GAS ENGINE EXHAUST EMISSION LEVELS

Waukesha Engine's approach to exhaust emission levels is to offer various stages of emission control technology. This approach allows the customer to select the exhaust emission level required for a particular installation.

The following tables indicate emission levels that are valid for new engines for the duration of the standard warranty period and are attainable by an engine in good operating condition running on commercial quality natural gas of 900 BTU/ft^3 (35.38 MJ/m^3 [25, V(0; 101.325)]) SLHV, Waukesha Knock Index of 91 or higher, 93% methane content by volume, and at ISO standard conditions. Emissions are based on standard engine timing at 91 WKI® with an absolute humidity of 42 grains/lb. Refer to engine specific WKI® Power & Timing curves for standard timing. Unless otherwise noted, these emission levels can be achieved across the continuous duty speed range and from 75% to 110% of the ISO Standard Power (continuous duty) rating. ***Contact the local Waukesha representative or Waukesha's Sales Engineering Department for emission values which can be obtained on a case-by-case basis for specific ratings, fuels, and site conditions.***

The tabulated emission levels for GL models are achieved at the standard engine settings. Trade off adjustments can be made to reduce emissions or fuel consumption, but not both. ***Contact the local Waukesha representative or Waukesha's Sales Engineering Department for more information.***

As an aid in evaluating emission requirements, tables of approximate unit conversion factors for exhaust emission levels are included.

Both G and GSI engines that are manually adjusted have the potential to achieve the same emission values as engines equipped with an air/fuel ratio control device. The exhaust emissions, however, must be monitored and the engine adjusted to compensate for changes in ambient conditions and the heating value of the fuel gas. Particularly with catalytic exhaust after-treatment, a Waukesha CEC AFM (Custom Engine Control® Air/Fuel Module) is recommended to achieve optimum emissions control.

Waukesha emission control systems are designed for long life and consistent engine emission levels as listed in the following tables. It must be recognized, however, that engine condition and the quality of engine maintenance have a direct bearing on emission control. ***A control system cannot compensate for engine or maintenance deficiencies.***

Some acceptable instruments for site engine adjustment of emissions are portable analyzers with two percent (2%) accuracy, for example:

- Horiba Mexa-201GE CO NDIR Analyzer with 0.5% and 2% ranges
- Teledyne Model 320A Oxygen Analyzer

NOTE: *Provision to lower the exhaust sample dew point to 40° F or less is required.*

Waukesha Engine has available a mobile emissions measurement van which can provide a non-certification engine emissions testing service. The instruments and systems in the van were selected to comply with the Environmental Protection Agency (EPA) heavy duty engine test requirements - reference 40CFR86. In addition, a proposed procedure, modified EPA Reference Method 20 for stationary internal combustion engines, can be employed if required. The following emittants can be measured: oxides of nitrogen (NO, NO_2, NO_X), carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2) and total and non-methane hydrocarbons (THC and NMHC). Contact Waukesha's Sales Engineering Department for further information.

Table 1 – ATGL EMISSION LEVELS‡

MODEL	CARBURETOR SETTING	GRAMS/BHP-HR				% OBSERVED DRY		MASS AFR[2]	VOLUME AFR[2]	EXCESS AIR RATIO
		NOx[1]	CO	NMHC[4]	THC	CO	O_2			
AT25GL	Standard	1.0	2.25	1.0	8.0	0.06	9.8	28.0:1	16.8:1	1.74
AT27GL	Standard	1.5	1.7	0.50	5.0	0.06	9.8	28.0:1	16.8:1	1.74
	Ultra Lean	1.25	1.5	0.40	3.5	0.05	11.2	32.0:1	19.2:1	2.00

‡ These AT-GL emission levels are based on 900 – 1000 rpm operation. For information at all other speeds contact Waukesha's Sales Engineering Department.

