Gaseous Fuel Specification for Waukesha* Engines

This specification covers gas engines of Dresser Inc. by and through its GE Gas Engine business ("Waukesha").

Gaseous fuels used in modern, spark-ignited, internal combustion engines can vary from commercial quality "dry" natural gas to various wellhead, digester, landfill, and process derived gases. In all cases, the fuel is a unique mixture of component gases that can be combustible or inert. The mixture is typically composed mostly of methane (CH_4) with smaller percentages of heavier hydrocarbons ranging from ethane (C_2H_6) to heptane (C_7H_{16}). Gases such as carbon dioxide (CO_2), carbon monoxide (CO), oxygen (O_2), nitrogen (N_2), helium (He), hydrogen (H_2), and hydrogen sulfide (H_2S) may also be present. See Appendix B. Some gases, particularly landfill gas, may contain contaminates such as water, siloxanes, and chlorinated hydrocarbons. See Fuel Gas Requirements Notes 1 and 2.

Consequently, it is necessary to evaluate each potential fuel gas for its suitability for use in an internal combustion engine. Fuel gas requirements for Waukesha gas engines are given in Table 1. Filtering, drying, or other treatment may be necessary before the gas can be used as a fuel. Refer to Figure 2 for a schematic of a basic fuel gas treatment system for non-commercial quality gas. The actual composition of the fuel gas and the site arrangement and operating conditions may require more, fewer, or different components than those illustrated to condition the gas properly.

WAUKESHA STANDARD COMMERCIAL QUALITY NATURAL GAS FUEL:

Natural gas, or commercial quality natural gas (CQNG) which can also be referred to as pipeline quality natural gas, is generically defined as the quality of gas provided by a commercial utility to a customer. Experience has proven that CQNG is not consistent and, in fact, varies significantly between countries, states, and even locally over time. For this reason Waukesha has found it necessary to define a standard commercial quality natural gas. See Table 2.

All Waukesha published engine data specifying natural gas as the fuel are based on a gas having the composition and characteristics given in Table 2. Unless a site specific fuel analysis is provided, all Waukesha performance and emissions quotes or guarantees for engines fueled with natural gas or CQNG are based on a fuel as defined in Table 2.

FUEL WAUKESHA KNOCK INDEX*:

Waukesha has developed a proprietary Waukesha Knock Index (WKI*) for evaluation of a potential fuel's ability to resist detonation (knock). See Fuel Gas Requirements Note 3. The WKI uses a nine-gas mix matrix to more accurately determine a fuel's knock resistance. The significant knock improving characteristics of non-combustible inert gases present in the fuel are also taken into account.

1. Calculate the WKI value of the gas mix using Waukesha's Windows™ based WKI computer program.
   Note: Calculation of a WKI value is a complex mathematical procedure because of the nine-gas mix matrix. Hand calculation forms are not available. The computer software is available from Waukesha's Application Engineering department. In addition to WKI, the software also calculates the lower heating value (LHV) and saturated lower heating value (SLHV) in both English and metric units and the specific gravity referred to standard air for a potential fuel gas.
2. The gas must meet the minimum WKI requirement for the specific engine model as given in the Waukesha Knock Index section of Gas Engine Technical Data before it can be classified as a suitable fuel.
3. A WKI value below the minimum requirement for rated load for the specific engine model will require a revised ignition timing specification or treatment of the gas to reduce the possibility of knock. See Fuel Gas Requirements Notes 1, 2, and 3.

FUEL LOWER AND SATURATED LOWER HEATING VALUES:

Both the lower heating value (LHV) and saturated lower heating value (SLHV) of a gas are measures of the amount of useable energy available in a specified volume of gas. The difference is that LHV is based on a dry gas without any water vapor while the SLHV is based on a gas 100% saturated with water vapor. Both are usually given in units of British Thermal Units per standard cubic foot (BTU/ft^3) in the English system or mega-Joules per normal cubic meter (MJ/m^3_N) in the metric system, at specified standard conditions. Both heating values may be measured or calculated. If they are to be calculated the gas analysis must be known. See Fuel Gas Requirements Note 3.

