Natural Gas Combustion
AP-42 Section 1.4
Reference Number
4

SYSTEMATIC FIELD STUDY OF NO_x EMISSION CONTROL METHODS FOR UTILITY BOILERS

AP42 Section 1.4
4/93
Reference 7

by
William Bartok
Allen R. Crawford
Gregory J. Piegari

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ESSO RESEARCH AND ENGINEERING COMPANY
Government Research Laboratory
Linden, New Jersey

TABLE 2-12

EMISSION FACTORS FOR GAS FIRED BOILERS

Boiler			Emission Factor					
			NO_x			CO		
Code	Size and Load(1) MW	Type of Firing(2)	ppm, at 3% O_2, Dry Basis	lb/10^6 BTU (3)	gm/10^6 cal. (3)	ppm, at 3% O_2, Dry Basis	lb/10^6 BTU	gm/10^6 cal.
	Small							
B	80F	FW	497	0.65	1.16	52	0.043	0.074
I	66F	V	155	0.20 316	0.36	12	0.010	0.017
	Medium							
A	180F	FW	390	0.51	0.92	14	0.011	0.020
C	315F	FW	992	1.29 1354	2.32	(6)	(6)	(6)
G	220F	AW	675	0.88 924	1.58	14	0.012	0.020
H	320F	T	340	0.44 462	0.79	175	0.145	0.249
D	355F	HO	946 (515) (4)	1.23 1291	2.21	86 (67) (4)	0.068	0.122
	Large							
E	480F	HO	736 (140) (5)	0.96 1033	1.73	20-400	0.016-0.33	0.028-0.57
F	600F	HO	570	0.74 777	1.33	8	0.006	0.011

(1) Load: F = Full Load, R = Reduced Load
(2) Type of Firing: FW = Front Wall
V = Vertical
AW = All Wall
T = Tangential
HO = Horizontally Opposed
(3) Expressed as equivalent NO_2
(4) Using "NO-ports"
(5) Using staged combustion
(6) Not available

NOTE: 1.36 lb/10^6 BTU / ppm @ 3% O_2

TABLE 2-13

EMISSION FACTORS FOR OIL FIRED BOILERS

Boiler			Emission Factor					
			NO_x			CO		
Code	Size and Load(1) MW	Type of Firing(2)	ppm, at 3% O_2, Dry Basis	$lb/10^6$ BTU (3)	$gm/10^6$ cal. (3)	ppm, at 3% O_2, Dry Basis	$lb/10^6$ BTU	$gm/10^6$ cal.
	Small							
B	82F	FW	580	0.78	1.41	64	0.052	0.094
K	66F	T	203	0.27	0.49	28	0.023	0.041
	Medium							
A	180F	FW	367	0.50	0.89	19	0.016	0.028
J	250F	FW	360	0.49	0.87	30	0.025	0.044
D	349F	HO	457 (300) (4)	0.62	1.11	66	0.055	0.097
G	220F	AW	235	0.32	0.57	19	0.015	0.028
H	216R	T	161	0.22	0.39	13	0.011	0.019
	Large							
E	359F	HO	246 (200) (4)	0.33	0.60	14	0.017	0.021
L	415F	CY	530	0.72	1.29	6	0.005	0.009

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(1) Load: F= Full Load, R = Reduced Load

(2) Type of Firing: FW = Front Wall
HO = Horizontally Opposed
AW = All Wall
T = Tangential
CY = Cyclone

(3) Expressed as equivalent NO_2

(4) Using "NO-ports"

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1.4 NATURAL GAS COMBUSTION

1.4.1 General[1-2]

1:
2: page 7-8

Natural gas is one of the major fuels used throughout the country. It is used mainly for power generation, ~~for~~ industrial process steam and heat production, and ~~for~~ domestic and commercial space heating. The primary component of natural gas is methane, although varying amounts of ethane and smaller amounts of nitrogen, helium and carbon dioxide are also present. Gas processing plants are required for recovery of liquefiable constitutents and removal of hydrogen sulfide (H_2S) before the gas is used (see Natural Gas Processing, Section 9.2). The average gross heating value of natural gas is approximately 9350 kilocalories per standard cubic meter (1050 British thermal units/standard cubic foot), usually varying from 8900 to 9800 kcal/scm (1000 to 1100 Btu/scf).

1.4.2 Emission And Controls[3-26]

3: 302-364
4: 31-32
5: 11
6: [illegible]
7: 18-49
8: I-16
9: all
10: all
11: 37-42
12: 83
13: 37-402
14: 3-7
15: all
16: all
17: all
18: all
19: 1-2
20: 4,17
21: 4
22:
23: N/A
24: 1-5
25: 1-5
26: all

Even though natural gas is considered to be a relatively clean fuel, some emissions can occur from the combustion reaction. For example, improper operating conditions, including poor mixing, insufficient air, etc., may cause large amounts of smoke, carbon monoxide and hydrocarbons. Moreover, because a sulfur containing mercaptan is added to natural gas to permit detection, small amounts of sulfur oxides will also be produced in the combustion process.

