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Technical Reference

Capstone MicroTurbine Fuel Requirements

This document presents the Gaseous and Liquid Fuel Requirements for satisfactory operation of a Capstone Turbine Corporation MicroTurbine.

Introduction

This Technical Reference outlines all the approved fuels for use with Capstone MicroTurbines. Compliance with the requirements detailed in this document are necessary to avoid conditions that may affect the performance, life, reliability, warranty, and in some cases, the safe operation of the Capstone MicroTurbine.

Many fuels that are not yet approved may be acceptable, either conditionally or unconditionally. Those considering the use of an unapproved fuel are encouraged to check the new fuel against the specific fuel requirements detailed herein. It is also requested that any newly proposed fuel specification and any associated technical data be submitted to Capstone Applications Engineering for review and consideration.

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Definitions

The following three tables contain definitions of the various terms as used within this document. Table 1 presents general terms and definitions for a Capstone MicroTurbine.

Table 1: Capstone MicroTurbine General Terms and Definitions

General Terms	Definitions
ASTM	American Society for Testing and Materials
Biofuel	A renewable fuel derived from biomass
Biodiesel	A biofuel that closely imitates the properties of diesel fuel. It is manufactured from vegetable and/or animal oils and fats, as well as recycled cooking oils. The typical process for manufacture is methyl esterification, and the properties of the final product often vary with the feedstock.
C1	Total amount of hydrocarbon species containing 1 carbon atom per molecule
C2	Total amount of hydrocarbon species containing 2 carbon atoms per molecule
C3	Total amount of hydrocarbon species containing 3 carbon atoms per molecule
C4	Total amount of hydrocarbon species containing 4 carbon atoms per molecule
C5	Total amount of hydrocarbon species containing 5 carbon atoms per molecule
C6	Total amount of hydrocarbon species containing 6 or more carbon atoms per molecule
Cloud Point	The temperature at which a cloud or haze of wax crystals begin to precipitate from the fuel
ft^3	Standard cubic feet of gas at 60 °F and 14.696 psia
HHV	Higher Heating Value (Gross Heating Value)
ISO	International Standards Organization
JIS	Japanese Industrial Standards
LHV	Lower Heating Value (Net Heating Value)
LSL	Lower Specification Limit
m^3	Normalized cubic meter of gas at 0 °C and 101.325 kPa (absolute)
USL	Upper Specification Limit
Flashpoint	The minimum temperature at which a liquid gives off vapor in sufficient concentration to ignite

Gaseous Fuel Requirements

Gaseous fuel requirements, including composition, contaminants, and properties are detailed in this section. Refer to the respective Capstone Product Specifications to determine which models can operate with each fuel type.

Gaseous Fuel Composition

Table 2 and Table 3 present allowable gaseous fuel parameters for a Capstone MicroTurbine. The heating properties of gaseous fuels are displayed in Table 2. Table 3 presents major fuel components that make up the fuel gas compositions allowed for use in the Capstone MicroTurbine. These are the major gas species in the fuel that are usually determined by gas chromatography per ASTM D1945. See Table 4 and Table 5 for limits on other components in small percentages.

Table 2: Gaseous Fuel Heating Property Definitions

Fuels	Gas Heating Properties [HHV]			
	Calorific Value Btu/ft^3 (MJ/m^3)		**Wobbe Index**[(1)] Btu/ft^3 (MJ/m^3)	
	LSL	USL	LSL	USL
Medium Btu Gas[(2)]	350 (13.8)	875 (34.5)	348 (13.7)	1021 (40.2)
Type A	350 (13.8)	600 (23.6)	348 (13.7)	706 (27.8)
Type B	550 (21.7)	875 (34.5)	552 (21.7)	1021 (40.2)
Natural Gas	825 (32.5)	1275 (50.2)	877 (34.5)	1444 (56.9)
High Btu Gas	1250 (49.2)	1811 (71.3)	1329 (52.3)	1741 (68.6)
Propane[(3)]	2450 (96.5)	2550 (100.4)	2025 (79.7)	2046 (80.6)

NOTES:

(1) Wobbe Index is equal to: Calorific Value / (Specific Gravity)$^{0.5}$.

(2) Type A fuels are typical of landfill gases and Type B fuels are typical of digester gases. Check actual fuel compositions and properties before making final MicroTurbine selection.

(3) As defined in ASTM D1835, similar to HD-5 Special Duty Propane.