Table 2 – VHP EMISSION LEVELS

MODEL	CARBURETOR SETTING	GRAMS/BHP-HR				% OBSERVED DRY		MASS AFR[2]	VOLUME AFR[2]	EXCESS AIR RATIO
		NOX[1]	CO	NMHC[4]	THC	CO	O_2			
G, GSI	Lowest Manifold (Best Power)	8.5	32.0	0.35	2.3	1.15	0.30	15.5:1	9.3:1	0.97
	Equal NOx & CO	12.0	12.0	0.35	2.3	0.45	0.30	15.9:1	9.6:1	0.99
	Catalytic Conv. Input (3-way[3])	13.0	9.0	0.30	2.0	0.38	0.30	15.95:1	9.6:1	0.99
	Standard (Best Economy)	22.0	1.5	0.25	1.5	0.02	1.35	17.0:1	10.2:1	1.06
F3524GSI L7044GSI	Equal NOx & CO	14.0	14.0	0.25	1.1	0.45	0.30	15.85:1	9.5:1	0.99
	Catalytic Conv. Input (3-way[3])	15.0	13.0	0.20	1.0	0.38	0.30	15.95:1	9.6:1	0.99
	Standard (Best Economy)	23.0	2.0	0.20	0.8	0.02	1.35	17.0:1	10.2:1	1.06
L5794GSI	Equal NOx & CO	13.5	13.5	0.45	3.0	0.45	0.30	15.85:1	9.5:1	0.99
	Catalytic Conv. Input (3-way[3])	14.5	11.0	0.45	2.9	0.38	0.30	15.95:1	9.6:1	0.99
	Standard (Best Economy)	22.0	3.0	0.35	2.4	0.02	1.35	17.0:1	10.2:1	1.06
GL	Standard	1.5	2.65	1.0	5.5	0.06	9.8	28.0:1	16.8:1	1.74
L5774LT#	Standard	2.6	2.0	0.60	4.0	0.04	8.0	24.7:1	14.8:1	1.54
L5794LT#	Standard	2.6	2.0	0.60	4.0	0.04	7.8	24.5:1	14.7:1	1.52

L5774LT and L5794LT emission levels are based on 1000 – 1200 rpm operation. For information at all other speeds contact Waukesha's Sales Engineering Department.

NOTE:

The above tables indicate emission levels that are valid for new engines for the duration of the standard warranty period and are attainable by an engine in good operating condition running on commercial quality natural gas of 900 BTU/ft^3 (35.38 MJ/m^3 [25, V(0; 101.325)]) SLHV, Waukesha Knock Index of 91 or higher, 93% methane content by volume, and at ISO standard conditions. Emissions are based on standard engine timing at 91 WKI® with an absolute humidity of 42 grains/lb. Refer to engine specific WKI® Power & Timing curves for standard timing. Unless otherwise noted, these emission levels can be achieved across the continuous duty speed range and from 75% to 110% of the ISO Standard Power (continuous duty) rating. ***Contact the local Waukesha representative or Waukesha's Sales Engineering Department for emission values which can be obtained on a case-by-case basis for specific ratings, fuels, and site conditions.***

Table 3 – VGF EMISSION LEVELS

MODEL	CARBURETOR SETTING	GRAMS/BHP-HR				% OBSERVED DRY		MASS AFR[2]	VOLUME AFR[2]	EXCESS AIR RATIO
		NOX[1]	CO	NMHC[4]	THC	CO	O_2			
G	Lowest Manifold (Best Power)	12.0	28.0	0.30	2.0	1.1	0.30	15.5:1	9.3:1	0.97
	Equal NOx & CO	15.0	15.0	0.30	2.0	0.70	0.30	15.8:1	9.5:1	0.98
	Catalytic Conv. Input (3-way[3])	16.0	10.0	0.30	2.0	0.38	0.30	15.95:1	9.6:1	0.99
	Standard (Best Economy)	28.0	0.8	0.25	1.3	0.20	2.4	18.0:1	10.8:1	1.12
GSID	Catalytic Conv. Input (3-way[3])	16.0	8.0	0.25	1.5	0.35	0.18	15.95:1	9.6:1	0.99
GL, GLD 11:1 CR	Standard (High Speed Turbo Only)	2.6	1.75	0.75	5.0	0.04	7.8	24.5:1	14.7:1	1.53
	T.A. Luft Emissions	1.25	1.65	0.45	3.5	0.03	8.2	25.4:1	15.2:1	1.59
GLD/2[+] (200 BMEP) 11:1 CR	Standard (High Speed Turbo Only)	1.25	2.1	0.65	4.2	0.04	9.0	26.2	15.7:1	1.65
GL 8.7:1 CR	Standard (High Speed Turbo Only)	2.0	1.7	0.45	3.0	0.04	7.8	24.5:1	14.7:1	1.53
GL 11:1 CR	Code 1105 (High Altitude Low NOx)	1.0[++]	1.45	0.35	3.90	0.033	8.0	24.8	14.9:1	1.54

