FOR

THE

PROFESSIONAL

SERVICEMAN

guide to oilheat

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S E R V I C E M A N

guide *to* oilheat

Beckett

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Acknowledgements

R.W. Beckett Corporation is pleased to present this new, revised edition of *Guide to Oilheat for the Professional Serviceman* (formerly known as *The Professional Serviceman's Guide to Oilheat Savings*). This new edition has been expanded to include updated information and several additional topics of importance to the industry as we approach and enter the 21st Century. These topics include direct, side-wall venting and outside combustion air. We hope this new edition will help you achieve greater success for your business while providing outstanding service to your customers.

Beckett has distributed many thousands of copies of this book, in various editions, since its first printing in 1979. The original *Professional Serviceman's Guide to Oilheat Savings* was based primarily on material developed in 1978 by the Massachusetts Better Home Heat Council and distributed by them as a manual entitled *Oil Heat Energy Conservation Manual.* This material is gratefully used with their permission.

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If we have inadvertently left anyone off this list, we sincerely apologize, and assure you that your contribution is very much appreciated.

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Purpose of Manual

This manual has been prepared for use by oilheat service managers and service technicians. It provides a brief overview of oilheat systems, as well as a review of basic oil burner combustion theory. Included are suggested procedures for adjusting and maintaining oil burners–and other oilheat system components–to provide your customers with maximum efficiency, comfort, and safety.

Modification and installation procedures recommended herein apply to domestic oil burners installed in houses ranging from single-family dwellings to multi-family units. They apply generally to a capacity range up to approximately 400,000 Btu/hr. input.

The procedures in this document should be used as a supplement to the equipment manufacturer's recommended installation and service instructions and do not preclude other accepted guideline documents on good industry practice.

COMBUSTION THEORY

This chapter reviews the basic concepts about the process of combustion. You should understand this process before tackling the other chapters in this manual! It's likely that a good deal of material presented is familiar to you, but there's an even better chance that you might learn something new. It's worth reading, since this information develops the foundation from which every dependable oilheat service technician should work.

FUEL OIL

No. 2 distillate fuel oil (domestic heating oil) is a product of the refining of crude oil, which was formed underground through decomposition of marine organisms, fish, and vegetation. This organic matter eventually became liquid or gas concentrated underground in pockets or pools. All petroleum products, including natural gas, gasoline, kerosine, No. 2 fuel oil, etc., are chemical compounds that make up crude oil, and they all contain carbon and hydrogen.

The process of separating these various components can be quite complex, but is commonly referred to as "refining". Eventually, one of the products of the refining process is No. 2 fuel oil, which is suitable for use as a fuel in residential oil burners. The designation "No. 2" is used as a specification guide that defines some physical characteristics such as flash point, ash, viscosity, etc.

All fuel oil is not alike, and variations can have an impact on burner operation. Here are a few of the variations within each grade of fuel oil which are measured by ASTM (American Society for Testing and Materials standards):

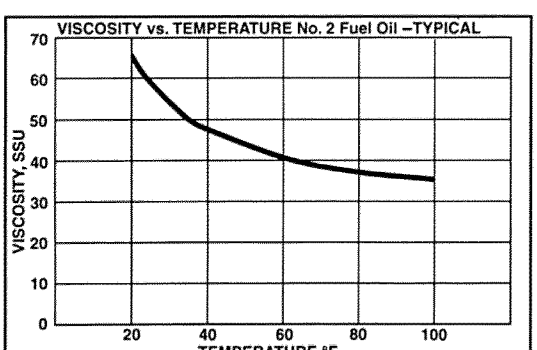


FIGURE 1 Viscosity vs. temperature, No. 2 fuel oil

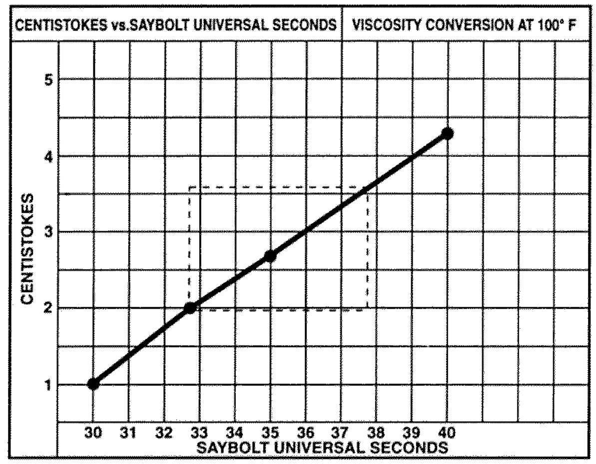


FIGURE 2 Viscosity conversion, Centistokes vs. Saybolt Universal Seconds

Viscosity

This is the oil's resistance to flow. The viscosity rating is a measure of how much oil flows through a standard orifice within a certain amount of time. Oil with high viscosity can contribute to poor atomization, delayed ignition, noisy flame or pulsation, increased input and possible sooting. This is particularly true in temperatures below 50°F. (See Fig.1.) Viscosity measured by the Kinematic viscometer is reported in centistokes. (See Fig. 2 for cross reference.)

Pour Point

Pour point is the temperature at which oil will barely flow. This is usually 5°F above the point where oil forms a solid mass. The ASTM D396 Standard for fuel oils lists 20°F as the maximum pour point for No. 2 fuel oils. However, random analyses show that the typical pour point is approximately -20°F. To avoid problems in certain cold ambient applications, No. 2 fuel oil is sometimes blended with approximately 25% or more of No. 1 distillate fuel (kerosine) to lower the pour and cloud points.

Cloud Point

This is the temperature at which wax crystals begin to form, typically 10°to 20°F above the pour point. These crystals can clog filters and strainers, restricting oil flow. Raising the oil temperature causes the wax to go back into solution. ASTM D396 does not list a specification on cloud point.

Distillation Temperature

No. 2 fuel oil can be vaporized and distilled (condensed) to determine the volatile components. Modern refinery methods use straight-run distillation and catalytic cracking processes, resulting in slightly different chemical hydrocarbon composition which can affect combustion performance. Therefore, the distillation temperature test is valuable. It consists of fuel oil being heated gradually in a flask until it vaporizes, then is condensed into a graduated cylinder. The temperature at which condensation begins is called the initial boiling point (IBP). The rising temperature is recorded for each fraction distilled. It is usually reported in 10% increments until the final drop is recovered or end point is reached.

The initial boiling point could cause ignition problems if it is too high (over 400°F). The ignition arc must provide enough heat energy to elevate the temperature of the atomized oil droplets to the initial boiling point. If the IBP is low, the ignition should be immediate. For the flame to be sustained, the 10% point or temperature at which 10% of the total volume is distilled must be relatively close. If the spread is too large, then the flame could pulsate or even be extinguished.

For an established flame, the remaining fractions of 20 - 80% should not present any combustion problems, but the 90% and the end point could. The 90% point is the temperature where 90% of the oil is distilled. ASTM D396 requires this to be between 540°F minimum and 640°F.
A wide spread between the 90% and end point can cause poor combustion, soot and carbon deposits on the heat exchanger because the remaining heavy ends may not burn completely.

Detecting "Out of Spec" Oil

Your first clue that oil is not within ASTM specs might be a sudden rash of problems: delayed ignition, smoky fires, appliance sooting and noisy, dirty flames. If an analysis by a competent laboratory shows the oil is out of spec, the supplier should be advised. However, if it is within spec, but is near the maximum level for viscosity, pour point or has an IBP above 400°F, chemical additives or blending with about 25% kerosine might be considered to make the oil more compatible with cold temperatures, and to improve its ignition and combustion qualities.

COMBUSTION

When fuel oil is burned, the chemical energy that is stored in the oil is released in another form of energy: **heat**. But to create this conversion of energy, an external source of heat must be applied to the oil droplets to start the reaction. The electric spark delivered by the electrodes of an oil burner provides the initial heat. The heat from the electrodes causes oil droplets to become oil vapor and eventually burn continuously. This burning then heats the surrounding oil droplets causing them to burn. This process continues until all or most of the droplets are vaporizing and burning. If the conditions for combustion are ideal, all oil droplets will burn completely and cleanly within the combustion zone.

Combustion is the process of burning!

Combustion, as we normally think of it, is generally described as "rapid oxidation" of any material which is classified as combustible matter. The term "oxidation" simply means the adding of oxygen in a chemical reaction, and "combustible matter" means any substance which combines readily and rapidly with oxygen under certain favorable conditions. Since fuel oil primarily consists of carbon (85%) and hydrogen (15%), combustion of fuel oil, according to our previous definition, is the rapid combining of carbon and hydrogen with oxygen.

As you know, the oxygen needed for combustion comes from the air provided by the burner blower. Approximately 21% of the air is oxygen. The other 79% is nitrogen. Therefore, to supply the oxygen needed for combustion, a great deal of nitrogen goes along for a free ride. This will become an important factor in later discussions of proper oil burner adjustment!

What we see and feel from combustion—flames, smoke, heat—is a result of chemical reactions. Since we can't see carbon, hydrogen or oxygen atoms (smallest units to combine), we symbolize the reactions with formulas that describe the process. For example:

$$\text{Carbon} + \text{Air} \begin{bmatrix} \text{oxygen} + \\ \text{nitrogen} \end{bmatrix} \xrightarrow{\text{forms}} \text{carbon dioxide} + \text{nitrogen} + \text{heat} \qquad (1)$$

$$\text{Hydrogen} + \text{Air} \begin{bmatrix} \text{oxygen} + \\ \text{nitrogen} \end{bmatrix} \xrightarrow{\text{forms}} \text{water vapor} + \text{nitrogen} + \text{heat} \qquad (2)$$

These reactions can be rewritten using symbols in the following manner:

$$C+O_2+N_2 \rightarrow CO_2+N_2+heat \quad (1)$$

$$2H_2+O_2+N_2 \rightarrow 2H_2O+N_2+heat \quad (2)$$

Both chemical reactions produce entirely new products, and each reaction gives off heat. However, you may have noticed that in each reaction nitrogen (N_2) has not changed, indicating that nitrogen does not participate in the reaction. Consequently, because of the large amounts of nitrogen in the air, the bulk of the flue gas is made up of unreacted nitrogen.

Note: Some nitrogen does react with oxygen to create a small amount of nitrogen oxides or NO_X.

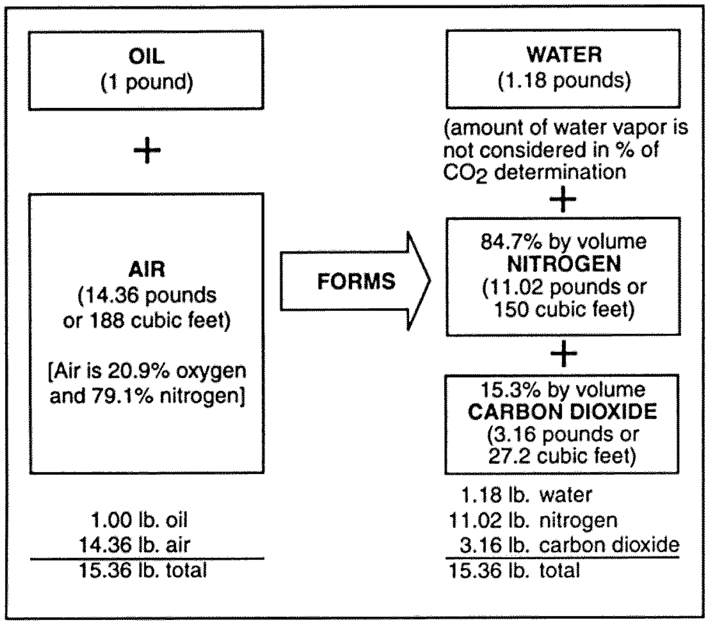


FIGURE 3 Amount by weight and volume of combustion products when 1 lb. of fuel oil is burned (0% excess air)

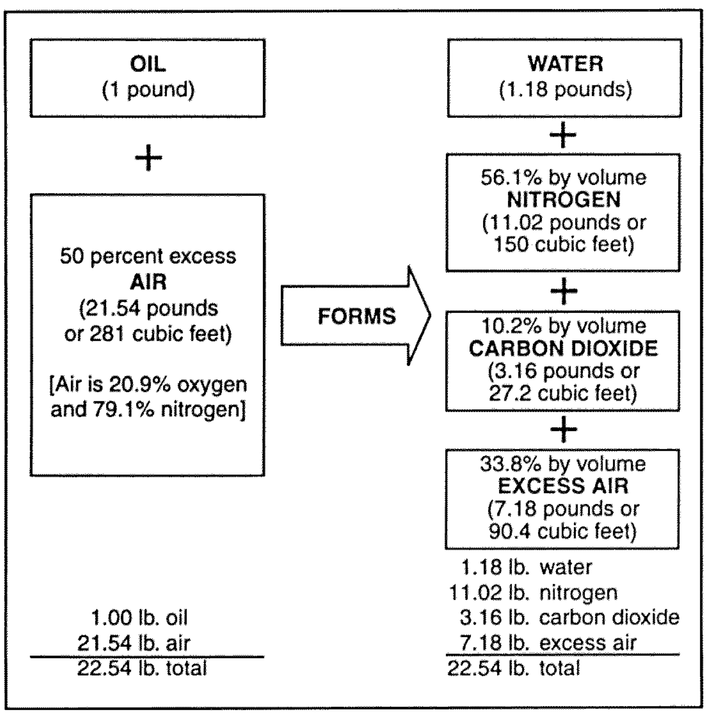


FIGURE 4 Amount by weight and volume of combustion products when 1 lb. of fuel oil is burned (50% excess air)

If exactly the right amount of air (no excess air) were supplied for complete combustion of the carbon and hydrogen in the fuel oil, the products of combustion would be as indicated in Figure 3. However, with typical oilheat equipment, it is usually not possible to get a perfect mixture in which all the carbon and hydrogen are supplied with the exactly correct quantity of oxygen. To insure that all the carbon and hydrogen come into contact with enough oxygen to burn completely, **excess** air must be supplied. The excess air is simply air over and above the theoretical requirement for the combustion of fuel oil. With excess air needed for combustion, reaction (1) becomes:

$$C+O_2+N_2 \rightarrow CO_2+N_2+O_2+heat \quad (3)$$

Note that the only difference between reaction (3) and reaction (1) is that O_2 (oxygen) is a product of the reaction. This O_2 is the oxygen in the excess air that does not combine with carbon to make carbon dioxide. In essence, extra O_2 is provided, as a component of the excess air, to ensure that all the carbon and hydrogen comes in contact with the oxygen and burns.

This excess air does not react during the combustion process, but enters the heating unit at room temperature and reduces the temperature of the combustion gases so less heat is available to be transferred to the distribution medium. As a result, excess air is a source of heat loss. By introducing 50% excess air, the situation shown in Figure 4 is created. Compare this with Figure 3. Note that:

- The amount (weight) of H_2O, CO_2, and N_2 formed in Figure 4 is the same as that in Figure 3.
- Percent by volume of CO_2 and N_2 in Figure 4 is less than is formed in Figure 3.
- Oxygen (as part of excess air) is a product in Figure 4 but not in Figure 3.

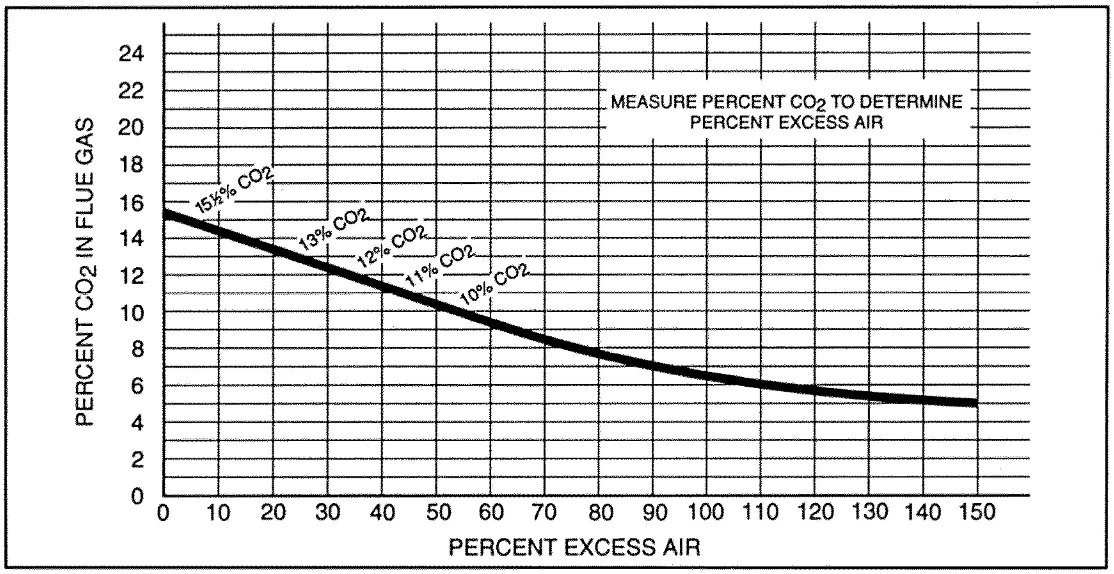


FIGURE 5 Relationship between excess air and CO_2

In Figure 4, since 20.9 percent of the excess air is oxygen, 7.1 percent of all the combustion gases is oxygen. You determine this by multiplying the percent excess air (33.8%) times that portion of excess air which is oxygen (.209). This gives approximately 7.1 percent oxygen.

Note that in Figure 4 the percentage of CO_2 or O_2 changed from Figure 3 as a result of excess air, therefore, we can use the percent CO_2 or O_2 in the flue as a measure of excess air or vice versa —as a general rule.

- The more CO_2, the less excess air
- The more O_2, the more excess air

Figure 5 displays the relationship between CO_2 and excess air.

The above discussion is a simplification of the actual combustion process. The chemical reactions provided are only those that are important to the overall combustion process. Nevertheless, the information in this section is sufficient to support you in your oil burner service work. Make sure you understand the concepts and, if necessary, reread this section or ask a knowledgeable person to assist you. Don't go on without understanding the basic concepts!

Role of Excess Air in Combustion

You have seen that excess air must be supplied to insure adequate mixing of fuel and oxygen. However, excess air is one of the major causes of low efficiencies. To see how this occurs consider that excess air:

- dilutes combustion gases
- absorbs heat
- drops overall temperature of combustion gases

The dilution of combustion gases occurs simply because of the presence of additional gas in the form of excess air. The excess air absorbs heat in the combustion zone and reduces the flame temperature. This in turn reduces the transfer of heat to the heat exchanger since a significant amount of heat is transferred by radiation. Moreover, as excess air is introduced, the overall temperature of the combustion gases drops because the heat from these combustion gases is used to raise the temperature of the excess air. Think of this process as being similar to adding refrigerated cream to a cup of coffee as shown in Figure 7. The cup of coffee is originally 160°F (high temperature) and occupies a small volume (half a cup). Adding cream at 40°F increases the volume (almost a full cup) and lowers the overall temperature to 120°F (mild temperature). Note that the temperature of the mixed coffee and cream is higher than the temperature of the cream alone and lower than the temperature of the coffee alone. Heat from the coffee went into heating the cream and the overall temperature dropped. In other words, the cream absorbed some heat from the coffee.

Also, by looking at Figure 6 you can see that the coffee example illustrates the effect of excess air (shown as water) in diluting the gas (coffee) and the resulting reduction in the CO_2 percent.

Bear in mind that this temperature reduction and dilution takes place in the combustion zone, not in the flue or stack. It is important to note that the effect of excess air on the temperature of the flue gas is different. With more excess air, the flue gas temperature tends to rise. This happens because the volume of combustion gas per unit of fuel burned is now greater than before, so the gases pass over the heat exchanger surfaces more rapidly, reducing the contact time. This reduces the heat transfer rate to the heat exchanger.

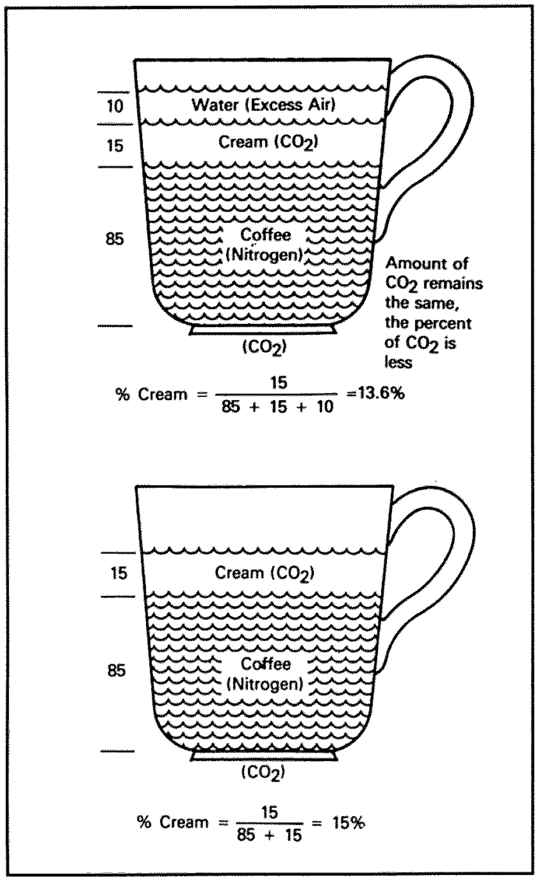


FIGURE 6 The effect of excess air on CO_2

To review, remember that excess air causes the following:

- lower flame temperature
- lower combustion gas temperature
- higher flue stack gas temperature
- poorer heat exchange to the distribution medium

All of these changes reduce the efficiency of the heating system. So minimizing excess air is essential in the proper adjustment of oil burners. However, you will find out in the next section that simply reducing excess air without concern for other factors could lead to a great deal of trouble! Keep reading, you'll see what we mean.

Excess Air - Smoke Relationship

During the combustion of oil, some smoke is usually generated, since some of the oil droplets do not contact enough oxygen to complete the reaction which forms carbon dioxide. This smoke consists of small particles of mainly unburned carbon. Some of these particles stick to the heat exchanger surfaces acting as insulation and can eventually clog up the flue passages, while others are emitted through the stack.

Now you are ready for discussion of the issue that is all important to the proper adjustment of oil burners: excess air-smoke relationship.

You have learned that there must be sufficient excess air to provide good mixing of combustion air and fuel oil. Without this excess air, incomplete combustion occurs and smoke is formed. Thus, to minimize smoke, you generally add excess air.

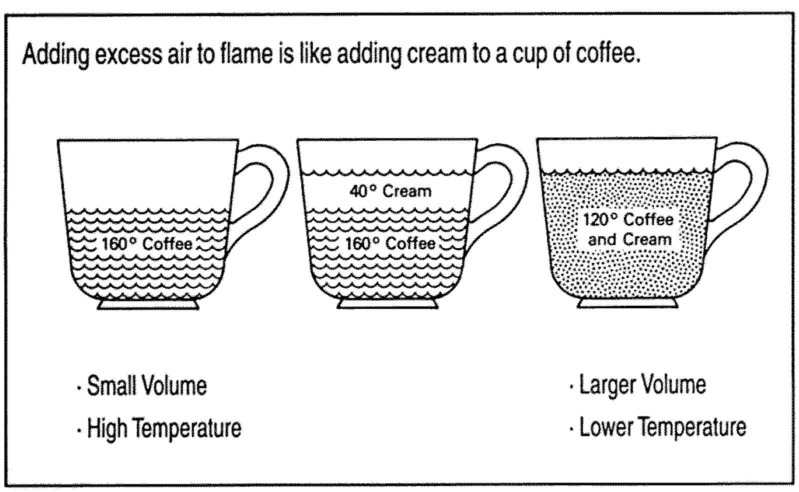


FIGURE 7 Representation of the effect of excess air on combustion gas temperature

Unfortunately, as you have learned, as the amount of excess air is increased, the transfer of heat to the heat exchange medium (hot water, warm air, or steam) is reduced. A delicate balance must be achieved between smoke generation (caused by insufficient excess air), reduced heat transfer (due to reduced combustion gas temperature), and an increased volume of combustion products (caused by unnecessary excess air). Figure 8 illustrates the typical relationship between smoke, efficiency, and excess air. Notice that smoke and efficiency increase as the excess air is decreased. The exact shape of this curve varies from unit to unit. Knowing this, the curve can give you a general idea of where the burner air should be adjusted. The highest efficiency occurs when you properly balance the trade-off between smoke and excess air.

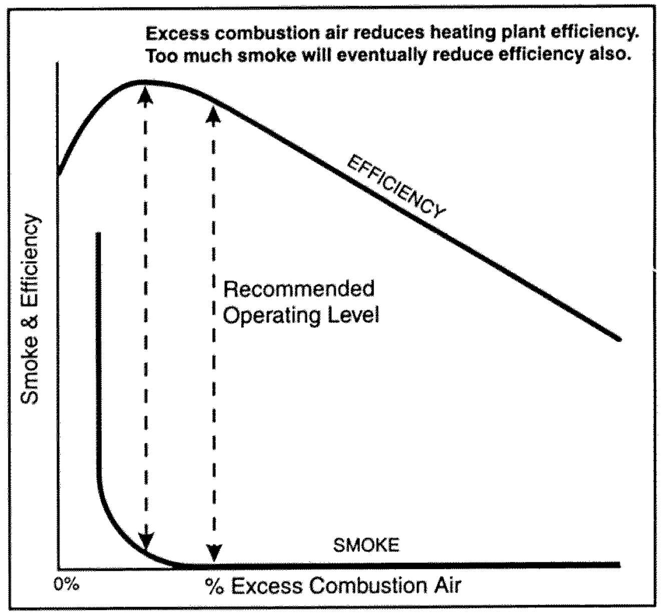


FIGURE 8 Smoke & efficiency vs. excess air curve

Effect of Air Leaks

Now that you understand what goes on inside the heating unit, it will be easier to follow why air leakage into the appliance causes lost efficiency. This air leaks into the combustion gases before they pass through the heat exchanger and acts like excess air. The air leaks dilute the combustion gases, cooling them and increasing their volume so that they pass through the heat exchanger more quickly. However, an air leak is even worse than excess air in the combustion chamber because an air leak can not reduce the smoke formed in the combustion zone.

OILHEAT SYSTEMS

Overview of Oilheat Systems

The primary emphasis of this manual is on oil burners. However, a brief look at total oilheat systems would be appropriate. Maximum heating efficiency, reliability, and safety cannot be achieved unless all components of the system are compatible and in top working condition. It is vital, therefore, that the technician consider the entire system when installing new equipment or servicing existing equipment.

The purpose of any oilheat system is to convert fuel oil into heat, and distribute as much of that heat as possible to the home.

