Santa Barbara County
Air Pollution Control District

Our Vision Clean Air

SANTA BARBARA COUNTY APCD
PISTON IC ENGINE TECHNICAL REFERENCE DOCUMENT

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I. INTRODUCTION

This Technical Reference Document is intended to help permit engineers with performing IC engine calculations. This document was originally drafted in 1995 as a support document to CAPCOA for implementing the statewide portable equipment registration program. That document was never finalized, but is now made final for general usage. Please note that the calculations were geared towards the PERP rule, but are still useful for general calculation purposes.

Section II (Calculations) of this Technical Reference Document contains the necessary calculations needed for Registration evaluation and issuance. The emission calculations are based upon brake-specific (e.g., "g/bhp-hr") emission factors. This method is consistent with the Portable Equipment Rule structure and with how most manufacturers provide emissions data. Also included are calculations needed for assessing compliance with the Registration once issued. These latter calculations are based on the fuel usage emission factor method (e.g., "lb/1000 gallon") to provide the most user friendly and efficient method for both the sources and Districts. The compliance records needed will be either fuel usage or hours of operation (the hour data will be converted to fuel usage using a pre-defined conversion factor). The fuel usage emission factors will be specified in the Registration, thus allowing both the source and the inspectors to easily assess compliance in the field. This Section also includes other conversion factor equations to help the user move between the different emission factor units (e.g., "g/bhp-hr" to "ppmv").

Section III (Data Tables) of this Technical Reference Document contains various data tables for implementing the Portable Equipment Rule. A general discussion regarding emission factor applicability is provided to help the user understand the basic approach used to implement the Rule. This is followed by the specific emission factor tables by engine type. Standard default emission control efficiencies, fuel property data and engine specifications are also identified.

Section IV (References) is a compilation all references.

II. CALCULATIONS

A. CALCULATIONS REQUIRED FOR REGISTRATION ISSUANCE

A1. Daily Emissions - All Fuels:

$E_D = EF \times H \times T1 \times 1/CF1$ *brake specific horsepower method*

where:

E_D = daily pollutant emissions (lb/day)
EF = pollutant emission factor (g/bhp-hr)
H = maximum-continuous rated brake-horsepower (bhp)
T1 = operating hours per day (hr/day)
CF1 = grams to pounds conversion factor (453.6 g/lb)

A2. Annual Emissions - All Fuels:

$E_Y = EF \times H \times T2 \times 1/CF1 \times 1/CF2$ *brake specific horsepower method*

where:

E_Y = annual pollutant emissions (tons/yr)
EF = pollutant emission factor (g/bhp-hr)
H = maximum-continuous rated brake-horsepower (bhp)
T2 = operating hours per year (hr/year)
CF1 = grams to pounds conversion factor (453.6 g/lb)
CF2 = pounds to tons conversion factor (2000 lb/ton)

A3. Grain Loading:

$E_C = EF_{PM} \times CF3 \times 1/F_D \times 1/BSFC \times 1/EAC \times 1/CF1 \times 10^6$

where:

E_C = exhaust grain loading (gr/dscf)
EF_{PM} = particulate matter emission factor (g/bhp-hr)
F_D = F-factor exhaust volume at 0% O_2 and T_{STD} (dscf/MMBtu)
BSFC = engine brake-specific fuel consumption - HHV based (Btu/bhp-hr)
EAC = excess air correction (0% O_2 to actual exhaust % O_2)
CF1 = grams to pounds conversion factor (453.6 g/lb)
CF3 = grains to pounds conversion factor (7000 gr/lb)

and

$F_D = [T_{STD}/528] \times 10^6 \times \{[(3.64)(H_2) + (1.53)(C) + (0.57)(S) + (0.14)(N_2) - (0.46)(O_2)] / [HHV]\}$ [a]

where:

T_{STD} = standard temperature (520 R)
CHONS = weight percent of carbon, hydrogen, sulfur, nitrogen and oxygen from the fuel ultimate analysis
HHV = fuel higher heating value taken from ultimate analysis sample (Btu/lb)

