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GUIDELINES FOR BURNER ADJUSTMENTS OF COMMERCIAL OIL-FIRED BOILERS

Oil-Burner Adjustment Procedures to Minimize Air Pollution and to Achieve Efficient Use of Fuel

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Guidelines intended for use

— by skilled service technicians in adjustment of commercial oil burners.

— as a training guide for advanced burner service courses.

— as a supplement to manufacturers' service instructions.

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- National Oil Fuel Institute.

GUIDELINES FOR BURNER ADJUSTMENTS OF COMMERCIAL OIL-FIRED BOILERS

In the past, the most important reason for adjustment of oil burners has been to ensure reliable automatic operation. A second important reason has been to provide efficient fuel utilization. Common good practice of adjusting a burner for minimum air setting, consistent with acceptable smoke levels, is an effective way of meeting both objectives.

Recently, a third objective has been added; that of minimizing air pollution. It is important to recognize that any burner adjustments for this purpose must still meet the former requirements. Fortunately, adjustments for low air-pollutant emissions can still meet the objectives of reliable and efficient operation.

PURPOSE OF THESE GUIDELINES

These Guidelines have been prepared (1) for use by skilled service technicians or skilled operators in adjusting commercial oil-fired boilers and (2) as an aid to service managers engaged in training of service technicians. By following these Guidelines, the skilled oil-burner service technician will be able to adjust commercial oil burners to minimize air pollution and get the most useful heat from the fuel fired.

The Guidelines should be used as a supplement to the equipment manufacturer's installation and service instructions and the handbooks and manuals on good service practice developed by oil-heating industry specialists[(1-4)*]. These Guidelines add the perspective of minimizing air-pollutant emissions.

Scope of Commercial Boilers Covered

The recommendations and discussions in these Guidelines apply to adjustment of oil-fired boilers larger than residential sizes but smaller than industrial sizes -- they apply to oil-fired boilers of cast iron, firetube, and watertube construction. The capacity range of "commercial boilers" considered in these Guidelines is approximately as follows in terms of firing rate, Btu output, and boiler horsepower:

Oil firing rate --- 3 to 100 gallons per hour**
Btu output --- 300,000 to 10,000,000 Btu per hour
Boiler horsepower --- 10 to 300 BHP.

The principles in these Guidelines also apply generally to any single-burner boiler in the industrial size range.

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* References are included in Appendix E.

** Separate Guidelines are being issued by EPA covering adjustments for residential oil burners generally having oil firing capacities below 3 gallons per hour (Report Number EPA-600/2-75-069-a).

Background Information

In addition to recommended adjustment steps, these Guidelines include pertinent background material that will aid in the overall understanding of air pollutants and their control by combustion adjustments for commercial boilers. Additional information is provided in the Appendix on the following topics:

A. Pollutants of Major Concern

B. Field-Type Instruments and Significance of Measurements

C. Characteristics of Fuel Oils for Commercial Boilers

D. Typical Emission Characteristics of Commercial Boilers

E. References

F. Short-Form Adjustment Procedure for Commercial Oil-Fired Boilers.

Burner service organizations may wish to develop their own short-form recommendations that tie in with overall company policy, service training doctrine, abilities of service technicians, and local regulations. Appendix F is an example short form.

Fuel Conservation --
An Indirect Approach to Emission Control

In addition to burner adjustments for efficient boiler operation, attention should also be called to the importance of fuel conservation by reducing demands on the boiler. The burner technician can perform an additional service by advising the building owner as to opportunities for reducing heating loads by modifications in the building or its operation (for example, better insulation and weather stripping, clock operation or set-back of thermostats for intermittent occupancy, and reduced ventilation air). Reductions in heating load can have an important benefit in reducing overall pollutant emissions.

RECOMMENDED ADJUSTMENT PROCEDURES FOR COMMERCIAL BOILERS

The following procedures are recommended for adjustment of oil-fired commercial boilers and are supplemental to manufacturers' instructions and other service handbooks[1-4].

1. <u>CLEAN & SEAL</u> Clean the boiler heat-transfer surfaces, flue passages, and burner if needed--especially the atomizer and air-handling parts. Seal any air leaks affecting the combustion chamber or flue passes.

2. <u>SET OIL PREHEAT</u> Be sure that the oil to be fired is suitable for the installation. (See Appendix C for information on grades of fuel oil.)

   Use the proper oil temperature for pumping and atomization. Firing a boiler with either too high or too low a preheat temperature can give poor combustion performance. Check the manufacturer's operating manual to determine the proper oil temperature for firing a particular fuel. (See Figure 4 in Appendix C for viscosity-temperature chart for different fuel oil grades.)

   Special attention should be paid to selecting preheat temperatures for low-sulfur oils (which may have become available since the operating manual was written). Some low-sulfur oils have unusual viscosity-temperature relationships.

   Normally, the preheat temperature should be adjusted for the following oil viscosity ranges (at the nozzle).

	Usual Range of Firing Viscosity	
Atomization Method	Saybolt Seconds Universal	Equivalent Kinematic Viscosity, centistokes
Pressure	35-150 SSU	4-32 cs
Steam or Air	35-250 SSU	4-55 cs
Rotary	150-300 SSU	32-60 cs

   If the viscosity of the particular fuel is unknown, start at 250 degree F preheat level and back off to lower preheat temperature until best combustion performance is obtained.