Typical Oilheat System Components

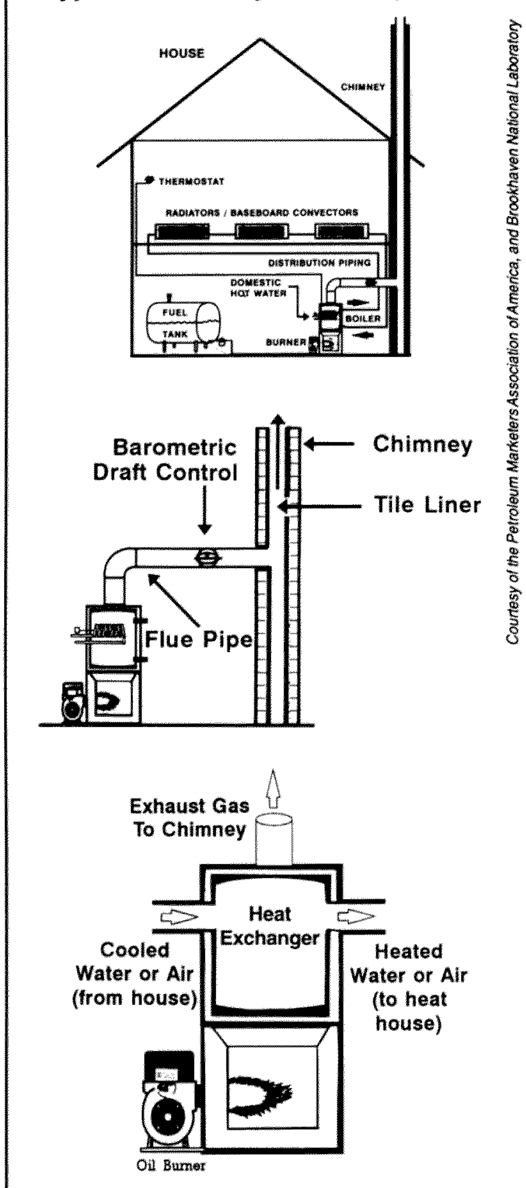


FIGURE 9 Typical oilheat system components

Storage Tanks

Residential fuel oil storage tanks fall into three categories: underground, above ground, and indoor. Each has its advantages and disadvantages.

Underground Tanks

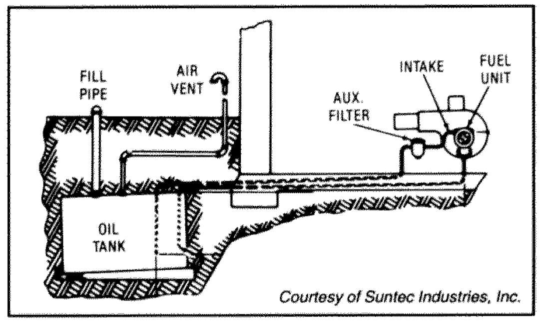


FIGURE 10 Underground tank

Advantages:

(1) Take up no space inside or outside the home.

(2) Tanks are out of sight.

(3) A large quantity of oil can be conveniently stored.

(4) Better insulation from cold, compared to above ground tanks.

Disadvantages:

(1) Expensive to install, inspect, and service.

(2) Subject to effects of cold and underground moisture.

(3) Well-made, properly installed tanks seldom leak—even after decades of service. However, leak detection and clean up are still important environmental concerns.

Above Ground Tanks

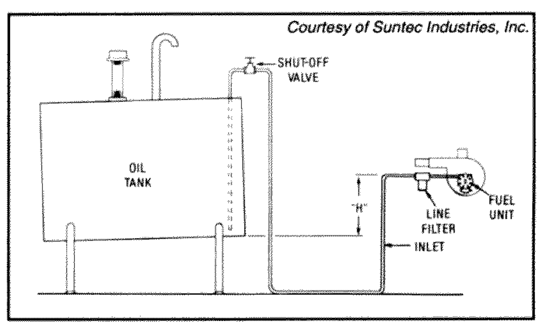


FIGURE 11 Above ground tank

Advantages

(1) Less expensive than underground tanks to install and service.

(2) If leaks occur, they can be easily detected in time to avoid environmental problems.

Disadvantages:

(1) Exposed to cold and moisture. (These problems can be reduced by providing a shelter for the tank.)

(2) Take up outdoor space.

(3) May detract from appearance of home.

Indoor Tanks

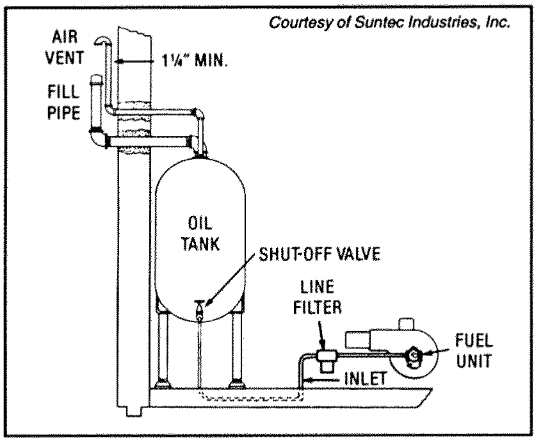


FIGURE 12 Indoor tank

Advantages:

(1) Not affected by outside cold and moisture.

(2) Less expensive to install and service than underground tanks.

(3) Leaks are unlikely to occur. If they do, they are easily spotted and repaired.

Disadvantages:

(1) Take up space inside home.

(2) Some oil smell may be present.

Oil Delivery Systems

The oil delivery system includes all components required to transport oil from the storage tank to the burner. These include pumps, pipes, valves, filters, and controls. Inspecting these components should be a part of scheduled maintenance service.

When diagnosing combustion problems, the oil delivery system should always be considered as a possible contributing factor. Check for proper oil pressure, viscosity, and cleanliness. Filters should be changed at regular intervals. Compression fittings can cause air leaks and should not be used.

In some cases combustion problems can be alleviated by increasing oil pressure to the nozzle. If cold oil is a problem, oil line heaters can be installed. Always follow burner manufacturer's instructions when adjusting oil pressure or installing heaters.

Oil Burners

The functions of an oil burner are to break fuel oil into small droplets, mix the droplets with air, and ignite the resulting spray to form a flame.

Combustion Chambers

The purpose of the combustion chamber is to reflect heat back into the flame to aid the combustion process and achieve more complete burning of oil. See page 14 for more details.

Heat Exchangers

The purpose of the heat exchanger is to transfer heat from the burner flame to the water or air used to heat the home. The heat exchanger is an integral part of the boiler or furnace. The role of the serviceman is usually limited to inspection and cleaning. However, this is an extremely important role. If soot is allowed to accumulate on the heat exchanger, the efficiency of the heating appliance can be seriously impaired. Proper adjustment of the burner to avoid smoke (the cause of soot) is essential to keeping the heat exchanger clean. See page 18 for more details.

Flue Pipes

Flue pipes serve two vital functions:

(1) They convey combustion gases from the heating appliance to the chimney or vent. Since these gases are potentially harmful to the home and its residents, these pipes must be sealed tightly to prevent leakage. In most chimney systems, flue pipes are under a negative pressure created by draft, which aids in preventing leaks.

(2) Flue pipes convey combustion gases that create the draft to assist in drawing combustion air into and through the burner in chimney systems.

Draft Regulators

Many flue pipes include a barometric draft regulator. This consists of a counterweighted swinging door which opens and closes to help maintain a constant level of draft over the fire.

Modern high-speed, flame retention burners are much less sensitive to changes in natural draft—allowing draft regulators to be eliminated in some cases. However, check the burner manufacturer's instructions, and local codes, before eliminating draft regulators. See page 22 for more details.

Chimneys

Chimneys have been used since the earliest days of indoor heating to draw combustion gases out of the home and provide draft to help draw in combustion air. Correct chimney design and careful maintenance are essential to the operation of any oilheat system.

When chimneys are inadequate or absent entirely (such as in electric-to-oil conversions), alternative venting systems are available. See page 25 for more details.

Heat Distribution Systems

With furnaces, warm air, propelled by fans, is distributed throughout the house through metal ducts. With boilers, hot water or steam is distributed through pipes. These heat distribution systems can be important sources of heat loss. Check air ducts for leaks, and consider insulation for water and steam pipes.

Controls

The controls used to regulate typical oilheat systems include the following:

(1) **The Thermostat** "tells" the burner when to turn on and off to maintain the desired temperature in the house. Programmable thermostats automatically lower and raise temperature settings at timed intervals throughout the day and night, to conform to the changing needs of the home occupants. This can produce significant fuel savings.

(2) **The Aquastat** regulates the temperature of boiler water.

(3) **The Fan Control** turns the fan on and off in warm air furnace systems.

(4) **Pump and Zone Valve Controls** regulate the flow of water or steam in boiler systems.

(5) **Safety Controls** such as pressure relief valves, high temperature limits, low water cut offs, and burner primary controls protect against appliance malfunctions.

When adjusting controls, follow manufacturer's instructions.

The House

The house itself has a major effect on the performance of the heating system, especially on the combustion air supply. Newer, tightly sealed houses have different requirements than older houses with greater air infiltration. Exhaust fans, vented clothes dryers, and ventilating systems also have an effect on available air for combustion. It is essential that the technician consider these factors when recommending a heating system, or diagnosing system problems.

Basic Oil Burner Design

Most oil burners in use today operate as follows: (See Figure 13.)

(1) Oil is delivered under pressure (usually about 100 psig—although some models require pressures in the 140-200 psig range) by the oil pump (A) to the nozzle (B). Check manufacturer's specifications for proper pump pressure settings.

(2) The nozzle breaks up the oil into a spray of tiny droplets from .0002 to .0100 inches in diameter which evaporate rapidly into a vapor.

(3) The vapor is mixed at the burner head with a stream of air from the blower wheel (C).

(4) The oil vapor combines with oxygen from the air stream and is ignited (initially) by an electric arc from the electrodes (D), powered by a high voltage transformer (E), to produce a flame.

(5) Heat is reflected back into the flame by the combustion chamber, to help evaporate the oil droplets. This helps achieve more complete burning of the oil.

(6) This combustion process continues until the burner is shut down for the off cycle.

(7) The entire process begins again with the next on cycle.

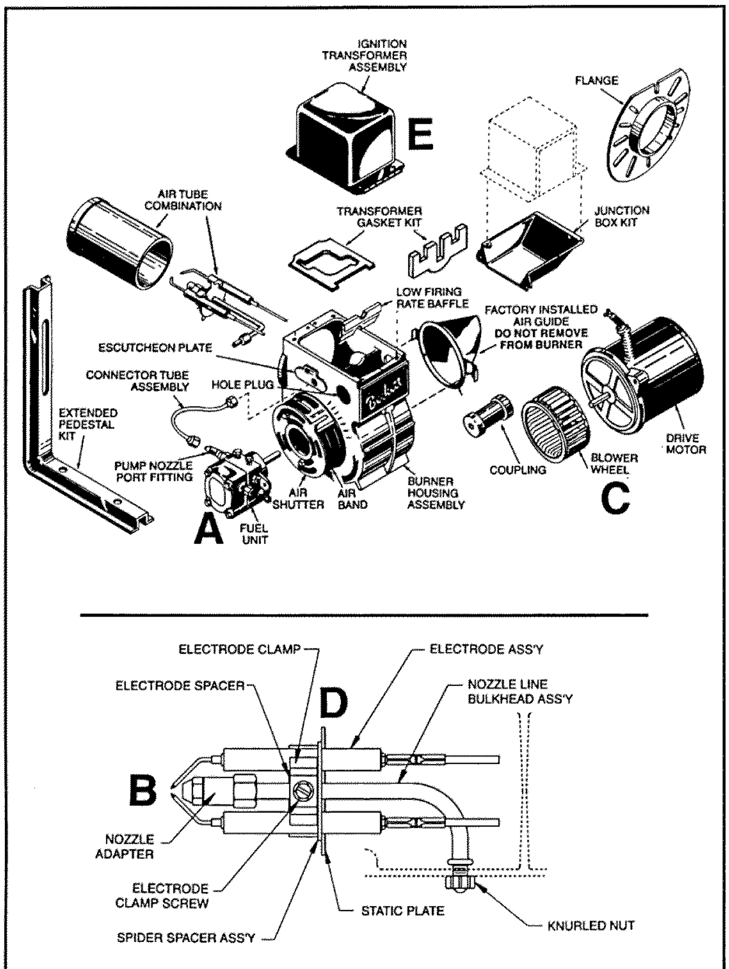


FIGURE 13 Typical oil burner components

Flame Retention Burners

Most oil burners currently being manufactured and installed are flame retention burners. The name comes from the combustion heads which are designed to hold-in or "retain" the flame. High-speed motors are used to produce high air pressures. This allows the burner to do a superior job of mixing air and oil. An intense swirling motion produces a compact, highly stable flame which is held (retained) close to the burner head. Flame gases are recirculated, to aid evaporation of oil droplets and achieve cleaner, more efficient combustion compared to non-flame retention burners.

In most cases, your customers can obtain substantially improved heating system efficiency by replacing old non-flame retention burners with new high-speed flame retention burners. Beckett supplies a full line of these burners to accommodate a wide range of residential and commercial boilers and furnaces. See Chapter 6 for specific burner recommendations.

Combustion Heads

The combustion head (also referred to as the turbulator, fire ring, retention ring, or end cone) creates a specific pattern of air at the end of the air tube. The air is directed in such a way as to force oxygen into the oil spray so the oil can burn.

Flame Retention Heads vs. Non-Flame Retention Heads

The majority of combustion heads in the field today are flame retention heads. These heads differ from the non-flame retention heads in that the flame is held very close to the face of the head. The flame is smaller and more compact, and usually is 300°F to 500°F hotter than with non-flame retention heads. (See Figure 15.)

The flame retention head incorporates three basic elements: (1) center opening, (2) primary slots, and (3) secondary opening. The **center opening** is an orifice in the center of the head which allows the oil spray and the electrode spark to pass through the head. The **primary slots** are the slots that radiate out from the center opening toward the outside of the head. The **secondary opening** is a slot which is concentric to the center opening and follows the circumference of the combustion head. All three openings affect the way air is delivered to the oil spray.

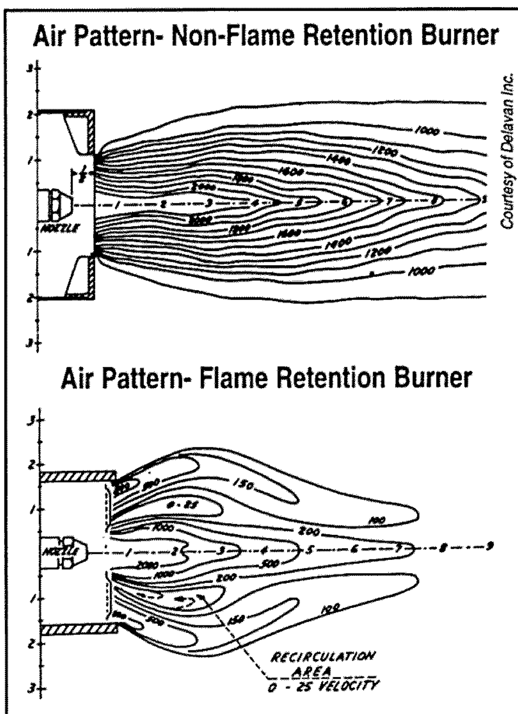


FIGURE 14 Burner air patterns

Generally speaking, it is advisable to choose a flame retention head over a non-flame retention head in the majority of applications. There are a few existing heating units in the field which have used a non-flame retention head in a steel chamber. These units can be retrofitted with a new burner and non-flame retention head, or could use a flame retention head with the addition of a chamber liner for protection against the hotter flame temperatures produced by the flame retention head.

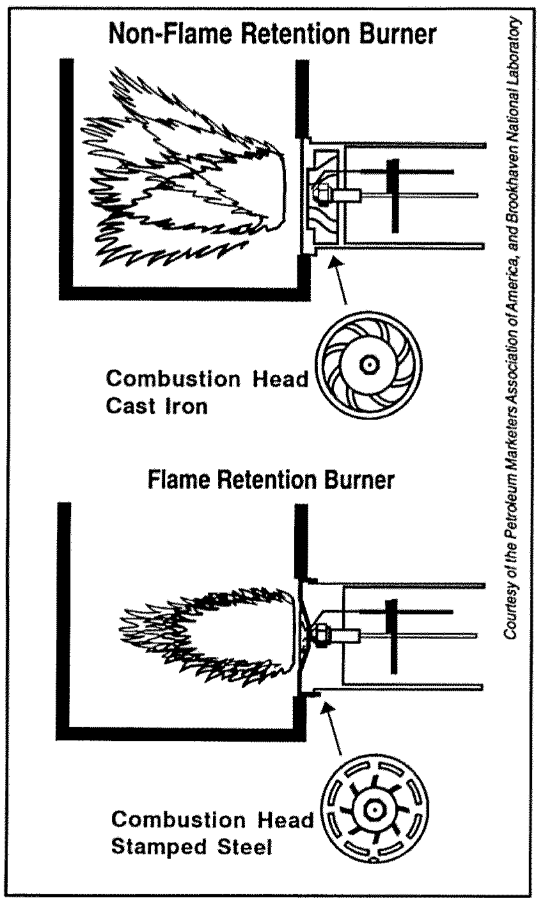


FIGURE 15 Burner flame configurations

Fixed Heads vs. Variable Heads

Most flame retention heads found today can be classified as either **fixed head** or **variable head**. The only major difference is the method of controlling the secondary opening. The fixed head group has the secondary opening preset to a specific size for a specific firing rate range. The variable head group allows the head to move forward and backward according to the firing rate requirements.

The **fixed head** is an excellent performer in most warm air applications. Since the chamber in these units becomes approximately 2000°F, any oil which is not burned in the flame is usually ignited by the heat of the chamber. As with warm air units, a fixed head will also work very well in the majority of boiler applications.

The **variable head** is an excellent performer in most wet base or wet leg boiler applications that have minimal or no combustion refractory. The variable head gives the user two advantages over the fixed head. The first advantage is the ability to fine tune the position of the head so as to supply the flame with the precise amount of air through the secondary slot that it needs in order to achieve the highest performance levels. The second advantage is that most variable heads are actually recessed into the air tube, which protects the flame base from being affected by recirculating combustion gases within the chamber.

Firing Range

It is always necessary to choose a head whose firing rate range is closely matched to the firing rate requirements of the heating unit. As an example, if the firing rate of the heating unit is 1.50 gph, head #1 has a range of .85-1.65 gph, and head #2 has a range of 1.10-2.00 gph, the head to choose for the highest performance would be head #1 (the .85-1.65 gph head).

The reason is that the higher rated head #2 has a larger secondary slot than the lower rated head to enable it to reach the top end of its range. Either head will work, but the higher rated head #2 will probably not reach the same high CO_2 performance levels as the lower rated head because of the extra air it will allow through the secondary slot.

The Effects of Pre-Purge and Post-Purge on Oilheat Burners

Without purge capabilities, burner blowers are turned on at the time the flame is ignited, and turned off when the flame is extinguished. This works well in most cases, but some applications present problems. When a heating system thermostat signals the need for heat, it is desirable to supply it promptly. Any delay in providing heat can cause discomfort for home or building occupants, precipitate nuisance service calls, and have a negative effect on fuel efficiency. To supply heat quickly, the burner flame must ignite instantly and smoothly. It requires adequate airflow (draft) to accomplish this. Typically, when an oil burner has been off for a while, natural draft in the chimney can become neutral. Cold chimneys contain heavy air that must become heated and start to flow upward before draft can occur. There could even be a down draft due to wind gusts. In chimneyless, direct vented systems there may be no draft at all at start up. With power vented systems, draft levels may fluctuate widely. That's where pre-purge comes in.

Pre-Purge

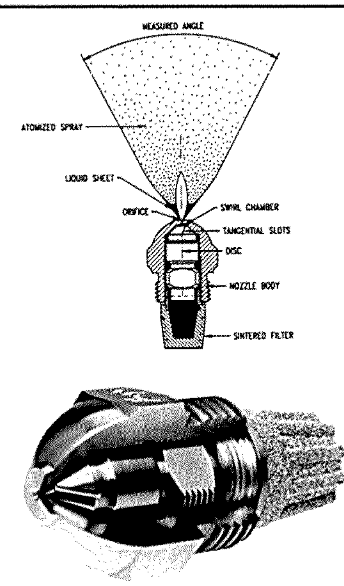
The pre-purge controls currently offered by Beckett as a factory-installed option on its models AF II and AFG burners turn the blower on several seconds before the flame is ignited. This establishes the level of airflow required for fast, smooth ignition. This airflow is already fully established when ignition occurs. The burner doesn't have to "struggle" to achieve ignition under inadequate draft conditions. Another significant factor is the stability and capacity of the ignition arc. The arc should be at full strength and well established when the oil is delivered from the nozzle—otherwise, delayed ignition, noisy pulsation, and smoking can occur under certain adverse conditions. With pre-purge, the arc is allowed to reach its maximum potential, contributing to easier ignition of the oil droplets, and producing a cleaner burning flame from the moment of ignition. In addition, the oil pressure level in the pump is stabilized well before the oil solenoid valve opens. Oil is delivered to the nozzle at a steady pressure, for optimum atomization of the fuel.

Post-Purge

Post-purge is involved with the other end of the burner cycle. When the desired heat level in the home or building has been achieved, the thermostat calls for burner shut-off, which occurs immediately without post-purge. As a result, combustion gases may still be present in the flue without sufficient airflow to evacuate them. Draft reversals may also occur, forcing flue gases back into the flue pipe and the combustion chamber. This can cause odor problems and/or the leaking of combustion gases into the home. The heat from the gases can also affect nozzles and other system components. Post-purge keeps the blower operating for a selected period after burner shut-off. Flue gases are evacuated, draft-reversal is eliminated, and nozzles are protected from overheating. Most controls used by Beckett are adjustable to the specific requirements of the heating system. Direct vent systems have created a special application for post-purge capability. With direct venting, the positive air pressure created by the burner blower is relied on to move combustion gases through the flue and evacuate them from the system. It is vital, therefore, that the blower continue to operate for a period of time at the end of each burner cycle. In the past, pre-purge and post-purge capability was obtained for the most part through retrofit installation of optional kits. Now, factory-installed controls, like those offered on the Beckett AF II and AFG burners, provide greater convenience for oilheat service technicians, and reduced costs for homeowners.

NOZZLES

Oil burner nozzles come in a wide range of designs and sizes. It is essential that the correct nozzle be used in each installation to assure compatibility with the burner and produce the desired spray pattern for the appliance in which the burner is used.



Cutaway View of A Fuel Oil Nozzle

FIGURE 16 Cutaway view of a fuel oil nozzle

When replacing nozzles, it is usually best to use a nozzle identical to the one supplied as original equipment by the burner manufacturer. Consult burner manufacturer specifications whenever possible. If these are unavailable, a call to the manufacturer might be advisable. Do not assume that the nozzle currently in use is the correct one. It may have been installed in error during a prior burner servicing.

In some cases, improved combustion can be achieved by changing to a nozzle of a size or design different from that of the original equipment nozzle. However, such changes should be attempted only after careful consideration of all relevant factors and checking with the appliance

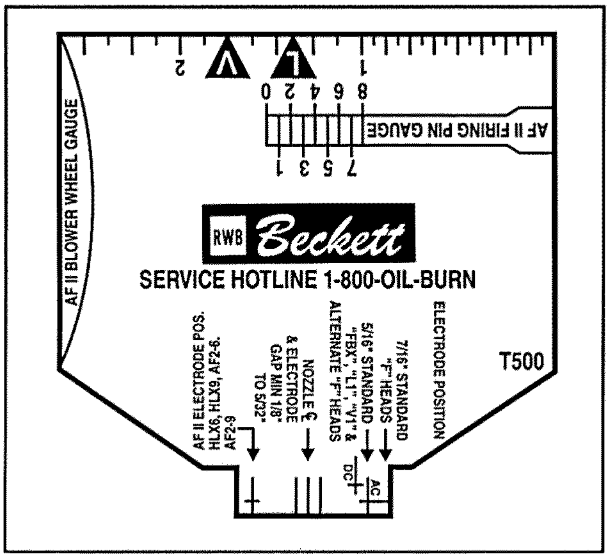


FIGURE 17 Beckett Multi-Purpose Gauge

manufacturer—and post-installation testing should be done, to make sure the new nozzle is performing properly.

When installing a nozzle, a gauge should be used to insure correct depth and concentricity. The gauge shown in Figure 17 is available from Beckett, free of charge, on request.

Proper Nozzle Installation

1. Make sure the fuel supply is clean and free of air or bubbles.
2. Make sure the pump pressure is set properly. For domestic applications it may be 100 psig to 200 psig. (Check manufacturer's specifications.)
3. Inspect the nozzle adapter before installing the nozzle. If there are deep grooves cut into it from over-tightening, replace it. Those grooves, or a scratched surface, can cause leaks.
4. When installing the nozzle, use extreme care to protect the nozzle orifice and strainer. If the orifice gets dirt in it, or becomes scratched, it will not function properly.
5. Do not over tighten the nozzle when tightening. Excessive tightening can cut grooves into the adapter and cause leaks when the next nozzle is installed.

Nozzle Spray Patterns and Angles

The size and shape of an oil burner flame are determined by the pattern and angle of the oil spray, which, in turn, are determined by the design of the nozzle and the pressure of the oil and air supplied to it.

The three principal types of **spray patterns** are solid, hollow, and semi-solid. (See Figure 18.)

Spray angle categories vary from 30° to 90°.

It is essential that the combustion air pattern conform to the oil spray pattern. If the air pattern is too wide, the droplets at the center of the oil spray will not be exposed to a sufficient quantity of air for efficient combustion. If the air flow is too narrow, the droplets on the outside of the oil spray will not receive sufficient air.

Finally, the shape and size of the flame (determined by the nozzle design, oil pressure, and air pressure) must conform to the dimensions of the combustion chamber. The flame should be large enough, and shaped in such a way, to almost fill

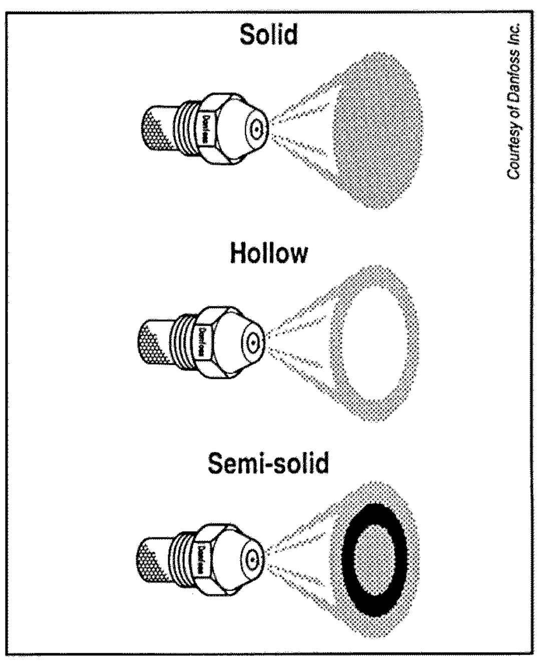


FIGURE 18 Nozzle spray patterns

the combustion chamber without actually touching any part of the chamber surface.