EAC = $[(20.9)/(20.9 - O_2)]^{b}$

where:

O_2 = actual volume percent of oxygen in the exhaust

A4. Fuel Sulfur Mass Balance - Liquid Fuels:

$EF_{SO2} = \%S/100 \times \rho_f \times CF1 \times 1/MW_S \times MR \times MW_{SO2} \times 1/HHV \times BSFC$

where:

EF_{SO2} = oxides of sulfur emission factor (g/bhp-hr)
%S = percent sulfur by weight (lb S/100 lb fuel)
ρ_f = density of fuel (lb/gal)
CF1 = grams to pounds conversion factor (453.6 g/lb)
MW_s = molecular weight of sulfur (32 g/g-mole)
MR = molar ratio ($S + O_2 \Rightarrow SO_2$ -- i.e., MR = 1)
MW_{SO2} = molecular weight of sulfur dioxide (64 g/g-mole)
HHV = fuel higher heating value (Btu/gallon)
BSFC = engine brake-specific fuel consumption - HHV based (Btu/bhp-hr)

dimensional analysis:

[g/bhp-hr] = [lb S/100 lb fuel] [lb fuel/gal fuel] [g S/lb S] [g-mole S/g S] × [g-mol SO_2/g-mol S] [g SO_2/g-mole SO_2] [gal fuel/Btu] [Btu/bhp-hr]

default values:

(using defaults from Section III - Tables 5 and 6)

Diesel Engine Naturally Aspirated	EF = 0.182 g/bhp-hr
Diesel Engine Turbocharged	EF = 0.175 g/bhp-hr
Diesel Engine TC/Aftercooled	EF = 0.166 g/bhp-hr
Gasoline Engine - Nat. Aspirated	EF = 0.135 g/bhp-hr
Gasoline Engine - Turbocharged	EF = 0.130 g/bhp-hr

A5. Fuel Sulfur Mass Balance - Gaseous Fuels:

$EF_{SO2} = ppmv\ S/10^6 \times 1/mv \times MR \times MW_{SO2} \times CF1 \times 1/HHV \times BSFC$

where:

EF_{SO2} = oxides of sulfur emission factor (g/bhp-hr)
ppmv S = parts per million sulfur by volume (ft^3 S/10^6 ft^3 fuel)
mv = molar volume (379 std ft^3 S/lb-mol S -- assumes std temp of 60°F)

MR = molar ratio ($S + O_2 => SO_2$ -- i.e., MR = 1)
MW_{SO2} = molecular weight of sulfur dioxide (64 lb/lb-mol)
CF1 = grams to pounds conversion factor (453.6 g/lb)
HHV = fuel higher heating value (Btu/std ft^3)
BSFC = engine brake-specific fuel consumption - HHV based (Btu/bhp-hr)

dimensional analysis:

[g/bhp-hr] = [ft^3 S/10^6 ft^3 fuel] [lb-mol S/std ft^3 S] [lb-mol SO_2/lb-mol S] ×
[lb SO_2/lb-mol SO_2] [g SO_2/lb SO_2] [std ft^3 fuel/Btu] [Btu/bhp-hr]

default value:

(using defaults from Section III - Tables 5 and 6)

Natural Gas Engine - Nat. Aspirated	EF = 0.061 g/bhp-hr
Natural Gas Engine - Turbocharged	EF = 0.059 g/bhp-hr

A6. Emission Factor Conversions:

(a) [g/bhp-hr] --> [lb/1000 gallons]

$$EF_{lb/1000\ gal} = EF_{g/bhp\text{-}hr} \times 1/CF1 \times 1/BSFC \times HHV \times 1000\ gal/1000\ gal$$

where:

$EF_{lb/1000\ gal}$ = emission factor in units of "lb/1000 gallons"
$EF_{g/bhp\text{-}hr}$ = emission factor in units of "g/bhp-hr"
CF1 = grams to pounds conversion factor (453.6 g/lb)
BSFC = engine brake-specific fuel consumption - HHV based (Btu/bhp-hr)
HHV = fuel higher heating value (Btu/gallon)