1. Measure the LHV / SLHV of the gas or calculate it using the WKI software or in accordance with the Procedure for Calculating Fuel Gas Saturated Lower Heating Value in General Technical Data.
2. The minimum acceptable heating value for all engine models, except the 220GL models, with the standard fuel system is 865 BTU/ft^3 (34.01 MJ/m^3_N) LHV or 850 BTU/ft3 (33.42 MJ/m^3_N) SLHV. Optional low BTU fuel systems are available for some engine models which allow operation with fuel as low as 407 BTU/ft^3 (16.00 MJ/m^3_N) LHV or 400 BTU/ft3 (15.73 MJ/m^3_N) SLHV.
3. The minimum acceptable heating value for all 220GL models is 763 BTU/ft^3 (30 MJ/ m^3_N) LHV or 750 BTU/ft^3 (29.48 MJ/m^3_N) SLHV.
4. Published ISO Standard (continuous duty) power ratings for naturally aspirated models are to be reduced when the fuel gas heating value is less than 916 BTU/ft^3 (36.01 MJ/m^3_N) LHV or 900 BTU/ft^3 (35.38 MJ/m^3_N) SLHV.
5. The maximum allowable fuel gas LHV / SLHV fluctuation at ISO Standard (continuous duty) power rating for stable, detonation free operation of VGF*, VHP*, and ATGL* engines, without readjustment to the fuel system and without an automatic air/fuel ratio control, is given in Figure 1. **Note that any Waukesha performance and/or emission guarantees are based on a specific fuel composition and carburetor setting and may not be valid over the entire fuel LHV / SLHV fluctuation given in Figure 1.** If fuel LHV / SLHV swings are beyond the ranges given in Figure 1 contact the Waukesha Application Engineering department for additional information. See Fuel Gas Requirements Note 5 for additional information on G and GSI models.

TABLE 1. FUEL GAS REQUIREMENTS

PARAMETER	SPECIFICATION [1,2,3,4]
Heating Value Requirement	Refer to individual model Technical Data
Heating Value Variability [5]	1. Less than 5% of nominal LHV per minute, and 2. Refer to Figure 1, if applicable, or 3. Contact Application Engineering
Inlet Gas Pressure	Refer to individual model Technical Data
Gas Pressure Range Allowed	Refer to individual model Technical Data
Inlet Gas Temperature [6]	1. 29° C to 60° C (-20° F to 140° F) 2. 0° C to 50° C (32° F to 122° F) for all 220GL models
Minimum WKI Value	Refer to individual model Technical Data
Hydrogen Content Limit	1. ≤ 12 %v 2. ≤ 3 %v for all 220GL models
H_2S Content Limit	See total sulfur
Total Sulfur Content as H_2S Limit [7]	1. ≤ 50 µg/BTU 2. ≤ 25 µg/BTU for all 220GL models
Ammonia Content Limit [8]	1. ≤ 1.4 µg/BTU 2. ≤ 0.9 µg/BTU for all 220GL models
Total Chlorine Content Limit	See halogenated compounds
Total Fluorine Content Limit	See halogenated compounds
Total Halogenated Compound Content as Chloride Limit [9]	1. ≤ 8.5 µg/BTU 2. ≤ 1.8 µg/BTU for all 220GL models
Total Siloxane and Other Silicone Bearing Compound Content Limit [10]	≤ 0.26 µg/BTU as as Silicone
Solid Particulate Matter Content Limit [11]	1. ≤ 5 microns size; and 2. ≤ 1.8 µg/BTU for 220GL models
Moisture / Water Content Allowed [12]	1. No liquid water anywhere in the fuel system 2. 100% relative humidity is acceptable for engines without a prechamber fuel system; less than 50% relative humidity is recommended for engines with a prechamber fuel system.
Liquid Hydrocarbon Content Allowed [12,13]	No liquids permitted
Miscellaneous [12,13,14]	1. Compressor carryover oil < 1.5 µg/BTU as vapor and ≤ 0.3 micron droplet size 2. No glycol permitted

FUEL GAS REQUIREMENTS NOTES:

1. This specification is not all inclusive and applies only to the engine itself. It does not apply to a catalyst or other exhaust aftertreatment. Always consult with the manufacturer of any exhaust aftertreatment for specific requirements. Also, the information contained in these notes provides recommendations to comply with the fuel gas requirements in common applications. The actual composition of the fuel gas, the site arrangement, and operating conditions may require more, less, or different treatment than these notes describe to condition the gas properly. For potential engine fuels containing components not explicitly covered in this specification or with unusual site or operating conditions, contact the Waukesha Application Engineering department.

2. The quality of the fuel gas provided to the engine directly affects the life of the engine and individual engine components. Engine emissions levels and performance may also be affected by fuel quality. Commercial quality natural gas, sometimes referred to as utility or pipeline quality natural gas, is the cleanest fuel. Low BTU fuels, such as digester and landfill gases, contain widely varying amounts of contaminants such as water, hydrogen sulfide (H2S), siloxanes, and chlorinated hydrocarbons. In general, cleaner fuel results in longer engine life expectancy and better engine performance. Thus, the best approach is to remove, as far as practical, all contaminants from the fuel gas before it reaches the engine. Various companies manufacture products aimed at reducing bio-fuel contaminants through the use of filtration and/or absorption products or processes. Waukesha makes no endorsement, recommendation, or representation of the effectiveness, quality, or compatibility of any of these products or services. Their applicability and performance is solely the responsibility of such product's manufacturer.