Be sure to follow specifications provided by manufacturers.

COMBUSTION CHAMBERS

The function of the combustion chamber is to surround the flame and radiate heat back into the flame to aid in combustion. The combustion chamber design and construction helps determine whether the fuel will be burned efficiently. The chamber must be made of the correct material, properly sized for the nozzle firing rate, shaped correctly, and of the proper height.

The chamber should be designed and built to provide the maximum space required to burn the oil needed to fire the heating plant and meet its load. Unburned droplets of oil should not touch the chamber surface, especially a cold surface. A cold surface will reduce combustion temperatures and cause soot and carbon formation. The hotter the area around the burning zone, the easier the oil droplets will vaporize and ignite, and the hotter the flame will be. If the chamber is too small, the oil will not have enough time to complete combustion before it strikes the colder walls.

When the chamber is too large, there will be areas in the chamber which the flame will not fill. This causes cooler chamber surfaces and reduces the reflected heat from the chamber walls. As a result, the fuel droplets will not evaporate as rapidly in the cooler chamber and will be more difficult to burn completely. More air will be required to burn smoke-free and the result will be low CO_2 (high O_2) and lowered efficiency.

Floor Size. The size of the combustion chamber is measured in square inches of floor space. The ideal size for a residential heating system is about 80 to 90 square inches per gallon of oil. If the burner is functioning well, and the chamber has quick heating refractory material and is properly designed, it is possible in most cases to use this formula up to 1.50 gph. For residential use, the chamber should not exceed 95 square inches per gallon for a high pressure burner.

When the combustion chamber is accurately sized to the heating plant capacity, using 80 or 90 square inches per gallon, it is extremely important that the nozzle pattern and spray angle conform to the characteristics of the burner air pattern and that the oil pressure at the nozzle should be set to the burner manufacturer's recommendations.

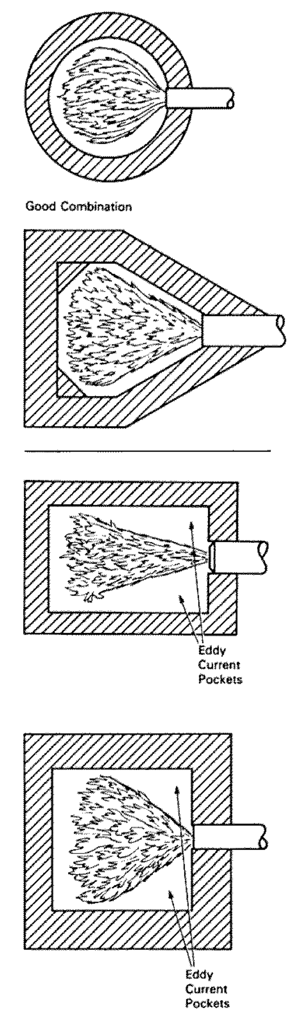


FIGURE 19 Combustion chamber design

Shape. The majority of combustion chambers are square, rectangular, cylindrical or round. Curved surfaces generally produce more complete mixing of oil and air. They also eliminate the pockets of air, often present in the corners of square or rectangular chambers, which reduce the reflected heat from the chamber walls to the flame. The air in these corners also does not usually become a part of the combustion process with non-flame retention burners and therefore dilutes the combustion products as they flow through the heating plant. This is particularly true of the corners at the front of the chamber where the oil is sprayed in, because the flame is narrow and the oil has not been heated up to maximum temperature at this point. (See Figure 19.) Modern flame retention burners are not as dependent on chamber shape.

A well designed chamber will confine the flame, and more reflected heat will enter the combustion process in its early stages. This will aid combustion and provide much smoother ignition. In making alterations in the chamber, you must keep in mind that you must use the nozzle spray pattern and angle to fit the chamber as recommended by manufacturer's specifications.

Walls. It is important that the walls of the chamber be high enough to assist combustion, but not so high as to interfere with the heat transfer from the combustion products to the heat exchanger. Figure 22 shows the height to be used based on the firing rate. The chamber wall should be 2 to 2-1/4 times as high above the nozzle as it is from the floor to the nozzle.

If the base of a heating unit has a tendency to overheat, the walls should be 2-1/2 to 3 times the height from floor to nozzle. This is sometimes a problem in gravity type air duct systems or boilers that have been converted from coal to oil. Be sure to use insulation between the furnace and chamber wall up to the top of the wall.

Space between the chamber wall and the heating plant should be filled with an insulating material, such as mica pellets—except in wet leg or wet base boilers. Poor grade of backfill shortens the life of the chamber, reduces the efficiency at which the oil burns, and increases combustion noise.

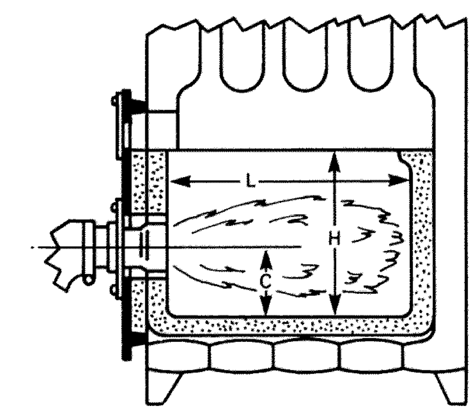
Burner Setting. The chamber must be installed so that the oil can burn cleanly without impinging on the floor and causing carbon to form. Figure 23 shows recommended inside dimensions. The burner end cone should be installed 1/4" back from the inside chamber wall. We recommend that you install refractory fiber material around the outside diameter of the burner end cone and air tube. If insulating material is not available, and chamber opening exceeds 4-3/8", burner end cone set back must be increased. (See Figure 20.)

Soft Fiber Refractory. Refractories of low specific heat and low conductivity (insulating) will rise in temperature more rapidly from a cold start and maintain a higher temperature during steady operation of an oil burner. This will help produce more complete combustion and increase the heat transfer by radiation to the heat transfer surfaces of the heat exchanger.

Tests by the National Bureau of Standards comparing a hard brick chamber to a precast soft chamber in the same boiler determined that losses by radiation, conduction, convection and incomplete combustion were 13.4% for the brick and 8.6% for the precast. The difference was equal to 8300 Btu's per hour in favor of the precast. This amounts to a possible saving of 6%.

Another advantage of soft fiber refractories is the fact that they *cool down* faster than hard refractories. This helps prevent nozzle overheating and afterdrip. Also—since soft refractories store less heat—off cycle heat loss is reduced. Examples of soft refractory chambers are shown in Figure 21.

Many modern residential boilers have no chamber, but often a target wall and/or a blanket on the floor.



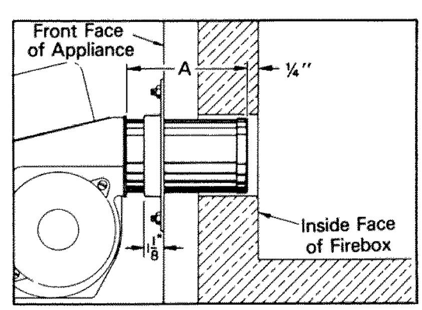
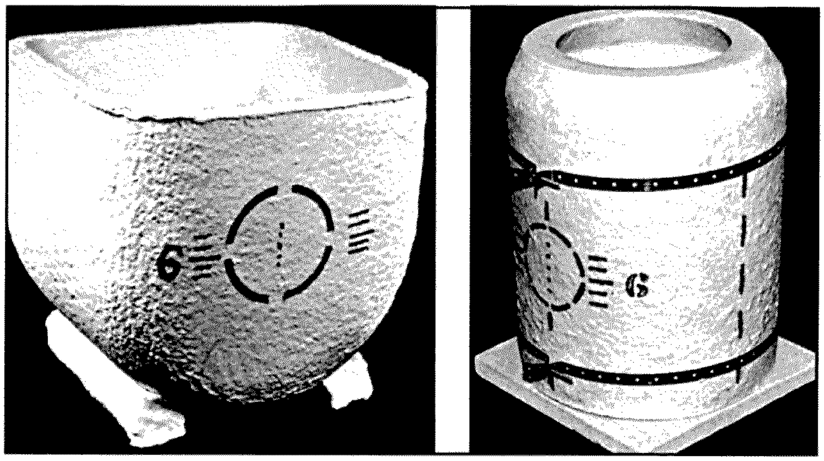


FIGURE 20 Air tube insertion

The burner head should be 1/4" back from the inside wall of the combustion chamber. Under no circumstances should the burner head extend into the combustion chamber. If chamber opening is in excess of 4 3/8", additional set back may be required.



Courtesy of Lynn Products Company, Inc.

FIGURE 21 Soft fiber refractory combustion chambers

Although it is possible to obtain a relatively good fire without a chamber, you should realize that a properly sized and shaped combustion chamber will substantially improve combustion, provide a hotter flame, and reduce the amount of soot accumulation associated with start up and shutdown. Large commercial burners are frequently fired without a chamber, but with small residential burners the chamber becomes extremely important. Modern materials for chamber construction reach operating temperature within 20 seconds after starting the fire, causing heat to be reflected back into the oil spray, speeding up the conversion of liquid oil to vapor, and making the flame smaller but hotter.

In general, combustion temperatures of high speed flame retention burners will be 100°F to 200°F higher than non-flame retention burners, even though the same oil rate, same air fuel ratio and same chamber are used. Some combustion chamber manufacturers recommend either slightly underfiring burners or slightly oversizing chambers when flame retention head burners are used.

You may find some applications where economics recommends the installation of a flame retention burner without the chamber. For example, if a customer has an obsolete rotary wall-flame burner in his home and is unable to afford the replacement of the boiler, a common solution would be to remove the rotary burner, seal the hearth with refractory cement, and install a flame retention burner fired through the door. This type of installation would be far less costly than the more desirable boiler and burner replacement which must eventually follow, but would permit the homeowner an interim improvement.

While we have had much to say about the improved combustion achieved through utilization of a chamber, there are also some other benefits to be considered. Chambers act as sound absorbers, and this feature is highly desirable since some flame retention burners have more intense flame noise than the older burners they are replacing. Another benefit obtained from combustion chambers is the protection of those portions of the dry base boiler or furnace which could not withstand prolonged exposure to intense heat or the rapid heating-cooling of the metal.

When the correct firing rate to match the heat load has been determined, the proper size combustion chamber should be selected to match that firing rate. This will result in maximum efficiency being achieved. The relation between the size of an existing chamber and the determination of the correct firing rate to fit that chamber is important, and should be considered whenever the firing rate is altered.

	Oil Consumption gph	Square Inch Area Combustion Chamber	Square Combustion Chamber Inches	Dia. Round Combustion Chamber Inches	Rectangular Combustion Chamber Inches	HEIGHT FROM NOZZLE TO FLOOR INCHES			
						Conventional Burner Width x Length	Conventional Burner Single Nozzle	Sunflower Flame Burner Single Nozzle	Sunflower Flame Burner Twin Nozzle
80 Sq. In. Per Gal.	.75	60	8 x 8	9	.....	5.0	x	5.0	x
	.85	68	8.5 x 8.5	9	.....	5.0	x	5.0	x
	1.00	80	9 x 9	10-1/8	.....	5.0	x	5.0	x
	1.25	100	10 x 10	11-1/4	.....	5.0	x	5.0	x
	1.35	108	10-1/2 x 10-1/2	11-3/4	.....	5.0	x	5.0	x
	1.50	120	11 x 11	12-3/8	10 x 12	5.0	x	6.0	x
	1.65	132	11-1/2 x 11-1/2	13	10 x 13	5.0	x	6.0	x
	2.00	160	12-5/8 x 12-5/8	14-1/4	6	x	7.0	x	
	2.50	200	14-1/4 x 14-1/4	16	12 x 16-1/2	6.5	x	7.5	x
	3.00	240	15-1/2 x 15-1/2	17-1/2	13 x 18-1/2	7.0	5.0	8.0	6.5
90 Sq. In. Per Gal.	3.50	315	17-3/4 x 17-3/4	20	15 x 21	7.5	6.0	8.5	7.0
	4.00	360	19 x 19	21-1/2	16 x 22-1/2	8.0	6.0	9.0	7.0
	4.50	405	20 x 20		17 x 23-1/2	8.5	6.5	9.5	7.5
	5.00	450	21-1/4 x 21-1/4		18 x 25	9.0	6.5	10.0	8.0
100 Sq. In. Per Gal.	5.50	550	23-1/2 x 23-1/2	Round Combustion Chambers usually not used in these sizes	20 x 27-1/2	9.5	7.0	10.5	8.0
	6.00	600	24-1/2 x 24-1/2		21 x 28-1/2	10.0	7.0	11.0	8.5
	6.50	650	25-1/2 x 25-1/2		22 x 29-1/2	10.5	7.5	11.5	9.0
	7.00	700	26-1/2 x 26-1/2		23 x 30-1/2	11.0	7.5	12.0	9.5
	7.50	750	27-1/4 x 27-1/4		24 x 31	11.5	7.5	12.5	10.0
	8.00	800	28-1/4 x 28-1/4		25 x 32	12.0	8.0	13.0	10.0
	8.50	850	29-1/4 x 29-1/4		25 x 34	12.5	8.5	13.5	10.5
	9.00	900	30 x 30		25 x 36	13.0	8.5	14.0	11.0
	9.50	950	31 x 31		26 x 36-1/2	13.5	9.0	14.5	11.5
	10.00	1000	31-3/4 x 31-3/4		26 x 38-1/2	14.0	9.0	15.0	12.0
	11.00	1100	33-1/4 x 33-1/4		28 x 29-1/2	14.5	9.5	15.5	12.5
	12.00	1200	34-1/2 x 34-1/2		28 x 43	15.0	10.0	16.0	13.0
	13.00	1300	36 x 36		29 x 45	15.5	10.5	16.5	14.0
	14.00	1400	37-1/2 x 37-1/2		31 x 45	16.0	11.0	17.0	14.5
	15.00	1500	38-3/4 x 38-3/4		32 x 47	16.5	11.5	17.5	15.0
	16.00	1600	40 x 40		33 x 48-1/2	17.0	12.0	18.0	15.0
	17.00	1700	41-1/4 x 41-1/4		34 x 50	17.5	12.5	18.5	15.5
	18.00	1800	42-1/2 x 42-1/2		35 x 51-1/2	18.0	13.0	19.0	16.0

FIGURE 22 Combustion Chamber Sizing Data

1 Firing Rate (gph)	2 Length (L)	3 Width (W)	4 Dimension (C)	5 Suggested Height (H)	6 Minimum Dia. Vertical Cyl.
0.50	8	7	4.0	8	8
0.65	8	7	4.5	9	8
0.75	9	8	4.5	9	9
0.85	9	8	4.5	9	9
1.00	10	9	5.0	10	10
1.10	10	9	5.0	10	10
1.25	11	10	5.0	10	11
1.35	12	10	5.0	10	11
1.50	12	11	5.5	11	12
1.65	12	11	5.5	11	13
1.75	14	11	5.5	11	13
2.00	15	12	5.5	11	14
2.25	16	12	6.0	12	15
2.50	17	13	6.0	12	16
2.75	18	14	6.0	12	18

FIGURE 23 Recommended minimum inside dimensions of refractory-type combustion chambers

NOTES:

1. Flame lengths are approximately as shown in column 2. Often, tested boilers or furnaces will operate well with chambers shorter than the lengths shown in column 2.
2. As a general practice any of these dimensions can be exceeded without much effect on combustion.
3. Chambers in the form of horizontal cylinders should be at least as large in diameter as the dimension in column 3. Horizontal stainless steel cylindrical chambers should be 1 to 4 inches larger in diameter than the figures in column 3 and should be used only on wet base boilers with non-retention burners.
4. Wing walls are not recommended. Corbels are not necessary although they might be of benefit to good heat distribution in certain boiler or furnace designs, especially with non-retention burners.

HEAT EXCHANGERS

The next step in the operation of the heating appliance is the transfer of heat energy from the combustion gases to the air in the furnace or to the water in the boiler. This is accomplished in the heat exchanger, which is simply a wall which keeps gases or liquids separated and allows heat energy to flow out of the hot medium and into the cooler medium. Heat is transferred in two ways:

- Hot combustion gases directly contact the heat exchanger surfaces and transfer heat.
- Radiant energy in the combustion chamber heats the heat exchanger surfaces (similar to being heated by the sun). The selection of wall material will depend on its ability to easily pass heat, its cost, and several other factors. This is a whole area of study in itself.

If the heat exchanger were a perfect transferer of heat, all the energy in the combustion products would be transferred to the distribution medium. This would mean no losses of heat! With no heat losses, the stack temperature would be reduced to room temperature. Of course you know this is not the actual case. Losses are caused by

- Temperature differences
- Contact time
- Insulation

The greater the temperature difference between the combustion gases and the temperature of the air or water to be heated, the more heat will be transferred in a given time. There is very little that can be done about the temperature of the air or water to be heated, but if the temperature of the combustion gases can be raised, more heat would be transferred. This is another reason why a high flame temperature from the burner is desirable.

The longer the hot combustion gases are in contact with the walls of the heat exchanger, the more heat will be transferred. The scrubbing of the heat exchanger walls by the combustion gases is essential. This means that small flue passages in the heat exchanger provide better contact than wide open flue passages. With greater heat exchanger surface area per volume of combustion gas, more intimate contact of heat and walls occurs.

Heat Exchanger Designs

Many types of heat exchangers—with varying degrees of efficiency—are in use today. The following are some major types:

Single-Pass, Vertical Tube Exchangers (Boilers)

Hot gases flow through the boiler in only one direction (up). (See Figure 24.)

Multi-Pass, Horizontal Tube Exchanger (Boilers)

Hot gases flow upward—then change direction and flow through horizontal tubes. (See Figure 24.)

Oil Furnace Heat Exchangers

A typical oil furnace heat exchanger actually consists of two exchangers. The hot gases first enter the primary exchanger (inner cylinder), then pass through a connector to the secondary exchanger (outer cylinder). This provides

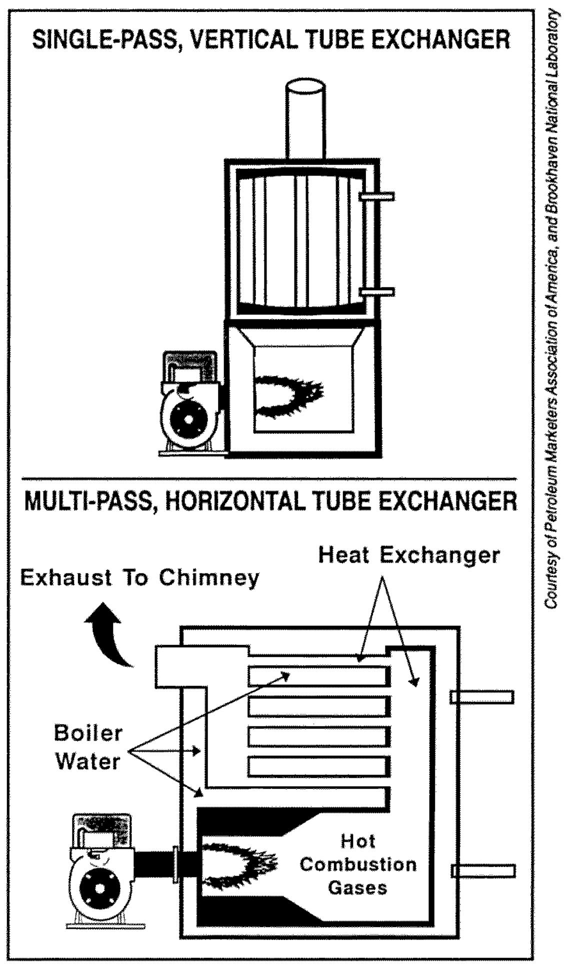


FIGURE 24 Heat exchanger designs

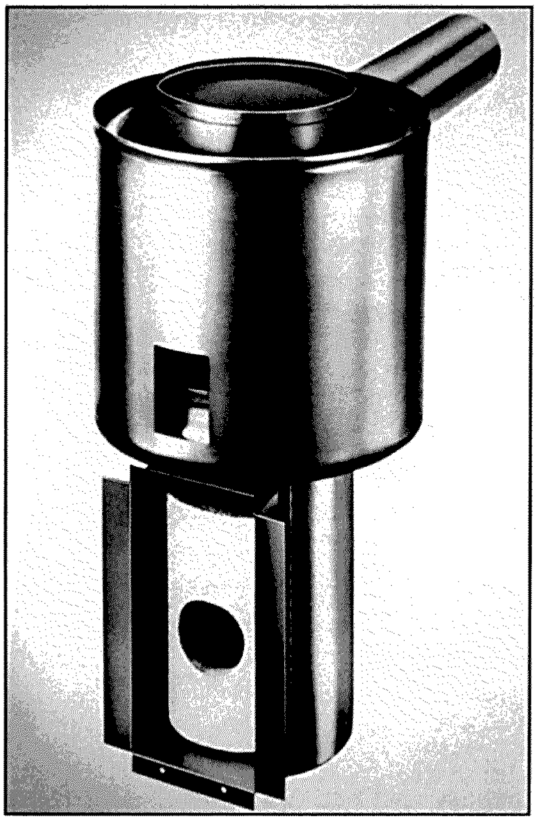


FIGURE 25 Oil furnace heat exchanger

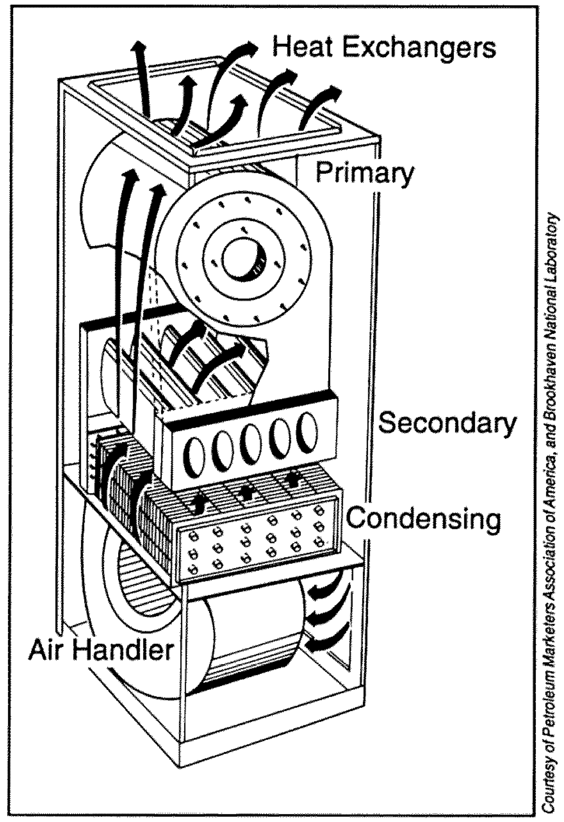


FIGURE 26 Condensing furnace heat exchanger

prolonged gas/exchanger contact, to capture more of the heat. (See Figure 25.)

Condensing Furnace Exchangers

Condensing furnaces have three separate exchangers: the primary exchanger, the secondary exchanger, and a condensing exchanger which cools gases below the dew point—converting some of the water vapor into water. This reduces water vapor heat loss and raises furnace efficiencies. (See Figure 26.)

Longer contact time can also be achieved by reducing the amount of combustion gases produced per gallon of fuel burned or per period of time. A smaller volume takes longer to flow over heat exchanger surfaces. Lowering the excess air can reduce the volume of combustion gases produced per gallon of fuel burned and reducing the nozzle firing rate can reduce the

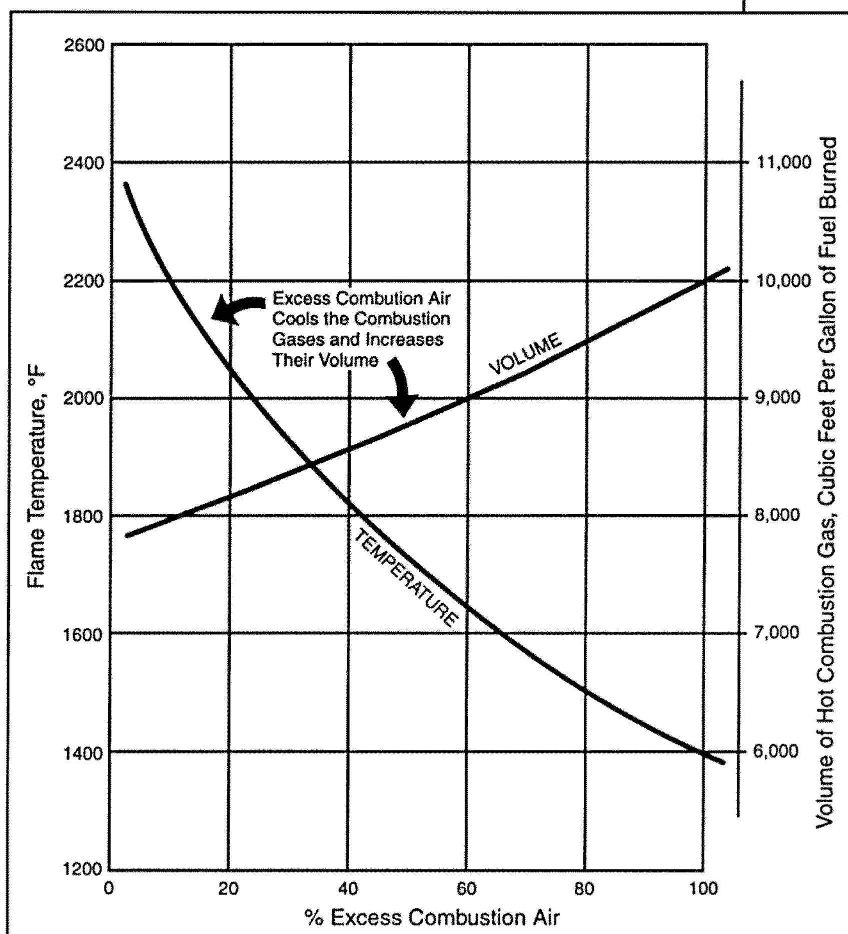


FIGURE 27 Approximate relationship of % excess air with flame temperature and volume of combustion gases

volume of combustion gases produced per unit of time. Figure 27 indicates the relationship between excess air and the flame temperature and volume of combustion gases.

