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GUIDELINES FOR ADJUSTMENT OF ATMOSPHERIC GAS BURNERS FOR RESIDENTIAL AND COMMERCIAL SPACE HEATING AND WATER HEATING

Adjustment Procedures to Minimize Air Pollution and to Achieve Efficient Use of Gas

- Service guide for skilled service technicians in adjustment of gas burners.
- Training guide for advanced burner service courses.
- Supplement to manufacturers' service instructions.
- Incorporates suggestions of reviewers from industry, including:

  Gas Appliance Manufacturers Association
  American Gas Association
  Independent Service Organizations
  Air Pollution Control Association

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The contents of this manual are offered as guidance. The United States Government, its employees, and its research contractors, Battelle-Columbus and A.G.A. Laboratories, do not assume responsibility or liability for consequences arising from the implementation or failure to implement the guidance contained herein.

GUIDELINES FOR ADJUSTMENT OF ATMOSPHERIC GAS BURNERS FOR RESIDENTIAL AND COMMERCIAL SPACE HEATING AND WATER HEATING

PURPOSE OF THESE GUIDELINES

The most important reason for adjusting a gas burner is to provide safe reliable operation. A second important reason is to provide for efficient fuel utilization, which helps to minimize operating costs. Effective means of meeting these goals include: (1) keeping the burner and pilot orifices, and the burner ports, free of dirt and lint; (2) properly adjusting the burner aeration; and (3) maintaining an acceptable CO level.

Recently, minimizing air pollution has become an additional important reason for proper adjustments. Of course, burner adjustments for this purpose must also meet the former objectives. Fortunately, adjusting for low air-pollutant emissions is consistent with adjusting for reliable performance and efficient operation.

These Guidelines have been prepared for use by service managers in training of technicians and by skilled technicians in their gas-burner service work.* By following the step-by-step procedures outlined in these Guidelines, the skilled gas-burner service technician will be able to adjust residential and commercial heating equipment and water heaters to minimize air pollution, attain optimum efficiency, and provide safe reliable operation.

Scope

These procedures are intended for adjustment of atmospheric-type gas burners for residential and commercial space heating and water heating systems. The procedures are supplemental to manufacturers' installation instructions, the National Fuel Gas Code[2], and other installation codes or handbooks[3,4,5].** They apply to burners fired with either natural gas or liquefied petroleum (LP) gases.***

*Similar Guidelines for oil-fired space-heating equipment are cited in Reference 1.

**Attention is called to the series of American Gas Association publications on fundamentals of appliance servicing, listed in the Bibliography.

****Information in these Guidelines pertaining specifically to LP gases is in italics.*

The adjustment procedures apply to atmospheric-type gas burners of the single-port and multiported types such as ribbon, slotted-port, and drilled-port burners (see Figure 1) as used in in manufacturer-designed burner/furnace units, burner/boiler units, or complete water heaters. Although the principles apply to conversion-type gas burners, these burners require special adjustment procedures. For conversion burners, the burner manufacturer's instructions should be followed.[6]

Retrofit modifications, such as those under study in the gas industry's Space Heating Efficiency Improvement Program (SHEIP) for improving seasonal efficiency, are not included in these Guidelines. Inquiries can be directed to the American Gas Association, 1515 Wilson Boulevard, Arlington, Virginia 22209.

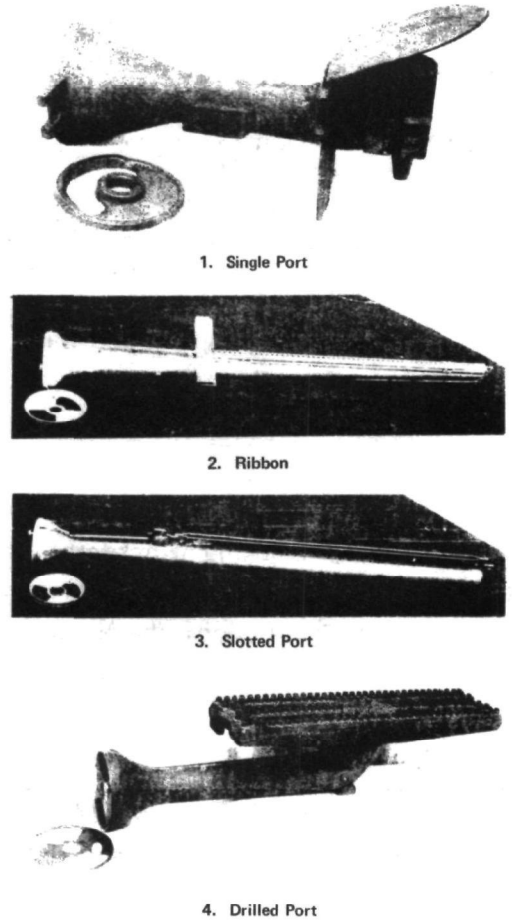

Figure 1. Types of gas burners frequently used in space-heating and water-heating appliances.

RECOMMENDED ADJUSTMENT PROCEDURES FOR GAS BURNERS

The following steps are emphasized from the viewpoint of minimizing air-pollutant emissions and maintaining peak efficiency and safe reliable operation. Fourteen steps are described; they cover preparation steps, combustion adjustment steps, diagnosis, and final checks.

PREPARATION STEPS

1. **Clean Burner and Pilot** The most common malfunction attributed to main burners and pilots is caused by excess dirt, lint, or other debris. Blockage of primary air openings can cause the burner to operate with incomplete combustion and can lead to soot and excess CO formation. Orifice blockage also can cause burner ignition problems. See Figure 2 for sketch and description of primary and secondary air.

   WARNING: Shut off all gas to appliance. Valve should be "tagged" to prevent its being inadvertently opened while system is being worked on. Remove burners and clean the burner ports, burner and pilot orifices, and primary air openings. Ports can be cleaned by passing a wooden dowel through the ports or by running water into the ports. If grease is present, wash with detergent. Make sure the burners are thoroughly dry before reinstalling. Shake out debris through burner mixing tube. Replace burners. Be sure that they are properly installed and that the orifice is centered within the mixing tube.

   Before reinstalling burner, visually inspect combustion chambers, furnace heat exchangers, and appliance flue ways to determine if there are any leaks. For conversion-burner installations, leaks between sections of many cast-iron furnaces can be repaired with furnace cement. If there are cracks or holes in steel heat exchangers, the heat exchanger must be replaced.

   Make preliminary adjustment of the primary air shutters, if any, by following Step 6. Turn on the gas and relight the appliance, following lighting instructions on the appliance.

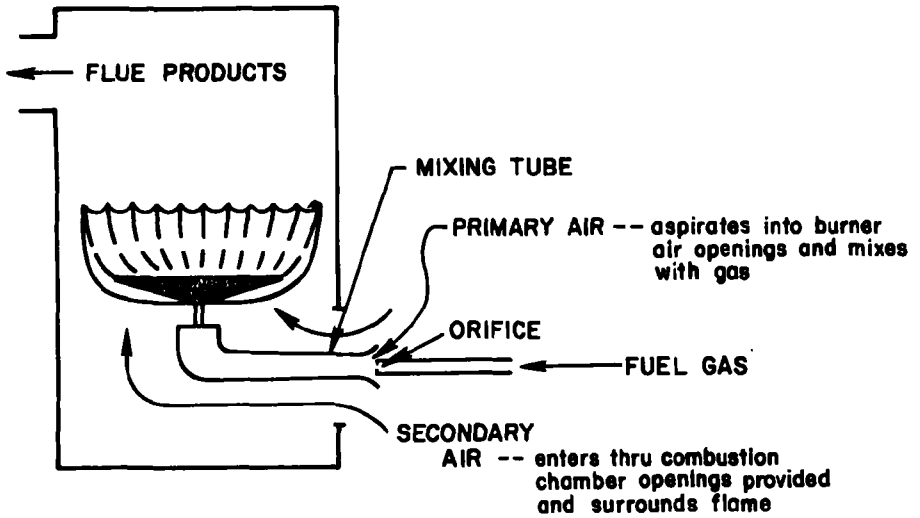

Figure 2. Definitions for burner air/fuel mixing.