Nitrogen oxides are the major pollutants of concern when burning natural gas. Nitrogen oxide emissions are functions of combustion chamber temperature and combustion product cooling rate. Emission levels vary considerably with the type and size of unit and with operating conditions.

In some large boilers, several operating modifications may be used for NO_x control. Staged combustion, for example, including off-stoichiometric firing and/or two stage combustion, can reduce emissions by 5 to 50 percent. 26 In off-stoichiometric firing, also called "biased firing", some burners are operated fuel rich, some fuel lean, and others may supply air only. In two stage combustion, the burners are operated fuel rich (by introducing only 70 to 90 percent stoichiometric air), with combustion being completed by air injected above the flame zone through second stage "NO ports". In staged combustion, NO_x emissions are reduced because the bulk of combustion occurs under fuel rich conditions.

Other NO_x reducing modifications include low excess air firing and flue gas recirculation. In low excess air firing, excess air levels are kept as low as possible without producing unacceptable levels of unburned combustibles (carbon monoxide, volatile organic compounds and smoke) and/or other operating problems. This technique can reduce NO_x emissions 5 to 35 percent, primarily because of lack of oxygen during combustion. Flue gas recirculation into the primary combustion zone, because the flue gas is relatively cool and oxygen deficient, can also lower NO_x emissions 4 to 85 percent, depending on the amount of gas recirculated. Flue gas recirculation is best suited for new boilers. Retrofit application would require extensive burner modifications.

[illegible]

TABLE 1.4-1. UNCONTROLLED EMISSION FACTORS FOR NATURAL GAS COMBUSTION[a]

Furnace size & type (10^6 Btu/hr heat input)	Particulate[b]		Sulfur dioxide[c]		Nitrogen oxides[d]		Carbon monoxide[e]		Volatile organics: Nonmethane		Volatile organics: Methane	
	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$
Utility boilers (> 100)	16 - 80	1 - 5	9.6	0.6	8800[h]	550[h]	640	40	23	1.4	4.8	0.3
Industrial boilers (10 - 100)	16 - 80	1 - 5	9.6	0.6	2240	140	560	35	44	2.8	48	3
Domestic and commercial boilers (< 10)	16 - 80	1 - 5	9.6	0.6	1600	100	320	20	84	5.3	43	2.7

[a] Expressed as weight/volume fuel fired.
[b] References 15-18.
[c] Reference 4. Based on avg. sulfur content of natural gas, 4600 g/10^6 Nm^3 (2000 gr/10^6 scf).
[d] References 4-5, 7-8, 11, 14, 18-19, 21.
[e] Expressed as NO_2. Tests indicate about 95 weight % NO_x is NO_2.
[f] References 4, 7-8, 16, 18, 22-25.
[g] References 16, 18. May increase 10 - 100 times with improper operation or maintenance.
[h] For tangentially fired units, use 4400 kg/10^6 m^3 (275 lb/10^6 ft^3). At reduced loads, multiply factor by load reduction coefficient in Figure 1.4-1. For potential NO_x reductions by combustion modification, see text. Note that NO_x reduction from these modifications will also occur at reduced load conditions.

b Part
15: all
16: all
17: all
18: all

c SO2
4: sulfur

d NOx
4: 31-32
5: 21
7: 42
8: I-17, I-22
11: 39-40
14: App E (E-1 - E-33)
18: all
19: 5-10, 13-15, 20-26, 31-38, 41-50
21: 17

f CO
4: 31-32
7: 42
8: I-22
16: all
18: all
22
23: N/A
24: 3
25: 3

g
16: all
18: all

Studies indicate that low NO_x burners (20 to 50 percent reduction) and ammonia injection (40 to 70 percent reduction) also offer NO_x emission reductions.

Combinations of the above combustion modifications may also be employed to reduce NO_x emissions further. In some boilers, for instance, NO_x reductions as high as 70 to 90 percent have been produced by employing several of these techiques simultaneously. In general, however, because the net effect of any of these combinations varies greatly, it is difficult to predict what the reductions will be in individual applications.

Although not measured, all particulate ~~has~~ have been estimated to be less than 1 micrometer in size.[27] Emission factors for natural gas combustion are presented in Table 1.4-1, and factor ratings in Table 1.4-2.

