production Conventional and *SoLoNOx* Combustion Turbines

M. Smolin, C. Holcomb
Solar Turbines Incorporated

PURPOSE

This Product Information Letter (PIL) describes the various purge configurations used with the fuel systems on *Solar*® gas turbines. Purge is used on all liquid fuel and dual fuel turbines, with both conventional and *SoLoNOx*™ combustion systems, to assure good combustion performance, adequate turbine life, and reliable fuel system operation. The primary purge media are externally supplied air and water as well as engine turbine compressor discharge air (PCD air). All liquid fuel circuits and some gas fuel circuits are purged, and the configuration varies with the turbine model. This PIL explains the function of each purge subsystem, when, where and why it is used, and the impact it has on the user.

For aftermarket applications, please consult Solar's local District Office for the appropriate purge system for installed equipment.

PURGE SYSTEM OBJECTIVES

Fuel purge systems are used to prevent three major problems: fuel injector coking, injector-to-injector cross flow (also referred to as crosstalk), and corrosion.

On liquid-fuel only turbines, purge is used to remove residual fuel from the injectors after a turbine shutdown to prevent coke formation in the injector passages. Injectors are exposed to the temperature of the PCD air during operation, but the fuel acts as a coolant to keep the liquid passage temperatures low. After shutdown, the injectors stay hot due to the large thermal mass of the hot turbine casings and, without the fuel cooling, the fuel passage temperatures increase. Fuel that remains in the injector will likely form coke under these conditions.

On dual fuel turbines, purge is used to (a) prevent fuel and combustor gases from entering the inactive fuel circuits during operation (cross flow), (b) cool fuel passages prior to introducing liquid fuel, and (c) remove residual liquid fuel from the fuel injectors following liquid fuel operation after either a turbine shutdown on liquid fuel or a transfer from liquid to gas fuel during turbine operation. The scenario for coke formation is the same as described above, except that it can extend for a longer time if the turbine continues to run on gas fuel.

Symptoms of injector fouling, primarily cased by liquid coke formation, may include increased emissions of nitrous oxide (NOx), carbon monoxide (CO) or unburned hydrocarbon (UHC), an increase in the T5 temperature spread, difficulty in starting, and combustor rumble or instability. Injector fouling may alter the flame profile and subject turbine components to damaging temperature levels.

The entrainment of fuel into an inactive or dormant fuel circuit is caused by cross flow between injectors. This cross flow occurs because of small pressure variations within the combustor that cause gases from the combustion chamber to flow into some injectors through the inactive fuel manifold, and back into the combustion chamber through other injectors. This cross flow can entrain fuel and/or combustion products with it, leading to several problems including coke formation, overheating of the fuel tubes and fuel manifolds, and corrosion of fuel system components.

Ingestion of fuel and/or combustion products into inactive fuel passages can cause overheating and mechanical failure of fuel system components. Combustion products that are entrained in the cross flow can raise the air temperature above the compressor discharge temperature. Fuel that entrains with the cross flow can auto-ignite under some conditions, and burn in localized regions inside fuel system components such as the supply tubes or distribution manifold.

If gas fuel with a high level of hydrogen sulfide (H_2S), e.g. sour gas, is entrained into the cross flow, the H_2S can react with water condensed in the fuel manifold to form sulfuric acid (H_2SO_4), which can corrode fuel system components and lead to mechanical failure.

All purge systems are designed with the expectation that the provided liquid fuel meets the requirements of Solar's specification ES 9-98. No purge system can overcome the shortcomings of poor fuel quality. Please refer to Solar's Product Information Letter 162, "Recommendations and Requirements for the Sourcing, Handling, Storage and Treatment of Fuels for Solar Gas Turbines" for guidance.

PURGE SYSTEM DESCRIPTIONS

Solar has developed specific purge systems for different turbine and package models and configurations. Multiple purge subsystems are typically used on any given package in order to accommodate the different operational modes: starting, steady-state operation, fuel transfer, and shutdown. Table 1 provides a summary of the different purge subsystems and where they are applied. A more detailed description of each of the different purge subsystems follows, along with purge media requirements.

Table 1. Fuel Purge Subsystems Used on Solar Products

	Low Pressure Air Purge (Customer Supplied Air)	**Water Purge (Customer Supplied Water)**	**Backward PCD Purge**	**Forward PCD Purge, Uncooled**	**Forward PCD Purge, Cooled**
When Used	Shutdown on Liquid Fuel	Gas-to-Liquid Fuel Transfer Liquid-to-Gas Fuel Transfer Shutdown on Liquid Fuel	Start-Up Steady-State Gas Fuel Operation Liquid-to-Gas Fuel Transfer Shutdown on Liquid Fuel	Steady-State Liquid Fuel Operation in Dual Fuel Application	Steady-State Gas Fuel Operation in Dual Fuel Application
Where Currently Applied	***SoLoNOx*** *Centaur*® 40 *Centaur* 50	***SoLoNOx*** *Taurus* 60 *Taurus* 70 *Mars*® 100 *Titan*™ 130	**Conventional & *SoLoNOx*** All Products	**Conventional** *Centaur* 40 *Mars* *Titan* 130	**Conventional & *SoLoNOx*** (when H_2S in the gas fuel exceeds 0.3% by weight) All Products
				Low BTU Fuel Conventional *Centaur* 50 *Taurus* 60 *Taurus* 70	**Conventional** *Centaur* 50 *Taurus* 60 *Taurus* 70 ***SoLoNOx*** *Taurus* 70
Where Planned to be Applied	-	***SoLoNOx*** *Titan* 250	**Conventional** *Titan* 250 ***SoLoNOx*** *Titan* 250	**Conventional** *Titan* 250	**Conventional** *Titan* 250 ***SoLoNOx*** *Titan* 250

Low Pressure Air

The low pressure air purge subsystem consists of a facility air supply package connection, one shutoff valve, and two isolating check valves, all located on-skid. The subsystem requires air that meets Solar's specification ES 2201 "Auxiliary Service Air", regulated to a pressure of 620 to 1380 kPag (90 to 200 psig). As this pressure is lower than the internal turbine operating pressure (PCD), this purge can only be used following a liquid fuel shutdown, and not during a fuel transfer. After a shutdown on liquid fuel, air is used to force the residual liquid fuel in the turbine distribution manifold(s) and injectors "forward" into the combustor. This air must be available for each turbine model at a pressure and flow rate per Table 2 below. These supply pressures are typical of most facility compressed air supplies. See Figure 1 for a diagram of Solar's typical low pressure air purge subsystem.

Conventional combustion *Centaur* 40 and *Centaur* 50 turbines do not require any external source of air for purging. *SoLoNOx* combustion *Centaur* 40 and *Centaur* 50 turbines use low pressure air purge of the liquid circuits.

Table 2. Low Pressure Air Purge Requirements for SoLoNOx Combustion Turbines

Turbine Model	Pressure	Flow	Duration
Centaur 40 *Centaur 50*	620 – 1380 kPag 90 – 200 psig	0.02 m^3/s 40 scfm	At shutdown, 230 seconds of on-off pulse timing
Taurus 60, 65 & 70 *Mars* 100 *Titan* 130	Not Required		

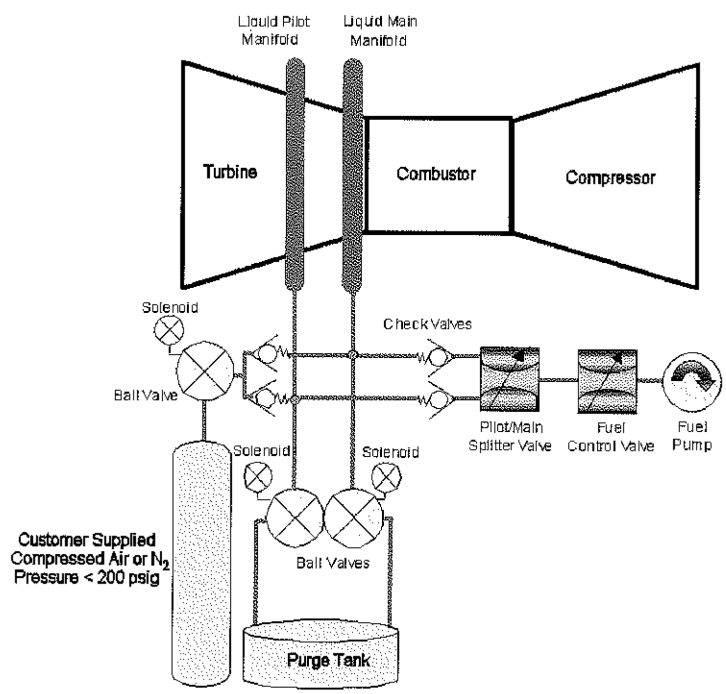


Figure 1 – Typical Air Purge Subsystem

Water Purge

Water is used to purge residual liquid fuel into the combustor after a liquid-to-gas fuel transfer or after a liquid fuel shutdown. In addition, before transferring from gas to liquid fuel, water is used to reduce the wall temperatures of the liquid fuel injector passages. Without this initial water purge, the liquid fuel can form coke as it first enters the injectors and possibly cause injector fouling.