2. **Adjust Manifold Pressure** Adjust pressure regulators to deliver gas to burners at the proper pressure.* If the appliance rating plate specifies a manifold pressure, adjust to that pressure. If not specified, set pressure for natural gas appliances with regulators at 3.5 inches water column.**

   For *LP gases, set at 11 inches water column. Regulator may be at tanks. (In some cases, it may not be possible to adjust the pressure.)*

3. **Adjust Pilot** The pilot flame should be soft blue in color. A propane pilot flame may have a slightly yellow tip. The flame should surround the tip of the thermocouple or flame sensor. If there is a separate ignition port, the flame should reach the main burners. There may be an adjusting screw for pilot gas on the main gas valve or pilot shut-off valve.

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*Measured at manifold pressure tap, with main burners operating.

**Although it is EPA policy to use metric units in its publications, nonmetric units are used here to reflect standard field practice.

4. **Adjust Main Burner Input** **a. Using a gas meter.** After the unit has been operating at least 10 minutes, check the gas input rate by timing one revolution of the gas meter test dial, making sure that no other gas burning appliance is operating. Note the number of seconds for one full revolution, and calculate input as follows:

$$\text{Input, Btu/hr} = \frac{\text{cu ft per revolution}}{\text{sec per revolution}} \times 3600 \text{ sec/hr} \times \text{HV}$$

where HV = gross heating value of gas, Btu/cu ft.

Obtain the heating value from the local gas company *or the LP gas supplier.*

b. Not using a gas meter. Measure the orifice size using a drill index and determine the input using Table 1 for utility gas or *Table 2 for LP gases.*

If necessary, adjust the gas input to within ±5 percent of the value noted on the manufacturer's rating plate, as follows. To adjust the input rate of an appliance with an adjustable pressure regulator, first remove the cap covering the pressure regulator adjustment. Turn the adjustment clockwise to increase manifold pressure and input rate. **Caution:** Do not change manifold pressure more than ±0.3 inch water column. To make larger input changes, resize the orifice.

If the appliance is not equipped with an adjustable pressure regulator, replace orifice with resized orifice using Table 1 for utility gas or *Table 2 for LP gases.*

5. **Check Ignition** Allow the burner to cool and check operation of ignition system by cycling several times while the burner is cold to ensure prompt ignition on cold start. Then operate the burner at least 10 minutes (or until thoroughly hot) and repeat several ignition cycle checks to ensure prompt ignition on hot start. (Wait approximately 5 seconds between cycles.)

TABLE 1. ORIFICE SIZING FOR DIFFERENT GAS PRESSURES – NATURAL GAS[2]

Values in table represent flow of gas, cubic feet per hour at sea level.

Specific Gravity = 0.60
Orifice Coefficient = 0.90
For utility gases of another specific gravity, select multiplier from Table 2-a.

Orifice or Drill Size	Pressure at Orifice — Inches Water Column								
	3	3.5	4	5	6	7	8	9	10
80	.48	.52	.55	.63	.69	.73	.79	.83	.88
79	.55	.59	.64	.72	.80	.84	.90	.97	1.01
78	.70	.76	.78	.88	.97	1.04	1.10	1.17	1.24
77	.88	.95	.99	1.11	1.23	1.31	1.38	1.47	1.55
76	1.05	1.13	1.21	1.37	1.52	1.61	1.72	1.83	1.92
75	1.16	1.25	1.34	1.52	1.64	1.79	1.91	2.04	2.14
74	1.33	1.44	1.55	1.74	1.91	2.05	2.18	2.32	2.44
73	1.51	1.63	1.76	1.99	2.17	2.32	2.48	2.64	2.78
72	1.64	1.77	1.90	2.15	2.40	2.52	2.69	2.86	3.00
71	1.82	1.97	2.06	2.33	2.54	2.73	2.91	3.11	3.26
70	2.06	2.22	2.39	2.70	2.97	3.16	3.38	3.59	3.78
69	2.25	2.43	2.61	2.96	3.23	3.47	3.68	3.94	4.14
68	2.52	2.72	2.93	3.26	3.58	3.88	4.14	4.41	4.64
67	2.69	2.91	3.12	3.52	3.87	4.13	4.41	4.69	4.94
66	2.86	3.09	3.32	3.75	4.11	4.39	4.68	4.98	5.24
65	3.14	3.39	3.72	4.28	4.62	4.84	5.16	5.50	5.78
64	3.41	3.68	4.14	4.48	4.91	5.23	5.59	5.95	6.26
63	3.63	3.92	4.19	4.75	5.19	5.55	5.92	6.30	6.63
62	3.78	4.08	4.39	4.96	5.42	5.81	6.20	6.59	6.94
61	4.02	4.34	4.66	5.27	5.77	6.15	6.57	7.00	7.37
60	4.21	4.55	4.89	5.52	5.95	6.47	6.91	7.35	7.74
59	4.41	4.76	5.11	5.78	6.35	6.78	7.25	7.71	8.11
58	4.66	5.03	5.39	6.10	6.68	7.13	7.62	8.11	8.53
57	4.84	5.23	5.63	6.36	6.96	7.44	7.94	8.46	8.90
56	5.68	6.13	6.58	7.35	8.03	8.73	9.32	9.92	10.44
55	7.11	7.68	8.22	9.30	10.18	10.85	11.50	12.34	12.98
54	7.95	8.59	9.23	10.45	11.39	12.25	13.08	13.93	14.65
53	9.30	10.04	10.80	12.20	13.32	14.29	15.27	16.25	17.09
52	10.61	11.46	12.31	13.86	15.26	16.34	17.44	18.57	19.53
51	11.82	12.77	13.69	15.47	16.97	18.16	19.40	20.64	21.71
50	12.89	13.92	14.94	16.86	18.48	19.77	21.12	22.48	23.65
49	14.07	15.20	16.28	18.37	20.20	21.60	23.06	24.56	25.83
48	15.15	16.36	17.62	19.88	21.81	23.31	24.90	26.51	27.89
47	16.22	17.52	18.80	21.27	23.21	24.93	26.62	28.34	29.81
46	17.19	18.57	19.98	22.57	24.72	26.43	28.23	30.05	31.61
45	17.73	19.15	20.52	23.10	25.36	27.18	29.03	30.90	32.51
44	19.45	21.01	22.57	25.57	27.93	29.87	31.89	33.96	35.72
43	20.73	22.39	24.18	27.29	29.87	32.02	34.19	36.41	38.30
42	23.10	24.95	26.50	29.50	32.50	35.24	37.63	40.07	42.14
41	24.06	25.98	28.15	31.69	34.81	37.17	39.70	42.27	44.46