[+] For VGF GLD/2 models, the above table indicates emission levels that are for engines running on Dutch natural gas of 790 Btu/ft^3 (31.45 MJ/m^3 [25, V(0; 101.325)]) SLHV, Waukesha Knock Index of 99 or higher, 81% methane content by volume, and at ISO Standard conditions.

[++] NOx emissions level applies at continuous BHP (160 BMEP) at 25 grains/lb. absolute humidity.

NOTE:

The above tables indicate emission levels that are valid for new engines for the duration of the standard warranty period or are attainable by an engine in good operating condition running on commercial quality natural gas of 900 BTU/ft^3 (35.38 MJ/m^3 [25, V(0; 101.325)]) SLHV, Waukesha Knock Index of 91 or higher, 93% methane content by volume, and at ISO standard conditions. Emissions are based on standard engine timing at 91 WKI® with an absolute humidity of 42 grains/lb. Refer to engine specific WKI® Power & Timing curves for standard timing. Unless otherwise noted, these emission levels can be achieved across the continuous duty speed range and from 75% to 110% of the ISO Standard Power (continuous duty) rating. ***Contact the local Waukesha representative or Waukesha's Sales Engineering Department for emission values which can be obtained on a case-by-case basis for specific ratings, fuels, and site conditions.***

Table 4 – VSG EMISSION LEVELS

MODEL	CARBURETOR SETTING	GRAMS/BHP-HR				% OBSERVED DRY		MASS AFR[2]	VOLUME AFR[2]	EXCESS AIR RATIO
		NOX[1]	CO	NMHC[4]	THC	CO	O2			
G, GSI, GSID	Lowest Manifold (Best Power)	10.0	38.0	0.45	3.0	1.15	0.30	15.5:1	9.3:1	0.97
		9.5	35.0	0.25	1.7	1.15	0.30	15.5:1	9.3:1	0.97
		9.5	35.0	0.25	1.7	1.15	0.30	15.5:1	9.3:1	0.97
	Equal NOx & CO	14.0	14.0	0.45	3.0	0.46	0.38	15.8:1	9.5:1	0.98
		16.0	16.0	0.25	1.6	0.54	0.29	15.8:1	9.5:1	0.98
		16.0	16.0	0.25	1.6	0.54	0.29	15.8:1	9.5:1	0.98
	Catalytic Conv. Input (3-way[3])	15.0	12.0	0.50	2.8	0.38	0.40	15.95:1	9.6:1	0.99
		18.0	15.0	0.25	1.5	0.52	0.30	15.95:1	9.6:1	0.99
		18.0	15.0	0.25	1.5	0.52	0.30	15.95:1	9.6:1	0.99
	Standard (Best Economy)	25.0	0.9	0.30	2.0	0.03	2.10	17.7:1	10.6:1	1.10
		28.0	0.8	0.25	1.2	0.02	1.40	17.0:1	10.2:1	1.06
		28.0	0.8	0.25	1.2	0.02	1.40	17.0:1	10.2:1	1.06