(b) [g/bhp-hr] --> [lb/MMBtu]

$$EF_{lb/MMBtu} = EF_{g/bhp\text{-}hr} \times 1/CF1 \times 1/BSFC \times 10^6\ Btu/MMBtu$$

where:

$EF_{lb/MMBtu}$ = emission factor in units of "lb/MMBtu"
$EF_{g/bhp\text{-}hr}$ = emission factor in units of "g/bhp-hr"
CF1 = grams to pounds conversion factor (453.6 g/lb)
BSFC = engine brake-specific fuel consumption - HHV based (Btu/bhp-hr)

(c) [g/bhp-hr] --> [lb/MMSCF]

$$EF_{lb/MMSCF} = EF_{g/bhp\text{-}hr} \times 1/CF1 \times 1/BSFC \times HHV \times 10^6\ SCF/MMSCF$$

where:

$EF_{lb/MMSCF}$ = emission factor in units of "lb/MMSCF"
$EF_{g/bhp\text{-}hr}$ = emission factor in units of "g/bhp-hr"
CF1 = grams to pounds conversion factor (453.6 g/lb)
BSFC = engine brake-specific fuel consumption - HHV based (Btu/bhp-hr)
HHV = fuel higher heating value (Btu/SCF)

B. CALCULATIONS REQUIRED FOR COMPLIANCE ASSESSMENT

B1. Liquid Fuel Usage: Hours to Gallons Conversion:

$$Q_L = T \times H \times BSFC \times 1/HHV$$

where:

Q_L = gallons used per selected time period (e.g., gallons/day, gallons/year)
T = hours of use per selected time period (e.g., hrs/day or hrs/year)
H = maximum continuous rated engine brake horsepower (bhp)
BSFC = engine brake-specific fuel consumption - HHV based (Btu/bhp-hr)
HHV = fuel higher heating value (Btu/gal)

B2. Gaseous Fuel Usage: Hours to Standard Cubic Feet Conversion:

$$Q_G = T \times H \times BSFC \times 1/HHV$$

where:

Q_G = SCF used per selected time period (e.g., SCF/day, SCF/year)
T = hours of use per selected time period (e.g., hrs/day or hrs/year)
H = maximum continuous rated engine brake horsepower (bhp)
BSFC = engine brake-specific fuel consumption - HHV based (Btu/bhp-hr)
HHV = fuel higher heating value (Btu/SCF)

B3. Daily Emissions - Liquid Fuels:

$$E_D = (EF/10^3) \times Q_{L1}$$ *fuel usage method*

where:

E_D = daily pollutant emissions (lb/day)
EF = pollutant emission factor (lb/1000 gal)
Q_{L1} = daily fuel used (gal/day)

B4. Daily Emissions - Gaseous Fuels:

$$E_D = (EF/10^6) \times Q_{G1}$$ *fuel usage method*

where:

E_D = daily pollutant emissions (lb/day)

EF = pollutant emission factor (lb/MMSCF)
Q_{G1} = daily fuel used (SCF/day)

B5. Annual Emissions - Liquid Fuels:

$E_Y = (EF/10^3) \times Q_{L2} \times 1/CF2$ *fuel usage method*

where:

E_Y = annual pollutant emissions (tons/year)
EF = pollutant emission factor (lb/1000 gal)
Q_{L2} = annual fuel used (gal/year)
CF2 = pounds to tons conversion factor (2000 lb/ton)

B6. Annual Emissions - Gaseous Fuels:

$E_Y = (EF/10^6) \times Q_{G2} \times 1/CF2$ *fuel usage method*

where:

E_Y = annual pollutant emissions (tons/year)
EF = pollutant emission factor (lb/MMSCF)
Q_{G2} = annual fuel used (SCF/year)
CF2 = pounds to tons conversion factor (2000 lb/ton)