Orifice or Drill Size	Pressure at Orifice — Inches Water Column								
	3	3.5	4	5	6	7	8	9	10
40	25.03	27.03	29.23	33.09	36.20	38.79	41.42	44.10	46.38
39	26.11	28.20	30.20	34.05	37.38	39.97	42.68	45.44	47.80
38	27.08	29.25	31.38	35.46	38.89	41.58	44.40	47.27	49.73
37	28.36	30.63	32.99	37.07	40.83	43.62	46.59	49.60	52.17
36	29.76	32.14	34.59	39.11	42.76	45.77	48.88	52.04	54.74
35	32.36	34.95	36.86	41.68	45.66	48.78	52.10	55.46	58.34
34	32.45	35.05	37.50	42.44	46.52	49.75	53.12	56.55	59.49
33	33.41	36.08	38.79	43.83	48.03	51.46	54.96	58.62	61.55
32	35.46	38.30	40.94	46.52	50.82	54.26	57.95	61.70	64.89
31	37.82	40.85	43.83	49.64	54.36	58.01	61.96	65.97	69.39
30	43.40	46.87	50.39	57.05	62.09	66.72	71.22	75.86	79.80
29	48.45	52.33	56.19	63.61	69.62	74.45	79.52	84.66	89.04
28	51.78	55.92	59.50	67.00	73.50	79.50	84.92	90.39	95.09
27	54.47	58.83	63.17	71.55	78.32	83.59	89.27	95.04	99.97
26	56.73	61.27	65.86	74.57	81.65	87.24	93.17	99.19	104.57
25	58.87	63.58	68.22	77.14	84.67	90.36	96.50	102.74	108.07
24	60.81	65.67	70.58	79.83	87.56	93.47	99.83	106.28	111.79
23	62.10	67.07	72.20	81.65	89.39	94.55	100.98	107.49	113.07
22	64.89	70.08	75.21	85.10	93.25	99.60	106.39	113.24	119.12
21	66.51	71.83	77.14	87.35	95.63	102.29	109.24	116.29	122.33
20	68.22	73.68	79.08	89.49	97.99	104.75	111.87	119.10	125.28
19	72.20	77.98	83.69	94.76	103.89	110.67	118.55	125.82	132.36
18	75.53	81.57	87.56	97.50	108.52	116.03	123.92	131.93	138.78
17	78.54	84.82	91.10	103.14	112.81	120.33	128.52	136.82	143.91
16	82.19	88.77	95.40	107.98	118.18	126.78	135.39	144.15	151.63
15	85.20	92.02	98.84	111.74	122.48	131.07	139.98	149.03	156.77
14	87.10	94.40	100.76	114.21	124.44	133.22	142.28	151.47	159.33
13	89.92	97.11	104.32	118.18	128.93	138.60	148.02	157.58	165.76
12	93.90	101.41	108.52	123.56	135.37	143.97	153.75	163.69	172.13
11	95.94	103.62	111.31	126.02	137.52	147.20	157.20	167.36	176.03
10	98.30	106.16	114.21	129.25	141.82	151.50	161.81	172.26	181.13
9	100.99	109.07	117.11	132.58	145.05	154.71	165.23	175.91	185.03
8	103.89	112.20	120.65	136.44	149.33	160.08	170.96	182.00	191.44
7	105.93	114.40	123.01	139.23	152.56	163.31	174.38	185.68	195.30
6	109.15	117.88	126.78	142.88	156.83	167.51	179.88	190.46	200.36
5	111.08	119.97	128.93	145.79	160.08	170.82	182.48	194.22	204.30
4	114.75	123.93	133.22	150.41	164.36	176.18	188.16	200.25	210.71
3	119.25	128.79	137.52	156.26	170.78	182.64	195.08	207.66	218.44
2	128.48	138.76	148.61	168.64	184.79	197.66	211.05	224.74	235.58
1	136.35	147.26	158.25	179.33	194.63	209.48	223.65	238.16	250.54

COMBUSTION ADJUSTMENT STEPS

6. **Adjust Burner** To adjust primary air, allow at least 10 minutes for the burners to heat up; close primary air shutter until yellow flame tips appear, then open air shutter until all yellow completely disappears. The flame should be clear blue.

   LP gas burner flames and large single-port natural-gas burner flames may have slightly yellow tips; these are satisfactory if no soot forms and there is no flame impinging on the heat exchanger. Single-port burner flames may have an orange quality; these are satisfactory. Any burner flame may have an orange quality, caused by dust; these, too, are satisfactory.

   The primary air setting for matched units has a relatively narrow range of adjustment. (Some burners, particularly on water heaters, do not have air shutters.)

   Too much primary air causes noisy hard flames which could result in flame lifting, flashback, and emission of unburned hydrocarbons. Too little primary air causes yellow flames which could produce high CO and soot emissions. Figure 3 illustrates the desired adjustment region for a typical gas burner, considering variables of input rate and primary air.

   Secondary air is controlled by the burner and appliance design; they should not need modification. Conversion burners, however, may need secondary air adjustment; the manufacturer's instructions should be followed.[6]

7. **Sampling** Flue gas samples for analysis* should be taken from inside the appliance approximately 1 inch ahead of the draft hood inlet. (See Figure 4.) If several flue outlets are provided, individual samples should be taken from each, or a partial sample should be taken from each outlet to make up the full sample. For example, if there are four outlets, 25 percent of the sample should be taken by inserting and traversing the probe in each outlet.

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*CO_2 is usually measured with a wet-chemical analyzer. CO is usually identified by using a color-sensitive chemical-indicator tube. (See Appendix, Section B, for instruments and their use.)

TABLE 2. ORIFICE SIZING FOR DIFFERENT GAS PRESSURES – *LP GASES*[2]

Values in table represent flow of gas, cubic feet per hour at sea level.

	Propane	Butane
Btu per Cubic Foot	2,500	3,175
Specific Gravity	1.53	2.00
Pressure at Orifice, Inches Water Column	11	11
Orifice Coefficient	0.9	0.9

For altitudes above 2,000 feet, first select the equivalent orifice size at sea level from Table 1-C4.

Orifice or Drill Size	Propane	Butane or Butane-Propane Mixtures
.008	500	554
.009	641	709
.010	791	875
.011	951	1,053
.012	1,130	1,250
80	1,430	1,590
79	1,655	1,830
78	2,015	2,230
77	2,545	2,815
76	3,140	3,480
75	3,465	3,840
74	3,985	4,410
73	4,525	5,010
72	4,920	5,450
71	5,320	5,900
70	6,180	6,830
69	6,710	7,430
68	7,560	8,370
67	8,040	8,910
66	8,550	9,470
65	9,630	10,670
64	10,200	11,300
63	10,800	11,900
62	11,360	12,530
61	11,930	13,280
60	12,570	13,840
59	13,220	14,630
58	13,840	15,300
57	14,550	16,090
56	16,990	18,790
55	21,200	23,510
54	23,850	26,300
53	27,790	30,830
52	31,730	35,100
51	35,330	39,400
50	38,500	42,800
49	41,850	45,350
48	45,450	50,300
47	48,400	53,550
46	51,500	57,000
45	52,900	58,500

TABLE 2. (Continued)

Orifice or Drill Size	Propane	Butane or Butane-Propane Mixtures
44	58,050	64,350
43	62,200	69,000
42	68,700	76,200
41	72,450	80,200
40	75,400	83,500
39	77,850	86,200
38	81,000	89,550
37	85,000	94,000
36	89,200	98,800
35	95,000	105,300
34	97,000	107,200
33	101,000	111,900
32	105,800	117,000
31	113,200	125,400
30	129,700	143,600
29	145,700	163,400
28	154,700	171,600
27	163,100	180,000
26	169,900	187,900
25	175,500	194,600
24	181,700	201,600
23	186,800	206,400
22	193,500	214,500
21	198,600	220,200
20	203,700	225,000
19	217,100	241,900
18	225,600	249,800

TABLE 2-a. MULTIPLIERS FOR UTILITY GASES OF ANOTHER SPECIFIC GRAVITY

Specific Gravity	Multiplier	Specific Gravity	Multiplier
0.45	1.155	0.95	0.795
0.50	1.095	1.00	0.775
0.55	1.045	1.05	0.756
0.60	1.000	1.10	0.739
0.65	0.961	1.15	0.722
0.70	0.926	1.20	0.707
0.75	0.894	1.25	0.693
0.80	0.866	1.30	0.679
0.85	0.840	1.35	0.667
0.90	0.817	1.40	0.655