Table 5 – F1197G EMISSION LEVELS

MODEL	CARBURETOR SETTING	GRAMS/BHP-HR				% OBSERVED DRY		MASS AFR[2]	VOLUME AFR[2]	EXCESS AIR RATIO
		NOX[1]	CO	NMHC[4]	THC	CO	O_2			
G	Lowest Manifold (Best Power)	10.0	39.0	0.50	3.0	1.35	0.30	15.5:1	9.3:1	0.97
	Equal NOx & CO	14.0	14.0	0.35	2.3	0.45	0.35	16.0:1	9.6:1	1.00
	Catalytic Conv. Input (3-way[3])	13.5	17.0	0.35	2.3	0.60	0.30	15.95:1	9.6:1	0.99
	Standard (Best Economy)	22.0	1.3	0.25	1.2	0.04	1.35	17.0:1	10.2:1	1.06

NOTE:

The above tables indicate emission levels that are valid for new engines for the duration of the standard warranty period or are attainable by an engine in good operating condition running on commercial quality natural gas of 900 BTU/ft^3 (35.38 MJ/m^3 [25, V(0; 101.325)]) SLHV, Waukesha Knock Index of 91 or higher, 93% methane content by volume, and at ISO standard conditions. Emissions are based on standard engine timing at 91 WKI® with an absolute humidity of 42 grains/lb. Refer to engine specific WKI® Power & Timing curves for standard timing. Unless otherwise noted, these emission levels can be achieved across the continuous duty speed range and from 75% to 110% of the ISO Standard Power (continuous duty) rating. ***Contact the local Waukesha representative or Waukesha's Sales Engineering Department for emission values which can be obtained on a case-by-case basis for specific ratings, fuels, and site conditions.***

Table 6 – F817G EMISSION LEVELS

MODEL	CARBURETOR SETTING	GRAMS/BHP-HR				% OBSERVED DRY		MASS AFR[2]	VOLUME AFR[2]	EXCESS AIR RATIO
		NOX[1]	CO	NMHC[4]	THC	CO	O_2			
G	Lowest Manifold (Best Power)	8.5	38.0	0.35	2.3	1.30	0.30	15.5:1	9.3:1	0.97
	Equal NOx & CO	13.0	13.0	0.30	2.0	0.45	0.35	16.0:1	9.6:1	1.00
	Catalytic Conv. Input (3-way[3])	12.0	15.0	0.30	2.0	0.50	0.30	15.95:1	9.6:1	0.99
	Standard (Best Economy)	18.0	1.3	0.30	2.0	0.04	1.35	17.0:1	10.2:1	1.06

NOTE:

The above tables indicate emission levels that are valid for new engines for the duration of the standard warranty period or are attainable by an engine in good operating condition running on commercial quality natural gas of 900 BTU/ft^3 (35.38 MJ/m^3 [25, V(0; 101.325)]) SLHV, Waukesha Knock Index of 91 or higher, 93% methane content by volume, and at ISO standard conditions. Emissions are based on standard engine timing at 91 WKI® with an absolute humidity of 42 grains/lb. Refer to engine specific WKI® Power & Timing curves for standard timing. Unless otherwise noted, these emission levels can be achieved across the continuous duty speed range and from 75% to 110% of the ISO Standard Power (continuous duty) rating. ***Contact the local Waukesha representative or Waukesha's Sales Engineering Department for emission values which can be obtained on a case-by-case basis for specific ratings, fuels, and site conditions.***

NOTE: ***(FOR ALL TABLES)***

1. NOx is measured as (NO + NO_2) and expressed as NO_2.
2. Air/fuel ratio values are based on a natural gas fuel with a stoichiometric mass air/fuel ratio of 16.05:1 and a H/C ratio of 3.85. Refer to S-7884-7, or latest revision, for the complete gaseous fuel specification for Waukesha engines.
3. Consult with individual catalyst manufacturers for their preferred air/fuel ratio set point and specific post-catalyst emission values.
4. Non-Methane Hydrocarbons (NMHC) includes all hydrocarbon gasses in the exhaust except for methane (CH_4). This value can be used for Reactive Organic Gasses (ROG), Reactive Organic Compounds (ROC), and Volatile Organic Compounds (VOC).