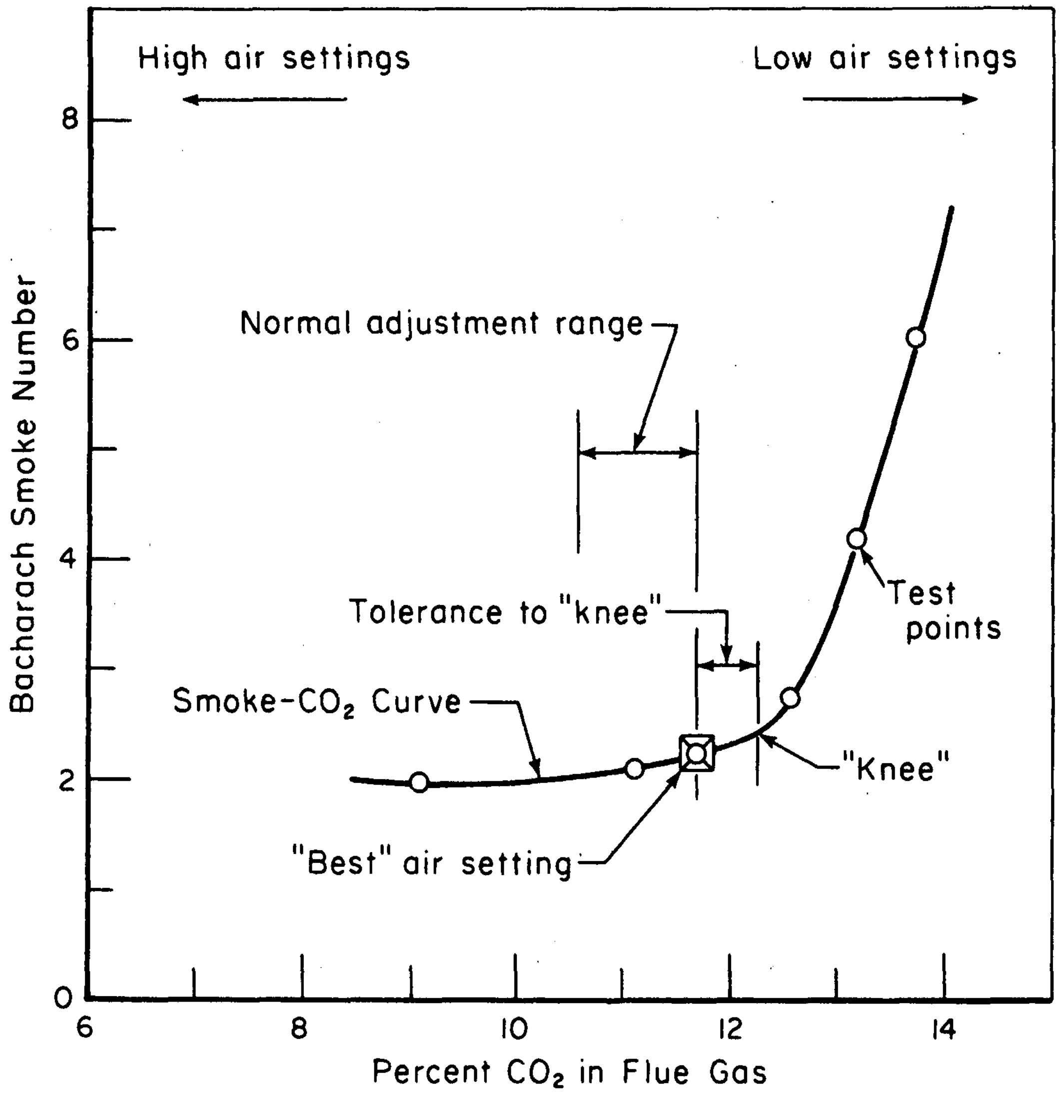

Figure 1. Smoke-CO_2 Characteristic for a Typical Commercial Oil Boiler Firing Residual Oil – With Recommended Air Adjustment

3. **ADJUST INPUT** Adjust the atomizing pressure to manufacturer's recommendations and the fuel input to full firing rate, giving consideration to the firing rate required for the connected load. Make sure atomizing nozzle is the type and capacity recommended by the manufacturer.

4. **SMOKE-CO_2 CURVE** The objective of the procedure outlined below is to attain the highest practical CO_2 value without exceeding the smoke limits listed below. (See Appendix B on field type instruments.)

The sampling hole in the stack for smoke and CO_2 readings should be located between the boiler and the draft control. Ideally, the sampling point would be in a straight section of duct, at least 8 diameters from the boiler or any upstream flow disturbance (bend, etc.) and at least 2 diameters from the draft control or any downstream flow disturbance. Sometimes, shorter distances from flow disturbances must be accepted due to space limitations.

The sampling tube inlet should be positioned to draw a representative gas sample. This is generally accomplished by positioning the inlet end of the sampling tube near the centerline of the duct.

Using an air setting for clean combustion, operate the oil burner at <u>full firing rate</u> until equilibrium is reached, usually indicated by a steady reading on the stack thermometer. Take readings of smoke and CO_2 sufficient to visualize the position of the characteristic curve as shown in Figure 1. This can be done by adjusting the control linkage and/or damper settings for several air settings over a range and by taking smoke and CO_2 readings at each point. Plot the readings on a chart or graph paper like the sample in Figure 2.

5. **ADJUST AIR SETTING** For the full firing rate, determine the location of the "knee" where the smoke curve begins to sharply break upward, as shown in Figure 1, then adjust the air setting to near the low CO_2 side of the "knee" of the smoke curve, about 1/2 percent CO_2 lower than the "knee".

For most commercial boilers, it should be possible to adjust for smoke levels below the following "maximum desirable" Bacharach smoke numbers. These smoke levels can usually be met with good practice.

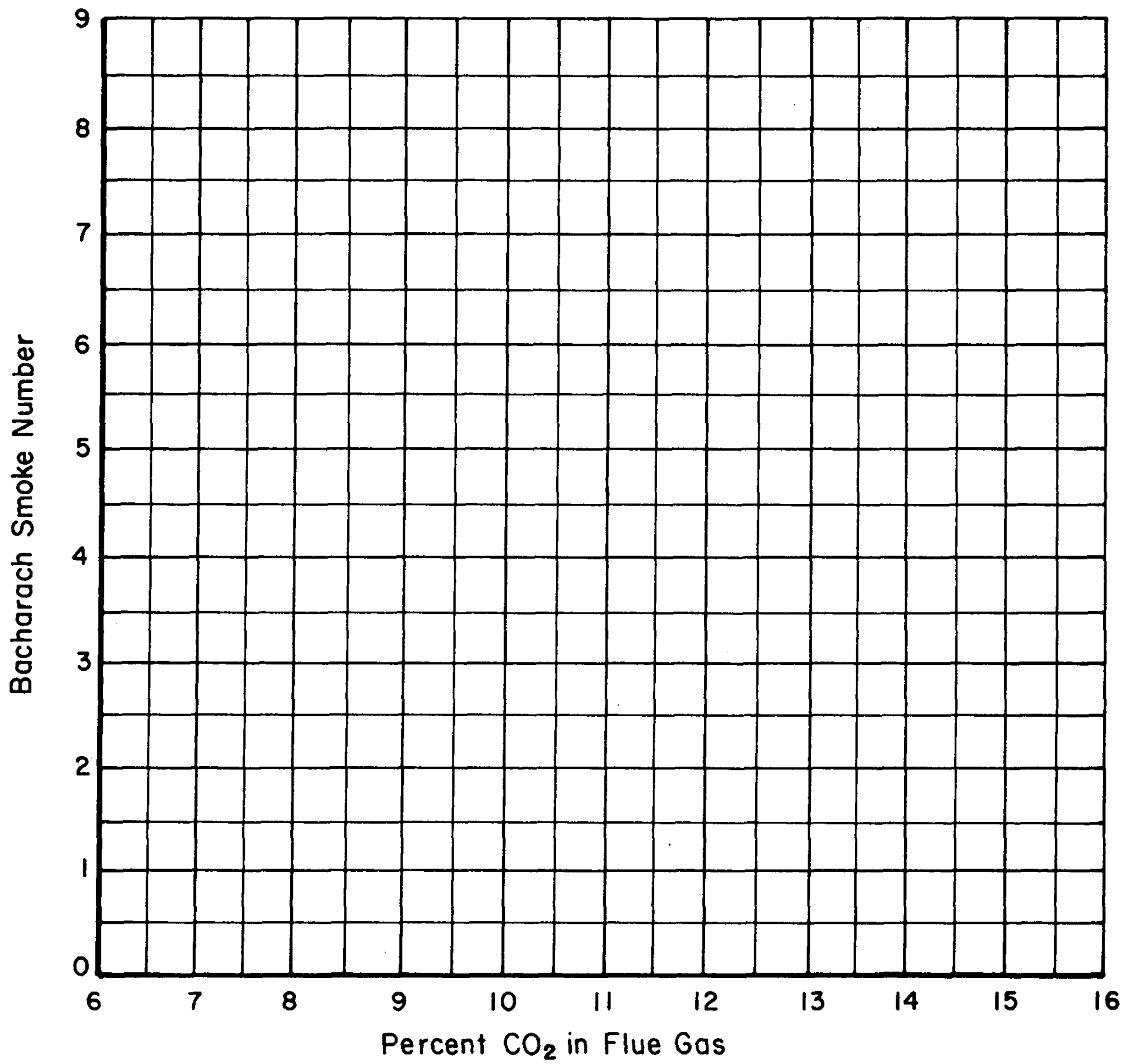

Figure 2. Sample Graph Paper for Service Technician's Plot of Smoke-CO_2 Characteristic