The Solar-provided water purge subsystem consists of items mounted on the turbine package and a separate water pump skid. A strainer and shut-off valve are located on the turbine package. The water pump skid contains a pump and motor assembly, suction strainer, relief valve, pressure transmitter, and water conductivity sensor and analyzer. This skid measures 1.22 m x 0.91 m (4 ft x 3 ft), and supports turbine models up to the *Titan* 130. The pump motor is driven by a variable frequency drive (VFD), and the associated Solar-supplied VFD must be located in a safe (non-hazardous) area. This system has certifications to meet either NEC or ATEX applications. See Figure 2 below for a diagram of a typical water purge subsystem.

The relatively small quantity of purge water required (Table 4), and the water quality requirements as stated in Solar's specification ES 9-98, are such that most applications, including those off-shore, should be able to support water as the turbine purge media.

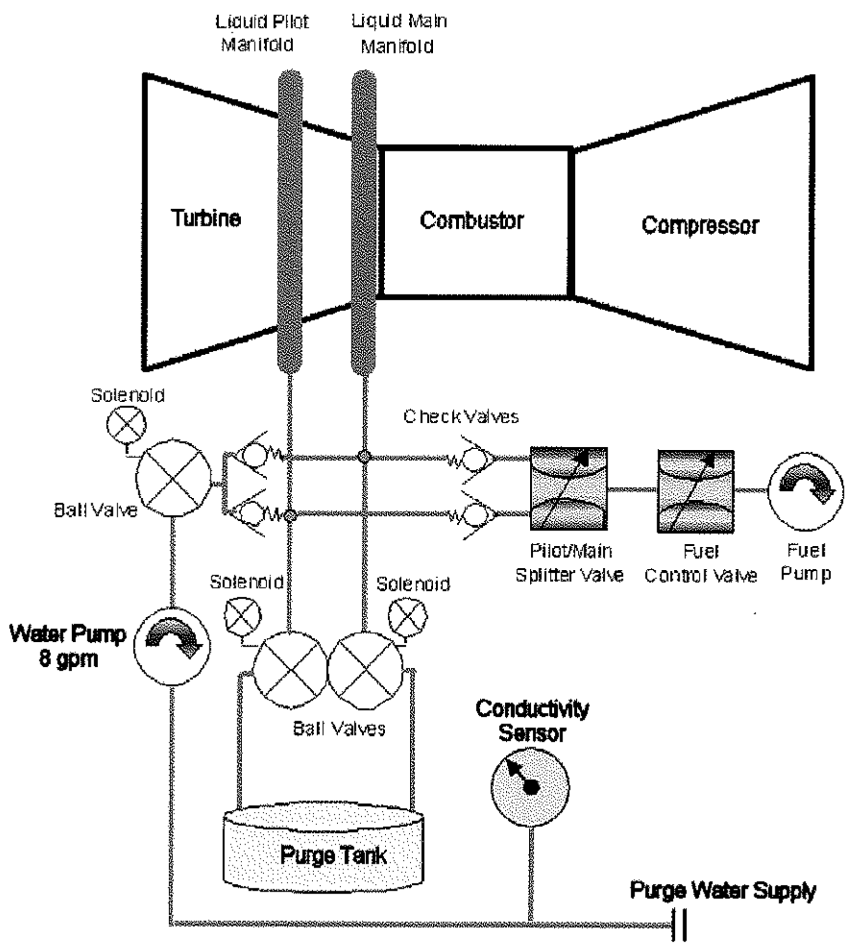


Figure 2 – Typical Water Purge Subsystem

When providing the water treatment system, the customer should consider Solar's requirements for both turbine compressor wash water and purge water. Designing for and maintaining acceptable water quality ensures highest turbine operating availability. Please refer to Solar's Product Information Letter 221 for guidance on water treatment system design and procurement.

Tables 3 and 4 below detail the water supply requirements to support the water purge system. Table 3 details the water pressure required to be maintained at the inlet of the water purge skid and Table 4 details the maximum water consumption and flow requirements of the water supply. In Table 4,the Maximum Water Consumption represents the maximum amount of water required to be supplied in any single transient condition, i.e. fuel transfer or shutdown, and the Maximum Water Flow represents the maximum instantaneous amount of water demanded at any time.

Table 3. Water Purge Pressure Requirements for SoLoNOx Combustion Turbines

Turbine Model	Pressure
Taurus 60 *Taurus* 70 *Mars* 100 *Titan* 130	Solar supplied pump/motor Customer to supply water at 69-276 kPa (10-40 psig) to pump suction
Taurus 65 [1] *Titan* 250 [1]	Under Development

[1] Liquid or dual fuel *Taurus* 65 and *Titan* 250 turbines will require water purge.

Table 4. Water Supply and Handling Requirements for SoLoNOx Combustion Turbines

Turbine Model	Fuel System	Maximum Water Consumption (per Event)		Maximum Water Flow	
		gal	L	gal/min	L/min
Taurus 60	Dual	7.5	28	5	19
	Liquid	5	19	5	19
Taurus 70	Dual	7.5	28	6	23
	Liquid	6	23	6	23
Mars 100	Dual	12	45	8	30
	Liquid	8	30	8	30
Titan 130	Dual	13.3	50	8	30
	Liquid	13.3	50	8	30

During and after a water purge cycle, the water and fuel being purged must be safely handled. The turbine has two skid edge connections from which the discharged liquid must be contained and handled safely: the Liquid Fuel Drain and the Combustor Drain. The recommended minimum capacities of these drain connections are detailed in Table 5 along with the assumptions associated with the volumes below. The drains may be connected to a plant waste handling system or to a dedicated drain tank(s).

Table 5. Minimum Recommended Fluid Waste Handling Requirements for SoLoNOx Combustion Turbines

Turbine Model	Fuel System	Liquid Fuel Drain		Combustor Drain	
		gal	L	Gal	L
Centaur 40	Dual	15	58	20	76
	Liquid	15	58	20	76
Centaur 50 *Taurus* 60	Dual	15	58	20	76
	Liquid	15	58	20	76
Taurus 70	Dual	15	58	24	91
	Liquid	15	58	24	91
Mars 100	Dual	15	58	32	121
	Liquid	15	58	32	121
Titan 130	Dual	15	58	54	182
	Liquid	15	58	54	182

To plan for water consumption and for drain tank or waste handling system sizing, the following assumptions apply:

1. All the water introduced during a purge after a fuel transfer evaporates and exits the turbine exhaust as steam
2. The recommended drain tank(s) or waste handling system is sized to handle a minimum of four (4) full water and back purge cycles. Site operating conditions and facility layout should be considered when sizing the drain tank(s) or waste handling system

Additional recommendations for the drain tank(s) or waste handling system are:

1. The drain tank(s) or waste handling system should be fitted with level switches, vented to a safe area, and fitted with a flame arrestor
2. Drain tank(s) or waste handling system inlets should ensure a downward sloping path from the skid edge connection
3. The drain tank levels and conditions should be monitored as part of the regular maintenance for the turbine

Backward PCD Purge or Liquid Fuel Back Purge

All packages that operate on liquid fuel have a back purge valve to drain the volume between the fuel isolation check valve and the liquid fuel injectors to a skid-edge connection. The drain system is designed without locations that might trap liquids since it depends on gravity and declining PCD during turbine roll-down to effectively drain liquid fuel from the system. The valve is closed during liquid fuel operation. On dual fuel packages, the back purge valve is opened after a fuel transfer to gas to allow PCD to push the remaining liquid fuel to a skid-edge drain connection. After a liquid fuel shutdown or a fail-to-start, the back purge valve is opened. Even when other purge subsystems are employed, the back purge valve is initially opened to drain as much fuel as practical before forward purging.

The purge tank for the disposal of spent liquids shown in Figures 1 & 2 is not usually in Solar's scope of supply. For air purge systems, a nominal 1 liter (1 quart) of liquid fuel is purged for each liquid to gas fuel transfer and on each liquid fuel shutdown. For water purge systems, a nominal 4 liters (1 gallon) of water and liquid fuel is purged for each liquid to gas fuel transfer and a nominal 15 liters (4 gallons) is purged on each liquid fuel shutdown.

Continuous PCD Forward Purge of Gas Manifold (Hot or Uncooled)

This subsystem prevents liquid fuel from migrating to the dormant gas fuel system passages when the turbine is running on liquid fuel. The subsystem consists of two high temperature purge valves, a bleed orifice, and a pressure transmitter. PCD purge air is delivered through the purge valves to the gas fuel manifold. These valves are closed when running on gas fuel (purge not needed), and the volume between the two closed purge valves is monitored with a pressure transmitter and connected to a vent through a small orifice (Figure 3). This pressure transmitter is used to ensure that fuel gas and PCD do not inadvertently mix.