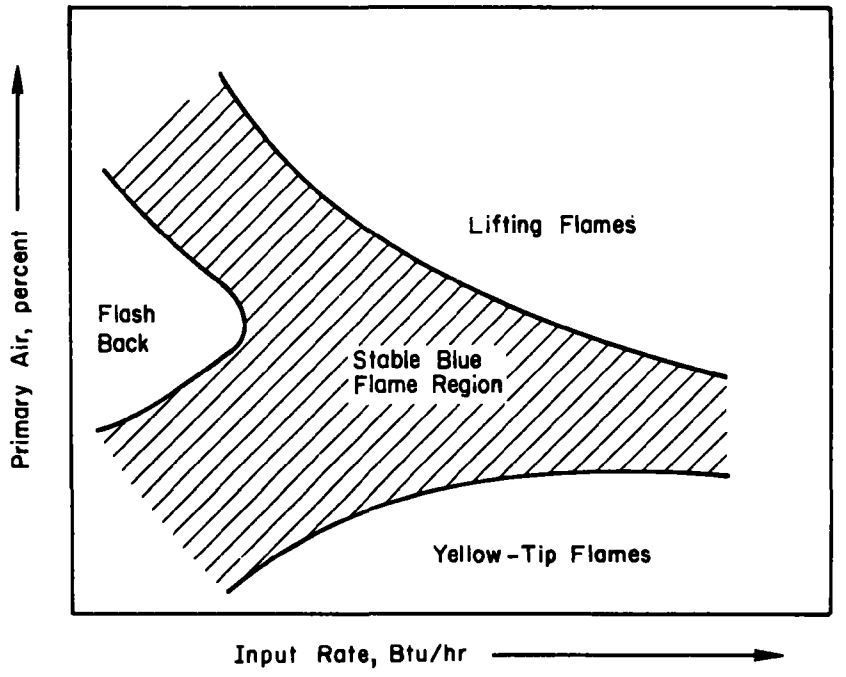
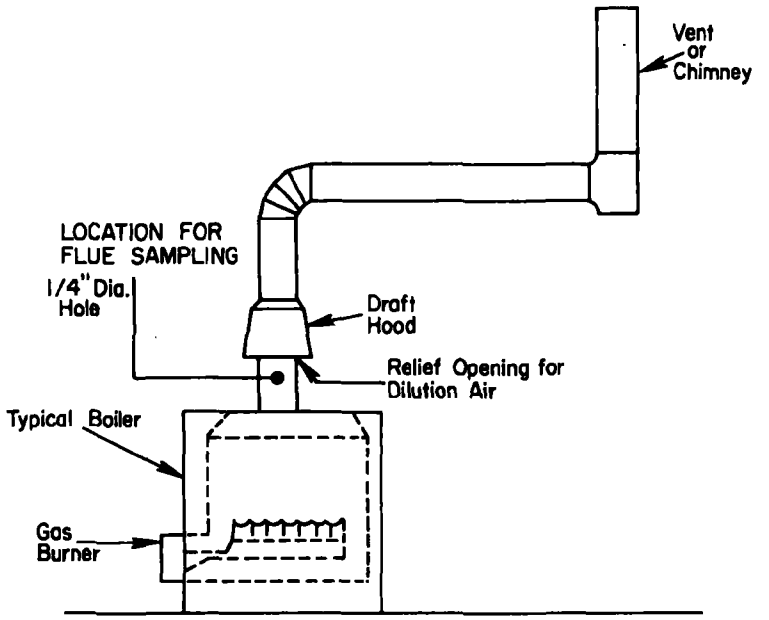


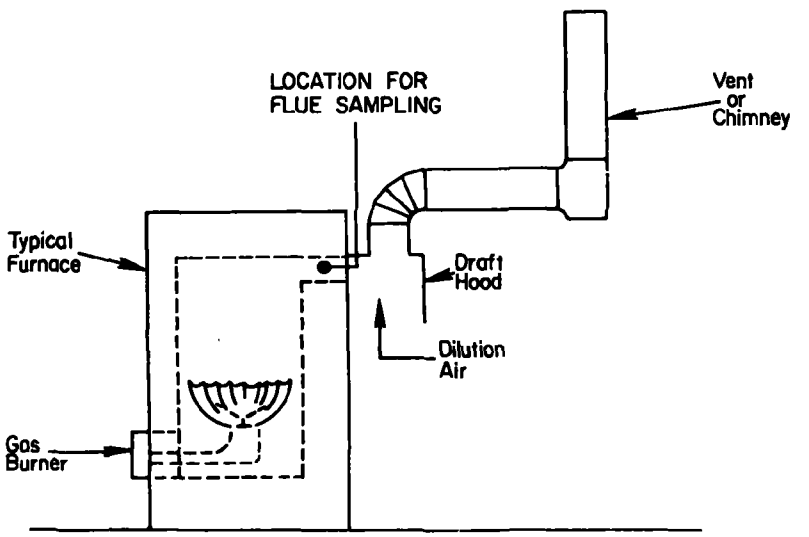
Figure 3. Typical characteristics of atmospheric gas burners — limits of lifting, yellow tipping and flashback.

8. **Check CO_2** To assess the burner adjustment in terms of the best practical efficiency, follow this procedure. **(This check should be in all cases where modifications are made to the burner, flues, or draft diverter that may change the originally approved design.)** After the burner has been in operation for at least 10 minutes, measure and record the CO_2 in the flue outlet (following the instructions provided by the CO_2 analyzer manufacturer; see Appendix, Section B). Ordinarily, for best operation, the CO_2 concentration should be near 8.5 percent for natural gas *(10.0 percent for LP gases)* provided CO limits are not exceeded. See Figure 5 for typical operating regions and Step 10 for proper adjustment.

9. **Check CO** **This step is important for safety, whether or not Step 8 is followed.** After the burner has been in operation for at least 10 minutes, make a CO measurement (following the CO analyzer manufacturer's instructions; see Appendix, Section B). The measurement should indicate low levels of CO.



a. Vertical flue outlet



b. Horizontal flue outlet

Figure 4. Location for sampling flue outlet of gas-fired appliances.

Typical CO values for properly adjusted appliances, operating at rated input, range from 25 to 100 ppm (0.0025 to 0.010 percent); however, values as high as 300 ppm may be encountered in the flue-gas sample, since this is equivalent to the maximum value of 400 ppm (air-free) at a CO_2 level of 8.5 percent, allowed by the ANSI standards[2]. See Step 10 for proper adjustment methods.

COMBUSTION DIAGNOSIS STEPS

10. **Check Performance** A well-adjusted gas burner should be capable of operating with a CO level not greater than 100 ppm in the flue gases with a CO_2 level between 6.0 and 8.5 percent for natural gas *and 7.0 to 10.0 percent for LP gases.* If these values cannot be reached, check the following:

    a. Too low a CO_2 level could mean circulating air leakage into the combustion air due to a faulty seal around the secondary air opening of the unit. Seal such leaks by tightening the screws or bolts or replacing the sealing gasket.

    Too low a CO_2 level could be caused by a defect in the furnace heat exchanger. If the CO_2 levels obtained with and without the blower operating differ by more than 0.4 percent, make a repeat check of the combustion chamber and heat exchanger; if a leaking heat exchanger is found, repair or replace it.

    b. If the CO_2 and/or CO levels are too high, this could mean an improper combustion air supply. Spillage from the appliance draft hood can be detected by placing a lighted match at the edge of the hood relief opening. If the match flame is not drawn into the hood, spillage is occurring. A negative pressure in the appliance room also can indicate inadequate air supply. Spillage can result from a blocked chimney or vent.

    If inadequate air supply is suspected, refer to Section 1.3.4 of the National Fuel Gas Code ANSI Z223.1 or comparable provisions in local codes for specific detailed recommendations for providing air for combustion and ventilation.[2] If this does not solve the problem, there may be internal blockage.