Insulation is any material that stops or slows down the normal rate of heat transfer. Obviously, you do not want to place an insulating material between the combustion gases and the heat exchanger walls. Smoke deposits (often called soot) act as an insulator! Smoke deposits from smoky combustion can collect on the heat exchanger surfaces and reduce the effectiveness of the heat transfer process. Estimates have been made indicating that a 1/8 inch thick coating of soot on heat exchanger walls has the same insulating ability as a 1 inch thick fiberglass sheet.

It should be understood at this point that smoke caused by a poorly operating oil burner is a bad thing, not only because the smoke represents unburned fuel, but because *Smoke Soots up Heat Exchanger Surfaces and Prevents Transfer of Heat to the Heating Load!* A good burner helps the heat exchanger be more efficient by:

- ▼ Providing combustion products at a high temperature. This means a high flame temperature.
- ▼ Providing combustion products which have a low volume per gallon of fuel burned. This means low excess air.
- ▼ Providing clean combustion products which contain a minimum of smoke.

Combustion Air Requirements

Buildings with Adequate Air Infiltration

In many cases, a burner operating in an unconfined space of a conventional frame, brick or stone building will receive adequate air supply from leakage in the building itself. But, if the burner is located in a confined space such as a furnace or boiler room, the enclosure must have one permanent opening toward the top of the enclosure and one near the bottom of the enclosure. Each opening must have a free area of not less than one sq. in. per 1,000 Btu per hour. Another way to measure it is 140 square inches per gallon per hour. Refer to NFPA 31.

Remember to take the total input of all air-using appliances into consideration when figuring the openings. The openings must connect with the inside of the building, which should have adequate infiltration from the outside.

As an example, if an oil burner was firing at 1.25 gph and a water heater was firing at .50 gph, each opening in the enclosure should be 245 sq. in. (1.25 gph + .50 gph = 1.75 gph, 1.75 gph x 140 sq. in. = 245 sq. in.) A 245 sq. in. opening would typically be 10" x 25" or 16" x 16".

Buildings with Less than Adequate Air Infiltration

If the burner is located in a tightly constructed building where there is inadequate outside air infiltration, outside combustion air must be supplied by some other means.

One method to accomplish this is through a permanent opening, or openings, in an exterior wall. The opening, or openings, must have a total free area of not less than one sq. in. per 5,000 Btu per hour, or 28 sq. in. per gallon per hour. All appliances must be taken into consideration. Refer to NFPA 31.

Another method is to supply outside air directly to the oil burner through round, smooth duct work. (See Figure 28.) Some burner manufacturers offer accessories which allow outside combustion air duct work to be coupled to the burner; for example, the Field Controls CAS-2B AirBoot™ (Beckett kit #51747). Consult the burner manufacturer for the recommended kit. The Beckett Model AF II burner allows outside combustion air duct to be connected directly to the burner, without an accessory kit.

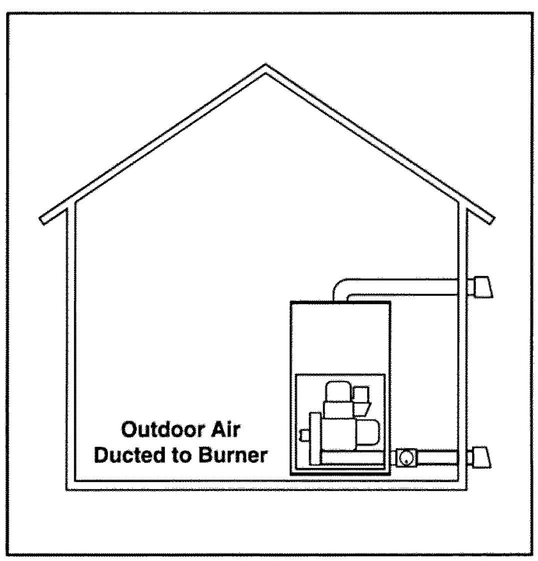
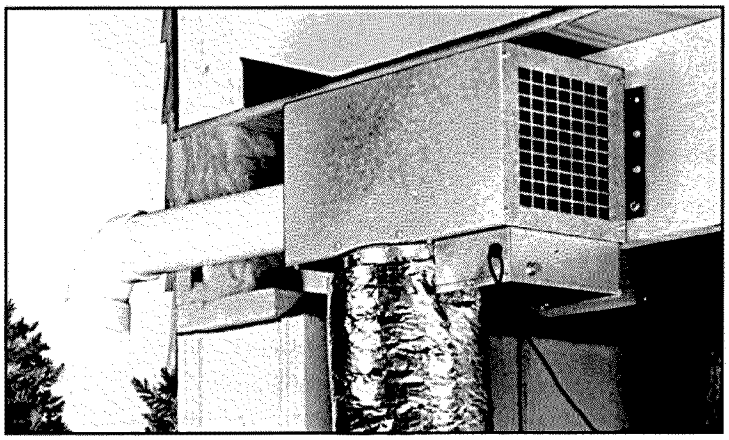
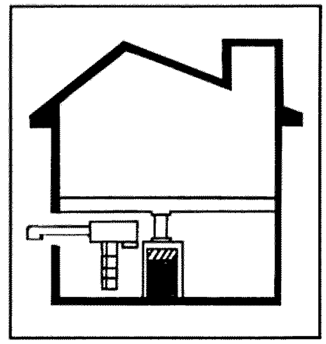
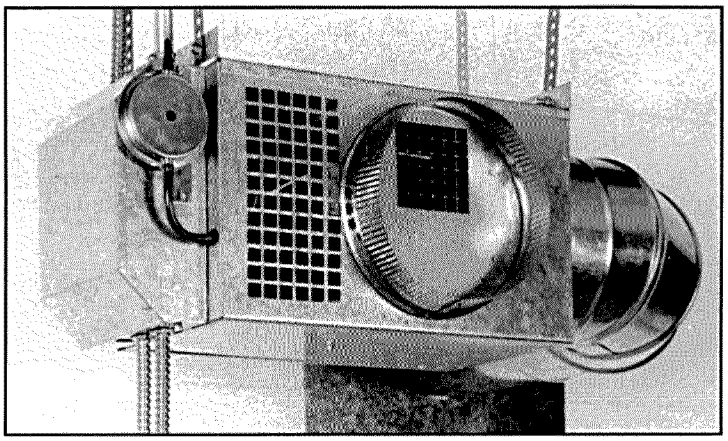


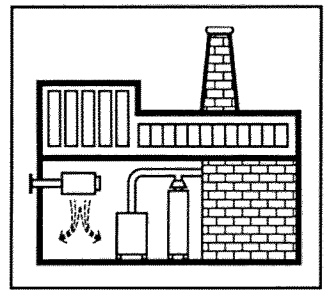
FIGURE 28 Outside air combustion





Residential system





Commercial system

The Tjernlund Combustion Air In-Forcer™ mechanically draws outside air indoors on demand to provide fresh air for safe and efficient operation of fuel burning equipment, without requiring direct connection to the appliances. The commercial system blends cold air with ambient room air before discharging in the home or building.

Courtesy of Tjernlund Products, Inc.

FIGURE 29 Tjernlund Combustion Air In-Forcer™

Draft

In the oilheat industry, the word "draft" is used to describe the slight vacuum, or suction, which exists inside most heating units. The amount of vacuum is called "draft intensity". Draft volume, on the other hand, specifies the volume (cubic feet) of gas that a chimney can handle in a given time. Draft intensity is measured in "Inches of Water Column" (W.C.). Just as a mercury barometer is used to measure atmospheric pressure in inches of mercury, a draft gauge is used to measure draft intensity (which is really pressure) in inches of water.

"Natural" draft is actually thermal draft, and occurs when gases that are heated expand so that a given volume of hot gas will weigh less than an equal volume of the same gas at a cool temperature. Since hot combustion gases weigh less per volume than room air or outdoor air, they tend to rise. The rising of these gases is contained and increased by enclosing the gases in a tall chimney. The vacuum or suction that you call "draft" is then created by this column of hot gases.

"Currential" draft occurs when high winds or air currents across the top of a chimney create a suction in the stack and draw gases up. "Induced draft" blowers can be used in the stack to supplement natural draft where necessary.

There are four factors which control how much draft a chimney can make:

- The height of the chimney—the higher the chimney, the greater the draft.

Condition	Outside Temperature, ° F	Chimney Temperature, ° F	Draft, Inches W.C.
Winter start up	20	110	-.050
Winter operation	20	400	-.136
Fall start up	60	80	-.011
Fall operation	60	400	-.112

FIGURE 30 Example of draft changes in a chimney

▼ Chimneys may not draft correctly due to problems such as the following:

A. Chimney is too big (See Figure 32, page 24).
B. Breaks in the chimney liner.
C. An improperly constructed or damaged flue system venting multiple appliances to a common chimney (See page 24).

For a list of common chimney problems and their solutions, see Figure 40, page 27.

▼ The weight per unit volume of the hot combustion products—the hotter the gases, the greater the draft.

▼ The weight per unit volume of the air outside the home—the colder the outside air, the greater the draft.

Since the outside temperature and flue gas temperature can change, the draft will not be constant. When the heating unit starts up, the chimney will be filled with cool gases. After the heating unit has operated for a while, the gases and the chimney surface will be warmer, and the draft will increase.

Also, when the outside air temperature drops, the draft will increase. To indicate the effect of these changes, the information in Figure 30 was determined for a 20 ft.-high chimney. You can see that the draft produced by this chimney could be expected to vary from -.011 to -.136 inches W.C. The high draft is over 12 times more than the low draft. This large variation cannot be tolerated for the following reasons:

▼ Too little draft can reduce the combustion air delivery of the burner, which can result in an increase in the production of smoke.

▼ Excessively high draft increases the air delivery of the burner fan, and can increase air leakage into the heating plant. This reduces CO_2 and raises stack temperature, resulting in reduced operating efficiency.

▼ High draft during burner off periods increases the standby heat losses up the chimney.

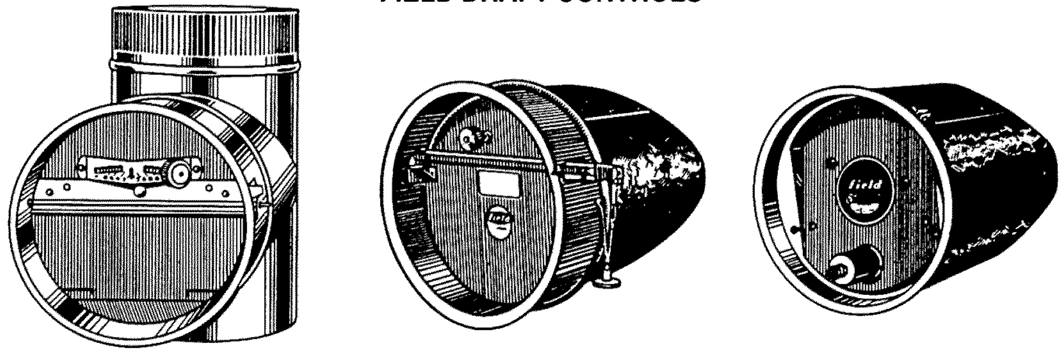
Because draft will not exist in any great amount during a cold startup, the burner should not depend on the additional combustion air caused by draft. The best way to be sure the burner does not depend on this air is to set the burner for smoke-free combustion with a low overfire draft (-.01 to -.02 inches W.C.). If a burner cannot produce good smoke-free combustion under low draft conditions, there is something wrong with the burner or combustion chamber, and it should be corrected. Using a high draft setting to obtain enough combustion air for clean burning is like depending on a crutch which is not always there. A burner which gives clean combustion only with high draft will cause smoke and soot any time the chimney is not producing high draft.

In a previous section, we described the effect of air leaks, and perhaps you now realize that air leaks occur because of draft inside the heating unit. It is easy to see that less draft will cause less air leakage and produce a higher efficiency. Therefore, sealing air leaks can aid in improving heating appliance efficiency.

Draft Regulators

From the previous information, you should realize that a constant draft is needed, and this draft should be no more than that which will just prevent escape of combustion products into the home. Since natural draft as obtained from a chimney will vary, it is necessary to have some sort of regulation. The normal draft regulator or "barometric damper" for home heating plants is the so called by-pass or air bleed type as shown in Figure 31. This type of regulator is simply a swinging door which is counterweighted so that any time the draft in the flue is higher than the regulator setting, the door is pulled in. When the damper is pulled open, room air flows into the flue, which helps regulate the draft overfire, so that it remains at the recommended level. If the draft is less than the regulator setting, the counterweight keeps the swinging door closed,

FIELD DRAFT CONTROLS



TYPE RC	TYPE M	TYPE M + MG2
Oil or Coal Residential and Commercial Calibrated to allow easy adjustment to furnace or boiler manufacturer's specifications. Designed for settings from .02" to .08". It is so sensitive that instrumentation should be used for adjustments.	**Oil or Coal Residential** Designed for settings from .01" to .1". Recommended for oil or coal fired residential heating applications. Features an infinitely variable screw adjustment, permitting an extremely fine instrument setting.	**Oil, Gas, Oil/Gas, or Solid Fuels Large Residential/Commercial** Compact, rugged, heavy duty control for any installation with 10" or larger diameter flue pipe. Adapts to any fuel. Requires only the simplest, on-the-job adjustments depending on fuel to be utilized.

FIGURE 31 Field draft controls

Illustrations courtesy of The Field Controls Company

and only flue gas flows into the chimney. This gives the highest draft possible under those conditions.

It is important to understand that the function of a draft regulator is to maintain a stable or fixed draft through the heating equipment, within the limits of available draft from the chimney, by means of an adjustable barometric damper.

Draft can be measured by using a draft gauge. It cannot be estimated or "eye balled." The draft should be checked at two different locations in the heating appliance: (1) over the fire, which indicates firebox draft condition, and (2) in the breech connection.

1. Draft Over the Fire

With appliances designed for negative draft operation, the draft over the fire is the most important and should be measured first.

The overfire draft must be constant so that the burner air delivery will not change. The overfire draft must be at the lowest level which will just prevent escape of combustion products into the home under all operating conditions. Normally, an overfire draft of -.01" to -.02" W.C. will be high enough to prevent leakage of combustion products and still not cause large air leaks or standby losses. If the overfire draft is higher than -.02" W.C., the draft regulator weight should be adjusted to allow the regulator door to open more. If the regulator door is already wide open, a second regulator should be installed in the stack pipe and adjusted. If the draft is below -.01" W.C., the draft regulator weight should be adjusted to just close the regulator door. Do not move the weight more than necessary to close the door. Never wire or weight a regulator so it can never open. There may be times when the outside air is colder, or the chimney hotter, or high wind is affecting draft, and the draft needs regulation. The overfire draft is also affected by soot buildup on heat exchanger surfaces. As the soot builds up, the heat exchange passages are reduced, and a greater resistance to the flow of gases is created. This causes the overfire draft to drop. As the overfire draft drops, the burner air delivery is reduced and the flame becomes even more smoky. It is a vicious cycle which gets increasingly worse. **Note: Some systems are designed for positive pressure overfire. Consult the manufacturer's specifications for draft and venting requirements.**

2. Breech or Stack Draft

After the overfire draft is set, the draft at the breech connection should be measured. The breech draft will normally be slightly more than the overfire draft because the flow of gases is restricted (slowed down) in the heat exchanger. This restriction, or lack of it, is a clue to the design and condition of the heat exchanger. A clean heat exchanger of good design will cause the breech draft to be in the range of -.03" to -.06" W.C. when the overfire draft is -.01" to -.02" W.C.

Flue and Chimney Exhaust

1. Flue Pipe

The flue pipe should be the same size as the breech connection on the heating plant. For modern oilheat units, this should cause no problem in sizing the flue pipe. The sizes generally are 4" to 6" under 1 gph, 7" to 1.50 gph, and 8" for 1.50 to 2.00 gph. The flue pipe should be as short as possible and installed so that it has a continuous rise from the heating plant to the chimney. Elbows should be minimized, and the pipe should be joined with metal screws and supported with straps where needed.

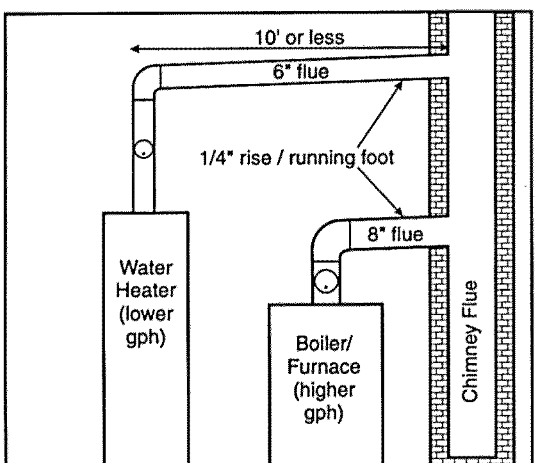
The draft regulator should be installed in the flue pipe before it contacts the chimney and after the stack primary control, if one is used. Make sure the draft regulator diameter is at least as large as the flue pipe diameter.

2. Chimney

Figure 32 shows recommended size and height for chimneys based on Btu input. Consult manufacturer's specs and NFPA 31. See Figure 40, page 27 for chimney troubleshooting tips.

Gross Btu Input	Rectangular Dim.	Round Dim.	Mimimum Height
144,000	8 1/2" x 8 1/2"	8"	20 feet
235,000	8 1/2" x 13"	10"	30 feet
374,000	13" x 13"	12"	35 feet
516,000	13" x 18"	14"	40 feet

FIGURE 32 Common chimney sizes vs. Btu input



The larger appliance firing rate enters the chimney below the smaller appliance firing rate.

FIGURE 33 Multiple appliances vented separately

Venting Multiple Appliances into a Common Chimney or Flue

Connecting more than one oilheat appliance to a common chimney can be easy and beneficial once you understand the basic guidelines:

1. Always follow the appliance manufacturer's recommendations on venting the particular appliance, and obey local codes and requirements.
2. The chimney must be of adequate size to properly vent the gases created by the total Btu input of all appliances **combined.**
3. The flue piping, whether for single or multiple appliances, should be as short a run as possible, and rise 1/4" per running foot up and toward the chimney. Whenever possible, do not exceed 10 feet of flue pipe length.
4. Avoid using more than two 90-degree turns in the piping. Additional 90-degree turns excessively restrict the exhaust system at burner start-up.
5. The piping, when inserted into the chimney entrance, should not extend beyond the inside surface of the chimney liner. The area around the flue piping should be sealed where it enters the chimney.
6. When venting two appliances separately into a common chimney, always install the smaller flue pipe (appliance with lowest gph input) at a higher point into the chimney than the larger flue pipe for the appliance with the largest gph input (Figure 33).

Basic Requirements

To determine the main flue size or manifold required to vent more than one appliance into the chimney, you combine the flue sizes of the individual appliances. Example: If you combine a furnace or boiler (8" flue) with a water heater (6" flue), refer to Figure 34 for sq. in. area of each individual flue size, and total the two areas.

6" flue = 28.27 sq. in.
8" flue = 50.27 sq. in.
TOTAL = 78.54 sq. in.

Refer to Figure 34 to determine the pipe diameter the total area corresponds with. In our example, 78.54 sq. in. calls for a 10" diameter pipe. The main flue or manifold required to properly vent these two appliances is a 10" diameter pipe.

Whether you are combining two appliances or more, you will follow the same method of totaling individual flue sizes to determine your main flue or manifold.

Common Systems

Figures 35 and 36 show the most common types of multiple appliance venting systems—the tapered manifold system and the constant sized manifold system.

When determining the sizing for the tapered manifold system (Figure 35), size each section according to the **combined** input of the appliances that vent through that section. The section furthest from the chimney vents only one appliance. The middle section vents two appliances. The section closest to the chimney vents three appliances.

Damper Locations

Finally, you should also be familiar with proper barometric damper locations. Figure 37 provides this information.

Alternative Venting Systems

In some cases, existing chimneys may be inadequate—or there may be no chimney at all (e.g., electric-to-oil conversions). Constructing a new chimney may be difficult. In these cases, alternative venting methods may be called for.

Power Chimney Venting

Sometimes an otherwise inadequate chimney can do the job with the help of a power draft inducer. (See Figure 38.)

This consists of a vent fan placed in the flue pipe, or at the top of the chimney, to create an "artificial" draft. If the fan is located in the flue pipe, the portion of the pipe between the fan and the chimney is under a positive pressure—which requires that portion of the pipe to be tightly sealed to prevent escape of flue combustion gases into the home.

A metal chimney liner and condensate drain may be required to prevent damage to the chimney.

Side-Wall Venting

If no chimney exists—or the existing chimney cannot be used, even with a liner—the only solution may be to vent through the wall (Figure 41).

Side-wall venting systems eliminate the need for a chimney. One way to side-wall vent, power venting, utilizes an induced draft fan, which provides the draft required to exhaust the combustion products through a side wall. This system normally requires an air-flow proving switch to confirm that the required draft is present before combustion begins. Another way is direct venting, without an induced draft fan. With both types of systems, discharge fittings are designed to pass through combustible walls and minimize the effects of wind on the venting of the combustion products. Burner, appliance, vent system and controls must be considered as a system, not just independent parts pieced together.

Flue Diameter	Equiv. Sq. In. Area	Flue Diameter	Equiv. Sq. In. Area
3"	7.06	11"	95.03
4"	12.56	12"	113.10
5"	19.63	13"	132.73
6"	28.27	14"	153.94
7"	38.48	15"	176.71
8"	50.27	16"	201.06
9"	63.62	17"	226.98
10"	78.54	18"	254.47

FIGURE 34 Square inch area of flue collars

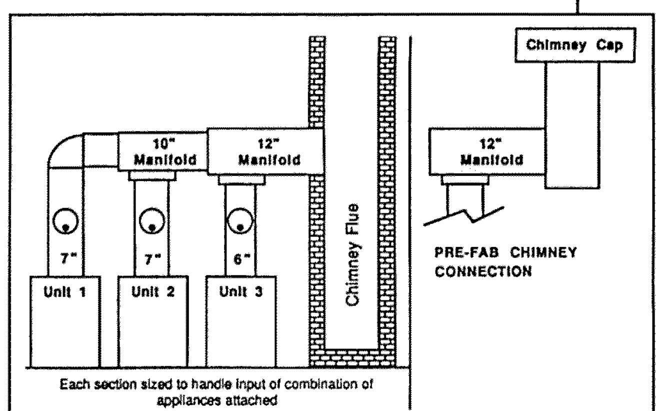


FIGURE 35 Tapered manifold vent system

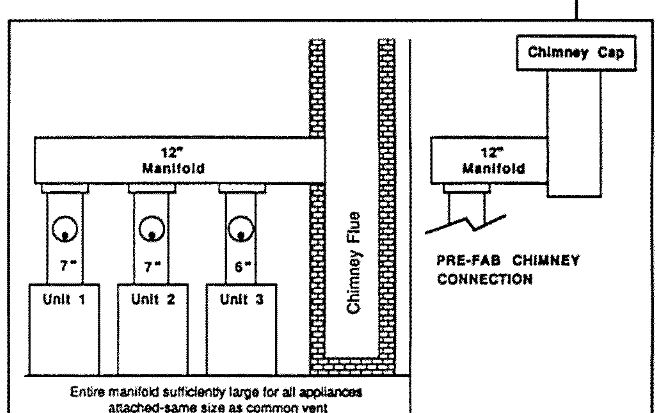


FIGURE 36 Constant sized manifold vent system

Benefits

The first benefit of a side-wall venting system is that it eliminates the need for a chimney. This can result in potential savings in new home construction. There is also the opportunity to retrofit chimneyless (i.e., electrically heated) homes.

The second benefit is the potential for increased efficiency. Condensation of acids in the flue gases occurs when the flue gas temperature drops to about 200°F. The minimum recommended gross stack temperature at the breeching is usually 500°F-550°F with conventional appliances, so that as the flue gases are cooled in the chimney, the flue gas temperature does not fall below the acid dew point.

In the side-wall vented system, flue gases are not cooled in a chimney. Heat that is typically lost in the chimney can be extracted in the heating appliance, dropping the gross stack temperature to 300°F-350°F. This raises the steady state efficiency. (See Figure 39.)

Acid will not condense in the short side-wall duct; water vapor won't either. Keep in mind that water vapor in the flue gas will condense if flue gas temperatures drop below about 120°F. Make sure, however, that you are operating at the 300°F-350°F gross stack temperature with power side-wall venting only when the manufacturer has designed or approved his furnace or boiler for this arrangement. However, the advantage of chimneyless construction and the reduction of exhaust gases to a safe 200°F-300°F range without a special high efficiency appliance can often be accomplished by dilution of the flue gases via a barometric damper upstream of the induced draft fan.