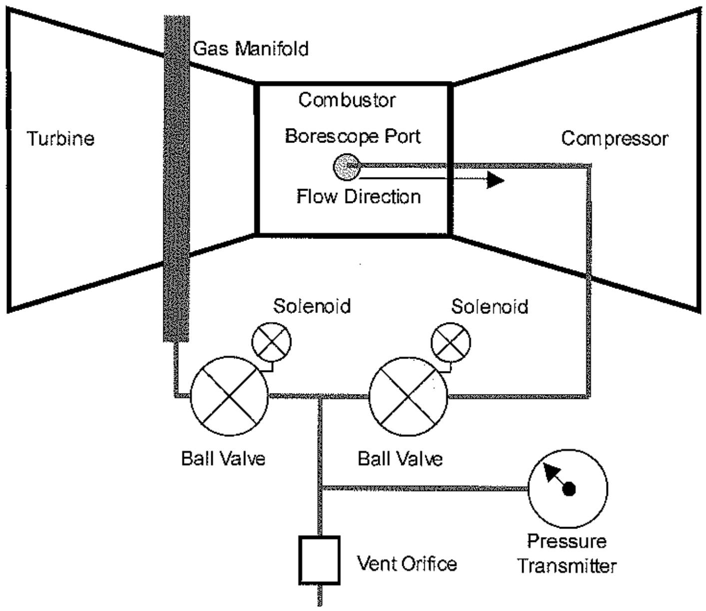


Figure 3 – Typical Hot PCD Forward Purge Subsystem

Continuous PCD Forward Purge of Liquid Manifold (Cooled)

This purge subsystem consists of a PCD cooler, a water trap, purge valves, a vent valve, an RTD, and a pressure transmitter. The purge stream is sourced from PCD and delivered to the cooler, then through the water trap and purge valves to the inlet to the liquid fuel distribution block(s). The water trap is continuously drained through an orifice to a skid-edge drain connection. The purge valves are closed when running on liquid fuel (purge not needed), and the pressure between the valves is monitored and, when required, vented through a small bleed valve to a skid-edge connection (Figure 4).

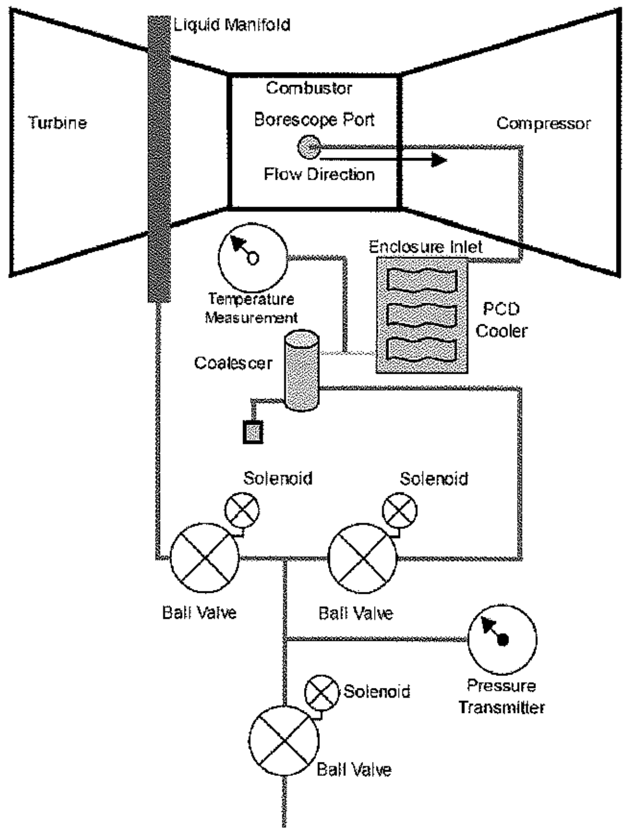


Figure 4 – Typical Cooled PCD Forward Purge Subsystem

Solar Turbines Incorporated
9330 Sky Park Court
San Diego, CA 92123-5398

LIQUID FUEL QUALITY

CITY OF SITKA, ALASKA

SOLAR PROJECT 3R901E

Fuel Sampling April 10, 2013

Project 3R091

Douglas Moore
For Greg Pawlowski
May 10, 2013/Rev0

Visit to Jarvis Power Generation Station, City of Sitka, Alaska, April 10-12, 2013, to Assess Fuel Source and Site Fuel Storage, and to Capture Fuel Samples.

SITE

General

The Jarvis Street Power Station now serves as a peak generation unit for the City of Sitka, to supplement power generated at by the Blue Lake hydro-power facility. Operation occurs when:

- Additional power is needed to meet present demand
- The Blue Lake plant is completely or partially out of service for any reason
- For lake level management for hydro power efficiency (as lake level declines, kWh/acre-foot declines, because head to the water turbine declines.)
- To exercise the four existing reciprocating diesel generators

Installation of the Land-based Titan 130 Mobile Power Unit will provide base-load capability for the City of Sitka for a minimum of 2 months during a major upgrade of the Blue Lake Facility, during which upgrade the Blue Lake facility will generate no power.
Thereafter, the Titan 130 unit will provide backup to the Blue Lake facility and, with existing diesels, provide a flexible generation mix for peaking and for demand growth.

At the recent range of diesel fuel cost, fuel costs $.22-.28/kWh

Existing Generators at Site

- One (1) Caterpillar 5.2 MW
- Two (2) Fairbanks Morse 2.8 kKW
- One (1) Fairbanks Morse 2.o MW

Site Fuel Storage and Conditioning

Existing (refer to attachment A, City of Sitka Sketch)

- One (1) nominally 210,000 gallon steel storage tank.
    - Fuel draw is from a 3 inch pipe 12 inches off the tank bottom (no floating suction)
    - Bottom Water removal is by a siphon pipe about 1 inch off the bottom of an approximately 20 gallon sump in the tank bottom.
    - Tank lower internals are coated
    - No forwarding pumps
- Small per-engine day tanks (<1500 gallon), with bulk filter and boost pump
    - Cat bulk filter is Velcon VF-81C housing, simplex, with 20 micron particulate and desiccant- bead filter elements (refer to attachment B, Velcon filters)
- On-engine coarse (metal screen) and fine (2 micron, for the Cat) final filters
- No facility to re-circulate the nominal 210,000 storage tank through existing filters, in a kidney loop.

Planned

- Additional 2x 30,000 gallon (size not decided) or 1x 50,000 gallon tank (size not decided), similar to existing storage tank. If two tanks, will be valved and piped so one tank, both tanks or the existing tank can be used to feed the T130 at any time.
- Customer is considering removal of the existing tank and dike, and replacing with a number of larger double-wall, self-bunkering tanks..
- Fixed or portable transfer pump and piping, to allow contents of any tank to be transferred to other tanks during tank draining, mandatory testing, and maintenance
- Possible piping and valves to allow any tank to be refreshed by passing through the new bulk filter and the Solar liquid fuel boost pump, filter and coalescer skid
- Possible forwarding pump, if required to meet minimum NPSH requirements for new Solar skid
- Forwarding and transfer pumps and pipes may be combined into one system.
- Filter similar to existing Velcon filter, but 10 micron element, dedicated to the new gas turbine

Present Fuel Inventory

Present fuel inventory is approximately 140,000 gallons, and is a mix of about 50:50 fuel from the latest supplier, Petromarine (110,000 gallons added February, 2012), and the alternate Sitka supplier. Average age is about 20 months. As inventory is consumed, replacement will lower the average sulfur content.

Fuel Additive (refer to attachment C, email)

The present supplier adds approximately 35-65 gallons of lubricity additive per 100,000 gallons of fuel, based on micron wear scar rating. Additive is FPPR Lubricity Custom 130000T. The City of Sitka has been adding an additional Lubricity 100 additive at the rate of 33 gallons additive per 100,000 gallons, but is investigating the possibility of relying solely on supplier lubricity additive.

The City of Sitka has been adding Killem biocide once per year, but plans to switch to a Solar Approved biocide when advised by Solar. Biobor JF is being considered (refer to attachment D)

Fuel Water Removal at Site

Storage tank bottom sump is tested for water at irregular intervals, but samples rarely show as much as an ounce of water. Sitka Utility Director, Mr. Christopher Brewton, believes this may result from:

- The low day-night temperature change at site because of the moderating effect of the ocean (typically 10 F or less).
- The low humidity level of the delivered fuel, absorbing water that condenses into the fuel

The bulk filter used at site for feeding the Cat day tank has a water-absorbing layer, having a capacity of about 1.8 liter.

A fuel sample was captured in March, 2013, by the City of Sitka directly from the 210,000 gallon storage tank bottom sump pipe, analyzed be Analysts, Inc, and found to contain 71 ppm water. (Refer to Attachment E)

Fuel Supply to Site

Fuel supply is competitively bid by the City, and the present supplier is Petro Marine. Petro Marine is expected to be the supplier of fuel for the Titan 130 during its expected 2 months base load run.