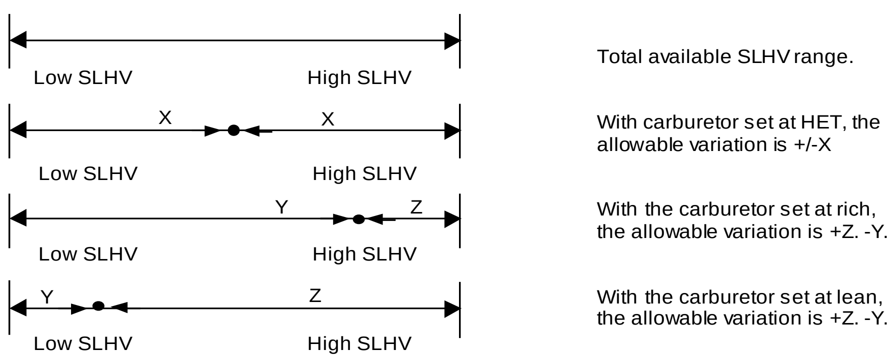
3. To be suitable as an engine fuel, the gas must meet minimum requirements for both WKI value and heating value. In general, as the molecular weight of a component gas increases, its LHV / SLHV increases but its WKI value decreases. For some potential fuel gases, then, it is necessary to remove some heavier hydrocarbon components in order to obtain an acceptable WKI value even though this results in a lower LHV / SLHV fuel.

4. The allowable limit for most fuel contaminants is specified in µg/BTU LHV (micrograms per BTU of fuel gas Lower Heating Value) rather than ppmv (parts per million volume) or mass per unit volume (cubic foot, cubic meter, or liter) because the mass per fuel energy specification provides for a more consistent contaminant level entering the engine independent of fuel heating value.

   The tabulated limit values apply to the gas at the point where it enters the first engine component – usually this will be the engine mounted regulator. For non-CQNG fuels, several fuel sample analyses are recommended to determine average and extreme contaminant values. Fuel treatment equipment should be sized to ensure that the maximum expected contaminant levels do not exceed the tabulated limits after treatment. Periodic samples should also be taken both before and after any fuel treatment equipment to monitor the on-going effectiveness of the equipment.

   Determining the level of a contaminant in a fuel gas on a mass per fuel energy basis is straightforward once a proper fuel sample analysis has been done. See Appendix A for example calculations.

5. For G, GSI, and GSID models without air/fuel ratio control, the highest exhaust temperature (HET) carburetor setting is approximately centered in the recommended operating air/fuel ratio range. It allows equal LHV / SLHV swings; e.g., ± 50 BTU/ft^3 (± 1.86 MJ/m^3_N), ± 100 BTU/ft^3 (± 3.73 MJ/m^3_N), etc., above and below the nominal value. Other carburetor settings will allow the same total LHV / SLHV range; e.g., 100 BTU/ft^3 (3.73 MJ/m^3_N), 200 BTU/ft^3 (7.46 MJ/m^3_N), etc., but the allowable high and low swings will not be equal. This can be illustrated:



   In addition, the fuel heating value cannot be allowed to change more rapidly than 5% of the nominal value per minute. For example, the SLHV of a gas with a nominal heating value of 800 BTU/ft3 should not change more rapidly than 40 BTU/ft3/minute to maintain proper engine control and stability. Do not exceed the allowable heating value range.

6. The fuel gas temperature must be held in the range of -29° C to 60° C (-20° F to 140° F). Temperature should not go below the -29° C (-20° F) value to protect the elastomeric components inside the engine mounted regulator and carburetor. The high temperature is limited to 60° C (140° F) due to elastomer limits and potential power loss. Note that some low heating value fuel applications may require a maximum gas temperature lower than 60° C (140° F) to provide sufficient fuel flow. In addition, engine performance will be affected and/or fuel system adjustments may be required if the fuel gas temperature varies significantly or rapidly.

   For all 220GL models, the gas temperature at the engine inlet must be held in the range of 0° C - 50° C (32° F - 122° F). The tighter temperature range for the 220GL models is based on the cooling requirements of the prechamber and main chamber fuel injection components.