B7. Emission Standard Verification ("ppmv" <==> "g/bhp-hr") Conversion:

(a) ppmvd $= [V_p/V_e] \times 10^6$

where:

ppmvd = concentration of pollutant in exhaust by volume (dry)
V_p = volume of pollutant (dscf/hr)
V_e = volume of exhaust (dscf/hr)

(b) $V_p = EF \times H \times 1/CF1 \times 1/MW_p \times mv$

where:

EF = pollutant emission factor (g/bhp-hr)
H = maximum continuous rated engine brake horsepower (bhp)
CF1 = grams to pounds conversion factor (453.6 g/lb)
MW_p = molec. weight of pollutant (lb/lb-mol=> NO_x= 46, CO = 28, VOC=16)
mv = molar volume (379 std ft^3 S/lb-mol S -- assumes std temp of 60°F) [c]

(c) $V_e = F_D \times EAC \times BSFC \times H \times 1/10^6$

where:

F_D = F-factor exhaust volume at 0% O_2 and 60°F (dscf/MMBtu)

EAC = excess air correction (0% O_2 to 15% O_2 => EAC = 3.5424)
BSFC = engine brake-specific fuel consumption - HHV based (Btu/bhp-hr)
H = maximum continuous rated engine brake horsepower (bhp)

and

$F_D = [T_{STD}/528] \times 10^6 \times \{[(3.64)(H_2) + (1.53)(C) + (0.57)(S) + (0.14)(N_2) - (0.46)(O_2)] / [HHV]\}$

where:

T_{STD} = standard temperature (520 R)
CHONS = weight percent of carbon, hydrogen, sulfur, nitrogen and oxygen from fuel ultimate analysis
HHV = fuel higher heating value taken from ultimate analysis sample (Btu/lb)

$EAC = [(20.9)/(20.9 - O_2)]$

where:

O_2 = percent oxygen by volume in exhaust (O_2 = 15%)

(d) substituting the equations for V_p and V_e yields:

$$ppmvd = [V_p/V_e] \times 10^6$$
$$= \{[EF \times H \times 1/CF1 \times 1/MW_p]/[F_D \times EAC \times BSFC \times H \times 1/10^6]\} \times 10^6$$

$$ppmvd = [EF_{g/bhp\text{-}hr} \times mv \times 10^{12}]/[F_D \times EAC \times BSFC \times CF1 \times MW_p]$$

The above equation may be used to establish the allowable "equivalent" pollutant concentration for a given standard. For compliance, this equation can be re-arranged and solved for the emission standard ($EF_{g/bhp\text{-}hr}$). Using source test results (i.e., ppmvd data) compliance can be determined.

$$EF_{g/bhp\text{-}hr} = [ppmvd \times F_D \times EAC \times BSFC \times CF1 \times MW_p]/[mv \times 10^{12}]$$

(e) Default Values: (substituting default values based on Section III data, Tables 5 and 6, at 60°F and referencing the concentrations at 15 percent excess oxygen)

(i) Diesel Naturally Aspirated:

$ppmvd\ NO_x = EF_{g/bhp\text{-}hr} \times 72$
$EF_{g/bhp\text{-}hr} = ppmvd\ NO_x/72$

(ii) Diesel Turbocharged:

$ppmvd\ NO_x = EF_{g/bhp\text{-}hr} \times 75$
$EF_{g/bhp\text{-}hr} = ppmvd\ NO_x/75$

(iii) Diesel Turbocharged/Aftercooled:

$ppmvd\ NO_x = EF_{g/bhp\text{-}hr} \times 80$
$EF_{g/bhp\text{-}hr} = ppmvd\ NO_x/80$

(iv) Gasoline - Naturally Aspirated:

$ppmvd\ NO_x = EF_{g/bhp\text{-}hr} \times 54$
$EF_{g/bhp\text{-}hr} = ppmvd\ NO_x/54$

$ppmvd\ VOC = EF_{g/bhp\text{-}hr} \times 155$
$EF_{g/bhp\text{-}hr} = ppmvd\ VOC/155$