Petro Marine manager Jerry Jacobs elaborated their fuel quality management program as follows:

- Fuel is delivered by barge to Sitka from a facility owned by Petro Marine in Ketchican, Alaska
- Barge compartments are inspected pre-shipment for cleanliness and water-free condition. Fuel is never shipped "over bilge water."
- Fuel inventory at the terminal is sampled and analyzed for sulfur content, flash temp, cloud point, and visually inspected for clarity
- Lubricity additives are added pre-shipment in Ketchican
- Red dye is not added for Off Road fuel, because Alaska is exempt from the requirement (red color of site inventory is a residue of shipments from the alternate supplier, who sources in the Lower 48)
- On loadout from Ketchican and on arrival at Sitka, each compartment is sampled and analyzed for Flash temp, SG, and sulfur. Samples for sulfur analysis are sent back to Ketchican on the delivery barge. Sampling and visual inspection is done on departure and arrival for clarity and settled water.
- After Petro Marine Terminal tank filling in Sitka, tank is sampled by dropping a "thief," visually observed for clarity, and sent to Ketchican for sulfur analysis.
- Water id drawn .25 inches off the tank bottom weekly, and rarely is as much as 4 ounces water recovered.
- Fuel is drawn 12 inches off the tank bottom. There is no floating suction.
- Diesel inventory turnover is 30 days or less.
- Petro Marine at present has contract for private aviation on Sitka, and sometimes has the contract for fuel supply to Alaska Air. Petro Marine routinely meets Alaska Air quality and quality verification requirements, which they say are are extreme.
- Biological Degradation of Diesel fuel is rare at Sitka, and never yet observed for shore consumers. Rarely, a boat does develop such contamination (Note: operating boats are warm below decks, and fuel is also warmed by recirculation from diesel injector tips) Biological additives by onshore consumers is, in Petro Marine's opinion, in an abundance of caution.
- Delivery from the Petro Marine dockside terminal at Sitka to City of Sitka Jarvis Street Station is by Petro Marine tanker truck, 3000 gallon, and fuel is filtered at delivery through a 20 micron delivery hose filter. (It is noted that about 9 tanker deliveries per 24 hour operation at full power will be required to fuel the gas turbine).

"The Competition" brings fuel to Sitka from the Lower 48 in container tanks, on deck.

Fuel Samples

Four samples were captured:
1) Sample to Cat bulk filter
2)Sample to Cat bulk filter
3)Sample downstream of Cat bulk filter
4)Sample from Petro Marine dockside terminal diesel storage tank

Sample Procedure

Samples 1,2 (Refer to attachments F and G)

Samples represent present storage tank contents, as delivered to Cat bulk filter

- Cat day tank drawn down 400 gallons by running Cat
- 200 gallons then run from 210,000 storage tank to day tank, at 20 gpm, to establish steady flow, and flow continues throughout sampling.
- Spigot fabricated, installed at Velcon filter top (inlet), flushed with 3+ gallons fuel at max velocity
- Samples captured into Solar .5 ltr super-cleaned sample bottles
- Samples bottles rinsed twice with sampled fluid before capture, after flushing
- Fresh rubber gloves worn by technicians.
- Samples drawn at max flow rate, filling to 80% of sample bottle. Bottle is immediately capped, labeled. Samples captured by Trevor Webb, witnessed for Solar by Doug Moore
- Sample 2 captured 1 minute/10 gallons after sample 1. Otherwise, is identical

Sample 3 (Refer to attachment H)

Samples represent present storage tank contents, after passing through Cat particulates (20 micron) and water bulk filter. This sample represents what will be initial fuel to MPU, except bulk filter will be 10 micron instead of 20 micron.

- Spigot moved to downstream of Velcon filter, flushed, bottle rinsed twice, sample captured, capped and labeled same as sample 1 and 2.

Sample 4 (Refer to attachment J)

Sample represents fuel that is expected to be typical of the contents of the 210,000 gallon storage tank during MPU commissioning and 2 month full-load run.

- Sample drawn from mid-level of Petro Marine's dockside terminal diesel storage tank.
- Technicians wearing fresh rubber gloves
- Petro Marine "thief" loaded with Petro Marine clean .5 ltr sample bottle, thief cork inserted, thief lowered into tank contents, thief cork pulled to capture sample, cork re-inserted.
- Sample transferred into Solar .5 ltr sample bottle. Bottle is immediately capped, labeled.
- Tank was last filled March 8, 2013. Has 17 feet level on date of sample

210,000 Gallon Storage Tank Bottom Water Sample

Water sample would indicate bilge water, if salty (very undesirable) or condensate water if fresh (less undesirable)

- 4 gallons drawn at a high rate of flow from the tank sump pipe

- Sample decanted 1/2 gallon at a time into ½ gallon fresh glass beer stein, and allowed to settle minimum 1 minute.
- Stein inspected against a light to observe cloudiness and settled water droplets. No cloudiness or water droplets observed.
- Last ½ gallon stein allowed to settle 5 minutes, then lamped. No cloudiness or water droplets observed.

Therefore, no water sample could be captured for analysis

Inferences From Record of 2 micron Cat filter Lifetime

Lifetime of 2 micron Cat filter, which appears to be about the same area as the proposed Hydac Solar 2 micron filter elements, is predictive of probably lifetime of the proposed 2 micron elements

1-16-12

- Changed day tank bulk filter, metal screen filter on Cat, 2 micron filter on Cat
- Meter reads 313,198 gallons total

9-6-12

- Changed day tank filter, only
- Meter reads 432,431 gallons total

4-25-13

- 2 micron fuel filter differential is 7 psid and will be changed

Therefore, the Cat 2 micron filter lasts more than 180,000 gallons total.
Assuming it is approximately the same area as the Cat filter, at 18 gpm for MPU fuel consumption, each 2 micron MPU filter can be predicted to last 7 days with similar fuel.

Sample Analysis Results

- Attachment K,L

Fuel Temperature, Viscosity

City of Sitka, Mr. Andy Eggen, described fuel temperature as follows:"The minimum fuel temperature of +15F is rare, maximu of 70F is rare and the average of 35-55F in the coast 90% of the year."

- Analysts, Inc., report #5700761 shows viscosity at 100F is 2.751 cSt
- This corresponds to a viscosity at 15F, the lowest expected fuel temperature, of approximately 10 cSt. See attachment M
- This is lower than the maximum of 12 cSt allowed by ES 9-98, so a fuel heater is not required to lower viscosity
-

Solar Recommendations to City of Sitka

- Contractually, fuel delivered to the inlet of the Solar-furnished boost pump/filters/coalescers skid must meet Solar Specification ES-9-98
- Solar's recommendations are without responsibility
- Two (2) source tanks are preferable to one larger tank because one tank can be settling while the other is being drawn from.
- Solar agrees the capability to draw from either source tank or the storage tank is desirable
- Solar agrees that a transfer pump, valve manifold, and piping to allow movement of the content of any tank to any other tank is desirable, for tank maintenance
- Solar recommends transfer/forwarding pumps should be 1800 rpm or less to avoid creation of water/fuel emulsions. Materials should be compatible with Diesel (no zinc or galvanizing). Head should be just sufficient to meet the requirements, to avoid the need for throttle devices, which will create water/fuel emulsions. Maximum inlet pressure to the Solar boost pump is 15 psig, static or flowing. Minimum pressure to the boost pump is 9 psi absolute. Maximum backpressure applied to the skid return-to-source-tank connection is 20 psig
- Transfer/forwarding pumps should be automatically stopped of ESD/Fire Detection, to avoid atomizing fuel through leaks and feeding a fire. Coordinate with Solar.
- Capability to circulate contents of any tank through the new Boost pump/filters/coalesce skid for the purpose of refreshing fuel in tanks and pipes is desirable. The skid is able to operate continuously in a "kidney loop" for fuel refreshing.
- Floating suction is desirable for extraction of fuel from a tank
- A regular tank water draining program is recommended.
- Request Solar PIL 162 Rev 1 RECOMMENDATIONS AND REQUIREMENTS FOR THE SOURCING, HANDLING, STORAGE . TREATMENT OF FUELS FOR SOLAR GAS TURBINES for additional information.