7. Sulfur bearing compounds are highly undesirable in a fuel gas because combustion will produce gases that can combine with water to form corrosive acids. Since any internal acid formation will lead to shortened engine life and/or decreased engine performance, Waukesha recommends that fuels having a total concentration of sulfur bearing compounds, expressed as equivalent hydrogen sulfide (H2S), greater than the tabulated limit be treated to lower that concentration to no more than the limit value. See Fuel Gas Requirements Note 2. See Appendix A for a sample calculation.

   Sulfur bearing compounds can be removed in various ways, including but not limited to the following:

   - Dehydrate the fuel gas and condense excess moisture by refrigerating the fuel gas to no higher than 4° C (40° F) then filtering the fuel gas with a 0.3 micron coalescing filter to remove liquids. Finally, reheat the gas to at least 16° C (61° F). Reheating the fuel gas to higher temperatures of 29° C – 35° C (85° F – 95° F) is recommended to provide a more substantial margin against downstream cooling and condensation. This dehydration process will remove significant amounts of water and, since H2S, halogen compounds, and siloxanes are water soluble to a degree, levels of those contaminants should also be reduced.
   - Run the gas through an iron sponge filter.
   - Treat a digester itself with suitable chemicals such as ferric chloride.
   - For information on engine oils specified for use with various gas fuels refer to the most recent version of Waukesha’s Lubricating Oil Service Bulletin or Engine Lubricating Oil Recommendations in General Technical Data.

8. Any ammonia present in the fuel gas will result in an increase in the exhaust NOx level above that of the normal engine NOx output. Corrosive combustion products may also be formed. See Appendix A for a sample calculation.

9. When burned in an engine, fuels containing halogens (fluorine, chlorine, bromine, iodine) or halogen compounds (chlorinated hydrocarbons, etc.) will produce highly corrosive products. Waukesha's experience indicates that halogens and halogen compounds are found only in landfill gases. See Fuel Gas Requirements Note 2. See Appendix A for a sample calculation. In order to maximize life expectancy for a Waukesha engine operating on a fuel gas containing halogens, Waukesha recommends the following:

- Perform a comprehensive gas sample analysis to determine the level of halogenated compounds in the fuel expressed as chloride. One company – there are others – that can perform this service is Air Toxics LTD, an environmental analytical laboratory. They can be contacted at 1.800.985.5955 or at http://www.airtoxics.com.
- Dehydrate the fuel gas and condense excess moisture by refrigerating the fuel gas to no higher than 4° C (40° F) then filtering the fuel gas with a 0.3 micron coalescing filter to remove liquids. Finally, reheat the gas to at least 16° C (61° F). Reheating the fuel gas to higher temperatures of 29° C – 35° C (85° F – 95° F) is recommended to provide a more substantial margin against downstream cooling and condensation. This dehydration process will remove significant amounts of water and, since halogen compounds, siloxanes, and H2S are water soluble to a degree, levels of those contaminants should also be reduced.
- Selective stripping with a chemical process, such as Selexol™, may be effective.

- Commercially available processes that filter the gas through activated carbon (charcoal, graphite, etc) may be used.
- For information on engine oils specified for use with various gas fuels refer to the most recent version of Waukesha's Lubricating Oil Service Bulletin or Engine Lubricating Oil Recommendations in General Technical Data.

10. Volatile siloxanes, silanols, and silanes are groups of chemical compounds composed of silicon, oxygen, and hydrocarbon groups in a gaseous form. These silicone bearing compounds are very commonly used and are most often found in cosmetics and personal care products such as shampoos, deodorants, and hand lotions but may also be found in oils, greases, hydraulic fluids, and water repellents among other products. Because of their presence in so many consumer and industrial products, silicone bearing compounds are commonly found in both landfill and digester gases. When burned in an internal combustion engine, they can form silicon based deposits that approach ceramic hardness within the engine – especially in the small passages found in prechamber fuel systems. See Fuel Gas Requirements Note 2. In addition, silicon is a well known catalyst masking agent. Even small amounts of silicon compounds or silicon bearing combustion products in the exhaust stream may quickly deactivate emission control catalysts and some types of exhaust sensors. See Appendix A for a sample calculation.