Concerns

Safety concerns are of primary importance with any heating system and should be with side-wall vented applications. As previously stated, air flow proving switches are typically used

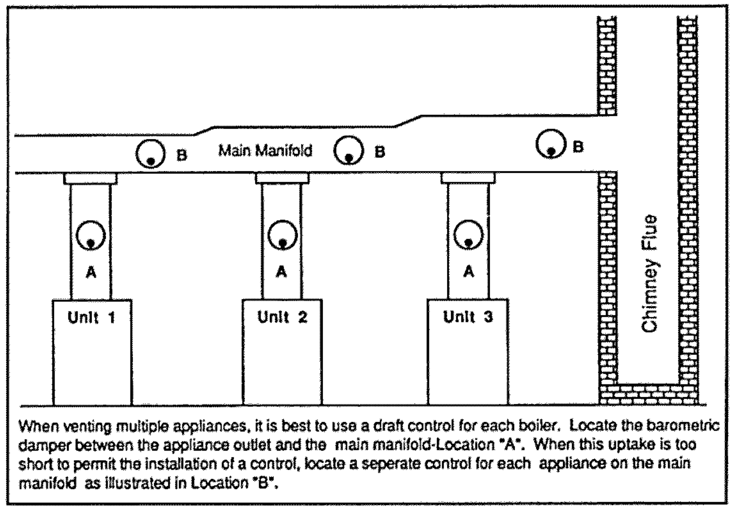


FIGURE 37 Barometric damper locations when venting multiple appliances

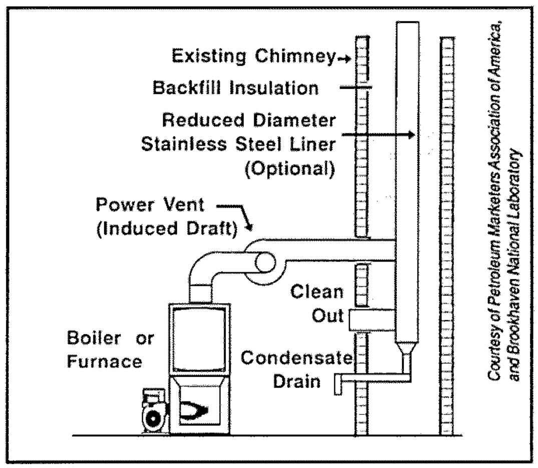


FIGURE 38 Power chimney venting system

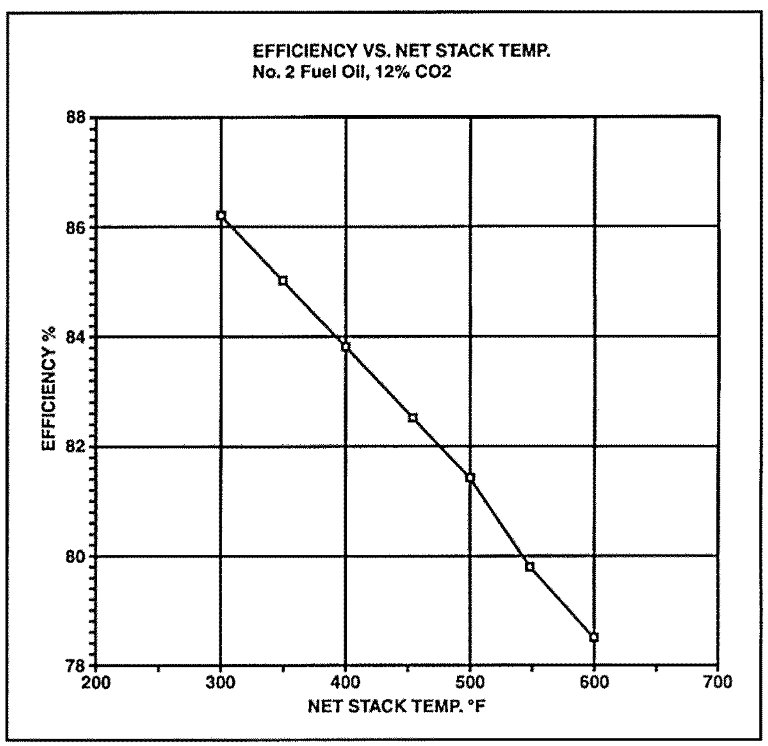


FIGURE 39 Efficiency vs. net stack temperature

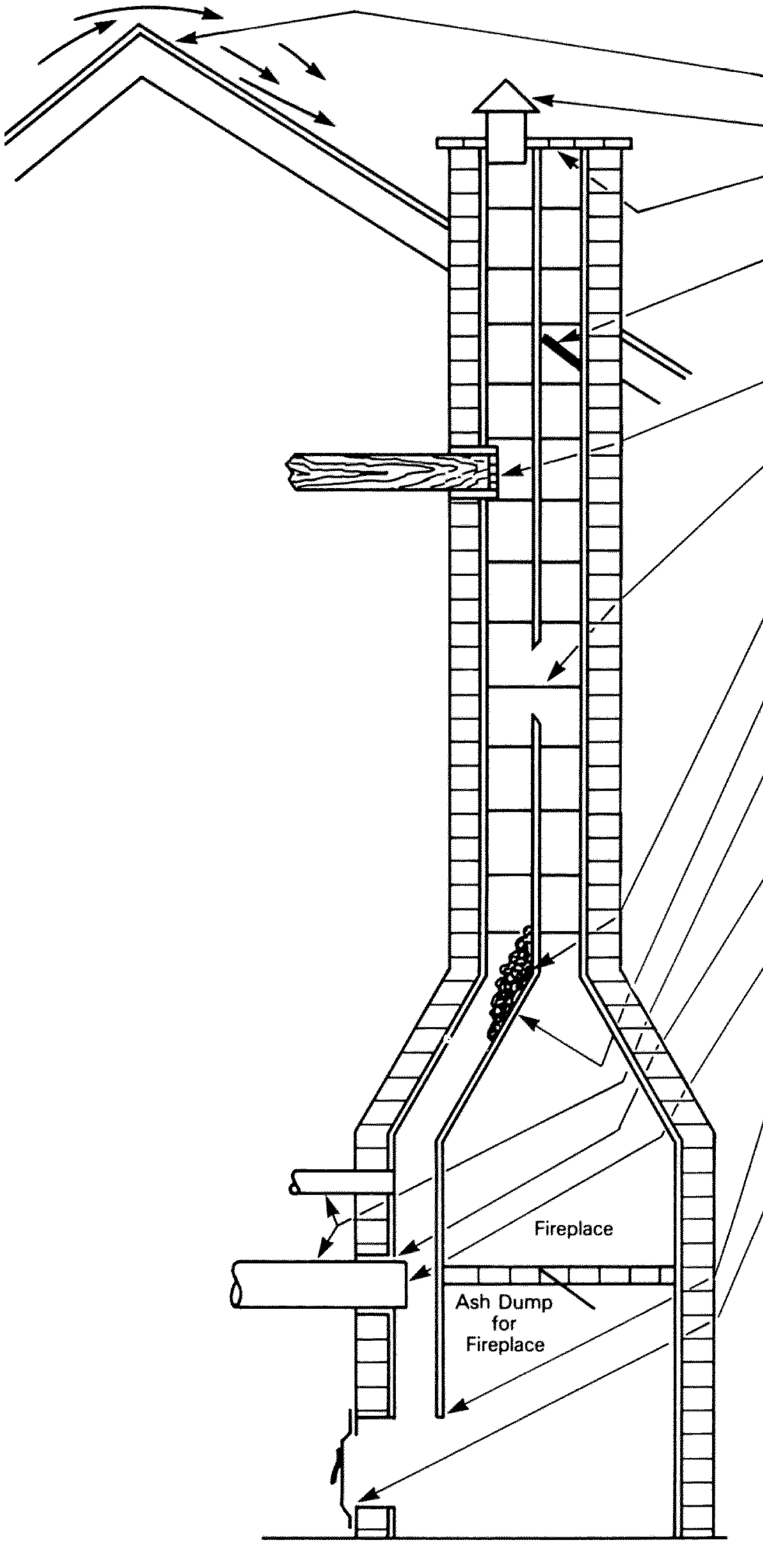


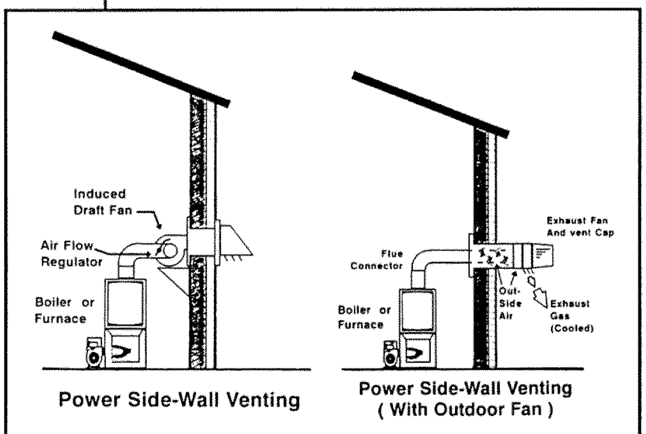
FIGURE 40 Common chimney troubles and their corrections

Troubles	Examination	Corrections
Top of chimney lower than surrounding objects.	Observation.	Extend chimney above all objects within 30 feet.
Chimney cap or ventilator.	Observation.	Remove.
Coping restricts opening.	Observation.	Make opening as large as inside of chimney.
Obstruction in chimney.	Can be found by light and mirror reflecting conditions in chimney.	Use weight to break and dislodge.
Joist projecting into chimney.	Lowering a light on extension cord.	Must be handled by a competent brick contractor.
Break in chimney lining.	Smoke test—build smudge fire blocking off other opening, watching for smoke to escape.	Must be handled by a competent brick contractor.
Collection of soot at narrow space in flue opening.	Lower light on extension cord.	Clean out with weighted brush or bag of loose gravel on end of line.
Offset.	Lower light on extension.	Change to straight or to long offset.
Two or more openings into same chimney.	Found by inspection from basement.	The least important opening must be closed, using some other chimney flue.
Loose-seated pipe in flue opening.	Smoke test.	Leaks should be eliminated by cementing all pipe openings.
Smoke pipe extends into chimney.	Measurement of pipe from within or observation of pipe by means of a lowered light.	Length of pipe must be reduced to allow end of pipe to be flush with inside of tile.
Failure to extend the length of flue partition to the floor.	By inspection or smoke test.	Extend partition to floor level.
Loose-fitted clean-out door.	Smoke test.	Close all leaks with cement.

to ensure proper draft from the induced draft fan. Temperature sensing switches can be utilized as backup protection for a blocked vent condition. Side-wall fittings must be designed for walls constructed of combustible materials. The side-wall presence of flue products at 200°F-300°F must be considered.

Reliable operation is a second concern. Wind direction and velocity can have a great impact on a side-wall exhaust vent and must be considered both in system design and in installation. A closed air system with outside intake on the same wall as the exhaust vent will tend to reduce this problem. Clean burner operation is critical to avoid fume and staining problems. Corrosion due to stack temperatures being too low (and resultant condensing) must be prevented.

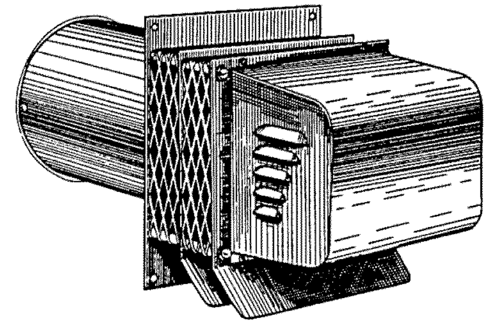
There are also local building code requirements that restrict the installation of side-wall vent systems. Industry progress is being made in this area, but check local/state building code requirements before planning a side-wall vented installation.



Courtesy of Petroleum Marketers Association of America, and Brookhaven National Laboratory

FIGURE 41 Power side-wall venting

Field Power Venter Model SWG



Combines fan, motor, and vent hood into one complete, compact unit that's easily installed outside the building, so noise and vibration are virtually eliminated from the occupied areas. Venting with negative pressure, the SWG prevents possible flue gas leakage from the venting system.

Illustration courtesy of The Field Controls Company.

FIGURE 42 Field power venter

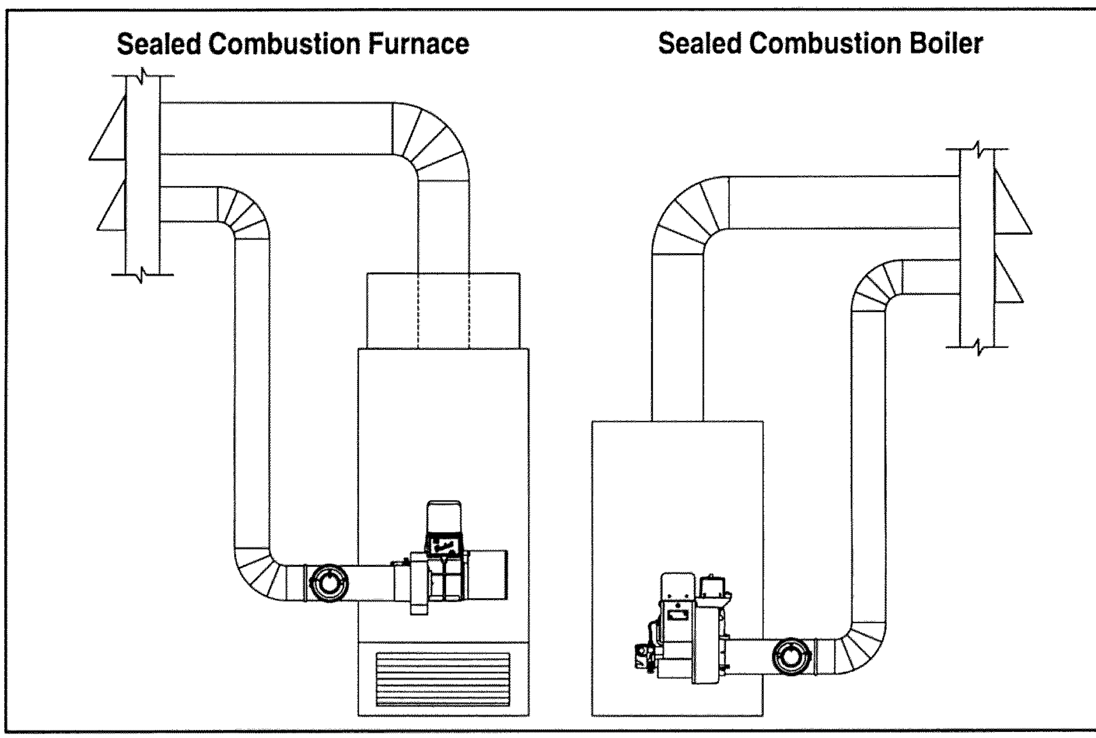


FIGURE 43 Direct side-wall venting and outside combustion air which features the Beckett AFII or AFG.

Power Venting

In this type of system, a power draft inducer fan is used as with power chimney venting. However, the gases are vented through the wall rather than up a chimney. If the fan is inside the house, any portion of the system between the fan and the outside vent is under a positive pressure and must be carefully sealed to prevent gases from leaking into the house. Also required, is a safety control to shut off the burner if the power venting system malfunctions.

Direct Venting

Modern high-speed burners sometimes provide enough positive pressure to exhaust gases through the wall (or up a chimney) without the use of a power fan. Since positive pressure is present throughout such a system, careful sealing is required to prevent leakage of gases into the house.

Sealed Combustion

When side-wall venting is combined with a sealed (or balanced) outside combustion air supply, the result is sealed combustion. This is highly recommended with side-wall venting. (See Figure 43.)

Outdoor Units

When the appliance itself is outside the home, no chimney or venting system is required, and adequate combustion air is assured. (See Figure 44.)

All venting (including alternative venting systems) should be per the appliance manufacturer's recommendations, and in compliance with all jurisdictional codes.

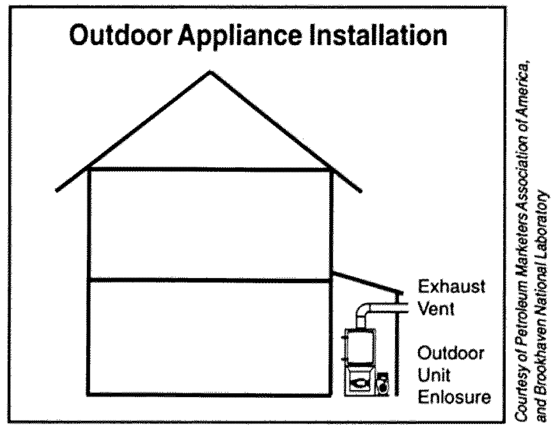


FIGURE 44 Outdoor appliance installation

Chapter 3

EFFICIENCY-DEFINITION OF VARIOUS TYPES OF EFFICIENCY

When the word efficiency is used, do you know what is meant? By definition, efficiency is a measure of how well something is produced as compared with what went into producing it. In terms of heating systems, efficiency is a measure of how well energy is transferred from one form or place to another form or place. In general, the energy output of a machine or device is compared with the energy input:

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$$

For residential heating appliances, the measurement of efficiency can be confusing, as there are several different efficiencies that can be discussed. Because of this, it is important to distinguish between the different efficiencies and understand the specific meaning of each.

COMBUSTION EFFICIENCY

Combustion efficiency characterizes the effectiveness of the combustion process in converting the chemical energy of the fuel to heat. You may be surprised to learn that the combustion efficiency of oil burners is quite high—usually 98 to 100 percent. This means that almost all of the chemical energy available in the fuel is changed into heat energy of the combustion products. Even in the case of a smoky flame, the amount of energy lost because of unburned carbon is very low. In fact, even with a smoke number of 9, the amount of energy lost is found to be about 0.1 percent.

At this point, you may be wondering why so much attention is given to the proper operation of the burner if it does an almost perfect job of getting the heat energy out of the fuel. Also, you may be thinking that if there is such a small amount of energy lost due to smoke generation, why worry about it. If these thoughts have occurred to you, it is recommended that you turn back to page 20 and reread the paragraph with the underlined words. This should explain the concern over smoke generation.

$$\text{Combustion efficiency} = \frac{\text{heat energy in the combustion gases}}{\text{chemical energy in the fuel}}$$

STEADY-STATE EFFICIENCY

Steady-state efficiency is the effectiveness of the heating unit in extracting heat from the chemical energy in the fuel and transferring it to the medium (air, water, or steam) used for space heat when the entire system is operating in a steady-state mode. This is the efficiency you are most familiar with—one that can be easily approximated by measuring the net stack temperature and the CO_2 or O_2 percent of the flue gases.

Measuring this efficiency requires that the heating appliance has been operating long enough so that steady-state (effectively unchanging) temperatures have been established throughout the system. In other words, the system must be thoroughly warmed-up. As you are aware, steady-state efficiencies are typically between 65 and 85 percent.

$$\text{Steady-State Efficiency} = \frac{\text{steady-state heat removal rate to transfer medium}}{\text{steady-state chemical energy input rate}}$$

AFUE RATINGS

In order to assist the consumer in purchasing heating appliances that conserve energy, the Department of Energy (D.O.E.) has established test procedures and Annual Fuel Utilization Efficiency ratings (AFUE). This information is presented on uniform rating labels for similar appliances, and the annual operating costs are estimated for comparison purposes.

The efficiency ratings of appliances are beneficial for the informed homeowner, and industry also uses them as a valuable tool. Many times the contractor is asked for his recommendation of the most energy efficient heating unit. He appreciates that there is more involved than mere numbers.

These ratings might be compared to the mileage ratings for automobiles. The "steady" highway driving MPG rating is always higher than the city or "average" driving MPG rating.

In both instance the AFUE and MPG ratings were obtained under very carefully controlled laboratory conditions. There are important reasons why the actual fuel consumption experienced in the field will be slightly higher.

There are many variables that occur throughout the heating season that can impact on the overall system efficiency. Some are: changes in draft, fuel, combustion air restriction (due to lint, dust, pet hair, etc.), temperature reduction in oil and air, inadequate fresh air supply, and other subtle environmental factors.

Experienced contractors view the AFUE ratings as a valuable tool for comparison purposes, **but they do not attempt to set the burner to operate at the CO_2 and smoke levels that were used in the D.O.E. controlled laboratory procedures.** Real world conditions require that consideration be given to the variable environmental effects. Therefore, effective safeguards are factored into the final burner adjustments, discussed on page 46 of Chapter 5.

There is a very small premium to pay for the added margin of air that will help keep the heat exchanger clean throughout the full heating season. How much would have been lost in real dollars if the appliance had gradually become sooted, losing efficiency until it required premature servicing?

Obviously, the efficiency ratings have an important role to play. However, there must be a balance between maximizing efficiency with little or no margin for variables, and practical field set-ups that have a reasonable amount of reserve air built in. These methods are field-proven and can help reduce nuisance, efficiency robbing soot-ups.

Chapter 4

STEADY-STATE EFFICIENCY MEASUREMENTS

This chapter covers the proper use of instruments to measure the steady state efficiency of residential oil-fired heating appliances. Since you should now understand what factors influence high or low efficiency, effective use of these instruments can aid you in improving the steady-state efficiency of oilheat equipment. Perhaps you are accustomed to adjusting burners by judging the flame by eye or following a series of "rules of thumb." Certainly, using these procedures can work some of the time! But, would you stake your reputation on it? What you are doing is similar to a doctor diagnosing an illness without the use of a stethoscope or an auto mechanic tuning a car without the proper diagnostic equipment. It is risky business!! Do yourself a favor, make your job easier, and assure yourself of leaving a heating system in good operating condition by properly using the instruments discussed in this chapter.

Stack Loss Theory

In Chapter 3, you learned that the steady-state efficiency is a measure of the effectiveness of the heating unit in extracting heat from the chemical energy in the fuel and transferring it to the distribution medium. Therefore, the most straightforward approach to measuring the steady-state efficiency would be to measure the heat transferred to the distribution medium and the chemical energy in the fuel, and then calculating the efficiency from these values. Unfortunately, in a residential oilheat system, it would be very difficult to measure the actual amounts of heat energy in the fuel and the heat transferred to the air, water, or steam. As an alternative approach, a simpler method, the "stack loss" method of efficiency measurement, is used.

The stack loss method is based on three assumptions:

1. All the chemical energy in the fuel is converted to heat energy. As was pointed out on page 32, this is essentially accurate for all burners as the combustion efficiency is normally 98 to 100 percent.
2. The chemical energy per unit of fuel is the same—140,000 Btu/gal. This means that from one shipment of fuel to another, variations in chemical composition that affect the chemical energy per unit of fuel oil are ignored. This can lead to small errors in the stack loss method.
3. The heat energy goes to one of two places:

▼ The heating load or

▼ Up the chimney

These assumptions are shown in Figure 45. From this figure, it can be seen that by measuring the heat loss up the flue and assuming an average value for the heat energy in the oil, you do not have to measure the heat transferred to the distribution medium. Fortunately, measuring the stack losses is not complicated. However, this assumes that there are no jacket losses. In other words, no heat is transferred through the walls of the heating plant. From your experience, you should know this is inaccurate and that in older, largely un-insulated units, the jacket losses can be significant. As a result, the stack loss method tends to give higher efficiencies than those which really exist.

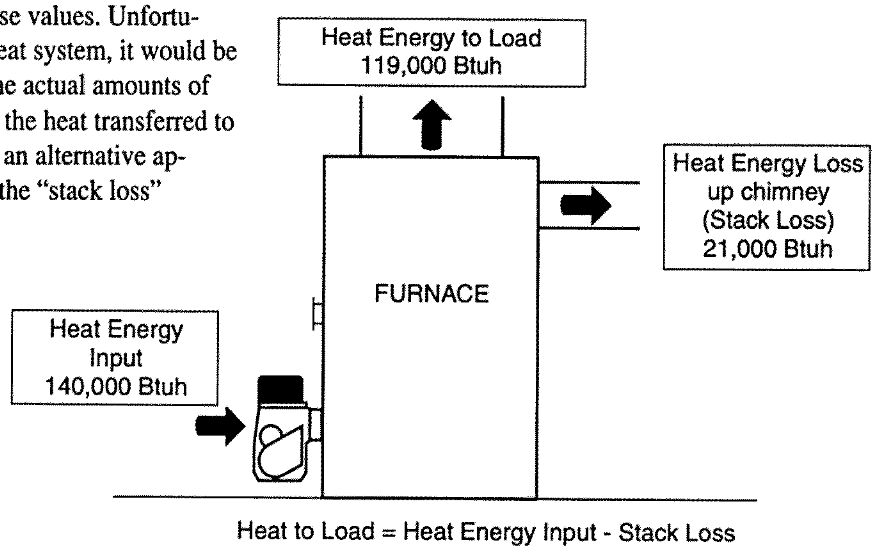


FIGURE 45 Distribution of heat as determined by the stack loss method

To measure the heat lost through the flue and chimney you must:

- ▼ Determine the amount of the combustion gases per gallon of fuel oil burned.
- ▼ Determine how much the combustion gas temperature was changed (the difference between the temperature at which the fuel and air entered the burner and the temperature of the combustion gases).

You should measure the amount and temperature of the combustion gases at an identical point in the flue pipe.

In Chapter 1, you learned how changes in volume of excess combustion air affect the heat exchanger efficiency. As you might imagine, these changes in volume of excess air per unit of fuel burned also affect the weight of the combustion gases formed from each gallon of fuel burned. Since knowledge of the percent excess air enables you to determine the weight of the combustion gases per gallon of fuel burned, and since the percent excess air can be determined by measuring the percent carbon dioxide or oxygen, you can determine the weight of combustion gases per gallon of fuel burned by knowing the percent carbon dioxide or oxygen.

Let's look at an example to make this more clear. In Figure 3, page 3, we showed that theoretically for every pound of fuel oil, exactly 14.36 pounds of air are required to completely burn the fuel. This was assuming that there was perfect mixing and that all the carbon and hydrogen in the fuel combined with the oxygen in the air to form carbon dioxide and water vapor. The figure also showed that exactly 3.16 pounds of carbon dioxide or 15.3% of the products were formed if this "perfect" situation occurred. On page 5, Figure 4, we showed a typical case for which excess air was needed to ensure that most of the carbon and hydrogen in the fuel would combine with oxygen to form the products. From Figure 4, you can see that the same weight (3.16 pounds) of carbon dioxide is formed, but that this represents only 10.2% by volume of the combustion products. So, by measuring the percent carbon dioxide, you not only can determine how much excess air exists, but also you can determine the weight of combustion products flowing up the flue pipe.

Oxygen measurements can also be used to determine the amount of excess air and, in turn, the amount of CO_2 in the flue gas. There is a direct and fixed relationship between the amount of CO_2 and O_2 in the flue gas as shown in Figure 46. This figure indicates that as the percent CO_2 increases, the percent O_2 decreases in the flue gas. When testing for efficiency, we try to obtain a low O_2 reading or high CO_2 reading (in both cases, low excess air).

Now we have one-half of what is needed to determine the losses up the stack. The second half is much easier. This is the temperature difference between the fuel and air going into the burner and the flue gases coming out of the heat exchanger. The fuel and air will normally enter the burner at about the temperature of the room in which the furnace or boiler is located. The temperature of the gases in the flue will vary from unit to unit but can be measured with a thermometer. The difference between the flue gas temperature and the furnace/boiler room temperature is called the NET STACK TEMPERATURE.