Table 3: Capstone Gaseous Fuel Major Component Definitions

Fuels	Major Gas Component Limits [vol.%] (1)													
	C1		C2		C3		C4		C5	C6	N_2	CO_2		O_2
	LSL	USL	LSL	USL	LSL	USL	LSL	USL	USL	USL	USL	LSL	USL	USL
Medium Btu Gas	24	75	0	14	0	6.0	0	4.0	1.0	1.0	64	0	60	9.0
Type A	24	59	0	3.0	0	2.0	0	1.0	0.5	0.5	64	0	60	9.0
Type B	55	75	0	14	0	6.0	0	4.0	1.0	1.0	10	12	41	3.0
Natural Gas	50	100	0	14	0	9.0	0	4.0	1.0	1.0	22	0	11	6.0
High Btu Gas	36	79	4.0	27	6.0	33	1.0	6.0	2.0	1.0	9.0	0	5.0	1.0
Propane(2)	0	(3)	0	5.0	95(4)	99	0	2.5	(3)	(3)	(3)	0	(3)	(3)

NOTES:

(1) Determined per ASTM D1945. Gas may be composed of other components in small percentages. See Table 4 and Table 5 for limits of other constituents.

(2) As defined in ASTM D1835, similar to HD-5 Special Duty Propane.

(3) Feed gas may contain trace amounts of these components (volume percent << 1%), but all fuel entering the MicroTurbine fuel system must remain a vapor.

(4) C3 hydrocarbon content must consist of less than 5 volume percent of propylene (C3H6) per unit of total gas volume.

Gaseous Composition & Properties Requirements

Approved gaseous fuels must be in accordance with the physical properties and referenced notes listed below. Table 4 presents gaseous fuel property requirements and test methods for allowable fuels.

Table 4: Gaseous Fuel Property Requirements

Physical Property	Units	LSL	USL	Test Method	Notes
Liquids	% Mass instantaneous	-----	0	-----	(1), (2)
Acetylene	% Volume	-----	2	ASTM D1945	-----
Carbon Monoxide	% Volume	-----	5	ASTM D1945	-----
Hydrogen	% Volume	-----	1	ASTM D1945	-----
Water Vapor	% Volume	-----	5	-----	(3)
Calorific Value Variation	% of average	-10	+10	ASTM D4891	(4)

NOTES:

(1) Consult Capstone Applications Engineering.

(2) The fuel temperature must remain a minimum of 10°C (18°F) above its dew point temperature at the maximum supply pressure for all operating conditions, including startup. If the fuel and/or the fuel system must be heated to a temperature above the ambient temperature in order to meet this requirement, then precautions must be taken to prevent the condensation of the fuel when the MicroTurbine is shutdown so that no combustible liquids may form or enter the fuel system.

(3) Any water vapor content must be at a minimum of 18°F (10°C) above its dew point anywhere within the MicroTurbine fuel system for all operating conditions.

(4) 95% Confidence Interval

Contaminant Limitations

Gaseous Fuels Contaminant Limitations

Gaseous fuels must be in accordance with the contaminant limitations listed in Table 5 below.

Table 5: Gaseous Fuel Contaminant Limitations

Contaminant	Units	USL	Test Method(1)	Notes
Lubricating Oil	ppm, mass	2	-----	-----
Particulate Size	microns	10	-----	-----
Particulate Qty	ppm, mass	20	-----	-----
Water	% mass liquid	0	ASTM D5454	-----
Fluorides	ppm, mass	250	-----	(2)
Chlorides	ppm, mass	1,500	-----	-----
Sodium plus Potassium	ppm, mass	0.51	ASTM D3605	-----
Vanadium	ppm, mass	0.5	ASTM D3605	-----
Calcium	ppm, mass	0.5	ASTM D3605	-----
Lead	ppm, mass	0.5	ASTM D3605	-----
Siloxanes	ppb, volume	5	-----	-----
Ammonia	ppm, volume	200	-----	(2)
Other	ppm, mass	0.5	-----	(3)

NOTES:

(1) Or equivalent test method.

(2) Nominal Trace Specification.

(3) If other contaminants are present at more than 0.5 ppm by mass, they may need treatment, precautions, and/or modifications. These items must be detailed to Capstone for additional consideration.