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TABLE 1.4-2. FACTOR RATINGS FOR NATURAL GAS COMBUSTION

Furnace type	Particulate	Sulfur oxides	Nitrogen oxides	Carbon monoxide	Volatile organics	
					Nonmethane	Methane
Utility boiler	B	A	A	A	C	C
Industrial boiler	B	A	A	A	C	C
Commercial boiler	B	A	A	A	D	D
Residential furnace	B	A	A	A	D	D

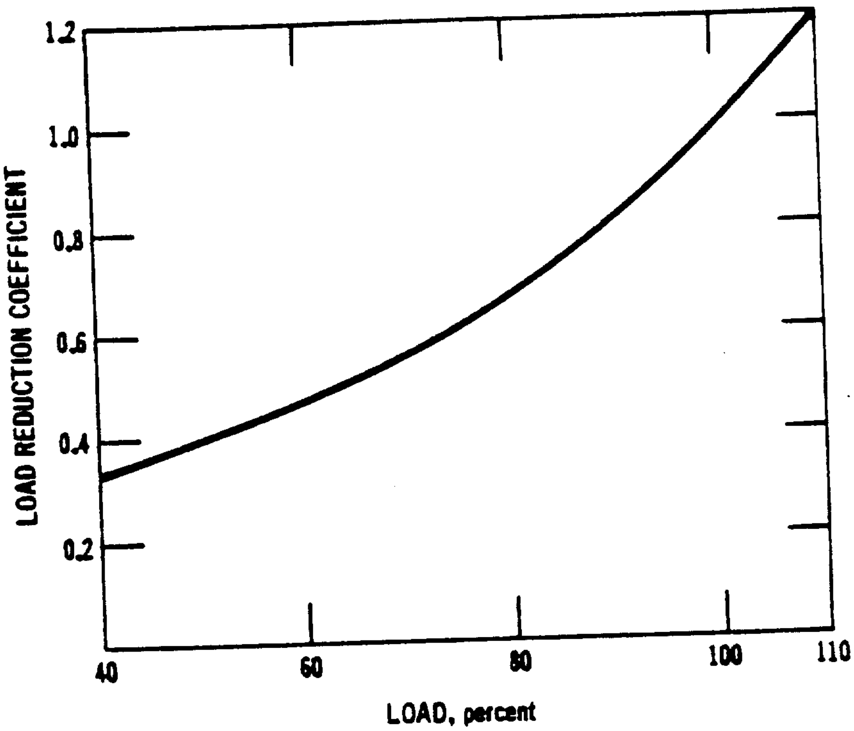

Figure 1.4-1. Load reduction coefficient as function of boiler load. (Used to determine NO_x reductions at reduced loads in large boilers.)

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Furnace Size & Type (10^6 Btu/hr heat input)	Particulates[b]		Sulfur[c] Dioxide		Nitrogen[d,e] Oxide		Carbon[f,g] Monoxide		Volatile Organics			
									Nonmethane		Methane	
	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$
Utility boilers (>100)	16-80	1-5	9.6	0.6	8800[h]	550[h]	640	40	23	1.4	4.8	0.3
Industrial boilers (10 - 100)	16-80	1-5	9.6	0.6	2240	140	560	35	44	2.8	48	3
Domestic and commercial boilers (<10)	16-80	1-5	9.6	0.6	1600	100	320	20	84	5.3	43	2.7

[a] All emission factors are expressed as weight per volume fuel fired.
[b] References 15-18.
[c] Reference 4 (based on an average sulfur content of natural gas of 4600 $g/10^6 Nm^3$ (2000 $gr/10^6$ scf).
[d] References 4-5,7-8,11,14,18-19,21.
[e] Expressed as NO_2. Test results indicate that about 95 weight % of NO_x is NO.
[f] References 4,7-8,16,18,22-25.
[g] References 16 and 18. May increase 10 to 100 times with improper operation or maintenance.
[h] Use 4400 $kg/10^6 m^3$ (275 $lb/10^6 ft^3$) for tangentially fired units. At reduced loads, multiply this factor by the load reduction coefficient given in Figure 1.4-1. See text for potential NO_x reductions by combustion modifications. Note that the NO_x reduction from these modifications will also occur at reduced load conditions.

TABLE 1.4-1. UNCONTROLLED EMISSION FACTORS FOR NATURAL GAS COMBUSTION[a]

Furnace size & type (10^6 Btu/hr heat input)	Particulate[b]		Sulfur dioxide[c]		Nitrogen oxide[d,e]		Carbon monoxide[f,g]		Volatile Organics			
									Nonmethane		Methane	
	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$
Utility Boilers (> 100)	16 - 80	1 - 5	9.6	0.6	8800[h]	550[h]	640	40	23	1.4	4.8	0.3
Industrial Boilers (10 - 100)	16 - 80	1 - 5	9.6	0.6	2240	140	560	35	44	2.8	48	3
Commercial Boilers and Furnaces (0.5 - 10)	16 - 80	1 - 5	9.6	0.6	1600	100	320	20	84	5.3	43	2.7
Residential Boilers and Furnaces (< 0.5)	16 - 80	1 - 5	9.6	0.6	1600	100	320	20	84	5.3	43	2.7

a Expressed as weight/volume fuel fired.
b References 15-18.
c Reference 4. Based on avg. sulfur content of natural gas, 4600 $g/10^6\ Nm^3$ (2000 $gr/10^6$ scf).
d References 4-5, 7-8, 11, 14, 18-19, 21.
e Expressed as NO_2. Tests indicate about 95 weight % NO_x is NO.
f References 4, 7-8, 16, 18, 22-25.
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