ATTACHMENTS

A EXISTING DIESEL FUEL SYSTEM

B VELCON FILTERS DATA

C LUBRICITY ADDITIVE

D BIOCIDE ADDDITIVE

E WATER CONTENT MARCH 2013

F SAMPLE 1 RECORD

G SAMPLE 2 RECORD

H SAMPLE 3 RECORD

J SAMPLE 4 RECORD

K LAB REPORT SAMPLE 1 + 2 COMBINED

L LAB REPORT SAMPLE 3

M FUEL TEMP EMAIL AND VISCOSITY CHART

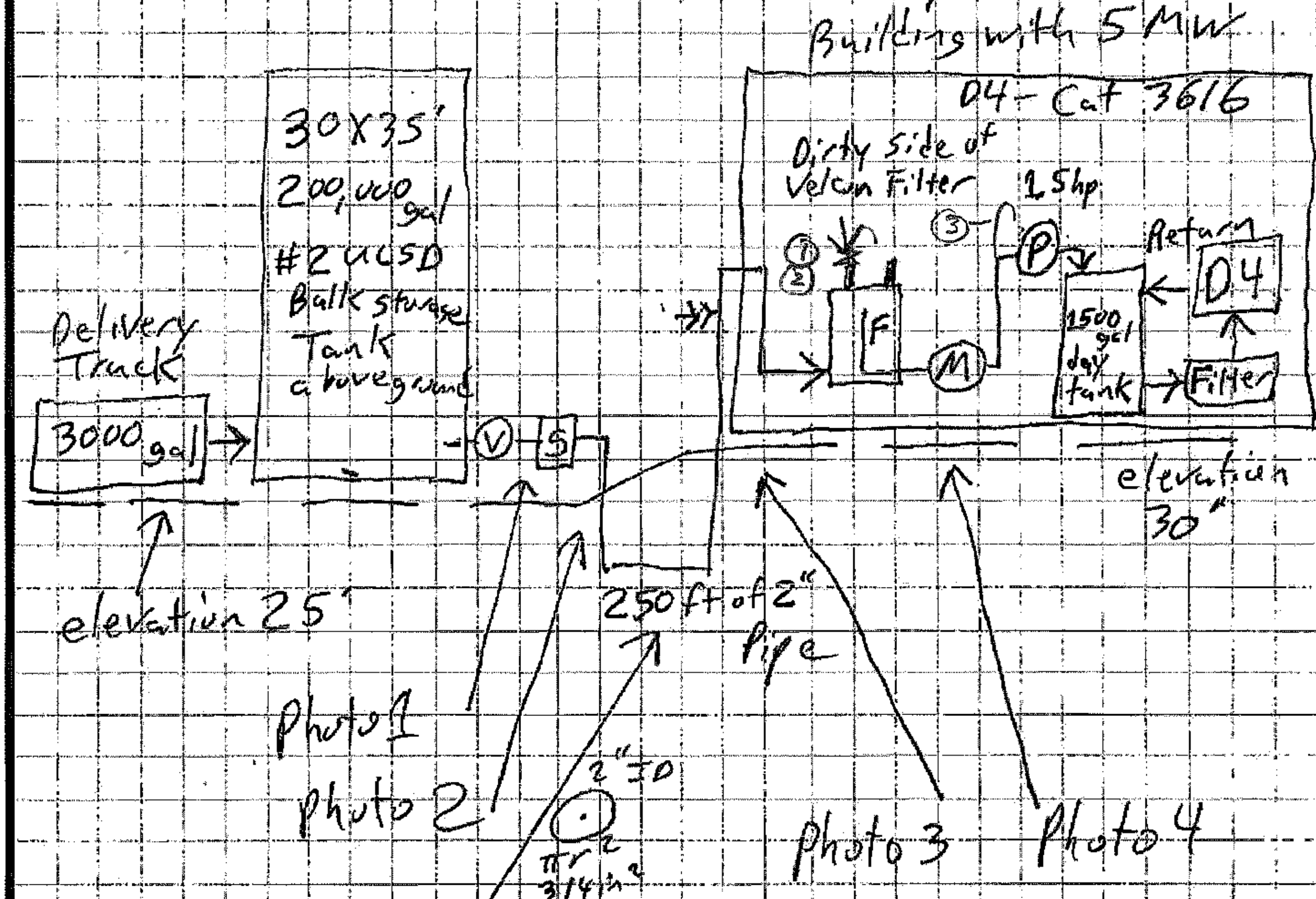
City & Borough of Sitka
ELECTRIC DEPARTMENT
105 Jarvis Street
Sitka, Alaska 99835
(907) 747-4000
FAX 747-3208

PROJECT Existing Diesel Fuel System
LOCATION Jarvis St. Sketch Profile
DATE 4-5-2013 BY A. E.
SCALE None SHEET 1 OF 1

$2400 Diesel Cost/pump cycle

Not to Scale

to start D4 to run 4MW for 2.8hrs X 250gal/hr to draw day tank to 850 gallon level to turn pump on and refilling 1/2 hr to 1400 gallons and pump turns off to day tank.



Diesel Velocity 2ft/sec in 2" ID pipe when D4 day tank refills from 850 gallons to 1400 gallons at measured 20 gals/min = 1200 gals/hr = 0.33333 gals/sec

$0.33333 \text{ gals/sec} \times \frac{231 \text{ in}^3}{1 \text{ gal}} = 77 \text{ in}^3/\text{sec}$

$\div 3.14 \text{ in}^2$

$24.5 \text{ inch/sec} = 2 \text{ ft/sec} < 7 \text{ ft/sec}$ to move H_2O with Fuel.

(A)

velcon FILTERS®

VF SERIES INDUSTRIAL HOUSING INSTRUCTIONS

DESCRIPTION

Velcon industrial housings are used in a variety of industrial filtration applications. Housings are shipped with no cartridges installed. Cartridges must be ordered separately.

HOUSING	CONNECTIONS	PRESSURE RATING	ASME CODE DESIGN	NO. OF 18" CARTRIDGES
VF-82B150	2" NPT	150 PSI	NO	2
VF-81C150	2" NPT	150 PSI	YES	1
VF-82C150	2" NPT	150 PSI	YES	2
VF-166C150	3" NPT	150 PSI	YES	6
VF-2012C150	4" NPT	150 PSI	YES	12

CARTRIDGE SELECTION

TYPE	MODEL NO.	NOMINAL MICRON RATING	COLLAPSE STRENGTH	MAXIMUM FLOW IN FUEL
PLEATED FILTER MEDIA (Dirt Removal Only)	FO-718PLP3	0.3	75 PSI	50 GPM*
	FO-718PL1/2	1/2	75 PSI	
	FO-718PL01	1	75 PSI	
	FO-718PL02	2	75 PSI	
	FO-718PL05	5	75 PSI	
	FO-718PL15	15	75 PSI	
	FO-718PL50	50	75 PSI	
FIBERGLASS DEPTH MEDIA (Colloidal Contaminant removal)	FO-618FGA5	5	75 PSI	50 GPM*
	FO-618FGA10	10	75 PSI	
	FO-618FGA25	25	75 PSI	
PLEATED FILTER MEDIA & WATER ABSORBENT MEDIA	AC-718P3	0.3	75 PSI	50 GPM*
	AC-718P4D	0.4	75 PSI	
	AC-7181/2	1/2	75 PSI	
	AC-71801	1	75 PSI	
	AC-71805	5	75 PSI	
(Dirt and Water Removal)	AD-71825	25	75 PSI	50 GPM*
	ACO-71801B	1	75 PSI	50 GPM
	ACO-71805B	5	75 PSI	
	ASL-71801	1	75 PSI	50 GPM
FULLERS EARTH	LA-61801B	N/A	75 PSI	6 GPM*

* Maximum flow rate in oils will vary with oil viscosity. Contact your Velcon representative for sizing information.

1673-R2 2/92

FILTER SIZING INFORMATION

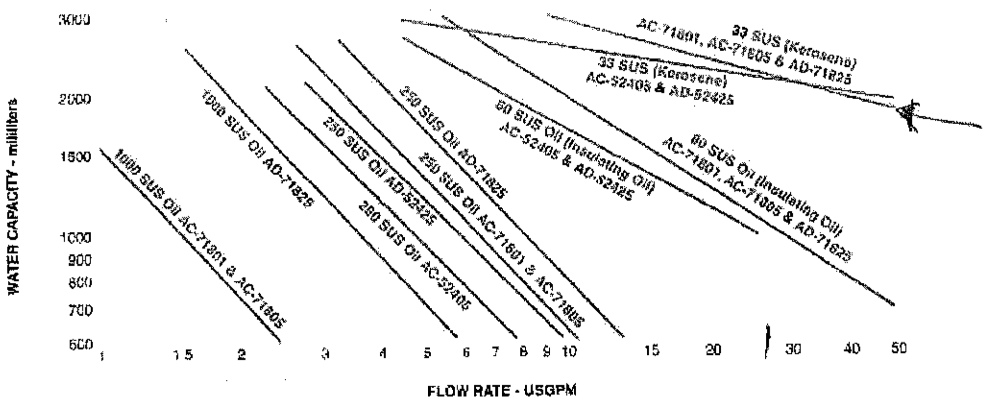
1. Select the desired filter cartridge type and micron rating.
2. Determine the viscosity at the operating temperature for the fluid being filtered. See Bulletin 1533.
3. From the cartridge flow rate data, estimate the flow rate that will result in a 2 psi differential pressure.
4. Divide the total desired flow rate by the flow rate determined in 3, above. This will give the required number of cartridges.
5. Select a filter housing that will hold the required number of cartridges.

NOTES: a) The recommended maximum flow rate can be exceeded by as much as 50% for "fuse-monitor" type applications with fuels and other low viscosity fluids. However, water holding capacity will be reduced and pressure losses from the filter housing itself may become excessive.