Sour Gaseous Fuels

MicroTurbine operation on gaseous fuels may have limitations due to their respective tolerances for hydrogen sulfide (H_2S). Gaseous fuels with less than five parts-per-million by volume (ppmv) are often called "Sweet" while fuels with more than 5 ppmv H_2S are often considered "Sour" fuels. All Capstone MicroTurbines can operate on sweet fuels, but each MicroTurbine model may have a different tolerance for the maximum level of H_2S in the fuel. The different tolerance ranges of H_2S are listed in Table 6. Refer to the respective Capstone Product Specifications to determine the H_2S limits for different models.

Table 6: Hydrogen Sulfide (H_2S) Limitations for Standard Gaseous Fuels

Level of H_2S	Units	LSL	USL
Range 1	ppm, volume	-----	5
Range 2	ppm, volume	-----	5,000
Range 3	ppm, volume	-----	70,000

Fuel Supply Pressure and Temperature Requirements

Allowable fuel temperatures and required fuel pressures at full power for each Capstone MicroTurbine product are provided in their respective Product Specification. Besides these temperature and pressure levels, other considerations must be made to ensure steady and reliable MicroTurbine operation.

For all gaseous-fueled Capstone MicroTurbine products, the inlet pressure must remain steady during normal operation. The fuel inlet pressure should not vary more than 1 psig per second during steady state operation or changes in load, otherwise nuisance flameouts may occur. Furthermore, continuous and steady operation of MicroTurbines at low load conditions may necessitate a reduction in the fuel pressure from full power levels for reliable operation. In some cases, the fuel inlet pressure required for steady state operation is also a function of the fuel type. For example, high energy fuels, like propane, may require a reduction of the inlet pressure if the MicroTurbine was originally designed for a different fuel, such as natural gas. Consult Capstone Applications for further information on these subjects.

Maximum allowable fuel temperatures for a Capstone MicroTurbine are dependant on the product, and are provided in the applicable Product Specification; however, the minimum required fuel temperature is often dependant upon the fuel type. For a gaseous-fueled MicroTurbine, the fuel system must remain free of any liquid condensate for all ambient temperatures and MicroTurbine operating conditions. The temperature at which condensate begins to form in the fuel, at the required MicroTurbine inlet pressure, is considered the dew point temperature of the fuel. All gaseous fuels must remain a minimum of 10 °C (18 °F) above the dew point temperature, or 0°C (32 °F), whichever is higher, throughout the fuel system of the MicroTurbine to minimize condensate related issues.

Liquid Fuels

Definitions

Table 7 provides definitions of the types of approved liquid fuels.

Table 7: Liquid Fuel Definitions

Fuels	Specifications
Diesel Fuel	ASTM D975 No. 1-D, 2-D Grade Low Sulfur No. 1-D and No. 2-D Japanese Diesel Grades 1, 2, 3, & 4
Aviation Fuels	ASTM D1655 (Jet-A), MIL-DTL-83133E (JP-8), and MIL-DTL-5624U (JP-5)
Kerosene	ASTM D3699 1-K JIS K2203
Biodiesel	ASTM D6751-07a (with modification, see Table 9 and Table 10). Blends with any approved diesel grade, methanol, or ethanol which meet the specifications of ASTM D6751 and D975, subject to the modifications given in Table 9 and Table 10.

Physical Properties Requirements

Approved liquid fuels must be in accordance with the definitions listed previously in Table 7. Liquid fuels that do not meet these specific definitions may still be satisfactory if they meet the requirements listed in Table 8 (or Table 9 for liquid biofuels) and Table 10. In such cases, please consult Capstone Applications with a detailed fuel analysis for further consideration.

Table 8: Liquid Fuel Property Requirements

Physical Property	Units	LSL	USL	Test Method[1]	Notes
Kinematic Viscosity	mm^2/sec	1.9	5.0	ASTM D445	(2)
Cloud Point	°C	-----	-----	ASTM D2500	(3)
Flash Point	°C	38	100	ASTM D93	-----
Calorific Value	MJ/kg	39.5	51.0	ASTM D240	-----
Distillation Temperature, 90% Recovery (T90)	°C	180	360	ASTM D86	-----

NOTES:

(1) Or equivalent test method as permitted by "ASTM Standards for Industrial Fuel Applications Including Burners, Diesel Engines, Gas Turbines, and Marine Applications."

(2) USL is maximum for all allowable fuel temperatures. Values greater than 5.0 may significantly reduce the life of the primary fuel pump. Best pump performance is achieved when the viscosity is maintained between 2.0 and 3.0 mm^2/sec.

(3) The fuel temperature must remain a minimum of 10°C (18°F) above the cloud point.