Fuel Grade	Maximum Desirable Bacharach Smoke Number
No. 2	1 or less
No. 4	2
No. 5 (light and heavy), and low-sulfur resid	3
No. 6	4

Keep in mind that high CO_2 settings are important for good thermal efficiency (see Appendix B). Therefore, adjust for the highest practical CO_2 level without excessive smoke.

6. DIAGNOSE ANY PERFORMANCE PROBLEMS

You should be able to adjust the burner to operate with smoke levels below the "maximum desirable" listed above, while maintaining the CO_2 value at 12 percent or higher.

If not, it is likely that the atomization and/or fuel-air mixing are poor. Make sure that the proper nozzle is installed and that the nozzle is clean. Check the atomizing pressure and preheat, trying different temperatures if necessary. Check the air handling parts.

7. ADJUST AIR CONTROL LINKAGE

For modulating burners, apply the procedure in Steps 4 and 5, then repeat at low-fire setting and at an intermediate firing rate. Typically, the optimum air setting at low fire will be at a lower CO_2 than for the high-fire condition.

The control linkage should proportion the air at intermediate load settings; however, several points at intermediate firing rates should be checked for CO_2 and smoke to validate linkage settings throughout the range. It is often convenient to use a felt pen to mark linkage setting, so as to retrace the direction and position of adjustments.

8. ADJUST FOR GAS FIRING

If the boiler is equipped for gas firing, use a similar procedure to adjust for operation on gas. However, maximum CO_2 readings for gas are somewhat lower than for oil. (See Figure 5, Appendix C). Equivalent values of CO_2 for gas and oil at different excess air levels are as follows:

Percent Excess Air	Percent CO_2 in Flue Gas		
	Gas Firing	No. 1 Oil Firing	No. 6 Oil Firing
0	12.0	15.0	16.5
10	10.8	13.5	15.0
25	9.4	11.8	13.0
50	7.9	9.8	11.0
75	6.6	8.3	9.3

As gas-fired units frequently emit CO at low air settings (before smoke is detected), it is necessary to check for CO at the extremes of the air-adjustment range, using a suitable CO detector. CO readings should not exceed 0.04 percent (400 ppm). See Appendix A.

On dual-fuel-fired units, after the gas settings are made, the oil settings <u>must</u> be verified. It is frequently impossible to obtain optimum performance on both fuels at both high- and low-fire rates; a compromise must be made in such cases.

9. <u>CHECK IGNITION</u> Adjust ignition electrodes to the manufacturer's recommendation. Make sure ignition occurs promptly at light-off firing rate. This will avoid startup emissions and deposits of unburned oil.

10. <u>SCHEDULE BOILERS</u> For multiple boiler installations, arrange the master control system so that individual boilers avoid operation at low fire or at full load for extended periods. Emissions are usually lowest and efficiency highest when boilers are operated at about 50 to 80 percent of rated load. Avoid excessive on-off cycling, since emissions of smoke, particulate, CO, and hydrocarbons tend to peak on startup and shutdown.

11. <u>ANNUAL CHECKUP</u> An annual overall tune-up, and safety check by a competent service technician is strongly recommended.

Adjustment by these procedures will be effective in assuring minimum air-pollutant emissions from commercial boilers and, at the same time, achieve a reasonable compromise with efficiency of fuel utilization.

APPENDIX: BACKGROUND INFORMATION

Information on the air-pollutant effects of different burner adjustment procedures have been developed in recent field and laboratory investigations(5-8), including those conducted cooperatively by the U. S. Environmental Protection Agency and the American Petroleum Institute(7-8). The findings of these investigations, combined with good field practice, are the basis for these Guidelines.

This Appendix contains additional background information as follows:

A. POLLUTANTS OF MAIN CONCERN

B. FIELD-TYPE INSTRUMENTS AND SIGNIFICANCE OF MEASUREMENTS

C. CHARACTERISTICS OF FUEL OILS FOR COMMERCIAL BOILERS

D. TYPICAL EMISSION CHARACTERISTICS OF COMMERCIAL OIL BURNERS

E. REFERENCES

F. SHORT FORM ADJUSTMENT PROCEDURE FOR COMMERCIAL OIL-FIRED BOILERS.

A. POLLUTANTS OF MAIN CONCERN

Pollutants and Their Measurement

The air pollutants of main concern for the purposes of these Guidelines can be divided into three broad classes, depending upon how much the serviceman can control them by his adjustments. These classes are

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

- Smoke and particulate *
- Carbon monoxide, CO
- Hydrocarbons, HC.

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

- Nitrogen oxides: NO and NO_2 (usually considered together and identified as NO_x). **

Class 3. Pollutants not affected by burner adjustment procedures but depending only on sulfur content of the fuel.

- Sulfur oxides (mainly SO_2 with traces of SO_3).

The following comments describe each of the Class 1 pollutants from the viewpoints of definition, hazards associated with the pollutant, how it is detected or measured, and how emissions of the pollutant are affected by service adjustments. (The Class 2 and Class 3 pollutants are not discussed further here, because the serviceman has little or no control over them by adjustment.)

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* Particulate that is formed from the ash content of fuel oil is not affected by burner adjustments. However, the carbon or soot portion of particulate, usually the larger portion, can be strongly affected by burner adjustments.

** Emissions of NO_x are generally greater with heavier grades of fuel because of usually higher content of fuel-bound nitrogen.

Smoke and Particulate

Smoke consists mainly of tiny unburned particles of carbon. Smoke has long been an important factor in the adjustment of oil-burning equipment to avoid fouling of heat-transfer passages with soot, to achieve efficient fuel utilization, and to avoid general complaints resulting from visible smoke and fallout of larger particles.

Over the past 25 years, the development and the use of the filter-paper method of smoke measurement (as used, for example, in the Bacharach Smoke Tester) has allowed a much more sensitive measurement than by visual means such as the Ringelmann Scale[2,3,9]. The method is now an accepted ASTM standard[10] and is widely used in the oil-burning industry to assist in field adjustments[3,11]. This type of smoke tester is a key tool for the service technician.

Smoke and CO_2 measurements, considered with the perspective presented in these Guidelines, provide a simple and relatively reliable means to avoid high emissions of other pollutants.