$ppmvd\ CO = EF_{g/bhp\text{-}hr} \times 88$
$EF_{g/bhp\text{-}hr} = ppmvd\ CO/88$

(v) Gasoline -Turbocharged:

$ppmvd\ NO_x = EF_{g/bhp\text{-}hr} \times 56$
$EF_{g/bhp\text{-}hr} = ppmvd\ NO_x/56$

$ppmvd\ VOC = EF_{g/bhp\text{-}hr} \times 161$
$EF_{g/bhp\text{-}hr} = ppmvd\ VOC/161$

$ppmvd\ CO = EF_{g/bhp\text{-}hr} \times 92$
$EF_{g/bhp\text{-}hr} = ppmvd\ CO/92$

(vi) Natural Gas - Naturally Aspirated:

$ppmvd\ NO_x = EF_{g/bhp\text{-}hr} \times 57$
$EF_{g/bhp\text{-}hr} = ppmvd\ NO_x/57$

$ppmvd\ VOC = EF_{g/bhp\text{-}hr} \times 163$
$EF_{g/bhp\text{-}hr} = ppmvd\ VOC/163$

$ppmvd\ CO = EF_{g/bhp\text{-}hr} \times 93$
$EF_{g/bhp\text{-}hr} = ppmvd\ CO/93$

(vii) Natural Gas -Turbocharged:

$ppmvd\ NO_x = EF_{g/bhp\text{-}hr} \times 59$
$EF_{g/bhp\text{-}hr} = ppmvd\ NO_x/59$

$ppmvd\ VOC = EF_{g/bhp\text{-}hr} \times 170$
$EF_{g/bhp\text{-}hr} = ppmvd\ VOC/170$

$ppmvd\ CO = EF_{g/bhp\text{-}hr} \times 97$
$EF_{g/bhp\text{-}hr} = ppmvd\ CO/97$

III. DATA TABLES

A. EMISSION FACTORS

A1. General: This Section defines the protocol for specifying the criteria pollutant emission factors of piston type internal combustion engines subject to the requirements of the CAPCOA Portable Equipment Rule. These are:

(a) *Manufacturer Based Emission Factors*: If available, manufacturer "guaranteed" emission factors are preferred. These factors must be based on maximum continuous rated brake-horsepower tests for the specific model of engine being registered. Manufacturer documentation must be provided with the Registration application for these emission factors to be considered. The documentation must clearly state that the factors are "guaranteed" and the document must be legible. Source test data will only be accepted if the test was performed at the maximum continuous brake-horsepower rating/rpm and the test was approved by staff from a Participating District. Emission factor data must be presented in units of "g/bhp-hr".

(b) *USEPA AP-42 Emission Factors*: If "guaranteed" manufacturer emission factors are not available, then the uncontrolled USEPA AP-42 (Vol. I) [d] factor tables are used. The latest release of AP-42 will always be used (which means that these Registrations may be updated after initial issuance). Sections 3.3 and 3.4 of AP-42 are used. Diesel engines rated 600 bhp and under use factors from Table 3.3-1. Diesel engines rated over 600 bhp use factors from Table 3.4-1. Gasoline engines use factors from Table 3.3-1.

(c) *CAPCOA Rule Standards*: Notwithstanding the emission factors discussed above, an applicant must comply with the emission standards stated in the CAPCOA Portable Equipment Rule [e]. In these cases, the emission standard from the Rule is used as the emission factor (e.g., 7.2 g/bhp-hr for turbocharged diesel engines). The exception is for *existing* diesel fired engines that do not need to meet a specific NO_x emission standard if 4-degree injection timing retard is employed (see Section 5.3.1 and 5.3.2). In these cases, the NO_x emission factor shall be based on either manufacturer or USEPA AP-42 uncontrolled emission factor coupled with a default emission control factor (e.g., 4-degree injection timing retard is credited with a 15 percent reduction in NO_x). Section III.B contains the standard default control efficiencies that should be used. All *new* diesel engines must meet the specified NO_x emission standard per Section 5.3.6 and 5.3.7 and therefore the NO_x emission standard should be used as the emission factor.