Biodiesel Fuels

Biodiesel fuel may be used in a liquid-fired Capstone MicroTurbine in any concentration, provided the overall properties satisfy the requirements of Table 10 and Table 9. Additional information related to the use of liquid biofuels in Capstone MicroTurbines is provided in Capstone's Liquid Biofuel Requirements Application Guide (480034).

Table 9: Liquid Biofuel Property Requirements

Contaminant	Units	LSL	USL	Test Method[1]	Notes
Kinematic Viscosity	mm^2/sec	1.9	5.0	ASTM D445	(2)
Cloud Point	°C	-----	-----	ASTM D2500	(3)
Flash Point	°C	38	80	ASTM D93	(4), (5)
Cetane Number	-----	40	65	ASTM D613	-----
Age	Months	-----	3	-----	(6)
Distillation Temperature, 90% Recovery (T90)	°C	180	360	ASTM D1160	-----

NOTES:

(1) Or equivalent test method.

(2) USL is maximum for all allowable fuel temperatures. Values greater than 5.0 may significantly reduce the life of the primary fuel pump. Best pump performance is achieved when the viscosity is maintained between 2.0 and 3.0 mm^2/sec.

(3) The fuel temperature must remain a minimum of 10°C (18°F) above the cloud point.

(4) Flashpoints higher than 80°C (176°F) are only permitted if the turbine is at operating temperature. This may require starting on Diesel #2 or Kerosene, then transitioning to biodiesel. Flashpoints over 60°C may indicate a high methanol content.

(5) Low flashpoints may change the hazardous classification of a fuel.

(6) Nominal requirement to avoid excess sediment and issues with biological growth in the fuel.

Contaminants Limitations

Liquid fuels must be in accordance with the contaminants limitations listed in Table 10 in addition to the referenced notes.

Table 10: Liquid Fuel Contaminant Limitations

Contaminant	Units	USL	Test Method(1)	Notes
Water (free)	% mass	0.05	ASTM D2709	-----
Particulate	micron	2	ASTM D2276	(2)
Particulate	qty ppm mass	5	ASTM D2276	(2)
Ash	ppm, mass	100	ASTM D482	-----
Fluorine	ppm, mass	150	-----	-----
Chlorine	ppm, mass	1,500	-----	-----
Sulfur	ppm, mass	15	ASTM D2622	(3)(4)
Sodium plus Potassium	ppm, mass	0.5	ASTM D3605	-----
Vanadium	ppm, mass	0.5	ASTM D3605	-----
Calcium	ppm, mass	0.5	ASTM D3605	-----
Lead	ppm, mass	0.5	ASTM D3605	-----
Cerium Oxide	ppm, mass	0	-----	(5)
Other	ppm, mass	0.5	-----	(6)
Copper Strip	% weight loss	0.005	-----	-----

NOTES:

(1) Or equivalent test method as permitted by “ASTM Standards For Industrial Fuel Applications Including Burners, Diesel Engines, Gas Turbines, and Marine Applications”

(2) If the fuel source has a high particulate concentration, than additional external filtration will be required.

(3) Sulfur limitations may be lower depending on the exhaust emission requirements.

(4) Sulfur limitations may be higher in non-heat recovery applications. Consult Capstone Applications for additional information.

(5) Cerium Oxide is often used as a fuel additive to improve diesel fuel combustion. Fuels with this additive must not be used with a Capstone MicroTurbine.

(6) If other contaminants are present at more than 0.5 ppm by mass, they may need treatment, precautions, and/or system modifications. These contaminants must be detailed to Capstone for additional consideration.

New Fuel Acceptance Criteria

Capstone evaluates three MicroTurbine system components when considering possible new fuels. These areas are identified as noted below, and as detailed in the paragraphs on the following pages.

- Combustion System Evaluation Concerns
- Fuel System Evaluation Concerns
- MicroTurbine (Engine) Evaluation Concerns

Additional information may be obtained from within the detail Specification ASTM D2880.

Combustion System Evaluation Concerns

The combustion system evaluation concerns include the items presented in the following paragraphs.

Stability Limits

The fuel type may affect the stability of the combustion system at both steady state loads and during load changes. For example, fuels highly diluted with inert constituents may have degraded stability at low power levels.

Flashback

Capstone MicroTurbines typically operate at lean and premixed conditions. Many fuels have high flame speeds compared to fuels like methane. As such, fuels with high concentrations of these fast burning fuels (e.g., hydrogen) may experience flame flashback to the fuel injectors. Flashback may result in permanent damage to the MicroTurbine combustion system.