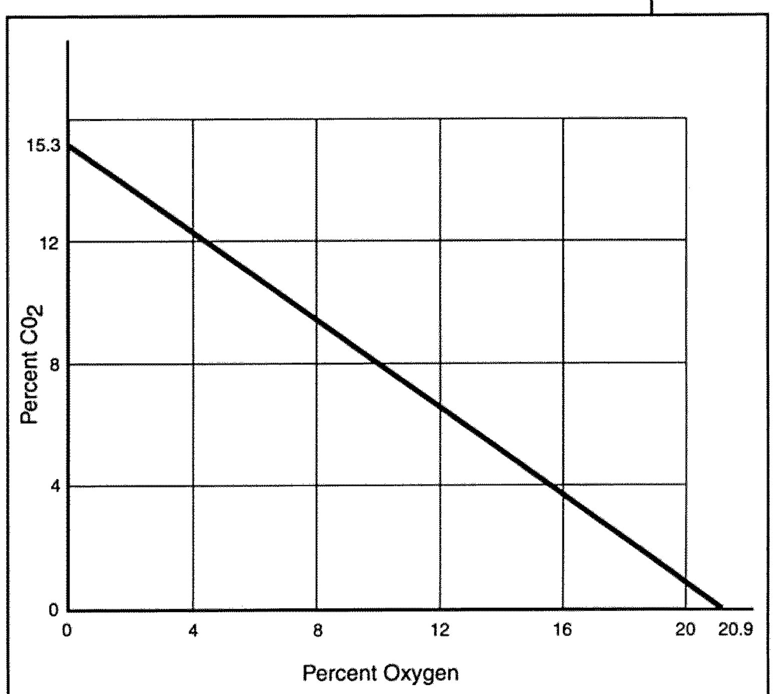


FIGURE 46 Theoretical combustion relationship between CO_2 and O_2 for #2 heating oil

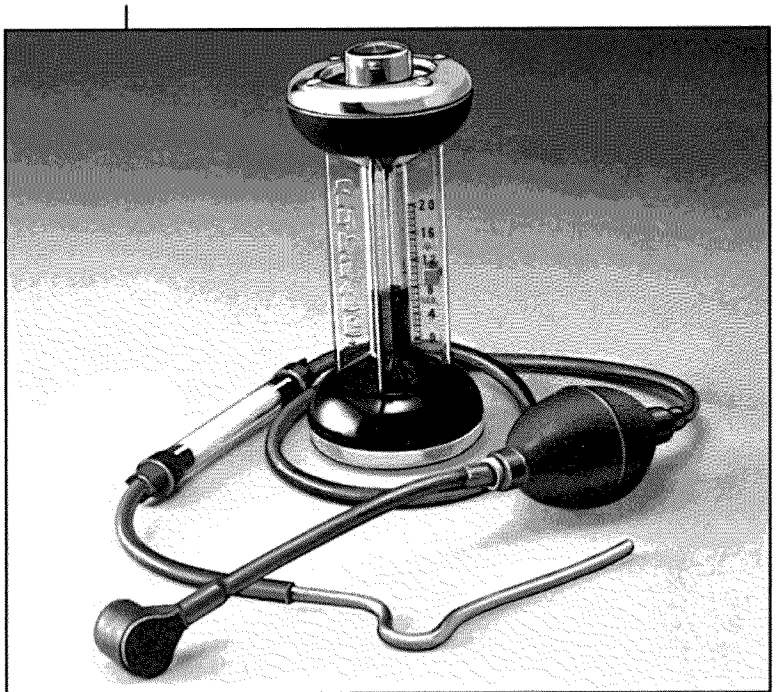


FIGURE 47 CO_2 gas analyzer

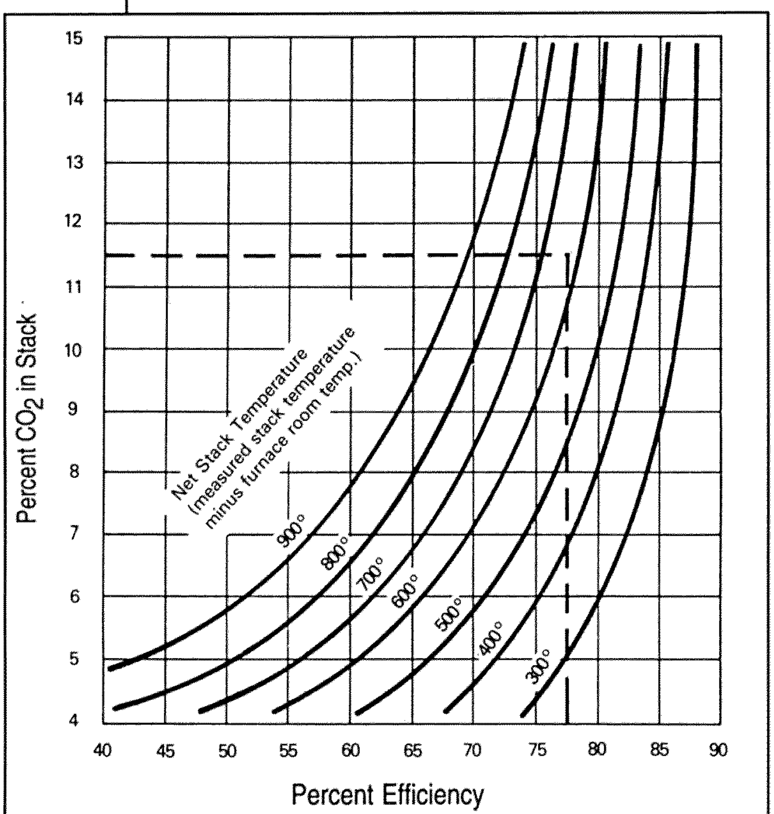


FIGURE 48 Graph of heating appliance efficiency

Once you know the percent CO_2 or oxygen and the net stack temperature, you can determine the steady-state efficiency based on the stack loss method. Remember that the stack loss will be determined per gallon of fuel oil burned, since this is how the weight of the combustion gases was measured. Because of this, you don't have to measure the fuel input into the burner. Since we assumed that each unit of fuel oil (a gallon) contains the same amount of chemical energy (140,000 Btu's), the stack loss calculated will be per each 140,000 Btu's of input energy. If we subtract this percentage loss from 100%, what remains will be the steady-state efficiency. Rather than make you go through the calculations to determine this value, an efficiency chart or table can be used which will give you the efficiency based on the percent carbon dioxide and net stack temperature. Many of you may be familiar with the Bacharach Instrument Company's Fire Finder Efficiency Chart. You can also use other tables or graphs to determine the steady-state efficiency. Examples are shown in Figures 48 and 49.

Now that you know what to measure and why, let's turn our attention to how to properly measure for steady state efficiency. As a minimum, you need to measure both the percent carbon dioxide or oxygen, and the net stack temperature, but, to get the complete picture and to do the job right, smoke and draft measurements are also required.

FIGURE 49 No. 2 fuel oil efficiency table

	Net Stack Temp. °F													
$\%O_2$	200	250	300	350	400	450	500	550	600	650	700	750	800	**$\%CO_2$**
1	89.6	88.4	87.3	86.2	85.1	84.0	82.9	81.7	80.6	79.5	78.4	77.3	76.2	14.7
2	89.4	88.2	87.0	85.9	84.7	83.6	82.4	81.2	80.1	78.9	77.7	76.6	75.4	14.0
3	89.2	87.9	86.7	85.5	84.3	83.1	81.9	80.7	79.4	78.2	77.0	75.8	74.6	13.2
4	88.9	87.7	86.4	85.1	83.8	82.6	81.3	80.0	78.7	77.5	76.2	74.9	73.6	12.5
5	88.7	87.3	86.0	84.6	83.3	82.0	80.6	79.3	77.9	76.6	75.3	73.9	72.6	11.7
6	88.4	87.0	85.5	84.1	82.7	81.3	79.9	78.5	77.0	75.6	74.2	72.8	71.4	11.0
7	88.0	86.5	85.0	83.5	82.0	80.5	79.0	77.5	76.0	74.5	73.0	71.5	70.0	10.3

Measurement of Carbon Dioxide or Oxygen

Historically, to determine the weight of the combustion gases per gallon of fuel oil burned, carbon dioxide has been measured with equipment like that shown in Figures 47 and 50. This is a rugged, inexpensive, and easy-to-operate device. However, if you recall from Chapter 1, the percent oxygen also can be used to determine the weight of the combustion gases. There are devices that measure oxygen rather than carbon dioxide percent for the determination of steady state efficiency, but let's turn our attention to the most common device first—CO_2 analyzers.

Bacharach Instrument Company manufactures a carbon dioxide analyzer called "Fyrite", which is the most well-known instrument on the market. The Fyrite (shown in Figures 47 and 50) and other similar instruments work on the following principles:

- ▼ Chemical absorption of a gas sample by a liquid chemical absorbent.
- ▼ Chemical absorbing fluid is also used as indicating fluid.

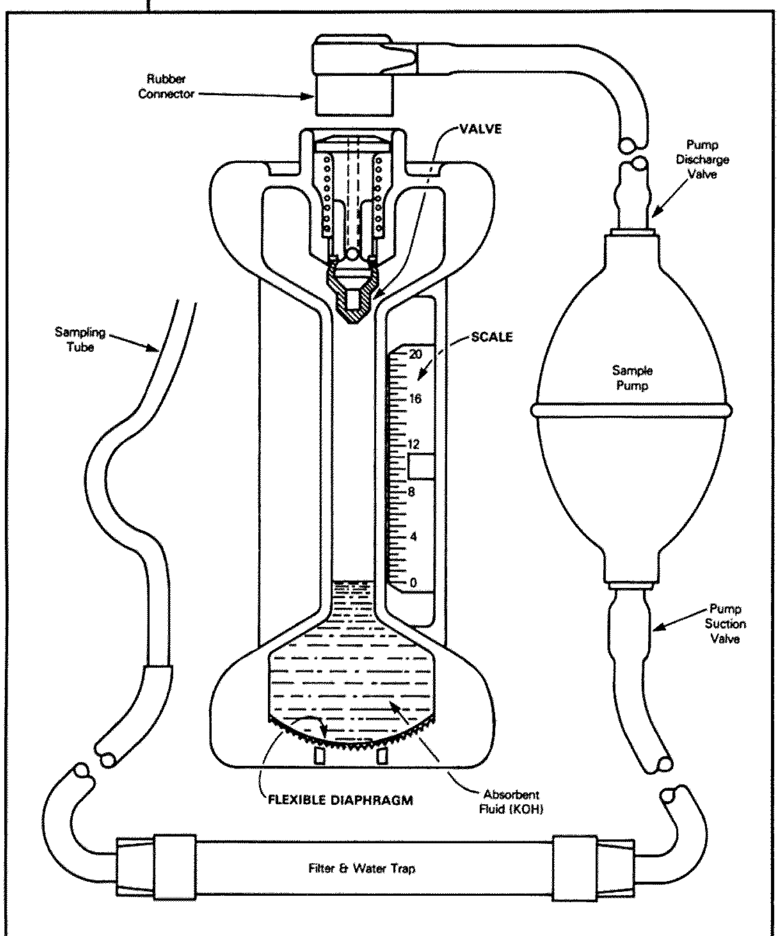


FIGURE 50 Construction of CO_2 analyzer

The Fyrite analyzer contains potassium hydroxide, a liquid with a capacity to absorb large amounts of carbon dioxide. The Fyrite consists of two main parts—sampling pump and analyzer.

The sampling pump consists of:

- ▼ A metal sampling tube which is inserted into the flue gases
- ▼ A yarn filter and water trap which stops soot and water droplets from entering the analyzer
- ▼ A sample pump—a rubber bulb with a suction valve and a discharge valve. These valves are rubber flapper check valves which allow flow in only one direction
- ▼ A rubber connector which seals the sampling pump system to the analyzer

The analyzer is molded of clear plastic containing top and bottom reservoirs and a center tube connecting the two reservoirs. The bottom of the lower reservoir is sealed off by a flexible rubber diaphragm which rests on a perforated metal plate. The upper reservoir is covered by a molded plastic cap which contains a double-seated plunger valve. A spring holds this valve against a finished seat in the top cap providing a seal which makes the instrument spill-proof in any position. When the valve is fully depressed, it vents the top reservoir to the atmosphere and seals the center tube beneath it. When the valve is partially depressed, the entire instrument is open to the atmosphere.

The bottom reservoir is filled with the absorbing fluid which extends about 1/4 inch into the bore of the center tube when the instrument is held upright. The scale, which is mounted to one side of the center tube, is movable so that before each test the scale may be conveniently adjusted to locate the zero scale division exactly opposite the top of the fluid column in the center tube.

To measure the amount of CO_2 in a gas stream, you must measure a known volume of gas, bring the gas into contact with the absorbing solution, and measure the loss in volume after the CO_2 is absorbed. To accomplish this, you must first prepare the instrument for sampling by purging the solution and adjusting the scale so that the zero mark is level with the liquid level. Be sure of the following:

- ▼ Allow instrument to reach room temperature. If you have just come in from the cold outdoors, place the Fyrite in a warm location such as near the boiler or furnace. Make sure it is not too hot, and don't forget to remove the instrument.
- ▼ Make sure sufficient liquid is in the reservoir. If the liquid level is low, add water to the top of the reservoir and depress plunger valve. Repeat until scale can be adjusted to the height of the liquid level.

Zero the instrument by turning the Fyrite upside down at least twice, forcing the gas within the reservoir to bubble through the liquid; then upright and depress the plunger valve fully. After five seconds (or some other known time interval), adjust the zero mark on the scale to the liquid level. The instrument is now ready for sampling. Liquid may continue to drip down the bore of the lower reservoir causing the liquid level to rise above the zero mark on the scale. Do not readjust the scale.

To make a test with the Fyrite, the metal sampling tube at one end of the rubber hose is inserted into the gas to be analyzed. Then, the connector plug at the other end of the rubber hose is pressed down on the spring-loaded valve at the top reservoir. This seals off the center bore. Next, a sample of the gas is pumped into the top reservoir by stroking the rubber bulb. At least 18 bulb strokes should be used to assure that the rubber hose and the top reservoir are thoroughly purged of the previously analyzed sample. (It doesn't matter if you "over squeeze" just as long as you compress the bulb a minimum of 18 times.) On the last bulb stroke, the finger is lifted from the connector plug which automatically returns the plunger valve to upper position against its top seat. With the valve in this position, 60 cubic centimeters of the gas sample are locked into the Fyrite and the top reservoir is opened to the center bore so that the gas sample can pass to the absorbing fluid. The Fyrite is then turned over, forcing the gas sample to bubble through the absorbing solution which absorbs the CO_2. This is repeated two additional times. The instrument is then turned back and held upright again. After five seconds (or the same time interval used when zeroing the instrument), read the scale adjacent to the liquid level. This is the carbon dioxide percent in the gas sample. Record this value on a data sheet.

The reason the liquid level will rise is because the absorption of CO_2 by the absorbing fluid creates a suction in the lower reservoir which causes the diaphragm at the bottom to flex up. This, in turn, permits the level of the absorbing fluid to rise in the center tube an amount equal to the CO_2 absorbed.

There is an easy check to determine if the strength of the absorbing solution is weakening and needs replacement. After you've completed a measurement and recorded the CO_2 value, turn the Fyrite over an additional two times forcing the gas sample to bubble through the absorbing solution. Return the analyzer to the upright position and read the CO_2 percent (after the same interval of time used before). If this value is greater than the recorded CO_2 percent, it is likely that the absorbing solution is weak and is not absorbing CO_2 at its normal rate. Replace the absorbing liquid before using the analyzer for further measurements. Refer to the manufacturer's instructions for the proper procedure on filling the analyzers.

Also, there is an easy check to determine if the sampling tube is leaking. Place your finger over the end of the connector plug and squeeze the bulb. If the bulb remains deflated and does not refill with air, the sampling tube is leak-free.

Bacharach Instrument Company also manufactures an oxygen Fyrite that operates on the same principle but uses a fluid that absorbs oxygen. The CO_2 analyzer is more widely used and the absorbing liquid is good for approximately 300 samples; the oxygen fluid is only good for about 100 samples. The use and operation of the O_2 analyzer is identical to the procedure followed for CO_2. The only difference is in checking the absorbing strength of the fluid. To determine the absorbing strength of the O_2 analyzer, pump a sample of room air into the analyzer and measure the O_2 content. It should read 21 per cent. If it reads less, you should replace the liquid.

Alternative Measurement Techniques

Lynn Combustion Efficiency Analyzers.

Lynn Products Company manufactures a line of Combustion Efficiency Analyzers that measure O_2, flue temperature and smoke level. The instruments employ an electrochemical oxygen sensor that produces a small electrical current proportional to the level of oxygen. The signal is then amplified through a solid state electronic amplifier and displayed either on an analog type meter, which has 1/2% oxygen scale division, or a digital meter, which reads in increments of 1/10th of a percent. The flue temperature is sensed by a thermocouple which is secured in the flue gas sampling probe. This thermocouple produces a millivoltage which is read on a meter in degrees Fahrenheit. In the case of the analog meter, a gross stack temperature reading is displayed on a meter, 10 degrees per scale division. The digital meters display net stack temperature in one degree increments by subtracting room temperature from the total reading. A smoke test is performed by pushing a button which in turn starts an electric pump that draws a certain volume of flue gas through a piece of filter paper, producing a smoke spot. This spot is then compared to a chart with standard smoke readings from zero to nine.

All models come in steel carrying cases to prevent damage to the instruments while they are being carried in cars or service trucks. The models that are removed for testing are in foam lined, steel carrying cases, while the other models are built into steel carrying cases, and need no removal for testing.

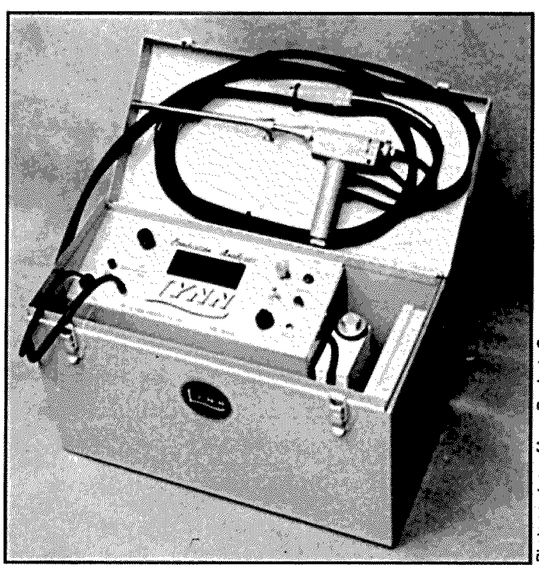


Photo courtesy of Lynn Products Company

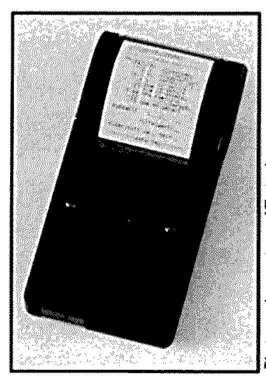
FIGURE 51 Lynn Model 6500 combustion efficiency analyzer

These instruments do not require pumping, and there are no fluids to change. However, some models require 115 volt house current. Other models are available with Ni-Cad rechargeable batteries which can operate the instruments for several hours between charges.

There is a distinct advantage in using the electronic analyzers, because most can measure O_2 or temperature continuously, and the effect of burner adjustments can be quickly observed. This allows you, after the draft has been set, to make a series of burner adjustments, observe and record O_2 and/or temperature. At the same time, you could also be taking smoke readings so that a smoke vs. O_2 curve could be established to pinpoint the optimum air setting for the burner.

Other Advanced Multi-Purpose Test Instruments

The following are just two of the many sophisticated, multi-purpose test instruments now available to assist technicians with heating system installation, adjustment, and maintenance.



Photographs courtesy of Testo, Inc.

FIGURE 52 Testo 342 Combustion Analyzer

Testo 342 Combustion Efficiency Analyzer (hand-held) measures O_2, CO_2, CO, NO, °F, inches of W.C., and efficiency. Backlit LCD screen enables use in dark areas. The unit can also communicate test results to an optional printer via wireless infrared transmission (similar to a TV remote control) for instant printouts.

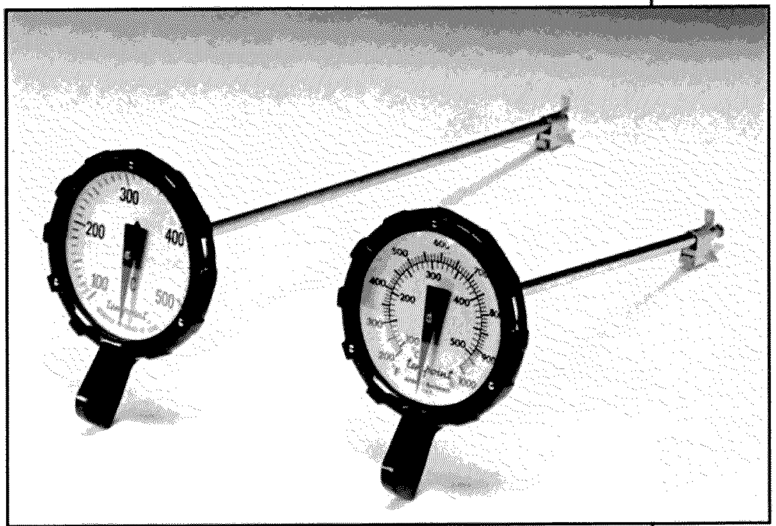
Bacharach CA 40H Combustion Analyzer (hand-held) measures and displays O_2, CO, draft, air temperature, and stack temperature while simultaneously computing and displaying combustion efficiency, net stack temperature, CO_2, excess air, and CO referenced to 3% O_2. An advanced version stores up to 100 tests in memory and downloads to a computer through a built-in RS 232 port.

Photograph courtesy of Bacharach, Inc.

FIGURE 53 Bacharach CA 40H Combustion Analyzer

Measurement of Flue Gas Temperature

Flue gas temperature (often called stack temperature) is normally determined with a bi-metallic dial thermometer with a range of 200°F to 1000°F. (See Figure 54.) The bi-metallic element is a single helix, low mass coil fitted closely to the inside of a stainless steel stem. The stainless stem is 3/16 inches OD and can be easily inserted into a 1/4 inch hole in a flue pipe. The sampling hole should be at least two flue diameters above the breeching or elbow, at the breeching but ahead of the barometric damper. (See Figure 60.) Stem mounting sleeves are also available, which make it possible to hold the thermometer in pipe ducts with the stem inserted at the proper length.



Photograph courtesy of Bacharach, Inc.

FIGURE 54 Flue gas thermometers

The thermometer should be inserted to the approximate mid-point of the stack.

On these types of thermometers, the dial can easily loosen from the stem and rotate so that inaccurate temperature readings are displayed. There have been cases where dial thermometers have been as much as 200°F off from the actual temperature. It is recommended that these thermometers be calibrated from time to time against a mercury thermometer by inserting both side-by-side in a heated flue or duct.

The net stack temperature is found by determining the room temperature and subtracting this value from the flue gas temperature. Don't forget to do this! Also, it is extremely important that flue gas temperature is measured at steady-state condition. This usually requires about fifteen minutes of burner operation. However, the best way to determine if the system is at steady-state is to insert the thermometer in the flue pipe. When the temperature rises less than 5°F during a one minute period, steady-state conditions exist. Remember, if you don't wait for steady-state you will record a temperature that is lower than actual, and this will produce a steady-state efficiency which is higher than actual. By doing this, you may think the unit is operating at a reasonable efficiency level when it really isn't. You may also be denying your oil company the opportunity to recommend the installation of a new, flame retention oil burner that can aid in achieving high steady-state efficiency, and represent a savings in fuel cost to the homeowner.

There are other devices that can be used to measure the flue gas temperature such as mercury-filled glass thermometers or thermocouples with potentiometers. Don't even consider a glass thermometer for other than calibration use, and even then it's risky! They are fragile and easily broken and, furthermore, mercury vapor is hazardous. Thermocouples, however, are a possible alternative to dial thermometers; they are accurate, have a quick response to temperature change, and are easy to use. Although thermocouples are inexpensive, a good potentiometer is considerably more expensive than a dial thermometer.

Smoke Measurement

You should realize by now that determining only the steady-state efficiency does not present the whole picture needed to properly adjust an oil burner. High efficiency with a high smoke level will likely become low efficiency or, even worse, require a service call resulting from plugged flue passages. The objective of a smoke test is to measure the smoke content in the flue gases and then, in conjunction with other steady-state test results, adjust the burner to optimum operation.

The American Society for Testing and Materials in 1965 adopted a standard method of test for smoke density in flue gases from distillate fuels (ASTM D2156). This method covers the evaluation of smoke density in the flue gases from burning distillate fuels. It is intended primarily for use with home heating equipment burning kerosine or heating oils.

A test smoke spot is obtained by pulling 2250 cubic inches of flue gas through a square inch of standard filter paper (or a proportionally smaller volume of flue gas and proportionally smaller filter area). The color (or shade) of the spot thus produced is visually matched with a standard scale, and the smoke density is expressed as a "smoke spot" number.

The most widely used smoke measuring device is based on the principle of filtering soot particles out of a sample of flue gas. The device is quite simple and rugged. (See Figure 55.) It consists of a hand held piston in a tube with a clamping device at the inlet to the tube to hold a piece of white filter paper. The inlet tube is connected through flexible rubber hosing to a solid steel probe that can be inserted into a 1/4 inch hole in a flue pipe or duct. At the outlet end of the piston is a handle that is used to stroke the piston within the tube. The smoke sample should be taken at the same stack location as the CO_2, O_2, and temperature readings.