Smoke and particulate are related. Particulate is the usual scientific term applied to air-pollution measurements in terms of weight of solid and liquid materials being emitted to the atmosphere. "Particulate" is defined by the U.S. Environmental Protection Agency as "any finely divided solid or liquid material, other than uncombined water, as measured by EPA Method 5"[12,13].

Particulate is composed of unburned fuel, carbon or soot, ash constituents in the fuel, and noncombustible-airborne dust that enters with the combustion air.*

Coarse particles do not carry far in the atmosphere and usually fall out near the stack. Fine particles, the predominant portion of particulate from oil burning, can remain in the atmosphere for long periods and can obscure long-range visibility. In addition, fine particles can deposit on lung tissues and result in respiratory impairment if present in high concentrations. These are the reasons that particulate is of concern to air-pollution control.

The serviceman can exert considerable control over particulates by ensuring that the fuel pump and safety shut-off valve have good cutoff characteristics, and by the burner adjustments he chooses.

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* Ash content is extremely low for No. 2 heating oil, usually below 0.005 percent. For No. 6 oil, the ash content is typically below 0.05 percent. The ash content for other grades usually falls between these limits.

Particulate measurements by EPA standard measuring techniques require special equipment and techniques, plus long sampling periods, which are neither practical nor necessary for most commercial boiler adjustments. For steady operation, smoke measurements by the filter-paper method are the most practical method to warn of high particulate levels, as discussed in Appendix D.

Carbon Monoxide, CO

CO is a toxic gas formed by incomplete combustion. When equipment is in good adjustment, CO levels are very low. But with improper combustion, CO emissions can reach dangerous levels if gases should leak into living spaces. When the low levels of CO that are emitted by properly operating oil-heating equipment are diluted in the atmosphere, CO is not considered dangerous and is depleted with time in the atmosphere.

For field adjustment of most conventional oil-fired commercial equipment by methods suggested in these Guidelines, it is seldom necessary to measure CO except when firing gas in dual-fuel boilers. With oil firing, smoke measurement can be used as an indicater of poor combustion that could lead to the onset of CO at low excess-air levels (high CO_2 levels). However, if the serviceman increases the air setting too far, CO levels occasionally will increase rapidly without smoke; therefore, the air setting should not be increased beyond that necessary to obtain a satisfactory smoke reading below the "knee" on Figure 1.

CO measurements are desirable when checking adjustments for gas firing on dual-fuel commercial boilers. For detection and measurement of CO at the low levels usually encountered in heating equipment*, CO instruments using color-sensitive tubes are currently the most practical and economical method for field use by servicemen.

Hydrocarbons, HC

Emission of hydrocarbons from oil-burning equipment occur when combustion is incomplete; they can consist of unburned or partially burned fuel vapors.

Although hydrocarbons are generally not toxic to the same extent as CO or NO_x, they can be accompanied by unpleasant odors, and can contribute to photochemical smog in the atmosphere. Essentially, no hydrocarbons are emitted when oil heating equipment is properly adjusted.

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* As a point of reference, standards for most gas-fired appliances specify a maximum limit of 0.04 percent CO or 400 parts per million on an air-free basis.[14]

If large amounts of unburned oil vapor should be emitted from an improperly operating installation, this can be detected as oily or yellow deposits on the filter paper during smoke measurements. At lower levels of hydrocarbon emissions, the emissions generally follow the trends of smoke or CO emissions and, hence, these measurements are usually a good indicator of whether hydrocarbon emissions are high or low (except at extremely high air settings where smoke readings may fail to indicate a rise in hydrocarbons). See Appendix D.

For routine adjustment of commercial oil burners in the field, it is not necessary to measure hydrocarbons. If the serviceman detects hydrocarbon odors (unburned oil vapor) near the burner or near a barometer draft control, he should check for flame impingement, improper nozzle size, improper adjustment of the combustion head, or improper pump cutoff on shutdown.

B. FIELD-TYPE INSTRUMENTS AND SIGNIFICANCE OF MEASUREMENTS

For the adjustment procedures outlined in these Guidelines, it is assumed that the oil-burner service technician is accustomed to using field-type instruments.[3] A typical kit includes the following:

- CO_2 tester for stack-gas analysis
  - Usually a simple wet-chemical absorbent-type analyzer (for example, Fyrite or Orsat apparatus).*
  - CO_2 readings are used to provide an indication of the combustion air setting.
- Smoke tester and shade scale
  - hand-pump version of the ASTM filter-paper method for smoke determination.
  - includes a shade scale for evaluating smoke spots from 0 to 9 (Bacharach or ASTM scale). (This is not a Ringlemann scale. Smoke levels below about 5 on the Bacharach scale are generally not visible from a small stack against the sky.)
- Thermometer for measuring stack temperature
  - usually the dial type, but liquid thermometers are more accurate.
- Draft Gauge
  - for draft measurements in the breeching or overfire, usually diaphragm type or a suitable manometer.
- CO detector for gas-fired commercial boilers
  - usually color-sensitive chemical in tubes.

Instruments which combine several of these readings in one device are being introduced to the market and offer convenience in use.

Some additional comments are in order with respect to CO_2 and smoke measurements.

The Significance of CO_2 Measurements

CO_2 readings are used to identify how much combustion air is being supplied to the burner, compared to the theoretical amount required for combustion. It is seldom possible to burn a fuel completely and cleanly unless air in excess of the theoretical amount is provided.

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* For more complete and accurate measurement of flue gas composition for adjustment of large equipment, a 3-tube conventional Orsat apparatus (CO_2, O_2, and CO) is recommended so a complete flue-gas analysis can be measured.

The following values will illustrate the relationship between excess air supplied for combustion and the CO_2 concentration in the flue gas. Comments on combustion performance and efficiency are also indicated.

Air/Fuel Mixture Settings	Excess-Air Supply (percent above theoretical)	CO_2 in Flue Gas No. 2 Oil	CO_2 in Flue Gas No. 6 Oil	Comments on Combustion Performance*
Theoretical or "Chemically Correct" Mixture	0 %	15 %	16.5 %	"Stoichiometric mixture" (cannot be achieved for reliable operation in practice)
Typical for Residential Equipment (below 400,000 Btu/hr output)	35 %	11 %	-	Excellent performance
	70 %	9 %	-	Typical performance
	150 %	6 %	-	Poor performance
Typical for Commercial Boilers	16 %	13 %	14 %	Excellent performance
	35 %	11 %	12 %	Typical performance
	70 %	9 %	9.5 %	Poor performance

* Assumes satisfactory smoke levels and negligible CO in stack gas.

The overall efficiency of fuel utilization is lowest at the low levels of CO_2 (high excess air), because the products of combustion are diluted by the excess combustion air and more hot gas is lost up the stack.

The Significance of Smoke Measurements

The ASTM filter-paper method of smoke measurement is useful in assessing the sooting characteristics of a combustion process, so adjustment can be made for clean burning.[3,11] In this method, a measured sample is drawn through a filter paper and smoke spots are compared to a standard shade scale, commonly known in the oil-heating trade as the "Bacharach shade scale".[3] The method offers a practical and sensitive means of judging the combustion process and can be used as a rough indicator of particulate emissions during steady-state operation.[7,8]

The following table provides comments on combustion performance and sooting as they relate to smoke readings.