Combustor Life

Operation on some fuels (e.g., carbon monoxide and acetylene) may cause high combustor temperatures, reducing the life of the combustor. Likewise, liquid fuels with poor atomization qualities will result in combustion characteristics that reduce the life of the combustor.

Emissions

Some fuels will have inherently higher emissions levels. Liquid fuel systems will generally have higher NO_x levels than natural gas systems. Landfill and digester fuels may have lower NO_x levels, as well as higher CO and THC levels at full power. Fuels containing significant amounts of carbon monoxide and acetylene will also result in higher NO_x emissions. For liquid fuels, atomization, which is highly dependent on fuel physical properties, also has a significant effect on emissions.

Vapor Lock

Liquid fuels with sufficiently high vapor pressures will cause vapor lock in the fuel injectors, resulting in decreased system reliability due to flame-outs, fail-to-light conditions, or unsteady MicroTurbine operation.

Fuel System Evaluation Concerns

The fuel system evaluation concerns include the items presented in the following paragraphs.

Gaseous Fuel Temperature

High or low temperature limits of the MicroTurbine raise concerns regarding liquid formation, high vapor pressure, high density, and high viscosity. High or low temperature extremes may also cause damage to the materials of construction of the fuel system component parts.

Degradation of Fuel System Components, Metals, and Elastomers

Fuel contaminants, additives, as well as some hydrocarbons may corrode or attack critical fuel system components. Combinations of contaminants such as water with hydrogen sulfide may lead to even more severe corrosion effects. Temperature may also accelerate the corrosive effects of some fuels.

Water Condensation and Freezing in a Gaseous Fuel System

The presence of condensed water or ice will result in fuel system malfunction and eventual system shut down.

Liquids in a Gaseous Fuel System

The presence of liquids in a gaseous fuel, either from the fuel, or from the fuel gas compressor lubricating oil, may result in fuel system malfunction. Additional risks exist if the liquids are also fuels (e.g., butane), since liquid hydrocarbons cannot be properly controlled or metered by a gaseous-fuel MicroTurbine, which can also result in over temperature/speed events, unreliable MicroTurbine operation, and engine damage.

Fuel Gas Booster (Gas Compressor) Life

Excessive gaseous fuel temperatures or corrosive contaminants will cause early component failure. Sub-atmospheric inlet pressure to the fuel gas booster can also result in air leaking into the gas fuel supply and the consequent risk of an explosive mixture. Sub-atmospheric or excessive inlet pressures will result in reduced fuel gas booster life. Additionally, the use of saturated or near saturated fuels may result in the formation of condensate within the fuel gas booster, which in turn, may lead to early component failure.

Liquid Fuel Viscosity

High fuel viscosity may result in increased heating of the fuel pump internal components, which may affect the fuel pump performance. High fuel viscosity may result in cold start problems due to its effect on fuel atomization, and may also increase emissions. Lower than specified fuel viscosity may result in increased internal leakage of the fuel pump, which may adversely affect the fuel metering accuracy, especially under low flow conditions.

Liquid Fuel Pump Life

Liquid fuel pump life may be adversely affected by the fuel viscosity, fuel lubricity, and fuel temperature, in addition to any contaminants in the fuel that are outside of the requirements detailed within this document.

Water in Liquid Fuels

Excessive water present in liquid fuels may result in freezing at cold temperatures that may result in fuel system malfunction and system shutdown. Excessive water may also result in biological growth in fuel system components, especially within the fuel filter.

MicroTurbine (Engine) Evaluation Concerns

The MicroTurbine (Engine) evaluation areas include the following items:

Damage of MicroTurbine Hot End Components

Due to their chemistry, some fuel contaminants (sulfur, for example) may lead to hot end component damage (combustor, and/or other components).

Combustible Liquids in a Gaseous Fuel System

The presence of liquids in a gaseous fuel, either from the fuel or from the fuel gas compressor lubricating oil, may result in MicroTurbine (engine) hardware damage.

Surge

Fuels with reduced volumetric heating values will reduce surge margin of the engine. This may result in unsteady operation of the MicroTurbine.

Reference Documentation

Table 11 lists applicable Capstone documentation.

Table 11: Reference Documents

Document No.	Document Title
480034	Liquid Biofuel Requirements Application Guide

Capstone Customer Service

If you have additional questions or need further assistance, please call Capstone Technical Support:

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