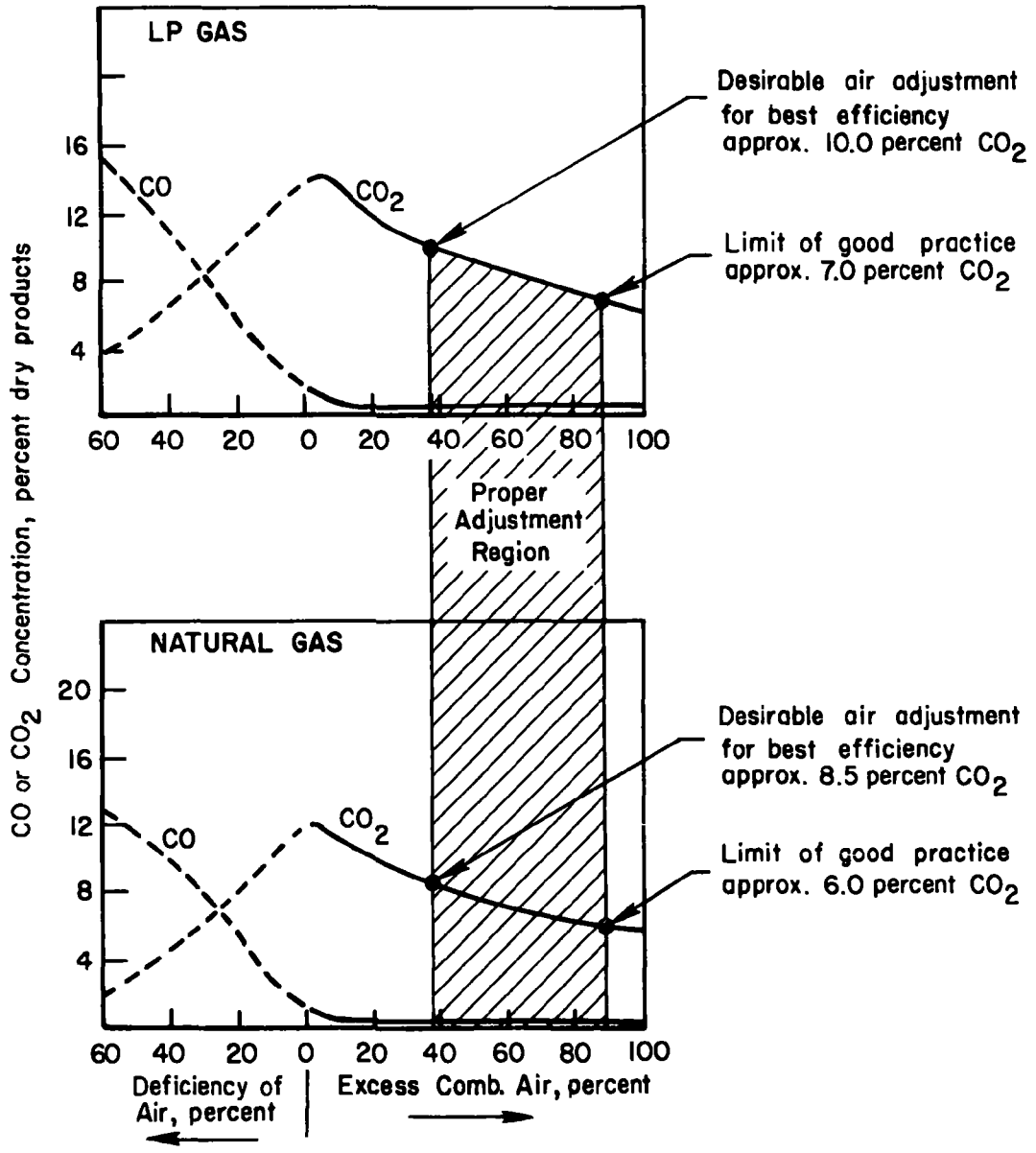


Figure 5. Effect of fuel/air ratio on CO and CO_2 concentration for typical natural gas and LP gas burners, showing proper adjustment region.

11. **Efficiency Checks** To determine the steady-state thermal efficiency of the furnace/burner or boiler/burner unit, follow this step. Measure the flue gas temperature, after at least 10 minutes of operation, at the same point that the CO_2 sample was taken. Determine the net flue gas temperature by subtracting the room temperature from the flue gas temperature reading. Using this net temperature value and the percent CO_2 (see Step 8), determine the appliance flue loss from Figure 6 for natural gas or *Figure 7 for LP gases.*[7] The appliance thermal efficiency is equal to 100 – flue loss. Use the values shown in Table 3 to determine if the unit is operating at a satisfactory efficiency level. (See Appendix B.)

FINAL CHECKS

12. **Ignition** Check operation over several repeated cycles, at about 5 second intervals, to ensure prompt ignition.

13. **Controls** Check settings of all operating and limit controls before leaving installation. For practical performance and good efficiency for modern forced-warm-air systems, usual practice is to set the fan control at 115–125°F ON and 90–100°F OFF. The water heater thermostat should be set to WARM or 120°F; where the water heater serves a dishwasher, settings up to 140°F may be needed. Higher settings reduce efficiency and shorten life of the storage tank.

14. **Regular Checkup** An annual burner checkup is recommended, with at least a visual inspection by a trained service technician, plus cleaning as necessary. Furnace blowers and motors and boiler circulating pumps should be lubricated before each heating season according to manufacturers' instructions. Furnace filters should be cleaned or replaced at least every 60 days during the heating season.

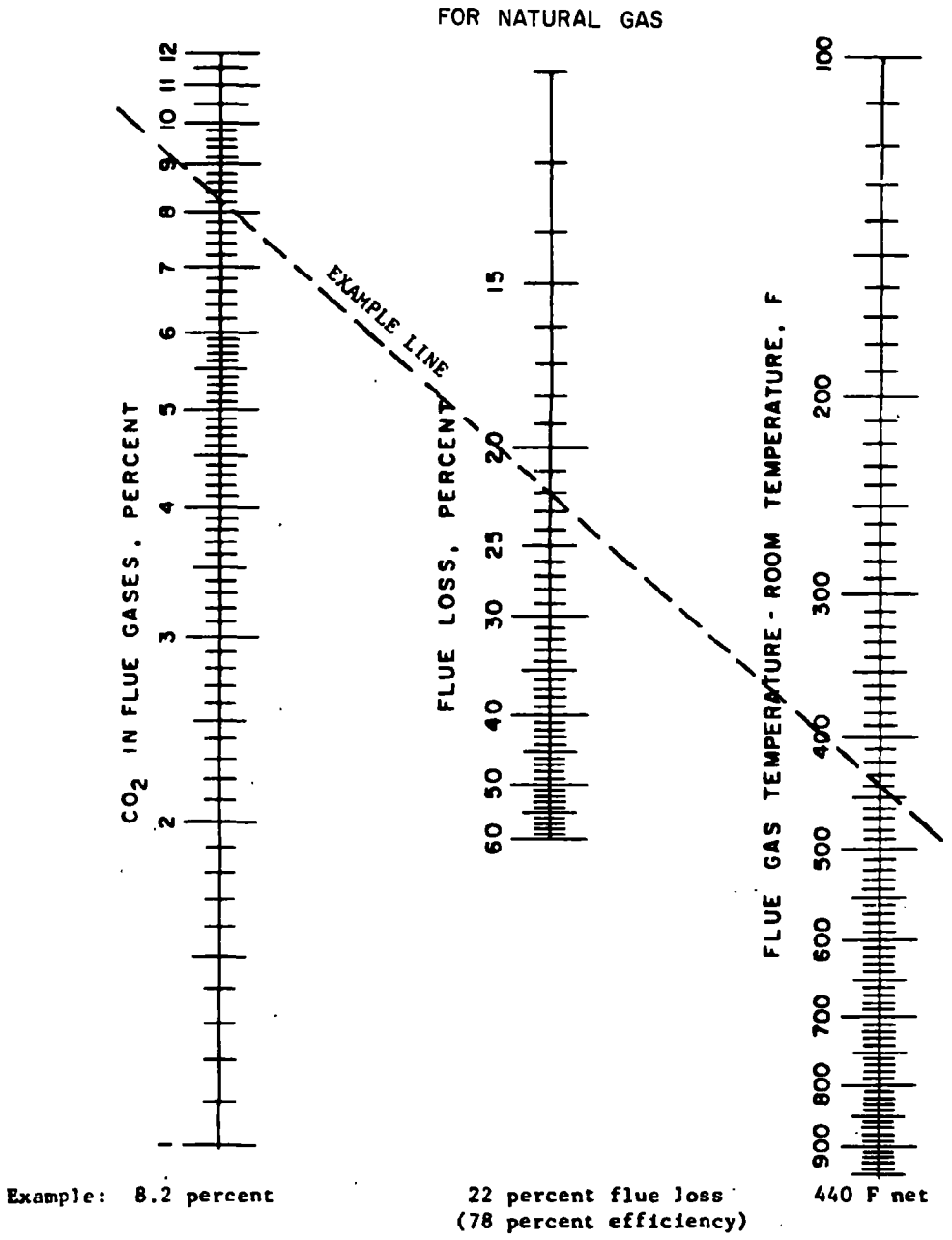


Figure 6. Nomograph for determining flue loss and steady-state efficiency from CO_2 and flue-gas temperature — firing natural gas[7].