Bacharach Smoke	Comments on Combustion Performance[a] No. 2 Oil	Comments on Combustion Performance[a] Residual Oil[b]	Comments on Sooting of Heating Surfaces Anticipated (Reference 3)
Less than No. 1	Excellent	Excellent	Minimal
No. 1	Good	Excellent	Extremely light
No. 2	Fair	Good	Slight sooting which will not increase stack temperature appreciably
No. 3	Typical for untuned burner	Good	May be some sooting but will rarely require cleaning more than once a year
No. 4	Marginal	Acceptable for No. 4 & 5 oil & LSR. Good for No. 6	Some units will require cleaning more than once a year
No. 5 or higher	Unacceptable	Poor to unacceptable	Potential for rapid and heavy soot buildup

(a) Assuming satisfactory CO_2 levels.

(b) Grades No. 4, 5, and 6, plus low-sulfur resid (LSR).

For reliable smoke readings, it is important that the manufacturer's instructions with the smoke tester be followed carefully. For example, the sample should be pumped slowly from the stack with full strokes, with several seconds pause at the end of the pull strokes to allow a full sample.[3]

The Significance of Stack Temperature: Its Effect on Efficiency

Stack temperature is significant in determining the effectiveness of fuel utilization, because it is an indicator of the amount of heat lost up the stack.

Stack temperature can be considered to be abnormally high if the net stack temperature (actual stack temperature minus boiler room temperature) exceeds 400° to 500° F for matched package units, or 500° to 600° F for conversion boilers. A high stack temperature reading may indicate one of the following conditions:

1. Excessive firing rate for the amount of heat-transfer surface in the boiler.
2. Dirty or soot-covered heating surfaces.
3. Need for effective baffling of flue passes (in the case of boilers converted from coal firing).
4. Improper adjustment or control of the draft, usually excessive draft through the unit.

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

"Overall thermal efficiency" (or "boiler efficiency")* is defined as the proportion of the heat energy in the fuel that is actually converted to steam or hot water during continuous burner operation. The principal losses are

- Heat loss up the stack and
- Heat lost from the boiler jacket through its insulation

The heat lost up the stack can be important and can be affected by the burner adjustments. The factors used to assess this loss for a given fuel are

- Net stack temperature (actual stack temperature minus the boiler room temperature) and
- Percent CO_2 in the flue gas.

Figure 3 shows the combined effects of these two factors on thermal efficiency. For high efficiency, it is desirable to operate the boiler with low net stack temperature and high CO_2 in the flue gas, consistent with a satisfactory smoke level. With most modern package commercial boilers, a boiler efficiency of 80 percent can be achieved with satisfactory smoke level when the boiler is operating continuously at rated load.

Seasonal efficiency is less than the continuous boiler efficiency at full firing rate, because of possible less-efficient operation at part load or low-fire operation and because of heat losses from the unit during off periods. Seasonal efficiency will be highest for installations that

1. Have high boiler efficiency during continuous operation (i.e., low stack temperature and high CO_2, with acceptable smoke)
2. Have a steady load that allows them to operate predominantly at their "base load" firing range where they are most efficient
3. Have relatively little cycling to low-fire setting or to on-off operation
4. Have good performance during starting, shutdown, and modulation, such that heating surfaces remain clean.

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* Overall thermal efficiency is sometimes referred to as "combustion efficiency", but it is also dependent on the effectiveness of the boiler heat-transfer surfaces.

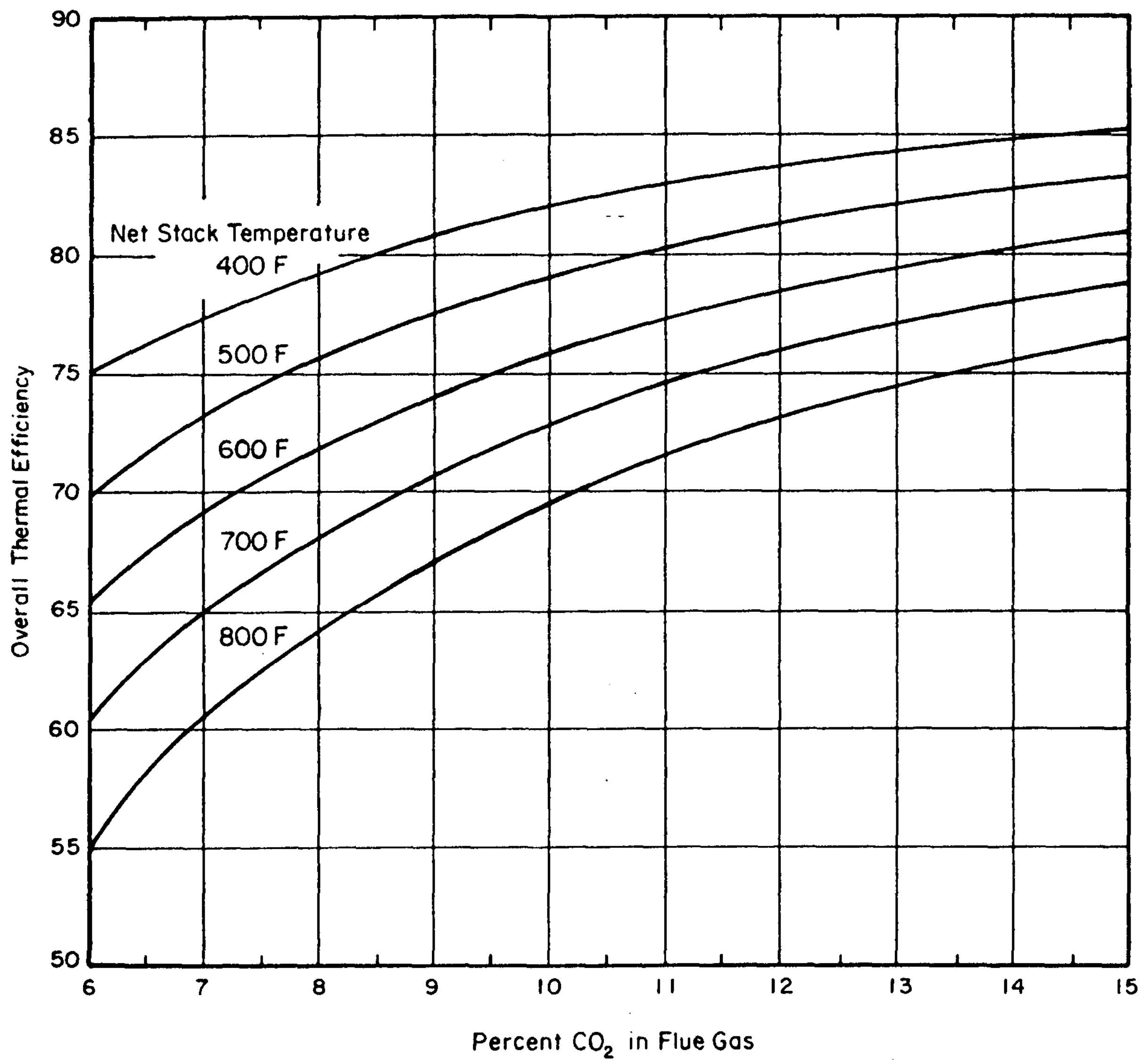

Figure 3. Effect of Stack Temperature and CO_2 on Overall Thermal Efficiency

Basis:
- Continuous operation
- No. 2 heating oil
- Heat lost from jacket is assumed to be useful heat.