    - Perform a comprehensive gas sample analysis to determine the level of silicone in the fuel. One company – there are others – that can perform this service is Air Toxics LTD, an environmental analytical laboratory. They can be contacted at 1.800.985.5955 or at http://www.airtoxics.com.
    - Dehydrate the fuel gas and condense excess moisture by refrigerating the fuel gas to no higher than 4° C (40° F) then filtering the fuel gas with a 0.3 micron coalescing filter to remove liquids. Finally, reheat the gas to at least 16° C (61° F). Reheating the fuel gas to higher temperatures of 29° C – 35° C (85° F – 95° F) is recommended to provide a more substantial margin against downstream cooling and condensation. This dehydration process will remove significant amounts of water and, since silicone compounds, halogen compounds, and H2S can be water soluble to a degree, levels of those contaminants can also be reduced.
    - Selective stripping with a chemical process, such as Selexol™, may be effective.
    - Commercially available processes that filter the gas through activated carbon (charcoal, graphite, etc) may be used.
    - For information on engine oils specified for use with various gas fuels refer to the most recent version of Waukesha's Lubricating Oil Service Bulletin or Engine Lubricating Oil Recommendations in General Technical Data.

11. Solid contaminant particles cause abrasive wear of cylinder liners, piston rings, bearings, etc., and must be removed as far as practical.

12. No liquid water is permitted in the engine fuel system at any time at the coldest expected gas temperature. The fuel system includes the engine mounted regulator, remote regulator pilot (if so equipped), carburetor or fuel mixer, and prechamber fuel system and regulator (if so equipped).

    Liquid water or hydrocarbon condensate is not allowed in any part of the engine fuel system because it frequently results in fouling, corrosion, and other problems. Particular attention must be paid to landfill and digester gases since these gases are commonly saturated with water. Due to extremely small clearances in the admission and check valves, absolutely no liquids can be tolerated in a prechamber fuel system. To help ensure that no liquid water forms in the fuel system, Waukesha recommends that the dew point of the fuel gas should be at least 11° C (20° F), about 50% relative humidity (RH), below the gas temperature measured at a point before all engine mounted regulators and engine remote regulator pilot valves (if so equipped). If liquid water is found, additional gas heating or other treatment may be required. On an engine without a prechamber fuel system, 100% relative humidity fuel gas at the carburetor inlet is acceptable.

A 0.3 micron coalescing filter should remove liquid droplets being carried along with the fuel stream. However, the filter in the fuel gas train should not be relied upon for gross liquids removal. Liquid content of the gas may be reduced to an acceptable level by several methods:

- Dehydrate the fuel gas and condense excess moisture by refrigerating the fuel gas to no higher than 4° C (40° F) then filtering the fuel gas with a 0.3 micron coalescing filter to remove liquids. Finally, reheat the gas to at least 16° C (61° F). Reheating the fuel gas to higher temperatures of 29° C – 35° C (85° F – 95° F) is recommended to provide a more substantial margin against downstream cooling and condensation. This dehydration process will remove significant amounts of water and, since halogen compounds, siloxanes, and H2S are water soluble to a degree, levels of those contaminants should also be reduced.
- Selective stripping with a chemical process, such as Selexol™, may be effective.
- By heating:
    i. If the gas is 17° C (30° F) or more above the ambient temperature, it can be cooled by passing it through a heat exchanger or refrigeration system, filtered, then reheated as above.
    ii. If the gas is 11° C (20° F) or more below the ambient temperature, about 50% RH, it can be filtered and heated. Heating of the fuel gas is limited to the maximum allowable temperature of 60° C (140° F) or 50° C (122° F) for 220GL models.

13. Hydrocarbon liquids, including liquid fuel gas compressor lubricating oil carryover, must be removed from the fuel stream. Using a coalescing filter with a 0.3 micron rating is adequate in most cases, however, the filter in the fuel gas train should not be relied upon for gross liquids removal. Oil condensation in the fuel system may require additional filtration or treatment. Even though compressor lubricating oil is hydrocarbon based and combustible, it may contain additives with calcium and other undesirable elements and compounds. Failure to remove hydrocarbon or carryover oil liquids can lead to fuel regulator problems, excessive spark plug and combustion chamber deposits, cylinder varnish, ring sticking, and other problems. See Fuel Gas Requirements Note 12.
14. Glycol is not permitted in a fuel gas because it can affect the engine in adverse ways.
One negative result of having glycol in fuel gas is that the lubricating qualities of the engine oil may be reduced resulting in bearing failure, piston ring sticking, excessive wear, and other problems. A 0.3 micron rated coalescing filter should remove liquid glycol from the fuel stream, however, the filter in the fuel gas train should not be relied upon for gross liquids removal. See Fuel Gas Requirements Note 12.
15. Refer to the most recent version of Waukesha's Glossary of Gaseous Fuel Terms in General Technical Data for additional information on gaseous fuel terminology.
16. All obligations of Waukesha under the Express Limited Warranty shall be waived and rendered void, and Waukesha will not be responsible for any damage or failure to a Product resulting from owner, operator or third party abuse or negligence, including but not limited to, any operation, installation, application, maintenance, or assembly practice not in accordance with the applicable laws, regulations or the guidelines and specifications established by Waukesha. For all terms, conditions, and limitations of Waukesha's Express Limited Warranty see form 0764, latest revision.