(d) *Oxides of Sulfur*: All SO_x emission factors should be based on mass balance calculations. Use of manufacturer or USEPA AP-42 factors typically will over-estimate potential SO_x emissions for diesel and gasoline fuel because they are based on higher sulfur contents. Further, these same references may under-estimate SO_x emissions from natural gas fuel usage.

(e) *VOC to TOC Ratios*: For diesel piston IC engines rated 600 bhp and under, ARB Profile #9 [f] is used. The specified VOC to TOC ratio = 0.884 (mass basis). For other engine types, AP-42 data is used.

(f) *PM_{10} to PM Ratios*: For diesel piston IC engines rated 600 bhp and under, ARB Profile #114 [g] is used. The specified PM_{10} to PM ratio = 0.976 (mass basis). For gasoline ARB Profile #115 [h] $PM_{10}/PM = 0.994$ (mass basis). For other engine types, AP-42 data is used.

A2. Compression Ignited (Diesel) Engines 600 bhp and Under:

The default emission factors for diesel engines 600 bhp and under are presented in the table below. New engines must meet the NO_x standards specified in the Rule. The NO_x emission factor for existing engines which utilize 4-degree injection timing retard are based on AP-42 data taking into account a control efficiency of 15 percent (no additional control credit for existing turbocharged engines is assessed since the AP-42 emission factor is based on both naturally aspirated and turbocharged engines). CAPCOA Rule standards are presented in **BOLD**. The SO_x emission factor is based on the default engine and fuel data. PM_{10} and VOC data reflect the application of default fractions of 0.976 and 0.884 respectively. Refer to USEPA AP-42 Table 3.3-1 (7/93).

TABLE 1 - DIESEL ENGINES 600 BHP AND UNDER

			EMISSION FACTORS (g/bhp-hr)					
STATUS	TYPE	4°-TR	NO_x	VOC	CO	PM	PM_{10}	SO_x
existing	nat asp	yes	11.9	1.00	3.03	1.00	0.98	0.198
existing	nat asp	no	**10.0**	1.00	3.03	1.00	0.98	0.198
existing	turboc'd	yes	11.9	1.00	3.03	1.00	0.98	0.161
existing	turboc'd	no	**7.2**	1.00	3.03	1.00	0.98	0.161
new	nat asp	--	**10.0**	1.00	3.03	1.00	0.98	0.198
new	turboc'd	--	**7.2**	1.00	3.03	1.00	0.98	0.161

A3. Compression Ignited Engines (Diesel) over 600 bhp:

The default emission factors for diesel engines over 600 bhp are presented in the table below. New engines must meet the NO_x standards specified in the Rule. The NO_x emission factor for existing engines which utilize 4-degree injection timing retard are based on AP-42 data (Table 3.4-1) taking into account a control efficiency of 15 percent (no additional control credit for existing turbocharged engines is assessed since the AP-42 emission factor is based on both naturally aspirated and turbocharged engines). CAPCOA Rule standards are presented in **BOLD**. The SO_x emission factor is based on the default engine and fuel data. PM and PM_{10} data are based on USEPA AP-42 Table 3.4-5.

TABLE 2 - DIESEL ENGINES OVER 600 BHP

			EMISSION FACTORS (g/bhp-hr)					
STATUS	TYPE	4°-TR	NO_x	VOC	CO	PM	PM_{10}	SO_x
existing	nat asp	yes	9.35	0.33	2.4	0.197	0158	0.198
existing	nat asp	no	**10.0**	0.33	2.4	0.197	0.158	0.198
existing	turboc'd	yes	9.35	0.33	2.4	0.197	0.158	0.161
existing	turboc'd	no	**7.2**	0.33	2.4	0.197	0.158	0.161
new	nat asp	--	**10.0**	0.33	2.4	0.197	0.158	0.198
new	turboc'd	--	**7.2**	0.33	2.4	0.197	0.158	0.161