FORMALDEHYDE EMISSION LEVELS

The following table provides formaldehyde (CH_2O) levels that are valid for new engines for the duration of the standard warranty period and are attainable by an engine in good operating condition running on commercial quality natural gas of 900 BTU/ft^3 (35.38 MJ/m^3 [25, V(0; 101.325)]) SLHV, Waukesha Knock Index of 91 or higher, 93% methane content by volume, and at ISO standard conditions. Values are based on standard engine timing at 91 WKI® with an absolute humidity of 42 grains/lb. Refer to engine specific WKI® Power & Timing curves for standard timing. Unless otherwise noted, these emission levels can be achieved across the continuous duty speed range at the load levels tabulated. ***Contact the local Waukesha representative or Waukesha's Sales Engineering Department for emission values which can be obtained on a case-by-case basis for specific ratings, fuels, and site conditions.***

Table 7 – Formaldehyde Emission Levels

MODEL	CARBURETOR SETTING	CH_2O GRAMS/BHP-HR		% OBSERVED DRY		MASS AFR[2]	VOLUME AFR[2]	EXCESS AIR RATIO
		PERCENT LOAD		CO	O^2			
		100%	75%					
AT25GL	Lean Burn	0.18	0.20	0.06	9.8	28.0:1	16.8:1	1.74
AT27GL	Lean Burn	0.18	0.20	0.06	9.8	28.0:1	16.8:1	1.74
	Ultra Lean	0.18	0.20	0.05	11.2	32.0:1	19.2:1	2.00
VHP G, GSI	Rich Burn	0.05	0.05	0.02 – 1.15	0.30 – 1.35	15.5:1 – 17.0:1	9.3:1 – 10.2:1	0.97 – 1.06
VHP Series 4 GSI	Rich Burn	0.05	0.05	0.02 – 0.45	0.30 – 1.35	15.85:1 – 17.0:1	9.5:1 – 10.2:1	0.99 – 1.06
L5774LT L5794LT	Lean Burn	0.22	0.25	0.04	7.8 – 8.0	24.5:1 – 24.7:1	14.7:1 – 14.8:1	1.52 – 1.54
VHP GL	Lean Burn	0.29	0.34	0.06	9.8	28.0:1	16.8:1	1.74
VGF G, GSID	Rich Burn	0.05	0.05	0.20 – 1.1	0.18 – 2.4	15.5:1 – 18.0:1	9.3:1 – 10.8:1	0.97 – 1.12
VGF GL, GLD, GLD/2	Lean Burn	0.19	0.22	0.03 – 0.04	7.8 – 9.0	21.5:1 – 25.4:1	13.9:1 – 15.2:1	1.53 – 1.65
VSG G, GSI, GSID	Rich Burn	0.05	0.05	0.02 – 1.15	0.29 – 2.10	15.5:1 – 17.7:1	9.3:1 – 10.6:1	0.97 – 1.10
F1197G	Rich Burn	0.05	0.05	0.04 – 1.35	0.30 – 1.35	15.5:1 – 17.0:1	9.3:1 – 10.2:1	0.97 – 1.06
F817G	Rich Burn	0.05	0.05	0.04 – 1.30	0.30 – 1.35	15.5 :1 – 17.0:1	9.3:1 – 10.2:1	0.97 – 1.06