Source: Bulletin 42, University of Illinois, Engineering Experiment Station Circular Series 44 (June 1942).

C. CHARACTERISTICS OF FUEL OILS FOR COMMERCIAL BOILERS

In fuel selection, it is important that the grade of oil is not heavier than the equipment is specifically designed to handle. For example, if the heavier grades of oil are to be used (No. 5 and No. 6), the system must be equipped for preheating upstream of the atomizer. For the heaviest grade of oil (No. 6), preheating of the oil is required for handling either at the tank or in a circulating system.

Basic grades of fuel are outlined in Table 1. This identifies the traditional grades of fuel defined in the ASTM standards, graded mainly according to viscosity.[15] In addition, the table provides a description of "low-sulfur resid" which is a category rapidly replacing conventional residual oil grades in local areas subject to sulfur regulations. The viscosity of low sulfur resid is usually in the range for No. 5 oil, but shifts in crude sources and refinery practices may change this pattern.[16]

In Table 1, viscosity values in brackets and typical API gravity values are averages for U.S. refined fuels taken from the 1975 ERDA survey on heating oils[17]. (These averages do not include imported fuel oils.)

Figure 4 illustrates typical viscosity-temperature relations for ASTM grades of fuel oil. In general, any given fuel will have a viscosity-temperature slope parallel to those shown on Figure 4 for the boundaries of the grade ranges[15]. Some low-sulfur residual oils have viscosity-temperature lines parallel to those shown on Figure 4 at high temperatures (above 140 F) but deviate toward even higher viscosity than predicted by these lines as the oil is cooled near the pour point. However, their viscosity in the firing range and their overall burning qualities make their handling and combustion performance generally superior to the traditional high-sulfur fuels[16].

In general, the No. 2 or No. 4 grades of fuel are more practical for smaller commercial boilers. They are also preferred as a standby fuel where interruptible gas is normally fired. The heavier grades of fuel oil demand more costly fuel handling facilities, greater care in adjustment of equipment, and greater overall maintenance.

Effect of Fuel Characteristics on Emissions

Characteristics of fuels available for commercial burners have an effect on smoke and particulate emissions. However, fuel characteristics have little effect on CO or HC, if the fuels are properly handled.

TABLE 1. FUEL OIL DESIGNATIONS AND TYPICAL CHARACTERISTICS

GRADE[a]	DESCRIPTION AND APPLICATION	PREHEATING REQUIREMENT For Pumping and Handling	PREHEATING REQUIREMENT For Burning	VISCOSITY RANGE Saybolt Universal at 100 F[e]	TYPICAL API GRAVITY Sec. at 60 F[f]
No. 1	Light distillate oil intended for vaporizing pot-type burners. Seldom used for pressure-type oil burners or commercial burners.	No	No	--	42
No. 2	Medium distillate oil for general purpose domestic and commercial heating equipment.	No	No	33-38 SSU [35]	35
No. 3	Obsolete grade designation.	--	--	--	--
No. 4	Heavy distillate oil that may contain some residual oil. Suitable for firing most commercial burners.	Usually No (c)	Usually No (c,d)	45-125 SSU [80]	19
No. 5 Light	Light residual oil for commercial-industrial burners. Generally contains a larger blended portion of distillate oil than No. 5 Heavy. Usually requires preheat for burning but not for handling.	Usually No (c)	Usually Yes (c)	>125-300 SSU [200]	18
No. 5 Heavy	Medium-viscosity residual fuel oil for commercial-industrial burners. Usually requires preheat for burning.	Usually No (c)	Yes	>300-900 SSU [550]	16
No. 6	High-viscosity grade of residual fuel oil for the largest commercial-industrial burners with full preheating. Sometimes referred to as "Bunker C".	Yes	Yes	>900-9000 SSU [5000]	13
Low-Sulfur Resid[b]	Residual fuel oil for commercial-industrial burners that is refined or blended to meet local sulfur regulations.	Usually No (c)	Usually Yes (c)	45-9000 SSU	--

(a) Grade numbers No. 1, No. 2, No. 4, No. 5 (light), No. 5 (heavy), and No. 6 are ASTM designations[15].

(b) "Low-sulfur resid" is a recent term used to describe residual oil grades recently shipped to meet local regulation; it is essentially replacing No. 5 and No. 6 where sulfur regulations are in effect, for example, along the East Coast. (The sulfur content of this grade of fuel oil is generally 1 percent, or less.) The viscosity of present low-sulfur resid is in the range of No. 5[16]. (It is not clear what the viscosity of these fuels may be in the future.)

(c) Preheating requirement depends on pour-point and viscosity in relation to climate.

(d) May require heating for burning when using mechanical atomization.

(e) Viscosity limits specified by ASTM D396-75 for number grade shown. Range for low-sulfur resid is estimated. Average viscosity for U.S. refined fuels from ERDA Heating Oils Survey, 1975[17], is shown in brackets and is presented as a typical value.

(f) Average API gravity for U.S. refined fuels from ERDA Heating Oils Survey, 1975[17].