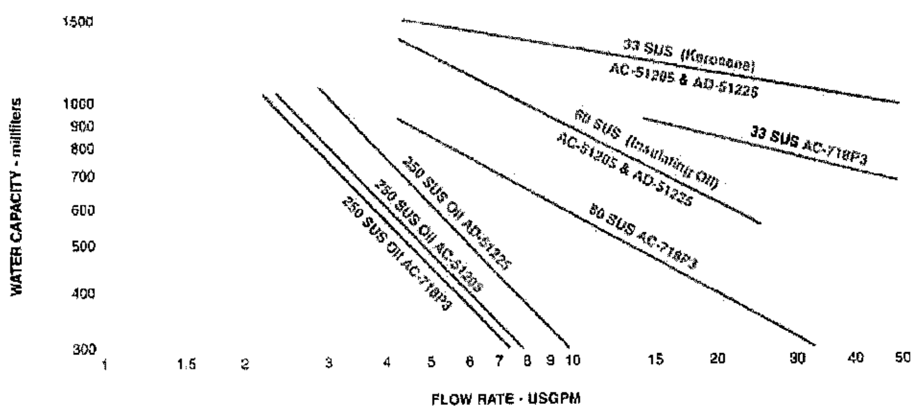
b) For higher viscosity fluids, a 5 psi differential pressure is frequently used for cartridge selection. This is acceptable, but you should consider the resulting loss in water capacity.

WATER HOLDING CAPACITY

Water capacity decreases when viscosity or flow rate increases. The graphs below show typical characteristics. For any specific application you must trade off between capacity (how much water the cartridge will hold before it must be changed) and flow rate (size of filter housing and initial cost). For long term operating cost benefits, it is always best to use a larger housing (reduce the flow rate per cartridge).



WATER CAPACITY AS A FUNCTION OF VISCOSITY AND FLOW RATE
AC-52405, AD-52425, AC-71801, AC-71805, and AD-71825 CARTRIDGES



WATER CAPACITY AS A FUNCTION OF VISCOSITY AND FLOW RATE
AC-51205, AD-51225, AC-718P3, and AC-7181/2 CARTRIDGES

Velcon

Velcon products are sold and serviced by a world-wide representative network. To order, contact Headquarters or your LOCAL REPRESENTATIVE:

COMPANY HEADQUARTERS:
Velcon Filters, LLC
1210 Garden of the Gods Road
Colorado Springs, CO 80907-3410
Phone: 1.800.531.0180 / 1.719.531.5855
Fax: 719.531.5690
e-mail: vfsales@velcon.com
www.velcon.com

MANUFACTURING PLANTS LOCATED AT:
Colorado Springs, Colorado
Sylacauga, Alabama
Henryetta, Oklahoma

OFFICES AND AFFILIATES IN:
Canada, Germany, Singapore, & Spain

Liquid Filtration and Separation Specialists

From: Jerry Jacobs <jerryj@harborent.com>
To: douglaswmooreinc <douglaswmooreinc@aol.com>; Andy Eggen <andy@cityofsitka.com>
Cc: chrisb <chrisb@cityofsitka.com>; Trevor Webb <trevor@cityofsitka.com>
Subject: Re: Sitka new 15 Mw Solar turbine generator and #2 ULSD diesel fuel specs.
Date: Fri, Apr 12, 2013 8:30 am

Andy,

Here's that info I received from our Ketchikan terminal regarding the lubricity additive:

The concentration of FPPF Lubricity Custom 130000T depends on the micron wear scar rating. Generally, the ratio is from 35 gallons to 65 gallons of lubricity per 100,000 gallon of ULSD. Goal is to reach a HFRR of between 460 & 520 microns.

I hope this is helpful.

C

jerry

>>> "Andy Eggen" <andy@cityofsitka.com> 4/11/2013 3:33 PM >>>
Hi Jerry,

Thanks for your help. We have a couple follow up items for the new 15 Mw turbine and #2 ULSD diesel fuel specs. This old email indicates the city of Sitka choose to add "lubricity 100" additive to the diesel refilling in Feb 2012 to end up with the storage tank concentration at 1 gallon per 3000 gallons of #2 ULSD.

Doug's work this week with you and Trevor Webb indicated the additive is presently added before transportation to Sitka. Please let me know the concentration as the City of Sitka will likely discontinue adding additional lubricity additive.

At present I believe we will only add a biocide once a year. A Brand and Type of biocide which the Solar Turbine warranty approves. This maybe the attached Biobor-JF instead of the Killem product which is not compatible with our existing Velcon fuel filtering.

Note

Please replay to all as I will be out of town, returning to work April 22nd.

Thanks
Andy

-----Original Message-----
From: Andy Eggen [mailto:andy@cityofsitka.com]
Sent: Friday, January 20, 2012 1:50 PM
To: 'Jerry Jacobs'
Subject: RE: Rescheduling 120,000 gallons #2 ULSD on PO #12-00257770to Feb 5-24 2012

Thanks Jerry on the February fuel rescheduling and updated Cat Lubricity information.

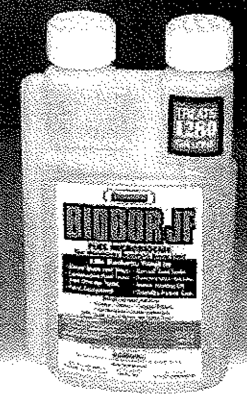
Bob will choose the lubricity agent and send a reply to the group on the separate e-mail.

Andy,

C

ANYWHERE EVERYWHERE
for diesel and jet fuel
3

BIOBOR JF®
MICROBIOCIDE
TECHNICAL DATA SHEET
TD-9610



Biobor JF® is a liquid fuel additive that combats fungus and other microbial life in hydrocarbon fuels such as diesel and jet fuels.

Biobor JF® eliminates growth of harmful slime producing fungi that clog filters and pipelines, attack rubber fuel system components and whose waste products aid in the corrosion of metal surfaces.

Biobor JF® is simple to use and harmless to the wide variety of fuel system parts, top coatings, sealants and elastomeric materials tested. It does not adversely affect fuel performance in any way.

Biobor JF® is an effective microbiocide because of its equilibrium solubility in both fuel and water under conditions of fuel storage.

Biobor JF® is used by a large number of aircraft operators, airlines, ships, boats, trucking fleets, railroads, bulk storage terminals, fuel suppliers and by other users of hydrocarbon fuels exposed to the possibility of contamination by fungus and bacteria.

GENERAL USAGE

If a system is badly contaminated, drain water bottoms thoroughly. Water bottoms in storage tanks should be kept to a minimum. Good housekeeping is important in treating slime problems, but it is not a cure. **Biobor JF®** is used at 270*ppm in fuel to effect sterilization, and subsequently at 135*ppm to maintain fungus-free fuel. Ideally, **Biobor JF®** should be injected to ensure proportionality and even distribution throughout the fuel tank. However, in the absence of metering equipment, **Biobor JF®** may be batch-blended. If batch-blended, as in tank trucks or small aircraft wing tanks, **Biobor JF®** should be introduced while the tank is being filled, after the tank is approximately 1/2 full. This will ensure faster and more complete dispersion.

*See chart on reverse side.

PRODUCT DATA

Chemical Composition

Active Ingredients
- 2,2'-oxybis (4,4,6-trimethyl-1, 3,2-dioxaborinane)
- 2,2-(1-methyltrimethylenedioxy) bis-(4-methyl-1, 3,2-dioxaborinane) 95.0%

Inert Ingredients
- Petroleum Naphtha 4.5%
- Inerts 0.5%

Total 100.0%

Boron Content 7.3%

Physical Properties (typical)
- Flash Point, Tag Closed Cup .... 102°F
- Pour Point .... -27°F
- Appearance .... Clear Liquid

Instructions for Storage and Handling

All **Biobor JF®** containers must be kept closed from the atmosphere. Protect **Biobor JF®** from any water contamination. The solvent action of **Biobor JF®** will attack coatings on paper linings of caps and lids, therefore, polyethylene liners or closures are recommended for storage of **Biobor JF®**.

EPA REG. NO. 65217-1
EPA EST. 61897-TX-0001
CANADIAN P.CP. REG. NO. 10301
CAS NO. 8063-89-6

ANALYSTS, INC.

ASTM REPORT

Analysts, Inc | ISO 17025 Accredited | 3401 Jack Northrop Ave, Hawthorne, CA 90250
Phone: 800-424-0099

City And Borough Of Sitka
Andy Eggen
105 JARVIS ST.
Sitka, AK, 99835

Lab Number: **0073**
Logged Date: **Mar 26 2013**
Sample Drawn: **Mar 20 2013**

Report Date: 4/2/2013
Record Ref. #: **5677182**

Unit ID: **Jarvis St. Bulk Tank**
Sample ID: **ULSD #2 Fuel Sample**
Worksite:
From: **City And Borough Of Sitka**

Mfg: **Please provide**
Model: **Please provide**
PO No.: **06-0016766**

Test	TESTING PERFORMED: Result	MEASURED for Sample 0073
ASTM D-6304 KARL FISHER	KF PPM (ppm)	71

Sample extracted by City of Sitka from sump drain

Maintenance Recommendations for Lab No. **0073**

ndition / Evaluation statements not applicable to this sample. Report issued to provide test results only.