TABLE 2. WAUKESHA STANDARD COMMERCIAL QUALITY NATURAL GAS

COMPOSITION	
Methane content	93% by volume minimum
Non-combustible inerts (N_2, CO_2, He, etc.)	3% by volume maximum
Non-methane hydrocarbon mass fraction	0.15 (15% by mass) maximum
Liquid hydrocarbons (Typically C_5+)	None
Oxygen	0.2% by volume maximum
Water vapor	100% relative humidity[1]
Methane Content	93% by volume minimum
PERFORMANCE CHARACTERISTICS	
Lower Heating Value	916 BTU/std. ft^3 (60° F, 14.696 psia) approx. 36.01 [25, V(0, 101.325)] MJ/m^3_N approx.
Saturated lower heating value	900 BTU/std. ft^3 (60° F, 14.696 psia) approx. 35.38 [25, V(0; 101.325)] MJ/ m^3_N approx.
Waukesha Knock Index	91 minimum
Stoichiometric air/fuel ratio	16.08:1 by mass, approx.
Hydrogen/carbon ratio	3.85:1 approx.

NOTES:

1. See Table 1 and Fuel Gas Requirements Note 12.

ENGINE MODELS WITHOUT AIR/FUEL RATIO CONTROL FUEL GAS LHV / SLHV VARIATION BEFORE CARBURETOR READJUSTMENT (WKI REQUIREMENTS MUST ALSO BE MET)

Basic carburetor adjustment:

- G, GSI, GSID – Highest exhaust temperature (See Fuel Gas Requirements Note 5).
- VGF-GL, GLD/GLD/2 and VHP-5794LT – 50% to 60% excess air (7.6% to 9.0% exhaust oxygen with 900 BTU/ft³ SLHV, Table 2, fuel).
- VHP-GL, GLD – 74% excess air (9.8% exhaust oxygen with 900 BTU/ft³ SLHV, Table 2, fuel).
- AT-GL – 74% to 100% excess air (9.8% to 11.2% exhaust oxygen with 900 BTU/ft³ SLHV, Table 2, fuel).

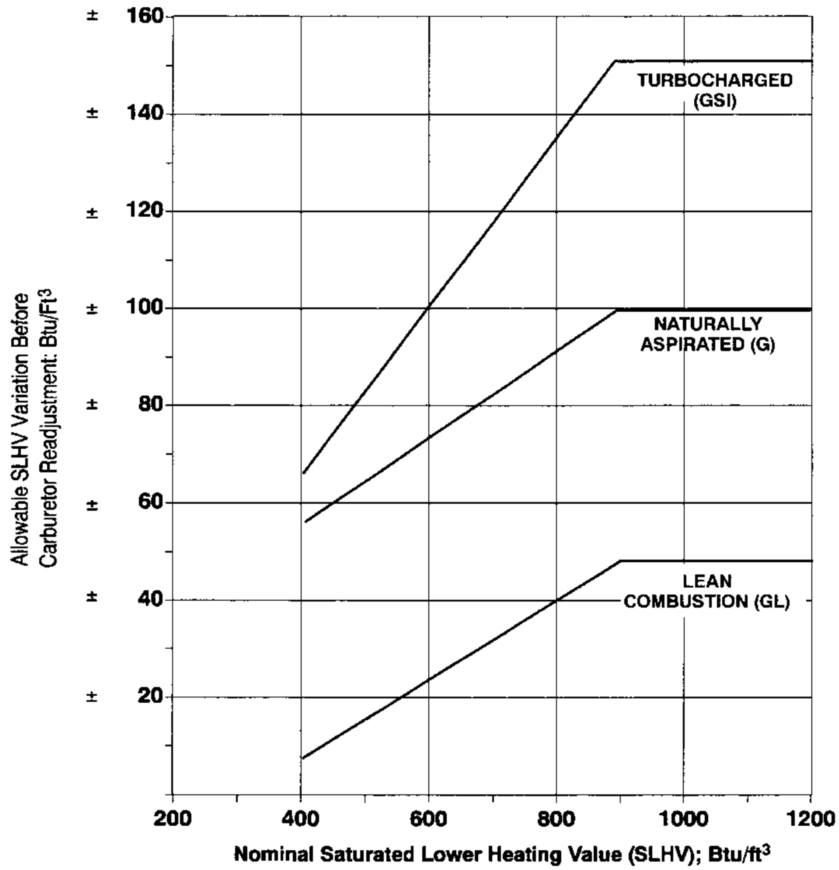


FIGURE 1

NOTE: Performance and/or emission guarantees are based on a specific fuel composition and carburetor setting and may not be valid over the entire fuel LHV / SLHV allowable variation given in Figure 1.