Limited to use with natural gas as follows:

Heating value, gross:	**970 — 1100 Btu/standard cubic foot**
Specific gravity:	**0.57 — 0.70**
Ultimate CO_2:	**11.7 — 12.2 percent**

TABLE 3. TYPICAL INSTALLED STEADY-STATE THERMAL EFFICIENCIES OF CONVENTIONAL GAS-FIRED DOMESTIC AND COMMERCIAL FURNACES, BOILERS, OR WATER HEATERS

System	Thermal Efficiency[a], percent	
	Excellent	Acceptable
Forced Air Heating	75 or more	72 – 75
Gravity Heating	70 or more	67 – 70
Hot Water or Steam Boiler	75 or more	72 – 75
Hot Water Heater	72 or more	68 – 72

(a) Overall thermal efficiency = 100 – flue loss, percent, where flue loss is expressed as a percent of the gas input (gross heating value) that is lost up the flue. This assumes that any jacket loss is useful heat.

Experienced service technicians will observe that these principles and/or procedures are essentially the same as recognized good practice. Adjustment of gas burners by these procedures will help to ensure safe and reliable operation, to minimize emissions, and to provide efficient use of fuel.

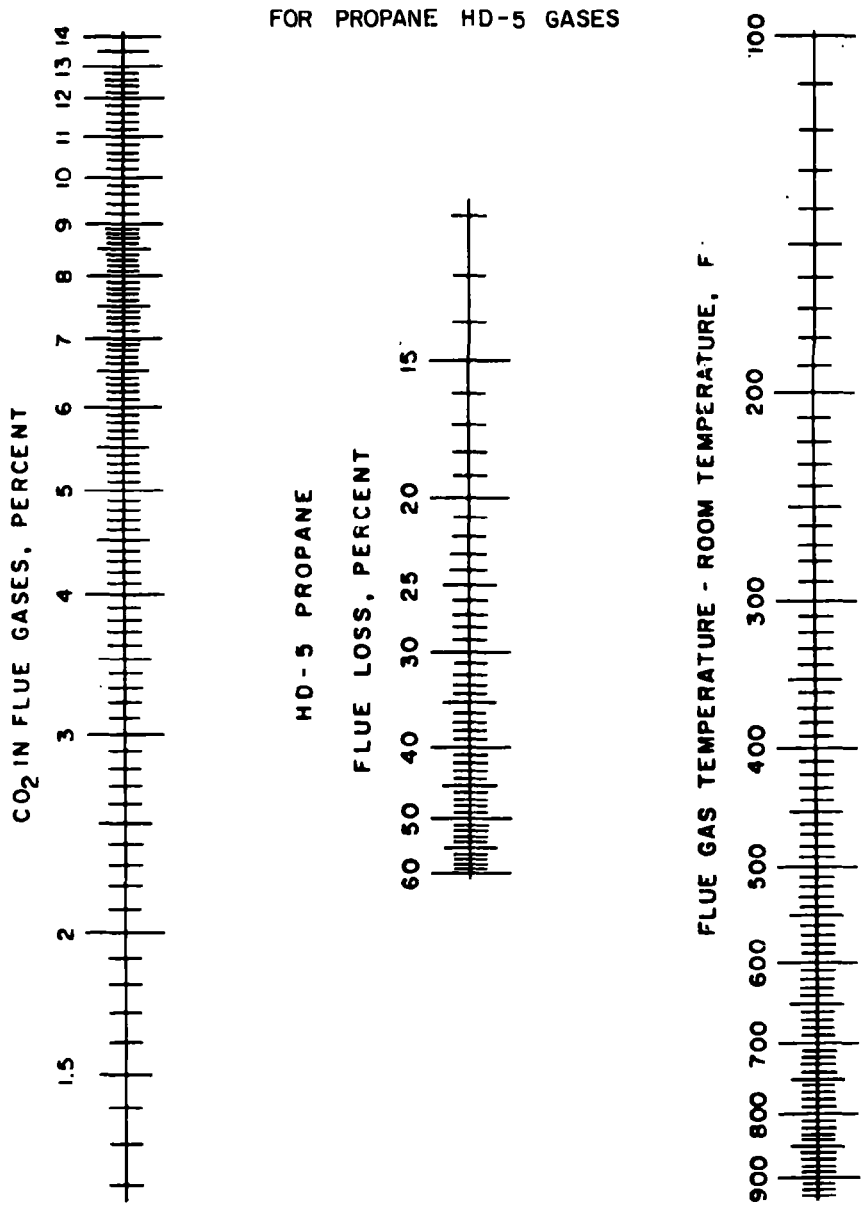


Figure 7. Nomograph for determining flue loss and steady-state efficiency from CO_2 and flue-gas temperature – firing LP gases[7].

Limited to use with LP propane gases as follows:

Heating value, gross:	2466 – 2542 Btu/standard cubic foot
Specific gravity:	1.522 – 1.574
Ultimate CO_2:	13.7 – 13.8 percent

APPENDIX: BACKGROUND INFORMATION

Information on the air-pollutant effects of residential burner adjustments has been developed in recent investigations[8-14]. The findings of these investigations, combined with good practice, are the basis for the Guidelines.

This Appendix contains additional background information:

A. **Pollutants of Main Concern**

B. **Field-Type Instruments and Significance of Measurements**

C. **Typical Emission Characteristics of Residential Gas Burners**

D. **References/Bibliography**

A. POLLUTANTS OF MAIN CONCERN

Pollutants and Their Measurement

Air pollutants of main concern for the purposes of these Guidelines can be divided into two broad classes, depending upon how much the service technician can control them by adjustment:

Class 1. Pollutants that may result from incomplete combustion and are generally strongly affected by burner adjustment:

- Carbon monoxide, CO
- Hydrocarbons, HC
- Aldehydes
- Particulates (smoke or soot).

Class 2. Pollutants only partially affected or unaffected by burner adjustment (and not recommended as adjustment criteria):

- Nitrogen oxides: NO and NO_2 (usually considered together and identified as NO_x)
- Sulfur oxides: SO_2 and SO_3 (usually considered together and identified as SO_x).

The following comments describe each of the Class 1 pollutants from the viewpoints of its definition, hazards associated with it, how it is detected or measured, and how its emissions are affected by service adjustments. (The Class 2 pollutants are not discussed further, because service adjustments have little or no control over them.)

Carbon Monoxide, CO

CO is a toxic gas formed by incomplete combustion. When gas burning equipment is properly adjusted, the CO emission level is extremely low. When the low levels of CO emitted

by properly operating residential gas-heating equipment are diluted in the atmosphere, CO is not considered dangerous and is depleted with time in the atmosphere by being oxidized to CO_2. With improper combustion, and if flue gases leak into living spaces, CO levels in living spaces can be dangerous.