Pipe of 210,000 gal tank.

Respectfully Submitted,

[signature]

JFRENCH
Analysts, Inc.

E

NALYSTS, INC.

FUEL SAMPLE SUBMITTAL FORM

Solar Turbines
A Caterpillar Company

Submit samples to Analysts, Inc.'s Regional Laboratory:

Analysts, Inc.
3401 Jack Northrop Ave.
Hawthorne, CA 90250
USA

~~**Reference sampling instructions for completing the information below and how to ship the sample.**~~

FUEL SAMPLE INFORMATION (MUST COMPLETE ALL INFORMATION)

Section I - Sample Identification		**Section II – Fuel Sample Information**			
Site Info:	City of Sitka, AK, Jarvis St Plant	Sample # 1 of 4			
Package SN:	NA				
Package PD:	NA	Additives in Use?	Lubricity Additive		
Fuel Type:	□ Grade 2-GT ☒ Diesel Fuel #2 □ Kerosene □ JET A □ JP 4 □ ~~Other~~: (off-Road Red Dyed)	Age of Fuel:	40,000 gal added Feb 2012	Sample Date:	April 10, 2013
Section III – Water Sample Information					
Water Sample Included: □ Yes ☒ No					
Water Source (please check one): □ Evaporative Cooler □ Water Injections □ Water Purge or Compressor Cleaning					
Problem(s) Suspected (describe below)					
Customer Witness Signature: [signature]					

SAMPLER INFORMATION [signature]

Section IV - Shipping Information		**Section V – Billing Information (if different from shipping)**
Worksite:		□ New Commissioning □ MMS □ Customer Service □ Other: Kim Dawson
District:		
FSR Name:		
Address:		
City/ST/Zip:		
Phone No:		
Fax No.		

DESIGNATE TESTING REQUIREMENTS (Check applicable)

X	Standard Fuel Test Package (per No. ES 9-98) – PLEASE Confer with Ms DAWSON
	Add-on Fuel Test: Water Test (per No. ES 9-98)

Comments / Requests or Special Instructions:	
FLOWING fuel FROM 210,000 gal Tank, upstream of VELCON FILTER, FIRST of Two Samples Taken (Second is for confirmation) from same Spigot	
For Lab Use Only	**EOM SAMPLES**

Always retain a copy of submitted forms for your records

3R90/E 56112001 (F)

NALYSTS, INC.

FUEL SAMPLE SUBMITTAL FORM

Solar Turbines
A Caterpillar Company

Submit samples to Analysts, Inc.'s Regional Laboratory:

Analysts, Inc.
3401 Jack Northrop Ave.
Hawthorne, CA 90250
USA

~~**Reference sampling instructions for completing the information below and how to ship the sample.**~~

FUEL SAMPLE INFORMATION (MUST COMPLETE ALL INFORMATION)

Section I - Sample Identification		**Section II – Fuel Sample Information**			
Site Info:	City of Sitka, JARVIS ST PLANT	Sample # 2 of 4			
Package SN:	NA				
Package PD:	NA	Additives in Use?	Lubricity additive		
Fuel Type:	☐ Grade 2-GT ☒ Diesel Fuel #2 ☐ Kerosene ☐ JET A ☐ JP 4 ☐ ~~Other:~~ Off Road Red Dye	Age of Fuel:	110,000 gal added FEB 2012	Sample Date:	April 10, 2013

Section III – Water Sample Information
Water Sample Included: ☐ Yes ☒ No
Water Source (please check one): ☐ Evaporative Cooler ☐ Water Injections ☐ Water Purge or Compressor Cleaning
Problem(s) Suspected (describe below)
Customer Witness Signature: Trevor Webb

Dayton Tilson

SAMPLER INFORMATION

Section IV - Shipping Information		**Section V – Billing Information (if different from shipping)**
Worksite:		☐ New Commissioning ☐ MMS ☐ Customer Service ☐ Other: Kim Dawson
District:		
FSR Name:		
Address:		
City/ST/Zip:		
Phone No:		
Fax No.		

DESIGNATE TESTING REQUIREMENTS (Check applicable)

X	Standard Fuel Test Package (per No. ES 9-98) – Please Confer with Ms Dawson
	Add-on Fuel Test: Water Test (per No. ES 9-98)

Comments / Requests or Special Instructions:	
Flowing fuel from 210,000 gal tank, upstream of velcon filter, 2nd of two samples taken from same spigot.	
For Lab Use Only	**EOM SAMPLES**

Always retain a copy of submitted forms for your records

NALYSTS, INC.

FUEL SAMPLE SUBMITTAL FORM

Solar Turbines
A Caterpillar Company

Submit samples to Analysts, Inc.'s Regional Laboratory:

Analysts, Inc.
3401 Jack Northrop Ave.
Hawthorne, CA 90250
USA

~~**Reference sampling instructions for completing the information below and how to ship the sample.**~~

FUEL SAMPLE INFORMATION (MUST COMPLETE ALL INFORMATION)

Section I - Sample Identification		**Section II – Fuel Sample Information**			
Site Info:	City of Sitka, AK, Jarvis St Plant	Sample #3 of 4			
Package SN:	ND				
Package PD:	NL	Additives in Use?	Lubricity Additive		
Fuel Type:	□ Grade 2-GT □ Diesel Fuel #2 □ Kerosene □ JET A □ JP 4 □ Other:______	Age of Fuel:	110,000 gal added Feb 2012	Sample Date:	April 10, 2013
Section III – Water Sample Information					
Water Sample Included: □ Yes ☒ No					
Water Source (please check one): □ Evaporative Cooler □ Water Injections □ Water Purge or Compressor Cleaning					
Problem(s) Suspected (describe below)					
Customer Witness Signature: [signature]					

SAMPLER INFORMATION [signature]

Section IV - Shipping Information		**Section V – Billing Information (if different from shipping)**
Worksite:		□ New Commissioning □ MMS □ Customer Service □ Other: Kim Dawson
District:		
FSR Name:		
Address:		
City/ST/Zip:		
Phone No:		
Fax No.		

DESIGNATE TESTING REQUIREMENTS (Check applicable)

X	Standard Fuel Test Package (per No. ES 9-98) – Please confer with Ms Dawson
	Add-on Fuel Test: Water Test (per No. ES 9-98)

Comments / Requests or Special Instructions:	
Flowing fuel from 210,000 gal tank, Downstream of Velcon filter and fill pump, one of 4, Represents fuel delivered to unit filters of existing Diesel Engines	
For Lab Use Only	**EOM SAMPLES**

Always retain a copy of submitted forms for your records

(H)

ANALYSTS, INC. **FUEL SAMPLE SUBMITTAL FORM** **Solar Turbines** *A Caterpillar Company*

Submit samples to Analysts, Inc.'s Regional Laboratory:

Analysts, Inc.
3401 Jack Northrop Ave.
Hawthorne, CA 90250
USA

~~**Reference sampling instructions for completing the information below and how to ship the sample.**~~

FUEL SAMPLE INFORMATION (MUST COMPLETE ALL INFORMATION)

Section I - Sample Identification		**Section II – Fuel Sample Information**			
Site Info:	City of Sitka, AK, JARVIS ST PLANT	Sample #~~1~~ of 4			
Package SN:	NA				
Package PD:	NA	Additives in Use?	Lubricity Additive		
Fuel Type:	☐ Grade 2-GT ☒ Diesel Fuel #2 ☐ Kerosene ☐ JET A ☐ JP 4 ☐ Other:______	Age of Fuel:	Tank filled MARCH 2013	Sample Date:	April 11, 2013
Section III – Water Sample Information					
Water Sample Included: ☐ Yes ☒ No					
Water Source (please check one): ☐ Evaporative Cooler ☐ Water Injections ☐ Water Purge or Compressor Cleaning					
Problem(s) Suspected (describe below)					
Customer Witness Signature: [signature]					

[signature]

SAMPLER INFORMATION

Section IV - Shipping Information		**Section V – Billing Information (if different from shipping)**
Worksite:		☐ New Commissioning ☐ MMS ☐ Customer Service ☐ Other: Kim Dawson
District:		
FSR Name:		
Address:		
City/ST/Zip:		
Phone No:		
Fax No.		