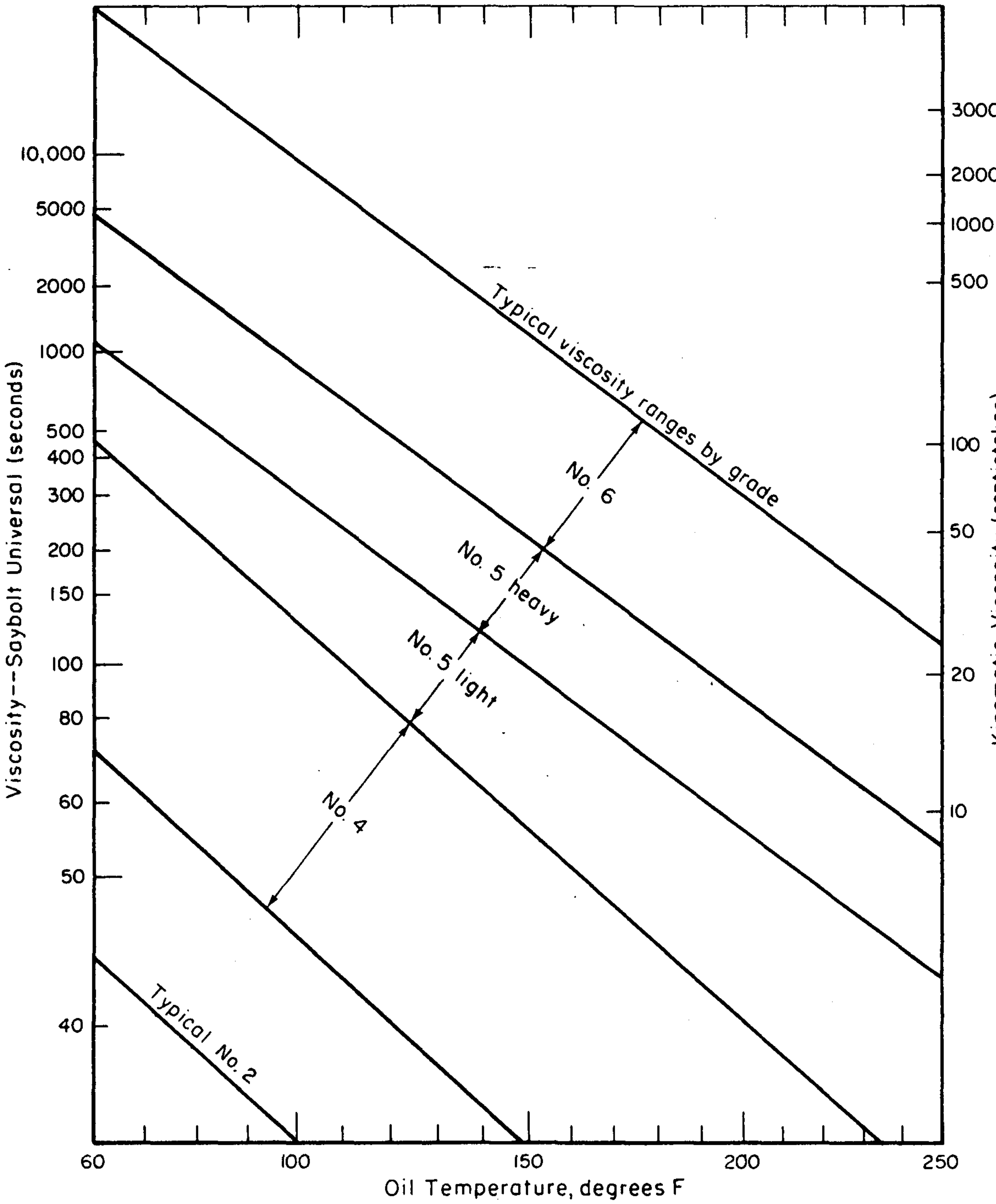

Figure 4. Typical Viscosity-Temperature Relation for Various Grades of Fuel Oil (ASTM D396-75)

Generally, the lighter grades of fuel produce less smoke and lower emission of particulate. For example, in a field investigation[7] when different fuels were fired by normal practice in the same boilers at similar conditions, particulate levels with No. 2 oil averaged only 4 percent of that for conventional No. 6 oil. Particulate for a typical low-sulfur resid (1 percent sulfur) averaged 30 percent of the level for a conventional No. 6 oil. This indicates that the blending and treatment to meet sulfur regulations for the new low-sulfur resid has the additional effect of providing a cleaner burning fuel than from conventional No. 6 oil.

Figure 5 shows the smoke-CO_2 characteristic of a typical commercial boiler firing three different grades of fuel oil (and natural gas). Other boilers show similar characteristics when firing different fuels. [The smoke characteristic with gas firing is also shown; it should be noted that the CO_2 level for natural gas is always lower than for fuel oils operating at the same excess-air level.]

Emissions of NO_x are generally higher with the heavier grades of fuel oil due to higher content of nitrogen in heavy oil. As pointed out in Appendix A, the service technician has relatively little control over NO_x emission levels within the range of adjustment available to him for a given burner-boiler combination in the commercial boiler size range.

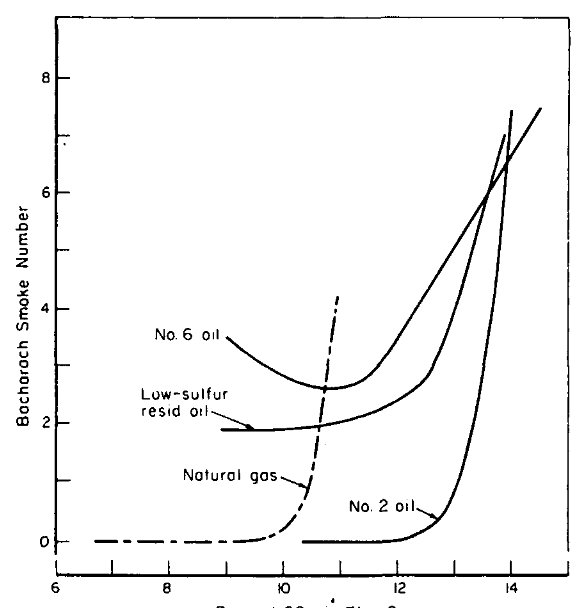

Figure 5. Smoke-CO_2 Characteristic of a Typical Commercial Boiler Firing Three Different Grades of Fuel Oil and Natural Gas

Sulfur in crude oil tends to stay with the heavier fractions during refining. Hence, SO_2 emissions can generally be expected to be higher with heavier grades of fuel, unless special refining treatment is provided, as is generally the case with low-sulfur resid. Until practical SO_2 removal systems become commercially available for small equipment, the service technician has no control over SO_2 emissions by his adjustment. At present, the most practical and economical method of SO_2 control for commercial boilers is by fuel selection.

D. EMISSION CHARACTERISTICS OF COMMERCIAL BOILERS

Effect of Air Setting

Figure 6 shows typical emission characteristics as affected by air setting for a commercial boiler operating at 80 percent load. Emissions of concern include smoke, CO, HC, and NO_x. Emissions of CO or HC are generally low within the normal range of CO_2 settings for oil-fired commercial boilers.

For oil firing, smoke rises sharply as the CO_2 setting is increased beyond the knuckle of the smoke curve; as the CO_2 setting continues to be increased, CO and HC emissions rise. Because the smoke curve usually begins to rise at lower CO_2 levels than the CO and HC curves, low smoke is a good indicator to prevent excessive CO and HC emissions. At the other extreme, as low CO_2 settings are approached, the CO and HC emissions may rise before smoke rises. However, setting the boiler to operate at the highest CO_2 level without excessive smoke avoids operation at the low CO_2 conditions (as discussed on page 5). (NO_x levels are not greatly influenced by air settings within the normal operating range where smoke and CO_2 are acceptable.)

For gas firing as high CO_2 values are approached, the CO curve usually rises sharply before smoke rises. Thus, use of a CO detector is recommended for minimizing emissions from commercial boilers firing gas.

Effect of Load

Figure 7 illustrates the characteristic curves of smoke versus CO_2 for a typical commercial boiler firing residual oil at two different loads (or firing rates). For modulating boilers that vary firing rate according to load, particulate levels are usually (but not always) higher at higher load operation than at mid-load. At low-fire operation, the air velocity of the combustion air is frequently reduced below that required for good mixing. This results in a poorer smoke CO_2 curve, as shown in Figure 7. Thus, it is common practice to set the air/fuel proportioning linkage to provide for a higher air setting (and lower CO_2 levels) at low fire.

For multiple boiler installations, particulate levels will generally be minimized if the boilers are programmed to operate at less than full load (say 50 to 80 percent load). Also, it is preferable to avoid operation at low fire, as this may result in higher emissions. Excessive on-off cycling should be avoided.