BASIC FUEL GAS TREATMENT SYSTEM FOR A NON-COMMERCIAL QUALITY GAS

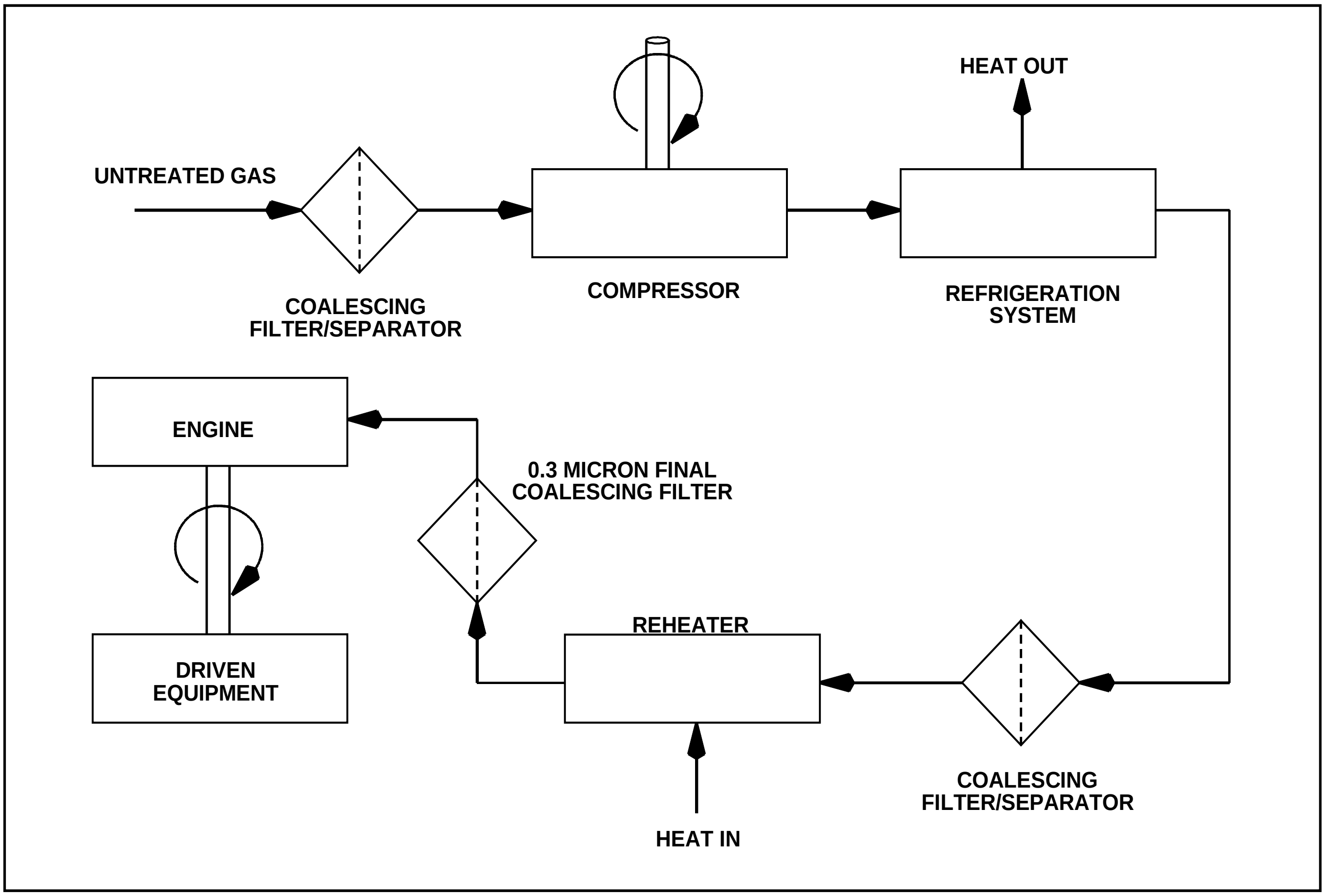


FIGURE 2

NOTE: Actual fuel gas composition and the site arrangements and operating conditions may require more, fewer, or different components than those illustrated to condition the gas properly.