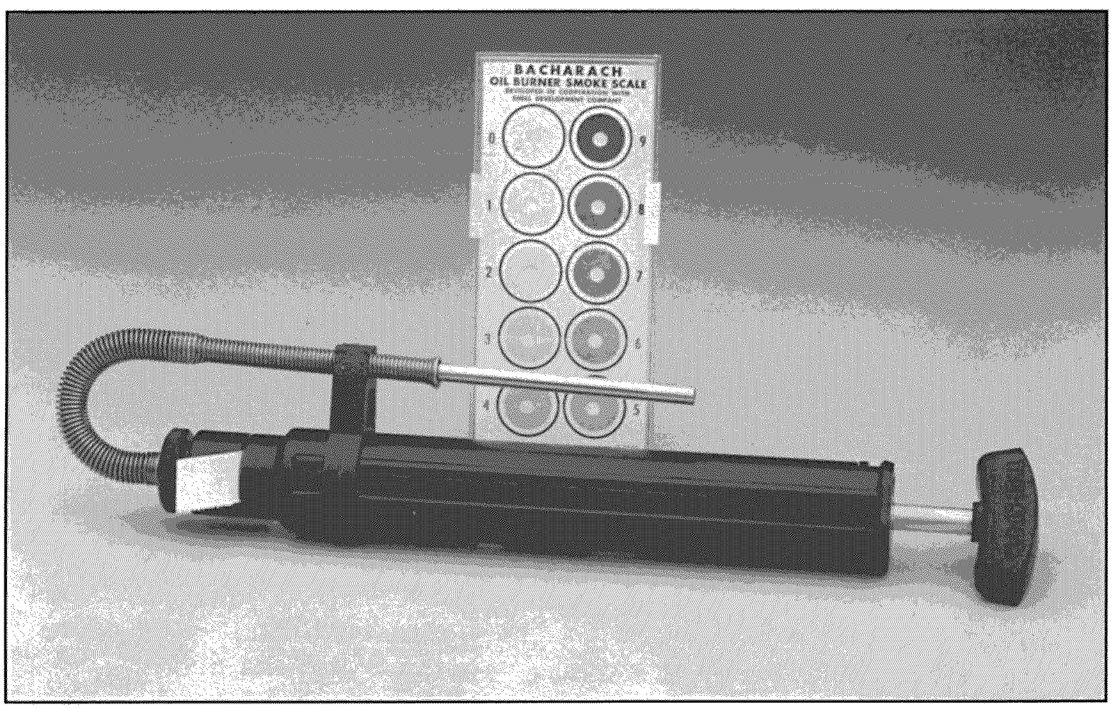


FIGURE 55 Bacharach smoke spot tester

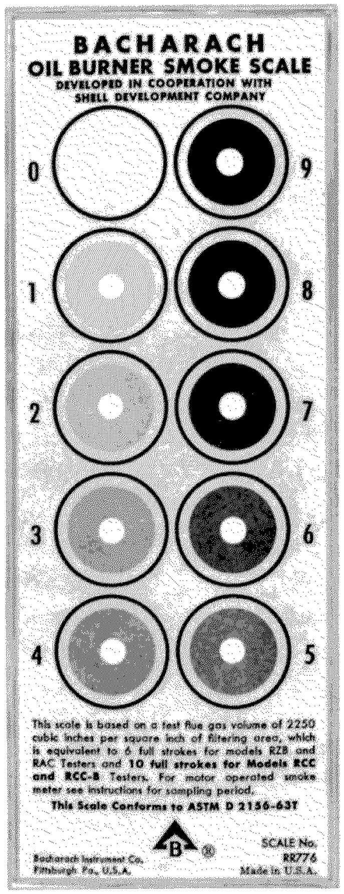


FIGURE 56 Oil burner smoke scale

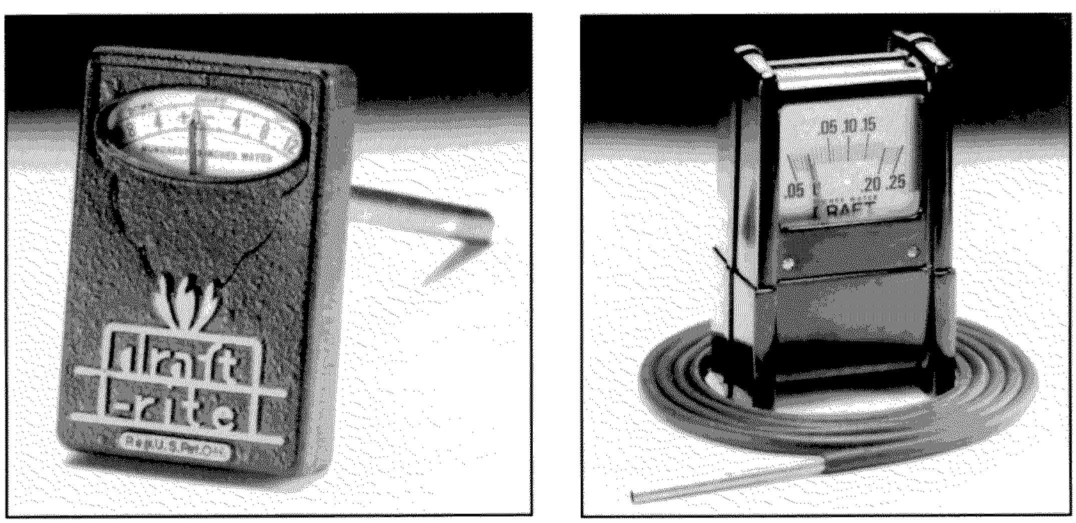
The operation of the device is simple and consumes very little time. After the burner has been in operation for at least five minutes, place the filter paper into the clamping device, insert the steel probe into the flue pipe hole, and slowly withdraw the piston fully from the tube. Hold the piston in the fully open position for about 3 seconds and then slowly push the piston completely in. Repeat the stroking procedure ten times. This allows an exact volume of gas to be passed through the filter paper. When the filter paper is removed, the amount of soot which has been filtered onto the paper will leave a circular colored spot. The darkness of the "smoke spot" is then compared against a Bacharach Oil Burner Smoke Scale (a scale from 0 to 9 representing increasing shades of darkness). If there is no soot, the paper will be white colored.

Figure 56 shows the rating scale used by Bacharach. Actual comparison to determine a number rating is made by holding the filter paper behind the smoke scale so that the spot on the filter paper fills the center hole in the spot on the smoke scale. This allows direct comparison with the various spots on the scale.

The Lynn Combustion Analyzers also measure smoke by using a diaphragm pump to draw a measured volume of flue gas (2250 cu. in. per sq. in. of filtering area) through filter paper (identical to the paper used in the Bacharach True-Spot Tester) that is inserted in the gun assembly. The "smoke spot" is then compared against an oil burner smoke scale.

Draft

Correct draft is essential for efficient burner operation. There are two types of devices that are commonly used to measure draft—a Bacharach Draftrite Pocket Draft Gauge or a Bacharach MZF Draft Gauge. The Draftrite is small and easy to use, while the MZF is more sensitive yet



Photos courtesy of Bacharach, Inc.

FIGURE 57 Draft measurement devices

also easy to use. The Draftrite is a slim, hand held, rectangular device with a curved draft scale placed behind a free floating pointer. The back of the device has an opening in which short metal tubes screwed in series can be inserted. The end of the metal tubes can be placed in the flue pipe, and the pointer will indicate the draft on the numbered scale. These metal tubes may melt if left in the flue for too long. Be careful!

The MZF Draft Gauge also contains a pointer located over a large scale. Rubber tubing is connected to an opening at the rear of the device and also is fitted, at the other end, onto a metal probe. Upon inserting the probe into a flue or over the fire in a boiler or furnace, the pointer moves in direct proportion to the magnitude of the draft.

Either of these devices are acceptable for use in determining draft, if they are used properly. Both draft measurement devices are shown in Figure 57.

Carbon Monoxide (CO) Testing

There is little chance of dangerous levels of carbon monoxide being produced by a properly installed, properly adjusted, well-maintained oil heat system which is supplied with adequate combustion air. However, the oilheat technician should **always** test for the gas as part of **every** service/maintenance call. This can be done quickly and easily with a wide variety of electronic test instruments now available. CO test capability is included in many multi-purpose instruments, and separate CO testers are also available. See Figure 59 for CO level standards.

The Lynn Model 7400 Carbon Monoxide Analyzer is a hand-held, battery powered CO tester that fits into hard-to-reach areas and features a clear digital display reading.

Photo courtesy of Lynn Products Company

FIGURE 58

FIGURE 59 CO level standards

CO Level Standards

The following standards were in effect at the time this book was edited (1997):

ASHRAE — **American Society of Heating, Refrigerating and Air Conditioning Engineers -** Standard 62-89

ASHRAE states the ventilation air shall meet the outdoor air standard. See U.S. EPA standards below.

EPA — **Environmental Protection Agency**

EPA recommends 9 ppm or lower as an ambient air quality goal averaged over eight hours.

EPA recommends 35 ppm or lower as an ambient air quality goal averaged over one hour.

OSHA — **Occupational Safety and Health Administration**

The maximum allowable concentration (50 ppm) for a worker's continuous exposure in any eight hour period.

ANSI Z21.1 — **American National Standards Institute**

Maximum concentration (200 ppm) allowed from an unvented space heater, when measured on an air-free basis.*

Maximum concentration (400 ppm) allowed in furnace flue gas, when sampled on an air-free basis.*

Maximum concentration (800 ppm) allowed from an unvented gas oven, when measured on an air-free basis.*

*Instruments can determine the amount of CO on an air-free basis by first measuring the amount of O_2 and CO present in the sample, and then calculating by the equation below:

$$\frac{20.9}{20.9-O_2} \times CO = CO\text{ Air-Free}$$

This compensates for the amount of excess air provided by the burner. Excess air from a burner dilutes the products of combustion and causes a test for CO to be understated. A CO **air-free** measurement eliminates the excess air dilution.

The above information was taken with permission from the pamphlet "Carbon Monoxide Safety," ©1996, Bacharach, Inc.

RESIDENTIAL OIL BURNER ADJUSTMENTS

Now that you have reviewed the basics of combustion, combustion efficiency, and the operation and use of measurement equipment, you are prepared to study testing and adjustment procedures. The first and most important procedure is the proper adjustment of the burner, whether it be for an annual tune-up, the installation of a new flame retention burner, or the reduction of a firing rate. Each of these procedures ultimately requires that the burner be adjusted properly for optimum fuel utilization. A newly installed flame retention burner adjusted to produce a No. 2 smoke or a 9 percent CO_2, when lower smoke and higher CO_2 levels are possible, will not provide the homeowner with the full benefits of this new unit.

This chapter describes in a step-by-step manner good industry practice for the proper adjustment of residential oil burners.

Be sure that on any heating installation there is adequate fresh air available to support combustion. Appliances located in confined spaces should have two permanent openings, one near the top of the enclosure and one near the bottom. Each opening should have a free area of not less than one square inch per 1000 Btu per hour input. Or, provide outside combustion air. See NFPA 31 for complete application details.

Facts About High CO_2 Levels

Modern flame retention burners permit adjustment to high or low CO_2 levels. For example, in certain packaged applications, 14% CO_2 at a trace of smoke level is not uncommon. On the surface, this appears to be excellent because the system efficiency can be in the 85+% range. However, there are some very important considerations:

1. Some boilers and furnaces have very generous combustion areas and flue passages. Non-flame retention burners operating at a nominal 8% CO_2 and No. 1 smoke could typically make it through a heating season without sooting the more generous, very forgiving units. AFUE rating was not the primary concern in the old days.
2. Many of today's appliances are more compact, with reduced combustion areas and tighter flue passages.
3. Burner adjustments have become more important, and adverse conditions such as sooted heat exchangers and even deterioration of refractories can occur if sound principles are ignored.
4. When flue passages are more restricted, the CO_2 vs. smoke level must be set to accommodate this.

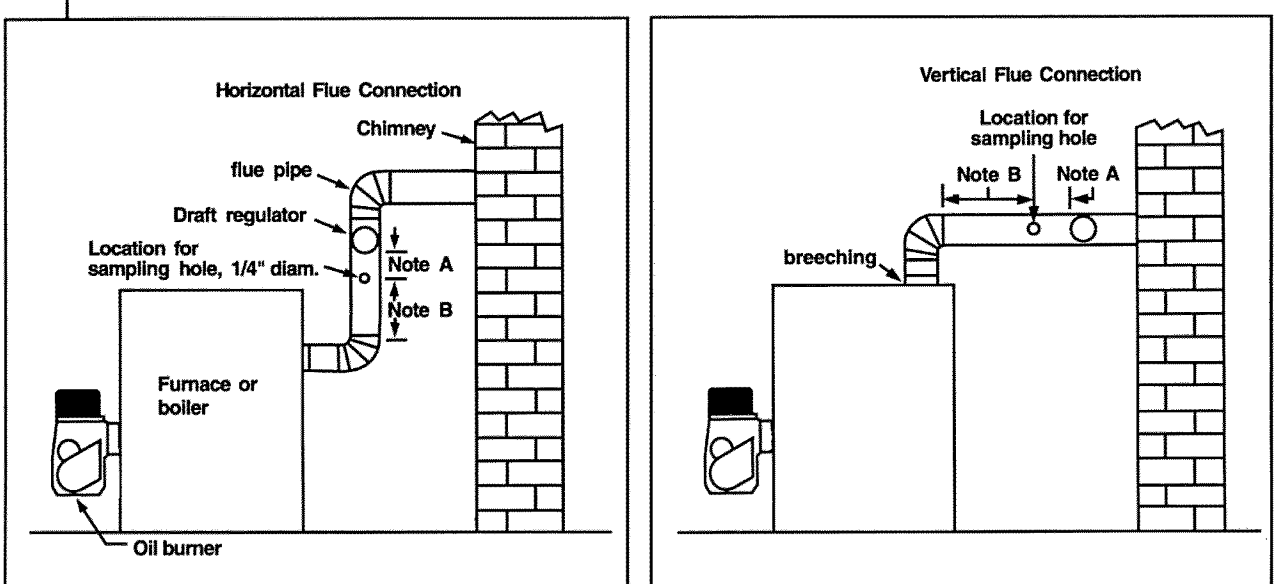


FIGURE 60 Desirable location for 1/4" flue pipe sampling hole for typical chimney connections

A. Locate hole at least one flue pipe diameter on the furnace or boiler side of the draft control.

B. Ideally, hole should be at least 2 flue pipe diameters from breeching or elbow.

5. Refractory material is generally capable of a maximum operating level rated at 2300°F. Wet-based boilers normally utilize a reduced amount of refractory, which is usually positioned so that it can transfer heat to the surrounding water-backed surfaces. There is little danger of overheating the refractory in this application. Therefore, higher CO_2 levels can be utilized with due consideration being given to item 4 above. In dry-base boiler models and furnaces, the refractories are selected to withstand the elevated temperatures of high performance burners. While each application is different, we do know that the highest flame temperature occurs at elevated CO_2 levels. For example, a burner operating at 13.5% CO_2 and zero smoke may be near the 2100°-2200°F range and could possibly exceed 2300°F at 14.5% CO_2 and a trace of smoke. Sustained firing at this level could seriously affect the integrity of the combustion refractory.

Keep in mind that actual performance levels vary among the broad range of burner applications. However, service "call backs" will be reduced whenever these principles and guidelines are understood and followed. Heating appliances should be adjusted with suitable combustion test instruments.

Combustion levels must be compatible with each design application. It is always good practice to consult the appliance manufacturer's installation literature for the recommended performance specifications.

Oil Burner Adjustment

1. PROCEDURE PREPARATION STEPS

A. **Calibrate and Check Operation of Measuring Equipment.** Follow manufacturer's recommended procedures for calibration and equipment check out.

B. **Prepare Heating Unit for Testing.** Drill a 1/4 inch hole in the flue between the appliance and the barometric draft regulator, if not already there, as shown in Figure 60. If space permits, the holes should be located in a straight section of the flue, at least two flue diameters from the elbow in the flue pipe and at least one diameter from the draft regulator. If one does not exist, another 1/4 inch hole should be drilled in the fire door or inspection cover to check over fire draft.

Correlation of Percent of CO_2, O_2 and Excess Air

Carbon Dioxide	Oxygen	Excess Air (approx.)
15.4	0.0	0.0
15.0	0.6	3.0
14.5	1.2	6.0
14.0	2.0	10.0
13.5	2.6	15.0
13.0	**3.3**	**20.0**
12.5	**4.0**	**25.0**
12.0	**4.6**	**30.0**
11.5	**5.3**	**35.0**
11.0	**6.0**	**40.0**
10.5	6.7	45.0
10.0	7.4	50.0

The ranges that you will use most frequently are bold-faced.

FIGURE 61 Correlation of percent of CO_2, O_2, and excess air

C. **Clean and Seal Heating Appliance.** Make sure the burner air tube, fan housing, and blower wheel are clear of dirt and lint. Seal any air leaks into the combustion chamber, especially joints between sections of cast-iron boilers (and around fire door).

D. **Nozzle Inspection.** Annual replacement of nozzles is recommended. The nozzle size should match the design load. DO NOT OVERSIZE. Short cycles and low percent "on" time result in higher overall emissions and lower thermal efficiency. All systems must have an oil filter installed in the oil supply line to protect the oil handling components. Care should be taken to prevent air leakage into the oil suction line. Use continuous runs of copper tubing and use a minimum number of joints and fittings. **Always use flare fittings.**

Select the nozzle and spray pattern, using burner manufacturer's instructions whenever possible. On burner-boiler or burner-furnace matched assemblies, use the appliance manufacturer's instructions.

E. Adjustment of Electrodes. Adjust ignition electrodes according to burner manufacturer's instructions to assure prompt ignition.

F. Operate Burner. Operate burner, adjust air setting for good flame by visual inspection, and run for at least 10 minutes or until operation has stabilized.

G. Check Pump Pressure. Bleed air from pump and supply piping. Check pump pressure and adjust to 100 psig, if necessary (or to manufacturer's specification).

2. COMBUSTION ADJUSTMENT STEPS

H. Set Draft. Check the draft reading over the fire with a draft gauge through a 1/4" hole drilled in the fire door or inspection door. (This hole should be in the inspection door for oil-fired matched units, and in the fire door for conversion installations. If possible, the hole should be above the flame level.) Adjust the barometric draft regulator on the flue to obtain the overfire draft recommended by the manufacturer. If no such recommendations are available, set overfire draft to assure a negative pressure within the combustion chamber (usually -.02 inches W.C.).

With some equipment, it will not be possible to take draft readings over the fire. In this case, adjust the draft regulator to give a breech draft reading between -.04 and -.06 inches W.C., taken at the sampling hole.

Seal draft or sampling hole in inspection or fire door after these tests have been made, using a plug, bolt, or high temperature sealant.

Some appliances are designed for positive pressure firing. Follow the manufacturer's recommended performance specifications for draft levels and venting requirements.

I. Check Smoke Readings. After burner has been operating 5 or 10 minutes, take a smoke measurement in the flue, following the smoke tester instructions. Oily or yellow smoke spots on the filter paper are usually a sign of unburned fuel, indicating very poor combustion, which could possibly produce high emissions of carbon monoxide and unburned hydrocarbons. When retrofitting in older appliances, this condition can sometimes be caused by too much air, or by other factors. If this condition cannot be corrected, major renovation or even equipment replacement may be necessary.

J. Adjust Air Setting.

(1) Set the burner air controls to obtain a trace of smoke at steady state operation.

Remember, as the excess air is reduced, the percent of O_2 decreases and the percent of CO_2 increases. By increasing the excess air, we lower the CO_2 percent and raise the O_2 percent. The relationship between CO_2, O_2, and excess air is shown in Figure 61. The levels most frequently encountered in oil burner servicing are in bold face.

(2) At the trace level, measure the CO_2 or O_2. This is typically around 13% CO_2 / 3.3% O_2. (See Figure 62.) Now, increase the air setting until the CO_2 is reduced by 1 to 2 percentage points from a trace of smoke, or the O_2 is increased by about 2 to 3 percentage points.

(3) Make a smoke test. It should be zero. You have built in a margin to accommodate variables that could be encountered during the heating season.

(4) Lock the air adjustment and repeat draft, CO_2/O_2, and smoke measurements to make sure the setting has not shifted.

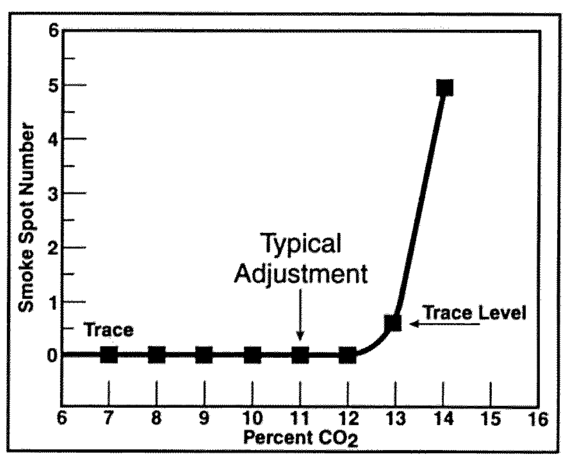


FIGURE 62 Typical smoke vs. CO_2 percent

RECORDING OF READINGS

Now that you've performed your adjustment, record the readings on a form similar to that shown in Figure 63. This will be left to inform the homeowner of the measurements you made. This type of information is important for homeowners to receive. It improves your image and indicates to the homeowner that you and your company are responsible and thorough. Remember, homeowners are being told that measurements are an essential part of proper burner/furnace/boiler adjustment. Fill the form out and leave it with the homeowner! If the test results indicate poor or fair efficiency, recommend to the homeowner that he or she contact your oil company representative for a complete evaluation and/or an energy conservation recommendation.

THE ANNUAL CLEAN-UP

We strongly recommend that the following procedures be performed each year in advance of the heating season:

A. Fire Test the Unit

Does it function normally? Ask the homeowner questions and listen to the answers. If there are troubles with the unit, you may need to make repairs or run a combustion test.

B. Clean the Flue

Turn off the power. Put on a respirator mask and leave the vacuum running with the snorkel inside the area being cleaned to catch airborne particles. Remove the flue pipe and clean it thoroughly. Check the chimney for blockage. Check the barometric regulator.

C. Clean the Secondary Heat Exchanger

Remove the flue collector box. Remove baffles and scrub passages with a flue brush. Shoot for "day one" condition to boost efficiency. Look for cracks, etc. Use any auxiliary clean-out ports.

D. Clean the Combustion Area

Older units may have a view or fire door for access to the combustion area. You may have to remove the burner and front plate to reach the primary heating surfaces. Note the refractory condition and repair or replace as necessary. Be careful not to damage the refractory material when cleaning ceramic fiber chambers. Use a soot snorkel or make one from 3/4" air conditioning or garden hose with duct tape wrapping for a bushing.

E. Replace, Seal and Fasten

Put everything back in place, sealing leaks or cracks with furnace cement and using sheet metal screws on stack joints.

F. Furnace or Boiler?

Furnace: Open the blower compartment to check filters, oil the motor and blower shaft bearings, check V-belt tension and pulley alignment. Brush lint and dirt from blower wheel. Check blower mountings for noisy operation.

Boiler: Oil circulator motor and bearing assembly. Check circulator coupling. Drain expansion tank if needed.

G. Service the Burner

1. Make sure the power is off.
2. Remove the pump strainer cover and clean strainer. Replace cover gasket. Secure cover.
3. Replace oil filter element, leaving the canister clean and tight. Sludge or water means the tank needs to be checked for the cause. Assure oil lines are clean, straight and all fittings are leak-free. Use flare fittings; never compression fittings.
4. Remove the firing assembly. Clean internal tubing. Check electrode porcelains for cracks. Replace nozzle with specified type. Do not over-tighten. Set electrodes to manufacturer's specs.
5. Clean any dirt from combustion head slots and holes. Inspect for damage and suitable firing range. Replace firing assembly.
6. If the burner has not been removed, check the condition of the combustion head using a flame mirror and flashlight. It should be recessed 1/4" from the inside chamber wall, but check manufacturer's specs to be sure. Also check nozzle concentricity.
7. Clean transformer bushings and springs as well as the cad cell surface. Check bracket alignment for good flame sighting.
8. Use a small brush and vacuum cleaner snorkel to clean the air inlets and blower vanes to "like new" condition.
9. Oil the burner motor with 3-4 drops of SAE 20 or 30 oil. Some motors are permanently lubricated, and should not be oiled.
10. Check to see that all wiring connections are secure and insulation is not broken or cut.
11. Time the safety lock-out while you bleed all air from the pump. Test pump pressure and set at 100 psig or to manufacturer's specs. Check the cut-off to see that pressure drops to approximately 80% of operating level.
12. Restore power. Turn the burner ON. View the flame for uniformity and concentricity with no impingement.

H. Combustion Testing

1. Refer back to combustion adjustment steps on page 46.
2. Take a gross stack temperature reading. Subtract room ambient temperature and use an efficiency chart to determine steady-state readings with the net stack temperature and CO_2 or O_2 levels.
3. Cycle the burner to assure prompt ignition and smooth operation. Repeat cycling, purging air bubbles from nozzle adapter until cut-off is clean with no after-squirt.

I. Check Safety and Auxiliary Controls

Cut power to the blower or circulator motor and cycle the burner until safety limits shut the burner off. Check automatic feed valves, low water cut-off and pressure relief valves. Flush low water cut-off valves. Use sight glass on steam units to check water level. Determine that limit controls will shut down the burner if operating controls fail. Be sure the installation meets current codes. Cycle the burner and observe one complete operation sequence.

J. Clean the Area

K. Reset Thermostat and Operating or Limit Control Temperature Settings

L. Record your Findings

Make a written record of anything unusual or needing service. Give a copy to the customer and your service manager. Arrange for follow-up.

FIGURE 63 Test report form

The following test results are based upon measurements of your heating system performed on ____________ :
date

Efficiency (%)	[ ]	
Smoke	________	
CO_2 (%)	________	
OR		
O_2 (%)	________	
Gross Stack Temperature (°F)	________	
Room Temperature (°F)	− ________	
Net Stack Temperature (°F)	= ________	
Overfire Draft	________	Inches W.C.
Stack/Breech Draft	________	Inches W.C.

Notes: ____

____

____

Technician ____

XYZ OIL COMPANY

555-6666

BASIC TROUBLESHOOTING

Recommended Equipment

1. Electrical test meter (VOLTS, OHMS, AMPS).
2. Ignition transformer tester.
3. Combustion analyzer kit (oxygen or carbon dioxide, smoke, stack temperature, draft, system efficiency).
4. Pressure/vacuum gauge (0-200 psig and 0-30: Hg).
5. Full assortment of standard hand tools.

Preliminary Steps

1. Check oil level in supply tank.
2. Make sure all oil line valves are open.
3. Examine combustion chamber for excessive unburned oil. Clean if necessary.
4. Measure line voltage at primary control input connections. It should be 120 volts. Lower than 105 volts AC may cause operating problems. If there is no reading, check for open switches or circuit breakers.
5. Make sure thermostat or other controlling device is calling for burner operation.
6. Check primary control to see if safety reset switch is "locked out."

Determining Malfunction Causes

1. Disconnect nozzle line connector tube and reposition it so that it will deliver oil into a container. Tighten flare nut at pump discharge fitting.
2. Reset primary control safety switch if it is locked out. Turn power ON. Observe the following:
   - **Contact action of primary relay control**. Does it pull in promptly, without arcing erratically or chattering?
   - **Oil delivery**. You should have an immediate, clear, steady stream. White frothy oil means air in the supply system, which must be corrected. No delivery means severe restriction somewhere.
   - **Ignition arc**. You should hear ignition arc buzzing. If not, test output voltage of transformer. If below 9,000 volts, replace.
   - **Motor**. Does it pull up quickly and smoothly? Listen for RPM change and audible "click" as the centrifugal switch disconnects start (auxiliary) winding.
3. If cause of failure has not been identified:
   - Reconnect nozzle line fittings for burner fire test.
   - Reset primary control if necessary. Run several cycles. Observe flame quality. Use a flame mirror, if possible, to see if flame base is stable and close to combustion head. Is flame centered, uniform in shape, and relatively quiet? Are head and chamber free of carbon formations or impingement? Sometimes a defective or partially plugged nozzle can cause trouble.

Additional Procedures:

If the problem still has not been identified, a more thorough evaluation of the basic system must be made. The following procedures may be helpful:

Primary Control System (Cad Cell Type) starts burner, supervises operating cycles, shuts burner off at end of heat call, and locks out ON SAFETY if there is a flame failure.

1. Measure electrical voltage at primary input (usually black) and neutral lead (usually white) connections. It should be 120 volts.
2. Jumper thermostat (TT terminals) or otherwise energize primary control.
3. Control relay should pull in. If not, make sure wiring connections are secure and cad cell is not "seeing" stray light (chamber glow).
4. If relay pulls in, but motor fails to start, measure voltage between neutral lead (usually white) and primary control lead for motor (usually orange). Relay switch contacts may be defective, causing a severe voltage drop.
5. If relay fails to pull in, or is erratic and chatters, even when wiring connections are secure, replace control.
6. Check safety lockout timing by removing one F (cad cell) lead from control. Start burner and count seconds until control locks out. Time should be reasonably close to rating plate specifications on control body.
7. To check cad cell, start burner and unhook both cad cell leads from control FF terminals. Jumper FF screw terminals to keep burner operating. Measure OHMS resistance across cad cell leads **as it views the flame**. It should be 1600 OHMS or less. Preferred reading is 300-1000 OHMS. Next, with meter connected to cad cell leads, turn burner OFF. DARK conditions should give a reading of 100,000 OHMS or infinity. If reading is lower, let refractory cool down, and check for stray light entering burner through air inlet, or around transformer base-plate. If cad cell is not performing within these guidelines, replace it.
8. The control may be governed by a room thermostat. Be sure heat anticipator setting or rating of the thermostat matches the 24 volt current draw.