A4. Spark Ignited Gasoline Engines:

The default emission factors for gasoline engines are presented in the table below. All gasoline engines must meet the CAPCOA rule standards for NO_x, VOC and CO. CAPCOA Rule standards are presented in **BOLD**. Therefore, these default emission factors assume use of an emission control device such as a NSCR catalyst coupled with a properly calibrated air-fuel ratio controller (or other similarly effective control strategy). The SO_x emission factor is based on the default engine and fuel data. PM and PM_{10} data are based on USEPA AP-42 Table 3.3-1 and the default PM_{10}/PM fraction ratio of 0.994:1.

TABLE 3 - GASOLINE ENGINES

	EMISSION FACTORS (g/bhp-hr)					
STATUS	NO_x	VOC	CO	PM	PM_{10}	SO_x
existing	**1.5**	**1.5**	**2.0**	0.439	0.436	0.123
new	**1.5**	**1.5**	**2.0**	0.439	0.436	0.123

A5. Spark Ignited Natural Gas Engines:

The default emission factors for natural gas engines are presented in the table below. All natural gas engines must meet the CAPCOA rule standards for NO_x, VOC and CO. CAPCOA Rule standards are presented in **BOLD**. Therefore, these default emission factors assume use of an emission control device such as a NSCR catalyst coupled with a properly calibrated air-fuel ratio controller (or other similarly effective control strategy). The SO_x emission factor is based on the default engine and fuel data. PM and PM_{10} data are based on USEPA AIRS Emission Factor Listing (EPA 45--4-90-003) Natural Gas IC Engine (Industrial). [i]

TABLE 4 - NATURAL GAS ENGINES

	EMISSION FACTORS (g/bhp-hr)					
STATUS	NO_x	VOC	CO	PM	PM_{10}	SO_x
existing	**1.5**	**1.5**	**2.0**	0.043	0.043	0.058
new	**1.5**	**1.5**	**2.0**	0.043	0.043	0.058

B. CONTROL EFFICIENCIES:

The need to utilize standard emission control efficiency for NO_x may arise with implementation of the Portable Equipment Rule. Specifically, one needs to assess a control efficiency value for *existing* diesel engines that opt for the 4-degree injection timing retard option (Re: Section 5.3.1 and 5.3.2 of the Rule). According to an ARB Report [j], the expected range of NO_x control expected from 4-degree injection timing retard is 4-20 percent (depending on engine design). For the purpose of applying the Portable Equipment Rule, a default value of 15 percent will be used. If an electronic injection timing system is installed, the expected control effectiveness should be increased to 25 percent [k].

C. FUEL PROPERTIES:

Default fuel characteristics are required to implement the Portable Equipment Rule. Default values for density and higher heating value are based on USEPA AP-42 Appendix A (the default value for the density of natural gas is based on an actual utility grade gas sample). It is usually necessary to convert manufacturer energy-based BSFC data from a lower heating value ("LHV") to higher heating value ("HHV") basis. The fuel correction factor ("FCF") is used for this purpose. For liquid fuels the a value of 1.06 is used. For natural gas a value of 1.10 is used. To determine the f-Factor (F_D), an ultimate analysis of the fuel must be performed. In lieu of such an analysis, default values may be used that are based on USEPA 40 CFR 60.45(f)(4)(iii) and (iv). Since the EPA values are based on standard conditions (T = 68°F) other than typical of most California Air Districts (T = 60°F), a corrected default value is present (T_{STD}/528) for use. Both f-Factors are at 0 percent excess oxygen. The sulfur content for diesel fuel is based on the Portable Equipment Rule limit (Section 5.3.3). For gasoline, the sulfur limit is based on the requirements set forth for retail grade motor vehicle gasoline in the California Code, Title 13, Section 2252. For natural gas, pipeline quality fuel is assumed (meeting PUC General Order 58-A standards). [1]