For field adjustment of gas-fired equipment by methods suggested in these Guidelines, CO should be measured, using a color-sensitive tube or portable electrochemical device. Yellow flames, smoke, and "smelly" combustion (as indicated by the presence of aldehydes), indicate incomplete combustion. However, these are not always reliable indicators: if the primary air adjustment is too far open, flame lifting could occur, and CO levels could increase rapidly without smoke or odor.

Hydrocarbons, HC

Emissions of hydrocarbons, which consist of unburned or partially burned fuel, occur when combustion is incomplete. Incomplete combustion can occur at very fuel-gas-rich settings (because of a lack of air) or at very fuel-gas-lean conditions (because of lifting flames).

Large amounts of unburned fuel gas emitted from an improperly operating installation can be detected by odor. (An odorant is added to fuel gases for safety purposes.) At lower levels of HC emissions, too low to be detected by smell, the emissions generally follow trends of CO emissions; hence, CO measurements are usually good indicators of hydrocarbon emissions. An exception may occur at extremely high primary air settings, where HC emissions may be higher than normal, while CO readings may be low.

Although HC emissions are generally not toxic to the same extent as CO, they can be accompanied by unpleasant odors and can contribute to photochemical smog in the atmosphere. Extremely low levels of HC are emitted when gas-fired equipment is properly adjusted.

For routine adjustment of residential gas burners, it is not necessary to measure HC because stable burner flames adjusted to acceptable CO levels will emit essentially no HC.

Aldehydes

Aldehydes, especially formaldehyde, are formed when fuel gas combustion is incomplete. The aldehyde smell is responsible for the strong penetrating odor generally associated with incomplete combustion. During incomplete combustion, however, the level of concentration of aldehydes is not as significant as the CO and HC which also are present.

Particulate and Smoke

Smoke consists mainly of tiny unburned particles of carbon and is an important indicator of severe maladjustment of gas-burning equipment. It can block flue passages and foul heat-transfer surfaces with soot. Fuel utilization efficiency is very poor and an unsafe condition may exist if smoke is present.

If smoke is suspected, check for visible signs from the vent or chimney (or from the draft hood of the appliance, using a flashlight). Low levels of smoke below the visible range can be detected using a smoke tester commonly used in adjusting oil burners.[15] Do not mistake condensed water vapor for smoke during cold weather.

A smoky condition should be remedied immediately. Shut down the unit and clean the carbon formation completely from all surfaces including the heat exchanger, burners, orifices, ignition system, and flue outlet. Check the complete venting system, and clean it as necessary. Then readjust the burner to correct the problem.

B. FIELD-TYPE INSTRUMENTS AND SIGNIFICANCE OF MEASUREMENTS

For the adjustment procedures outlined in these Guidelines, it is assumed that the gas burner service technician is familiar with field-type instruments. Typical instruments include:

- Flue-gas analysis (CO_2)
  - usually a simple wet-chemical absorbent-type CO_2 analyzer
  - Orsat or similar device
- Flue-gas analysis (CO)
  - usually color-sensitive chemical in tubes or
  - portable electrochemical device
- Flue-gas temperature
  - usually a continuous reading meter using thermocouples or resistance thermometer sensor
  - can be a dial-type thermometer or a liquid thermometer, although accuracy may deteriorate
- Manifold pressure
  - usually a water-type U-tube manometer.

Instruments, combining several of these functions in one device, are being introduced.*

The Significance of CO_2 Measurements

CO_2 readings are used to identify the amount of combustion air being supplied to the burner, compared to the theoretical amount required for combustion. It is seldom possible

*One valid approach is to base adjustments on O_2 readings, in which the O_2 reading is a more reliable indicator of the adjustment relative to stoichiometric air than is a CO_2 reading.[16]

to burn a fuel completely and cleanly unless air in excess of the theoretical amount is provided. The tabulation below illustrates the relationship between excess air supplied for combustion and the CO_2 concentration in the flue gas for residential gas burners operating on natural or LP gases.

Air/Fuel Mixture Settings	Excess Air Supply (Percent Above Theoretical)	Typical CO_2 in Flue Gas, percent		Comments on Combustion Performance (Assuming Satisfactory CO Levels)
		Nat. Gas	*LP Gas*	
Theoretical or "Chemically Correct" resulting in ultimate CO_2	0	12.0	*13.8*	Stoichiometric mixture (Cannot be achieved for reliable operation in practice)
Typical for Residential Gas Burners (including conversion burners)	37	8.5	*10.0*	Excellent
	55	7.5	*8.6*	Average
	90	6.0	*7.0*	Lower limit of acceptable performance within proper adjustment region

The efficiency of fuel utilization is lowest at the low levels of CO_2 (high excess air), because the greater the amount of excess combustion air, the larger the amount of heat carried up the stack.

The Significance of Fuel-Gas Temperature: Its Effect on Efficiency

Temperature of gases at the flue outlet ahead of any dilution air (see Figure 4) is significant in determining the effectiveness of fuel utilization because it (together with the flue outlet CO_2 reading) is an indicator of the amount of heat lost up the stack.[7] Temperature must be measured at the same point as the CO_2 sample is taken. The best way to take this measurement is with a small bead (24 gauge) iron-constantan thermocouple and suitable potentiometer, although currently available equipment of this type may be more expensive than thermometers. An effort should be made to obtain a representative flue gas temperature.

Net flue outlet gas temperature* can be considered abnormally high for air heating or water heating units if it exceeds 480°F. A high temperature may indicate one or more of the following conditions:

*Net flue gas temperature is the observed temperature minus room temperature.

1. Excessive firing rate for available heat-exchanger surface of the appliance.
2. Dirty or soot-covered heating surfaces.
3. Excessive sediment in bottom of water heater.
4. Deterioration of baffles in flue passageways.
5. Insufficient air or water flow over heat exchanger.

These points should be checked and remedied if temperatures are abnormally high.

Thermal efficiency of heating equipment is the percent of heat released from burning the gas which is actually transferred to the circulating air or water that is used to heat the dwelling (or, in the case of water heaters, to heat the stored water). Normally this efficiency is determined under steady-state conditions; e.g., with continuous burner operation after allowing the equipment to heat up for at least 10 minutes.

Thermal efficiency is equal to 100 percent minus the heat losses up the stack. These stack losses are generally referred to as flue losses. Other losses can include appliance jacket heat losses if these losses do not contribute to heating the dwelling. (The jacket losses usually will only amount to 1 or 2 percent.)

Two measurements are needed to determine flue losses and, therefore, thermal efficiency:

- Net flue gas temperature (average flue-gas temperature minus room temperature).
- Percent CO_2 in the flue gas.

Figures 6 and 7 show the combined effects of these two factors on flue losses: Figure 6 for natural gas, and *Figure 7 for LP gas.* These flue-loss charts, based on steady-state operation, apply only for the specific fuel gases indicated. To use the nomographs, place a straight edge on the chart with one edge crossing the **CO_2 in flue gases** scale at the observed level and the **flue-gas temperature – room temperature** scale at the observed net flue-gas temperature. Read the flue loss at the point where the straight edge crosses the middle **(flue loss)** scale.

In the example shown in Figure 6 (for natural gas), the flue loss is 22 percent for an observed 8.2 percent CO_2 in the flue gas and a net flue-gas temperature of 440°F. Thermal efficiency is 100 percent minus the 22 percent flue loss; or 78 percent.

Seasonal Efficiency and Its Potential for Improvement

Seasonal thermal efficiency is less than the continuous or steady-state thermal efficiency calculated from Figures 6 and 7 because the efficiency is lowered during cyclic operation by additional losses up the stack from the unit during OFF periods.[17] Seasonal efficiency will be highest for units that:

1. Have high overall thermal efficiency during continuous operation.

2. Have firing rates matched to the design load. (Overfiring results in excessively long shutdown periods.)

3. Have vents properly sized for burner input.

4. Have Intermittent Ignition Devices (IID's) instead of continuously burning pilots.

5. Have means to minimize the OFF cycle losses, other than IID.

In 1976, the gas industry initiated a Space Heating Efficiency Improvement Program (SHEIP) to accelerate the industry's continuing effort to help its customers increase the seasonal efficiency of heating equipment. The purpose of SHEIP is to determine the energy savings possible and to encourage implementation of useful and safe options for improving the energy efficiency of residential central heating systems. Procedures are being developed for implementing options that are most cost effective. The status of this program can be obtained by writing to the American Gas Association, 1515 Wilson Boulevard, Arlington, Virginia 22209.