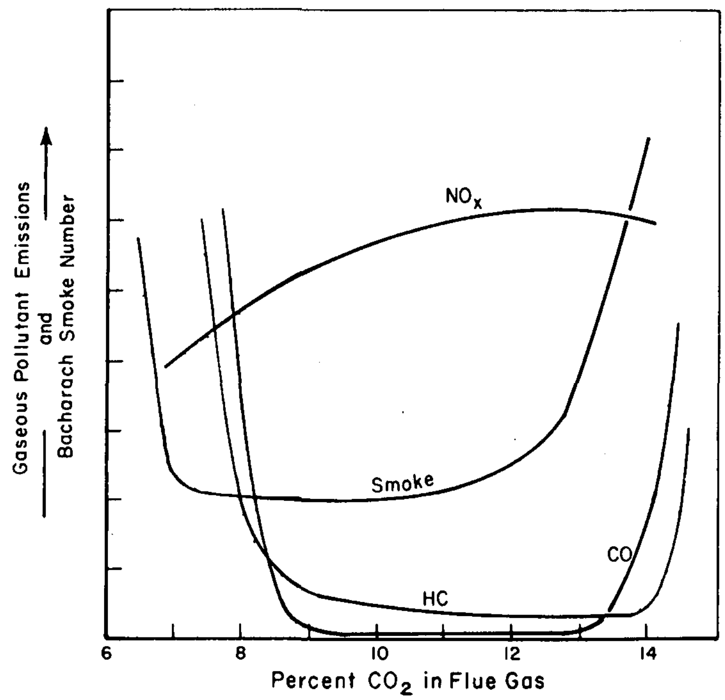

Figure 6. Gaseous Emissions Characteristic for a Typical Commercial Boiler as Influenced by Combustion Air Setting

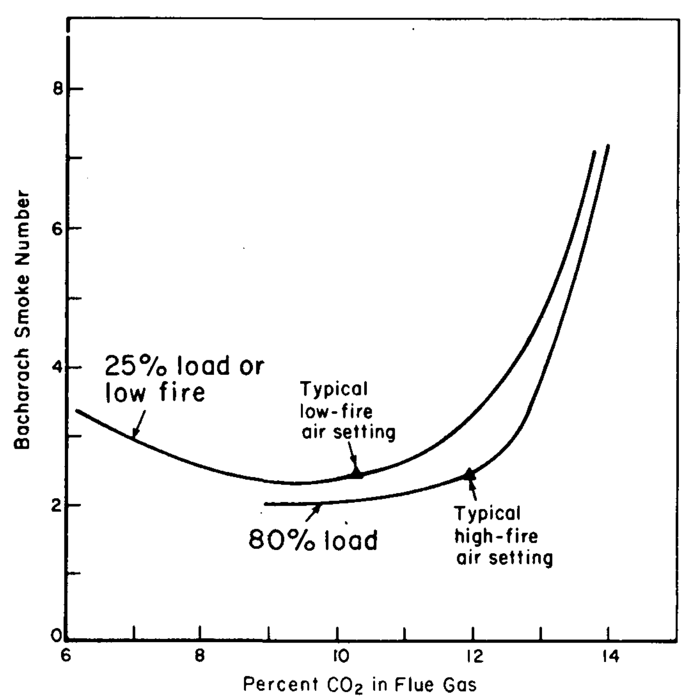

Figure 7. Typical Smoke-CO_2 Characteristic for a Commercial Boiler at Two Loads

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F. SHORT FORM ADJUSTMENT PROCEDURE FOR COMMERCIAL OIL-FIRED BOILERS

Burner service organizations may wish to develop short-form recommendations that tie in with overall company policy, service training doctrine, experience of service technicians and local regulations. The following is an example of a short form condensed from the recommended procedure outlined in these Guidelines.

1.	CLEAN & SEAL	Clean burner and boiler heat-transfer surfaces. Seal air leaks.
2.	SET OIL PREHEAT	Be sure that oil is suitable for burner. For residual oil, adjust the oil preheat temperature for proper pumping and atomization. If the fuel viscosity is not known, start at 250 degree F preheat level. Then back off to lower preheat temperature until best combustion is obtained.
3.	ADJUST INPUT	Adjust the atomizing pressure to manufacturer's recommendations and the fuel input to meet full load demand.
4.	SMOKE-CO_2	Operate the oil burner at full load until up to temperature, using an air setting for clean combustion. Take several readings of smoke and CO_2 as needed to identify the CO_2 value above which the smoke starts to rise rapidly.
5.	ADJUST AIR SETTING	Adjust the air setting about 1/2 percent CO_2 lower than the point where smoke begins to rise sharply. Keep in mind that high CO_2 settings are important for good thermal efficiency. Therefore, adjust for the highest practical CO_2 level without excessive smoke. (Smoke number should not exceed No. 4 when firing residual oil and No. 1 when firing distillate oil.)
6.	DIAGNOSE PROBLEMS	If unable to adjust the burner to operate at acceptable smoke levels while maintaining at least 12 percent CO_2, it is likely that the atomization and/or fuel-air mixing are poor. Check the air-handling parts, nozzle, atomizing pressure, and preheat.
7.	ADJUST CONTROL LINKAGE	Repeat adjustment procedure at low-fire setting and at an intermediate firing rate, by adjusting the air-fuel control linkage. Check several points at intermediate firing rates throughout the range.
8.	ADJUST FOR GAS FIRING	For dual-fuel boilers, use a similar procedure to adjust for operation on gas. CO_2 readings for gas will be somewhat lower than for oil. Check for CO using a suitable CO detector, especially at the extremes of the air-adjustment range. Verify oil settings.
9.	CHECK IGNITION	Make sure ignition occurs promptly at light-off firing rate.
10.	SCHEDULE BOILERS	Arrange the control system so that individual boilers avoid operation at low fire or at full load for extended periods. Avoid excessive on-off cycling.
11.	ANNUAL CHECKUP	An annual tune-up and safety check is strongly recommended.

Adjustment by these procedures will help to reduce air-pollutant emissions and also achieve efficient fuel utilization. For additional details, see the corresponding steps on pages 3-8 of these Guidelines.

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16. ABSTRACT
The Guidelines contain recommended oil-burner adjustment procedures for commercial boilers to minimize air pollution and for efficient fuel use. They are intended for use by skilled service technicians in adjusting commercial oil-fired boilers, and as an aid to service managers engaged in training service technicians. In addition to recommended steps for burner adjustment, the Guidelines include appendixes of background material on pollutants of main concern, field-type instruments and significance of measurements, fuel-oil grades, and emission characteristics of commercial boilers.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution; Space Heating; Combustion	Air Pollution Control	13B 13A 21B
Commercial Buildings; Burners; Boilers	Stationary Sources	13M
Furnaces; Nitrogen Oxides; Nitrogen Oxide (NO); Nitrogen Dioxide; Smoke	Emission Factors	07B
	Particulate	
Carbon Monoxide; Hydrocarbons; Sulfur Oxides; Sulfur Dioxide; Natural Gas	Distillate Fuel Oil	07C
Fuel Oil; Residual Oils	Oils (No. 2,4,5, and 6)	21D 11H

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