APPENDIX A

ILLUSTRATIVE EXAMPLE CALCULATIONS SEE NOTE	
A comprehensive analysis of a landfill gas fuel sample taken at the VHP engine mounted regulator inlet provides the following information. (Only information needed for the example calculations is shown. A comprehensive analysis will provide significantly more detailed information.):	
METHANE	49.5%v
CO_2	47.8%v
N_2	2.07%v
O_2	0.55%v
TOTAL SULFUR COMPOUNDS	525 ppmv (0.0525%v) assumed to be H_2S
AMMONIA	10 mg/m^3_N
TOTAL HALOGENS AS CHLORIDE	97 µg/liter
TOTAL VOLATILE SILOXANES	18.5 µg/liter
GAS LHV	450 BTU/ft^3
GAS SPECIFIC GRAVITY	1.026 referred to standard air

CALCULATION 1

Determine composition of the fuel gas on a mass basis:

GAS	MOL. WT.	(= %V/100)	MWT X VF	(= COL 4 / SUM COL 4)	(= COL 5 X 100)
CH_4	16	0.4	7.9	0.2664	26.64%m
CO_2	44	0.478	21.032	0.7075	70.75%m
N_2	28	0.0207	0.580	0.0195	1.9%m
O_2	32	0.0055	0.176	0.0059	0.5%m
H_2S	34	0.000525	0.018	0.0006	0.0%m
	SUM =	0.999725	29.726	0.9999	99.9%m

CALCULATION 2

Determine if total sulfur level, as H_2S, is acceptable:

525 ppmv	= 0.0606 %m (shown as 0.06%m in calculation 1)
gas density	= 1.026 x 0.0765 lb/ft^3 (standard air density) = 0.0785 lb/ft^3
sulfur content	= 0.0785 lb/ft^3 x 0.0606%m / 100 = 0.000048 lb/ft^3
sulfur content	= 0.000048 lb/ft^3 x 454 g/lb x 1000000 µg/g = 21792 µg/ft^3
sulfur content	= 21792 µg/ft^3 / 450 BTU/ft^3 = **48.4 µg/BTU**

[sulfur level is within limit]

CALCULATION 3

Determine if ammonia level is acceptable:

ammonia content	= 10 mg/m^3_N x 1000 µg/mg x m^3/1000 liter = 10 µg/liter
ammonia content	= 10 µg/liter x 28.32 liters/ft^3 = 283.2 µg/ft^3
ammonia content	= 283.2 µg/ft^3 / 450 BTU/ft^3 = **0.63 µg/BTU**

[ammonia level is within limit]

CALCULATION 4	
Determine if total halogen level as chloride is acceptable:	
halide content	= 97 μg/liter x 28.32 liters/ft^3 = 2747 μg/ft^3
halide content	= 2747 μg/ft^3 / 450 BTU/ft^3 = **6.1 μg/BTU**

[halide level is within limit]

CALCULATION 5	
Determine if total volatile siloxane level is acceptable:	
siloxane content	= 18.5 μg/liter x 28.32 liters/ft^3 = 523.9 μg/ft^3
siloxane content	= 523.9 μg/ft^3 / 450 BTU/ft^3 = **1.16 μg/BTU**

[Fuel is **not** within allowable total siloxanes limit and **must** be treated. See Fuel Gas Requirements Note 10.]

NOTE: These example calculations are based on a landfill gas fuel since landfill gas typically contains the contaminants for which there is a Table 1 limit. For fuels other than landfill gas, all of the constituent compounds must be included in the analysis – volume fractions should sum to 1.0. See Appendix B for additional information.

APPENDIX B

The following list contains the majority of hydrocarbon and other compounds commonly found in gaseous fuels. It is not all-inclusive and other compounds may be found in a fuel gas analysis. Refer to Waukesha Standard Sheet S-7032-2, latest revision, for additional information on calculating properties of gaseous fuels.

COMPOUND	CHEMICAL SYMBOL	APPROXIMATE MOLECULAR WEIGHT
Methane	CH_4	16
Ethane	C_2H_6	30
Ethene	C_2H_4	28
Propane	C_3H_8	44
Propene	C_3H_6	42
Iso-Butane	C_4H_{10}	58
Normal Butane	C_4H_{10}	58
Iso-Pentane	C_5H_{12}	72
Normal Pentane	C_5H_{12}	72
Normal Hexane	C_6H_{14}	86
Normal Heptane	C_7H_{16}	100
Carbon Monoxide	CO	28
Hydrogen	H_2	2
Hydrogen Sulfide	H_2S	34
Nitrogen	N_2	28
Oxygen	O_2	32
Helium	He	4
Argon	Ar	40
Carbon Dioxide	CO_2	44
Water Vapor	H_2O	18