DESIGNATE TESTING REQUIREMENTS (Check applicable)

X	Standard Fuel Test Package (per No. ES 9-98)	Please Confer with Ms DAWSON
	Add-on Fuel Test: Water Test (per No. ES 9-98)	

Comments / Requests or Special Instructions:	
"Thief" Fuel from #8 PETROMARINE TERMINAS TANK, Harbor, City of SITKA, From Approx elevation 8' of 17' level. Sample Captured by Steel Thief Bottle, Transferred to Solar Bottle	
For Lab Use Only	EOM SAMPLES

Always retain a copy of submitted forms for your records

(J)

Solar Turbines

A Caterpillar Company

ASTM REPORT

Solar Turbines - Kimberly Dawson
Kimberly Dawson
9330 Sky Park Ct
San Diego, CA, 92119

Lab Number: **0049**
Logged Date: **Apr 22 2013**
Sample Drawn: **Apr 10 2013**

Report Date: 5/9/2013
Record Ref. #: **5700761**

Unit ID: **City of Sitka, AK, Jarvis St Plant**
Sample ID: **Sample #1 & #2 Combined**
Worksite:
From: **Solar Turbines Inc.**

Mfg: **Please provide**
Model: **Please provide**
PO No.: **INP001012 / ADD PD#**

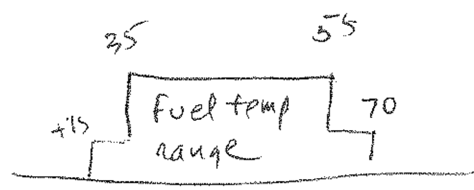
TESTING PERFORMED: Test	Result	MEASURED for Sample 0049
ASTM D-130 COPPER STRIP CORROSION	Time (Hr)	3
	Temp (°F)	122
	Classification	1A
ASTM D-1319 HYDROCARBON TYPES	Aromatics (% vol)	18.9
	Olefins (% vol)	1.4
ASTM D-240 HEAT OF COMBUSTION	Gross Heat Value BTU/lb (BTU/lb)	19679
	Net Heat Value BTU/lb (BTU/lb)	18469
TM D-2500 CLOUD POINT	Cloud Point (°F)	-11
ASTM D323 REID VAPOR PRESSURE	Reid Vapor Pressure (PSI)	<0.1
ASTM D-4294 SULFUR	Sulfur (% wt.)	0.020
ASTM D4629 NITROGEN	Nitrogen (ppm)	3.00
ASTM D-482 ASH	ASH (% wt.)	<0.001
ASTM D-6079 LUBRICITY	Wear Scar Diameter (μM)	460.000
	Temp (°C)	60.0
	Wear Scar Major Axis (mm)	0.49
	Wear Scar Minor Axis (mm)	0.43
ASTM D-6217 PARTICULATE CONTAMINATION	Particulate Contamination (mg/L)	1.00
ASTM D-6304 KARL FISHER	KF PERCENT (% vol)	<0.01
ASTM D-808 CHLORINE	Chlorine (% wt.)	<0.1
ASTM D-86 DISTILLATION	90% Temp (°F)	617
	End Point (°F)	657
	Recovery (mL)	98.0
	Residue (mL)	1.4
	Loss (mL)	0.6
ASTM D-93 FLASH POINT	Flash Point (°F)	134
ASTM D-97 POUR POINT	Pour Point (°F)	-27
SPECTROCHEMICAL	Sodium (ppm)	<0.25
	Potassium (ppm)	<0.25
	Sodium+Potassium (ppm)	<0.50
	Vanadium (ppm)	<0.5
	Calcium (ppm)	<0.25
	Magnesium (ppm)	<0.25

K

From: Andy Eggen <andy@cityofsitka.com>
To: douglaswmooreinc <douglaswmooreinc@aol.com>; chrisb <chrisb@cityofsitka.com>; juliet <juliet@cityofsitka.com>
Cc: jackwest <jackwest@cityofsitka.com>; trevor <trevor@cityofsitka.com>; pawlowski_greg_x <pawlowski_greg_x@solarturbines.com>; sthompson <sthompson@solarturbines.com>
Subject: RE: City of Sitka Jarvis St April 2013 diesel Fuel Lab ample results
Date: Mon, May 6, 2013 5:35 pm

Thanks Doug,

The minimum fuel temp at + 15'F is rare, maximum of +70'F is rare and average of 35 to 55'F in the coast 90% of the year.



Andy

From: douglaswmooreinc@aol.com [mailto:douglaswmooreinc@aol.com]
Sent: Monday, May 06, 2013 3:23 PM
To: andy@cityofsitka.com; chrisb@cityofsitka.com; juliet@cityofsitka.com
Cc: jackwest@cityofsitka.com; trevor@cityofsitka.com; pawlowski_greg_x@solarturbines.com; sthompson@solarturbines.com
Subject: Re: City of Sitka Jarvis St April 2013 diesel Fuel Lab ample results

Hi Andy,

Haven't got the results back yet, but will get you a copy when done.

The scientists decided to run the full spectrum of tests on the two samples taken upstream of the Cat 20 micron filter,combining them to have enough fluid, and to hold the sample from downstream of the filter and the one from the Petro Marine tank in reserve for a while.

Jerry Jacobs of Petro Marine told me every load is sampled and tested at Ketchicak for sulfur, then sampled at Sitka and the sample sent back for analysis in Ketchikan. So, he probably has the results from recent barge loads.

Andy, do you happen to have data about average fuel temp, as delivered to the Cat day tank? I'm looking at the viscosity limits, which depend on temperature as well as composition.

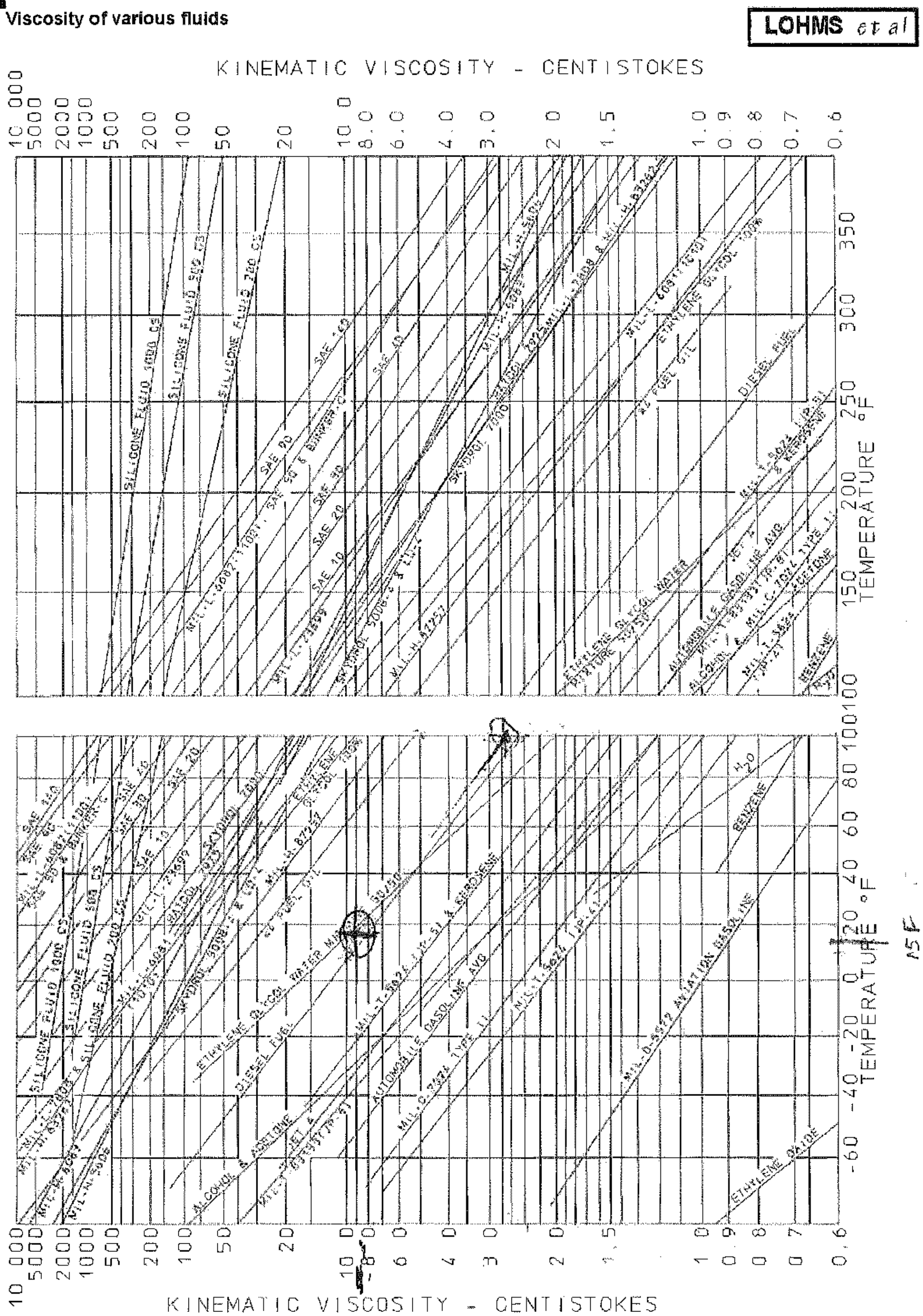
Doug

Viscosity of various fluids

Precision MicroHydraulics

Electro-Fluidic Systems

ASK LEE



M2