C. TYPICAL EMISSION CHARACTERISTICS OF RESIDENTIAL GAS BURNERS

When main burners are properly adjusted, the flue products from the combustion of gaseous fuels contain relatively harmless nitrogen, carbon dioxide (CO_2), and water vapor. When the main burner is operating with incomplete combustion, because of dirty conditions, or with an improper air-shutter adjustment, the flue products may also contain carbon monoxide (CO), soot, and hydrocarbons (HC). A by-product of the combustion reaction is the formation of nitrogen oxides (NO_x) due to the high-temperature flames in the presence of nitrogen and oxygen.

Figure 5 illustrates the effects of combustion air on CO and CO_2 concentrations. It demonstrates that the CO is very low within the proper CO_2 adjustment region. The figure also shows that the CO_2 reading does not always predict the CO level. With a deficiency of air, it is still possible to obtain a reasonable CO_2 level, but with an undesirable CO level. Therefore, the CO_2 level cannot be used as an indication of CO concentration. For this reason, it is important to measure the CO concentration to ensure that it is at an acceptable level.

Figure 8 demonstrates the expected effect of excess air on CO, HC, and NO_x emissions of a gas burner by showing the relationship of these emissions to excess-air supply (or CO_2 value). This figure shows the normal operating region of excess air for natural and LP gas appliances. As noted in the discussion of the CO/CO_2 relationship, CO emission levels are at unacceptable levels under a deficiency of combustion air. HC emissions also are high with a deficiency of combustion air and may increase under very high excess-air conditions because of lifting flames. The NO_x emissions reach a peak very near a stoichiometric air/gas mixture (zero percent excess air) because this is the condition of maximum flame temperature.

Figure 8 shows that it is desirable to operate under an excess-air condition of 37–90 percent in order to minimize the pollutant emission levels.

Most gas burners will perform as shown in Figure 8.[8,9,10] For some burners the normal region will be wider or narrower; a few burners will operate outside the region shown. The overall trend of the pollutant emissions, however, will be similar to that shown by the figure. In general, conversion burners will have a wider range of adjustment available to the service technician and will require greater care than designed units.[6]

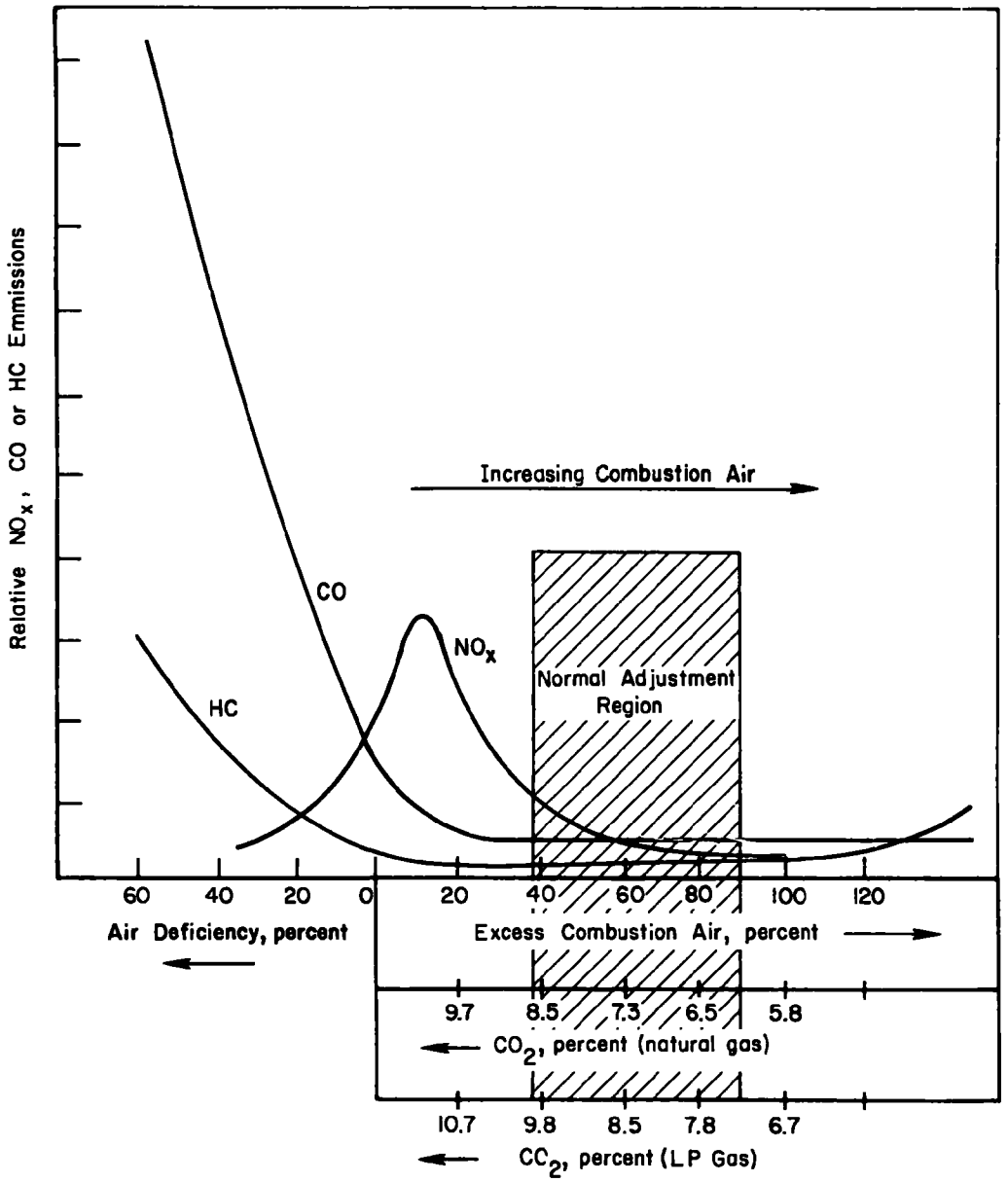


Figure 8. Effect of excess air on CO, HC, and NO_x burner emission for a typical natural and LP gas fired heating appliance.

The service technician should visualize the interaction of the various pollutants to develop an appreciation that the CO/CO_2 relationship is basic to setting a burner for minimum emissions by use of field measurements. Judging the combustion adjustment by using only CO_2 measurements could result in high CO and HC. This can be avoided by measuring both the CO_2 and CO levels.

Additional information on emission levels from various types of gas-fired equipment is contained in APCA papers by the staff of the American Gas Association Laboratories.[8,9,10]

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16. ABSTRACT

The guidelines contain recommended procedures for adjusting residential and commercial atmospheric gas burners used for space heating and water heating to minimize air pollution and for efficienct use of fuel. They are intended for use by skilled service technicians in adjusting burners, and as a aid to service managers engaged in training service technicians. In addition to recommended steps for burner adjustment, the guidelines also include appendixes of background material on pollutants of main concern, field-type instruments and significance of measurements, and emission characteristics of residential gas burners.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Boilers	Air Pollution Control	13B	
Space Heating	Aldehydes	Stationary Sources	13A	07C
Water Heaters	Carbon Monoxide	Energy Conservation		
Combustion	Hydrocarbons	Burner Tune-up	21B	
Nitrogen Oxides	Natural Gas	LP Gas	07B	21D
Smoke	Residential Buildings			13M
Heating	Conservation		13H	

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