APPENDIX A

CONVERSION FACTORS

NOTE: *ALL FACTORS ARE APPROXIMATE*

Excess Air Ratio(λ →)	TO CONVERT	INTO	MULTIPLY BY G, GSI(D) 0.93-1.06	VGF, GL(D) 1.53	VHP/AT-GL(D) 1.74	AT27-GL 2.00
For NOx (as NO_2)	grams/bhp-hr	PPMV@ 15% O_2	67	73	75	80
	lbs/bhp-hr	PPMV@ 15% O_2	3.039×10^{4}	3.311×10^{4}	3.402×10^{4}	3.629×10^{4}
	PPMV@ 15% O_2	grams/bhp-hr	1.493×10^{-2}	1.370×10^{-2}	1.33×10^{-2}	1.250×10^{-2}
	PPMV@ 15% O_2	lbs/bhp-hr	3.291×10^{-5}	3.020×10^{-5}	2.94×10^{-5}	2.756×10^{-5}
For CO	grams/bhp-hr	PPMV@ 15% O_2	110	120	123	128
	lbs/bhp-hr	PPMV@ 15% O_2	4.990×10^{4}	5.44×10^{4}	5.58×10^{4}	5.806×10^{4}
	PPMV@ 15% O_2	grams/bhp-hr	9.091×10^{-3}	8.34×10^{-3}	8.13×10^{-3}	7.813×10^{-3}
	PPMV@ 15% O_2	lbs/bhp-hr	2.004×10^{-5}	1.84×10^{-5}	1.79×10^{-5}	1.722×10^{-5}
For HC (as $CH_{3.85}$)	grams/bhp-hr	PPMV@ 15% O_2	194	212	212	212
	lbs/bhp-hr	PPMV@ 15% O_2	8.800×10^{4}	9.616×10^{4}	9.616×10^{4}	9.616×10^{4}
	PPMV@ 15% O_2	grams/bhp-hr	5.155×10^{-3}	4.717×10^{-3}	4.717×10^{-3}	4.717×10^{-3}
	PPMV@ 15% O_2	lbs/bhp-hr	1.136×10^{-5}	1.040×10^{-5}	1.040×10^{-5}	1.040×10^{-5}

$$\text{PPMV @ 15\% } O_2 = \text{PPMV}_{\text{observed}} \times \frac{(\ 5.9\ )}{(20.9 - \%O_2)}$$

$$\frac{\text{grams}}{\text{bhp-hr}} \times \frac{1\ \text{lb}}{453.6\ \text{grams}} = \frac{\text{lbs}}{\text{bhp-hr}}$$

$$\frac{\text{lbs}}{\text{bhp-hr}} \times \text{bhp} = \frac{\text{lbs}}{\text{hr}}$$

$$\frac{\text{lbs}}{\text{hr}} \times \frac{24\ \text{hrs}}{\text{day}} \times \frac{365\ \text{days}}{\text{year}} \times \frac{1\ \text{ton}}{2000\ \text{lbs}} = \frac{\text{tons}}{\text{year}}$$

APPENDIX B

METRIC (SI) CONVERSION FACTORS

NOTE: *ALL FACTORS ARE APPROXIMATE*

Current European practice is to express emission levels in grams or milligrams (g or mg) per normal cubic meter (nm^3) at 5% oxygen. Emission values expressed in these units can be converted into g/bhp-hr units and back with the following conversion factors:

A) For rich-burn, G and GSI, engines:

$$\frac{\text{g/bhp-hr}}{2.7} = \text{g/nm}^3 \text{ @ 5\% } O_2$$

$$\frac{\text{g/bhp-hr}}{0.0027} = \text{mg/nm}^3 \text{ @ 5\% } O_2$$

g/nm^3 @ 5% O_2 X 2.7 = g/bhp-hr

mg/nm^3 @ 5% O_2 X 0.0027 = g/bhp-hr

B) For lean-burn, GL and LT, engines:

$$\frac{\text{g/bhp-hr}}{2.47} = \text{g/nm}^3 \text{ @ 5\% } O_2$$

$$\frac{\text{g/bhp-hr}}{0.00247} = \text{mg/nm}^3 \text{ @ 5\% } O_2$$

g/nm^3 @ 5% O_2 X 2.47 = g/bhp-hr

mg/nm^3 @ 5% O_2 X .00247 = g/bhp-hr

NOTE:

To convert PPMV values into g/bhp-hr units refer to Appendix A. Normal cubic meter conditions are 32° F (0° C) and 29.92 in. Hg. (101.325 kPa).