TABLE 5 - DEFAULT FUEL PROPERTIES

FUEL	density (ρ_f)		Sulfur in Fuel		Higher Heating Value (HHV)			FCF	f-Factor -F_D (dscf/MMBtu)	
			% wt	ppmv	Btu/lb	Btu/unit	units		T = 60°F	T = 68°F
Diesel	7.05	lb/gal	0.05	--	19,433	137,000	Btu/gal	1.06	9080	9220
Gasoline	6.17	lb/gal	0.03	--	21,070	130,000	Btu/gal	1.06	9080	9220
Natl Gas	0.0472	lb/scf	--	80	22,246	1,050	Btu/scf	1.10	8608	8740

D. ENGINE SPECIFICATIONS:

The use of default engine specifications are necessary to simplify the implementation of the Portable Equipment Rule. Specifically, default values for the engine brake-specific fuel consumption ("BSFC") at the maximum continuous engine horsepower rating are required. The BSFC is a measure of the engine's fuel efficiency. Compression ignition ("CI") or diesel engines are more efficient than spark-ignited engines, and therefore they have lower BSFC values. Turbocharged CI engines are more efficient than naturally aspirated CI engines. Default values are presented below for use. Where possible, however, engine specific BSFC data is preferred. Data from manufacturer specification sheets present BSFC data in terms of energy (Btu/bhp-hr) or mass (gal/bhp-hr, lb/bhp-hr). Energy based BSFC data presented by manufacturers are almost always LHV based. In these cases, the value must be converted using the LHV to HHV fuel correction factor ("FCF") presented in the fuel properties table above.

TABLE 6 - DEFAULT ENGINE SPECIFICATIONS [m]

ENGINE TYPE	BSFC (Btu/bhp-hr)	
	LHV basis	HHV basis
Diesel - Naturally Aspirated	7,300	7,800
Diesel - Turbocharged	7,000	7,500
Diesel - TC/Aftercooled	6,600	7,100
Spark Ignited - Nat. Aspirated	9,500	10,500
Spark Ignited - Turbocharged	9,100	10,100
Spark Ignited - TC/Aftercooled	8,700	9,600

IV. REFERENCES

[a] Code of Federal Regulations, 40 CFR Part 60, Section 60.45(f)(5).
[b] USEPA APTI Course 427 Combustion Evaluation Student Manual, Feb. 1980, Equation 5.26
[c] *Ibid.*, Attachment 2-3, Molar Volumes of Ideal Gases at Standard Conditions.
[d] United States Environment Protection Agency, AP-42, Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Point and Area Sources, Fourth Edition, Supplement F, July 1993.
[e] California Air Polution Control Officers Assoiciation, Portable Equipment Rule, April 28, 1994
[f] California Air Resources Board, Identification of Volatile Organic Compound Species Profiles, ARB Speciation Manual, Second Edition, Volume 1 of 2, August 1991
[g] California Air Resources Board, Identification of Particulate Matter Species Profiles, ARB Speciation Manual, Second Edition, Volume 2 of 2, August 1991
[h] *Ibid.*
[i] United States Environment Protection Agency, AIRS Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants, March 1990, EPA 450/4-90-003, Internal Combustion Engines Industrial Natural Gas Reciprocating, value of 10 lb/MMSCF converted to 0.039 g/bhp-hr.
[j] California Air Resources Board, Noncatalytic NOx Control of Stationary Diesel Engines, *Don Koeberlein*, Table 4.
[k] United States Environment Protection Agency, Alternative Control Techniques Document -- NOx Emissions from Stationary Receiprocating Internal Combustion Engines, July 1993, EPA-453/R-93-032, pages 2-22 and 5-70.
[l] Public Utilities Commission of the State of California, Standards for Gas Service In the State of California, General Order 58-A, Title 7 - Purity of Gas.
[m] Memo - Backup Data for Default IC Engine Efficiencies, Steve Sterner to Mike Goldman, Santa Barbara County APCD, May 19, 1995.