This information is usually printed on the control body. Erratic operation may be caused by improper anticipator settings. Settings are typically .2 or .4 amps. This value can usually be measured by connecting a multitester in SERIES with one of the TT leads, and reading the value on the appropriate milliampere scale.

The Ignition System is generally comprised of an ignition transformer and two electrodes that deliver a concentrated spark across a fixed gap to ignite oil droplets in the nozzle spray. Delays in establishing spark at the beginning of the burner cycle can result in "puff backs," which can fill the room with fumes. If spark is inadequate, burner may lock out on safety. If transformer is suspect, make the following checks:

1. Measure voltage between transformer/primary lead and neutral connection. It should be 120 volts on the primary input side.
2. Secondary terminals of a good transformer deliver 5000 volts each to ground, for a total of 10,000 volts between the terminals. Measure this with a transformer tester or use a well-insulated screwdriver to draw an arc across the two springs. This should be at least 3/4" in length. Check **each** secondary output terminal by drawing a strong arc between the spring and base. If arc is erratic, weak, or unbalanced between the two terminals, replace transformer.
3. Transformer failures and ignition problems can be caused by the following:
   - An excessive gap setting on ignition electrodes will cause higher than normal stress on the internal insulation system. This can lead to premature failure. Set electrode gap according to manufacturer's instructions (typically 5/32").
   - High ambient temperatures can lower effectiveness of internal insulation system.
   - High humidity conditions can cause over-the-surface arc tracking, both internally and externally, on ceramic bushings.
   - Carbon residue and other foreign materials adhering to porcelain bushings can contribute to arc tracking and subsequent failure.
   - Low input line voltage can cause reduced transformer life. It should be at least 105 volts AC.
   - Ignition electrodes must have good contact with transformer springs. Any arcing here must be eliminated. The only arcing should be at the electrode tips.
   - Electrode insulating porcelains must be clean and free of carbon residue, moisture, crazing, or pin hole leaks. Leakage paths can contribute to faulty ignition.
   - Electrode settings must conform to specifications for gap width, distance in front of nozzle face, and distance above the nozzle center line. Improper positioning can produce delayed ignition, spray impingement on electrodes, carbon bridging, and loss of ignition, which can lead to safety lockouts.
   - Replace electrodes if tips are worn or eroded. Replace questionable porcelain insulators.

The Burner Motor drives the blower wheel and fuel pump by means of a shaft coupling. To diagnose motor problems, follow these guidelines:

1. Motor fails to start.
   - Check for adequate voltage between motor/primary lead and neutral connection with the motor energized. Line voltage must be within 10% of motor rating plate specified voltage.
   - If motor hums when energized, but shaft does not rotate, the start switch may be defective. With the power turned OFF, rotate blower wheel by hand. If it turns freely, replace motor.
   - If blower does not turn freely, check for a bound fuel unit, jammed blower, dry bearings, or a grossly misaligned shaft coupling. Oil bearings with SAE 20W oil. Or, if permanently lubricated, does not need to be oiled.
2. Other motor-related problems.
   - If overload protection has tripped, start motor and measure current draw. It should not exceed rating plate specifications under load conditions by more than 10%. Excessive amp draw usually indicates an overload condition, defective start switch, or shorted windings.
   - If motor is noisy, check alignment of shaft with coupling. Tighten or slightly loosen motor-to-burner-housing bolts in an alternate sequence. Check for loose blower wheel, excessive radial shaft play or loose start switch parts.
   - It is difficult, and usually not cost effective, to rebuild motors in the field. Replace them, instead.
   - If motor operates normally, but does not drive pump shaft, check coupling for slippage due to stripped end caps.

The Fuel Pump transfers oil from the supply tank, cleans it with a strainer or similar mechanism, pressurizes the oil for good atomization at the nozzle, and provides a good shutoff at the end of the run cycle. Manufacturers provide excellent installation and service information. Please read and follow it carefully. Many burner problems can be traced to incorrect installation of oil piping and fittings.

Chapter 6

ENERGY CONSERVATION OPTIONS

This manual is intended to provide you with information that can aid you in performing energy conservation modifications on residential oil-fired heating equipment. A sound understanding of the fundamentals of combustion theory is essential. Also, a full understanding of the significance of instrument measurements and their proper use is an integral part of analyzing all energy conservation options. Therefore, the five previous chapters offered background information that will be needed to adequately perform the recommended energy conservation modifications.

This chapter discusses the criteria and summarizes the procedures associated with the recommended energy conservation modifications. The two modifications are:

- Replacement of a poorly operating oil burner with a properly fired flame retention type burner.
- Replacement of a poorly operating heating appliance with the properly sized, high efficiency boiler/burner or furnace/burner unit.

In order to install a correctly matched heating unit with the proper firing rate for the dwelling, a heat loss calculation must be performed. See Figure 70 for outdoor winter design temperatures.

Flame Retention Oil Burners

Flame retention oil burners, introduced in the late 1960's, represented a major breakthrough in technology, and can produce significant improvements in overall oilheat equipment efficiency while simultaneously reducing the number of burner-related service calls. The term "flame retention" indicates that the combustion head is designed to impart considerable rotation into the air stream. Pressure drop across the head is greater than with non-retention heads. This causes high velocity air to enter the combustion chamber and holds the flame at, but not on, the retention head. (See Figure 65.) Flame retention combustion heads are designed in different sizes to match a range of nozzle firing rates. (Figure 66 shows recommended firing rates for Beckett AF and AFG burners. Figures 67 and 68 show recommended firing rates and air tube/head combinations for Beckett AF II burners.) Typically, flame retention burners use motors that operate at 3450 rpm rather than 1725 rpm.

The effect of this air handling design is to create better air-oil mixing and contain the flame within the air pattern. This produces a higher flame temperature with less excess air. From Chapter 1, you know this means better heat transfer and

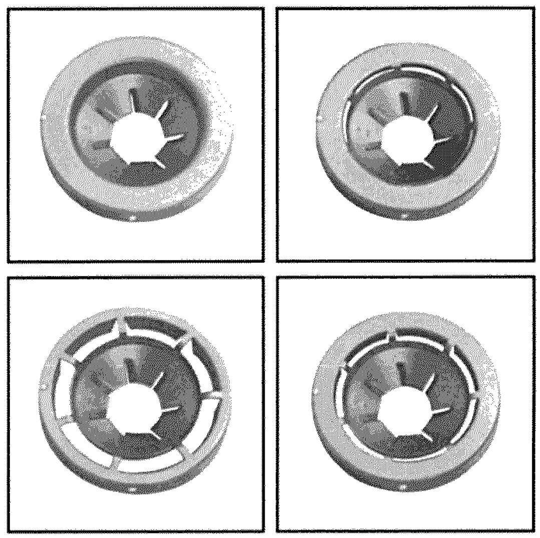
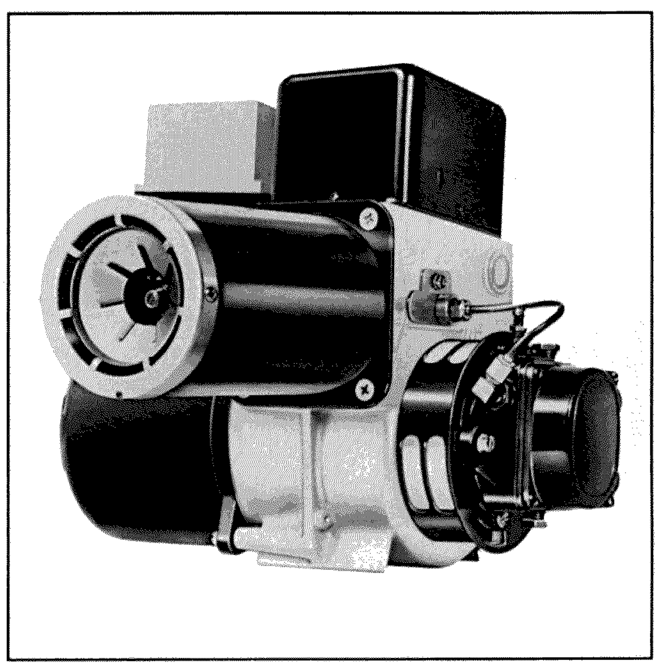


FIGURE 64 Flame retention combustion heads



BECKETT MODEL AFG Flame retention, high speed, .40 to 3.0 gph, broad firing range

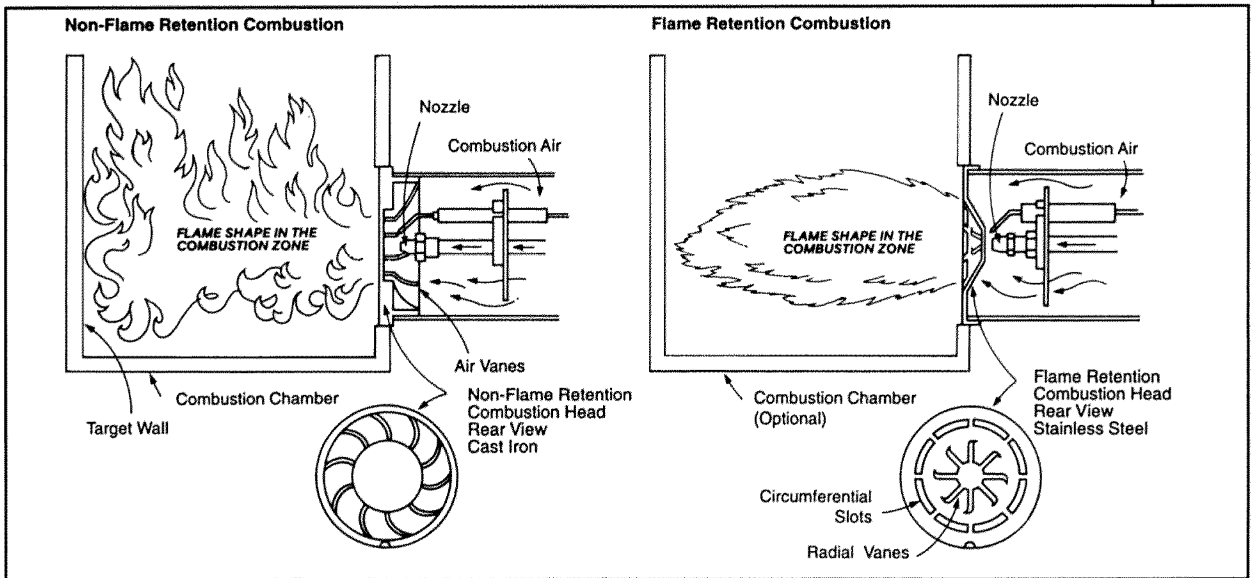


FIGURE 65 Non-flame retention and flame retention combustion

higher overall efficiency. More useable energy is produced from the same amount of oil consumed. There are other advantages to flame retention. There is less effect on the flame from stack draft variations, and pulsation is almost never a problem. There are fewer products of incomplete combustion to reduce burner efficiency and lead to maintenance. Another advantage is that during off-cycles the retention head reduces the flow of air through the burner, over the heat exchanger and out the stack. Therefore, less heated air is removed from the residence.

The Beckett AF II oil burner eliminates the need to stock numerous burner models to accommodate different types of applications. The AF II meets all the requirements of wet base and wet leg boilers, furnaces, dry base boilers, and water heaters. All that changes is the air tube/head combination you use. The AF II 150 provides capacities of .75 to 1.50 gph, 105,000 to 210,000 Btu/hr. For applications requiring lower firing rates, the AF II 85 can be used. See Figure 67.

Criteria for Installing Flame Retention Oil Burners

The decision whether to replace an old, low-speed burner with a high speed, flame retention unit is not difficult by any means. In general, most burners of older design should be replaced. However, there are some older units that still operate at high efficiency. Remember—recommending that a flame retention burner be installed does not mean that a customer will actually purchase the new burner. Nevertheless, the objective is to save energy and reduce fuel costs for homeowners, and flame retention burners can do this.

The following criteria should be used as a guide

RECOMMENDED FIRING RATES gph

HEAD DESIGN	ATC CODE	HEAD	STATIC PLATE	FRONT VENTURI	With Inlet Air Shut-Off MIN	With Inlet Air Shut-Off MAX	Without Inlet Air Shut-Off MIN	Without Inlet Air Shut-Off MAX
Fixed	XR	F0	3-3/8"	None	0.40	0.75	0.40	0.75
Fixed	XN	F3	2-3/4"	None	0.75	1.25	0.75	1.25
Fixed	YB	F6	2-3/4"	None	1.25	1.65	1.25	1.65
Fixed	XO	F12	2-3/4"	None	1.65	1.75	1.65	2.00
Fixed	XP	F22	2-3/4"	None	1.75	2.25	1.75	2.50
Fixed	XS	F31	None	None	2.50	2.75	2.50	3.00
Fixed	*MA	L1	3-3/8"	4 holes	0.40	0.75	0.40	0.75
Fixed	MB	L1	3-3/8"	8 holes	0.50	1.00	0.50	1.00
Fixed	*MC	L1	2-3/4"	8 holes	0.50	1.25	0.50	1.25
Adjustable	MD	V1	2-3/4"	8 holes	0.75	2.00	0.75	2.75
Adjustable	*ME	V1	2-3/4"	0 holes	1.00	2.00	1.00	2.75

NOTE: *Used on OEM applications Only.

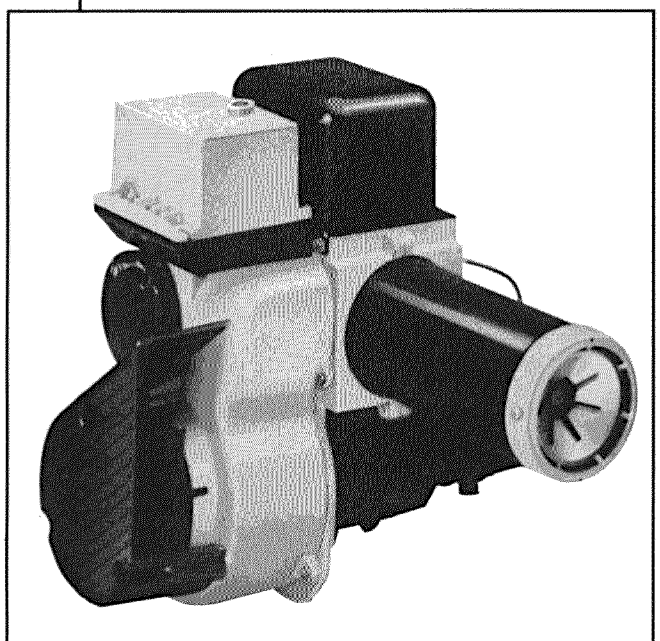
FIGURE 66 Recommended firing rates for Beckett AF and AFG burners

AFII AIR TUBE COMBINATION AND FIRING RATE CHART							
USABLE AIR TUBE LENGTH DIM. "A", See Fig. 3						FIRING RATE RANGE	
3"	5"	7"	9"	ATC CODE	HEAD	AFII 85	AFII 150
Head Design - Adjustable w/stop screw - typical applications, wet base boilers							
HLX30	HLX50	HLX70	HLX90	HB	AF2-6	.4-.85 GPH	.75-1.35 GPH
HLX30	HLX50	HLX70	HLX90	HC	AF2-9	N/A	.75-1.50 GPH
HLX30	HLX50	HLX70	HLX90	HD	AF2-6	.4-.85 GPH	.75-1.10 GPH
HLX30	HLX50	HLX70	HLX90	HE	AF2-9	N/A	.75-1.35 GPH
Head Design - Fixed- typical applications, furnaces, dry base boilers and water heaters							
FBX30	FBX50	FBX70	FBX90	HF	FB0	.4-.65 GPH	.75-1.00 GPH
FBX30	FBX50	FBX70	FBX90	HG	FB3	.55-.85 GPH	.85-1.20 GPH
FBX30	FBX50	FBX70	FBX90	HH	FB4	N/A	1.10-1.25 GPH
FBX30	FBX50	FBX70	FBX90	HI	FB6	N/A	1.15-1.35 GPH

FIGURE 67 Beckett AF II air tube/head combinations and firing rates

in recommending replacement of older oil burners. You should be familiar with these even though you may not be responsible for recommending replacement burners.

1. If, after burner adjustment, the steady-state efficiency is below 75 percent, the burner should be replaced with a flame retention burner.
2. If, after burner adjustment, the steady-state efficiency is greater than 75 percent but the smoke level is greater than 2, the burner should be replaced with a flame retention burner.



BECKETT MODEL AFII 85/150 with FBX air tube combination for dry base boilers, furnaces, and water heaters

The firing rate for the replacement burner should be determined by calculating the heat loss, but it should not be less that 75 to 80% of the manufacturer's rating for the particular boiler or furnace. Also, installing a new burner with a reduced firing rate often requires a new, smaller combustion chamber. Always remember to consider a new chamber or chamber liner when installing a new flame retention burner. If the appliance is equipped with a stainless steel combustion chamber, the use of a chamber liner is a must because the higher temperature levels produced by flame retention burners can exceed the temperature ratings of stainless steel chambers and cause them to burn out.

It may have occurred to you that, based on our criteria, almost all older oil burners should be replaced! That is exactly the intent. When you replace older, inefficient burners, your job becomes easier, homeowners enjoy reduced fuel consumption, and your company gains profitable

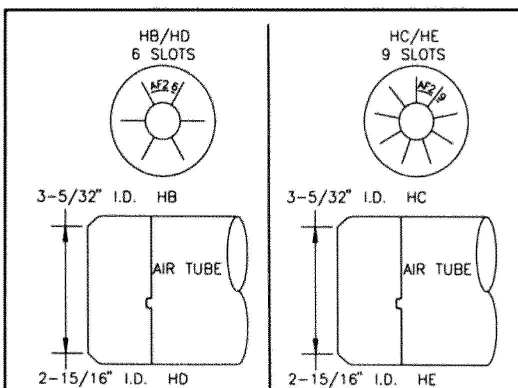


FIGURE 68 HLX air tube/head combinations for wet base and wet leg boilers

sales business. Unfortunately, not all homeowners will take your advice, and some homeowners presently can't afford the cost of a new burner. Also, it is much more cost effective to replace a burner operating at 55 percent efficiency than a burner operating at 73 percent.

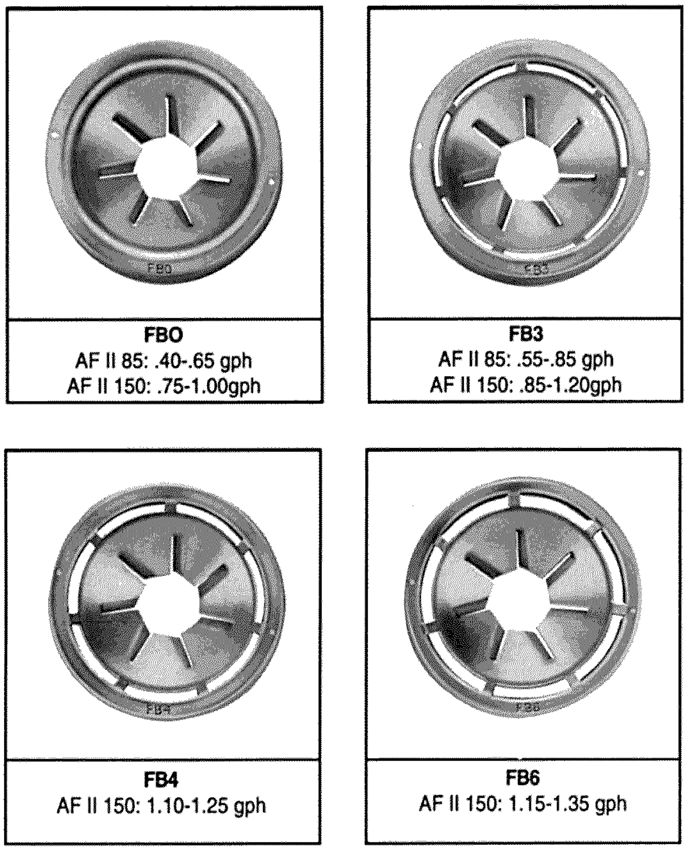


FIGURE 69 Flame retention heads for furnaces, dry base boilers, and water heaters

Installation of Matched Boiler/ Burner or Furnace/Burner Systems

The installation of a new heating appliance can involve the replacement of a steam system with a forced hot water system, or the replacement of an existing type of heating system with a similar, but more efficient unit. Often new controls and other auxiliary equipment are required in conjunction with the new boiler/burner or furnace/burner combination. We recommend that all coal converted boilers be replaced. These older boilers were not designed specifically for oilheat, so even a new flame retention burner can only offer limited improvement. Also, the wide open heat exchanger passages in coal converted units, even if baffled, will never achieve the heat transfer capability of modern boilers. Attempting to modernize an old boiler or furnace by installing new controls or components is similar to modernizing an old burner—they are both patch work jobs which provide only partial relief without solving the real problem.

The sizing of boilers or furnaces and the installation of a properly sized unit are beyond the scope of this manual. Even so, you should realize that the greatest cost savings to homeowners who own outdated, inefficiently operated heating systems is to replace the equipment with a new heating appliance. Make burner adjustments for optimum firing conditions following the procedure discussed in Chapter 5.

Most likely, your company has developed the techniques and marketing ability to inform homeowners of the long-term advantages and cost savings associated with new equipment.

FIGURE 70 Outdoor winter design temperatures

Outdoor Winter Design Temperatures

(°F / Dry-Bulb)* Source: *1993 ASHRAE Handbook - Fundamentals*

State	City	99%	97.5%
ALASKA			
	Anchorage AP	-23	-18
	Fairbanks AP	-51	-47
	Juneau AP	-4	1
	Nome AP	-31	-27
CONNECTICUT			
	Bridgeport AP	6	9
	Hartford, Brainard Field	3	7
	New Haven AP	3	7
	New London	5	9
	Norwalk	6	9
	Norwich	3	7
	Waterbury	-4	2
DELAWARE			
	Dover AFB	11	15
	Wilmington AP	10	14
DISTRICT OF COL.			
	Andrews AFB	10	14
	Wash. Natl. AP	14	17
IDAHO			
	Boise AP	3	10
	Pocatello AP	-8	-1
INDIANA			
	Evansville AP	4	9
	Fort Wayne AP	-4	1
	Indianapolis AP	-2	2
	Lafayette	-3	3
	Muncie	-3	2
	South Bend AP	-3	1
	Terre Haute AP	-2	4
MAINE			
	Augusta AP	-7	-3
	Bangor, Dow AFB	-11	-6
	Portland	-6	-1
MARYLAND			
	Baltimore AP	10	13
	Baltimore Co	14	17
	Frederick AP	8	12
	Hagerstown	8	12
	Salisbury	12	16
MASSACHUSETTS			
	Boston AP	6	9
	Framingham	3	6
	New Bedford	5	9
	Springfield, Westover AFB	-5	0
	Worcester AP	0	4
MICHIGAN			
	Battle Creek AP	1	5
	Detroit	3	6
	Flint AP	-4	1
	Grand Rapids AP	1	5
	Kalamazoo	1	5
	Lansing AP	-3	1
	Saginaw AP	0	4
	Sault Ste. Marie AP	-12	-8
MINNESOTA			
	Duluth AP	-21	-16
	International Falls AP	-29	-25
	Minneapolis/St. Paul AP	-16	-12
	Rochester AP	-17	-12
	St. Cloud AP	-15	-11
NEW HAMPSHIRE			
	Concord AP	-8	-3
	Manchester, Grenier AFB •	-8	-3
	Portsmouth, Pease AFB	-2	2
NEW JERSEY			
	Atlantic City Co	10	13
	Newark AP	10	14
	Trenton Co	11	14
NEW YORK			
	Albany AP	-6	-1
	Albany Co	-4	1
	Binghamton AP	-2	1
	Buffalo AP	2	6
	Elmira AP	-4	1
	Ithica	-5	0
	Newburgh, Stewart AFB	-1	4
	NYC Central Park	11	15
	NYC Kennedy AP	12	15
	NYC La Guardia AP	11	15
	Niagara Falls AP	4	7
	Poughkeepsie	0	6
	Rochester AP	1	5
	Schenectady	-4	1
	Suffolk County AFB	7	10
	Syracuse AP	-3	2
	Utica	-12	-6
	Watertown	-11	-6
NORTH CAROLINA			
	Asheville AP	10	14
	Charlotte AP	18	22
	Fayetteville, Pope AFB	17	20
	Greensboro AP	14	18
	Greenville	18	21
	Raleigh/Durham AP	16	20
	Wilmington AP	23	26
	Winston-Salem AP	16	20

(continued on next page)

FIGURE 70 Outdoor winter design temperatures

Outdoor Winter Design Temperatures (Continued)

(°F / Dry-Bulb)* Source: *1993 ASHRAE Handbook - Fundamentals*

State	City	99%	97.5%
OHIO			
	Akron/Canton AP	1	6
	Cincinnati Co	1	6
	Cleveland AP	1	5
	Columbus AP	0	5
	Dayton AP	-1	4
	Lima	-1	4
	Toledo AP	-3	1
	Youngstown AP	-1	4
OREGON			
	Eugene AP	17	22
	Medford AP	19	23
	Portland AP	17	23
	Portland Co	18	24
	Salem AP	18	23
PENNSYLVANIA			
	Allentown AP	4	9
	Altoona Co	0	5
	Erie AP	4	9
	Harrisburg AP	7	11
	Johnstown	-3	2
	Lancaster	4	8
	Philadelphia AP	10	14
	Pittsburgh AP	1	5
	Pittsburgh Co	3	7
	Reading Co	9	13
	Scranton/Wilkes-Barre	1	5
	State College	3	7
	Williamsport AP	2	7
	York	8	12
RHODE ISLAND			
	Newport	5	9
	Providence AP	5	9

State	City	99%	97.5%
SOUTH CAROLINA			
	Anderson	19	23
	Charleston AFB	24	27
	Charleston Co	25	28
	Columbia AP	20	24
	Florence AP	22	25
	Greenville AP	18	22
	Spartanburg AP	18	22
VERMONT			
	Burlington AP	-12	-7
VIRGINIA			
	Charlottesville	14	18
	Harrisonburg	12	16
	Norfolk AP	20	22
	Richmond AP	14	17
	Roanoke AP	12	16
WASHINGTON			
	Seattle, Boeing Field	21	26
	Seattle Co	22	27
	Seattle-Tacoma AP	21	26
	Spokane AP	-6	2
	Walla Walla AP	0	7
	Yakima AP	-2	5
WISCONSIN			
	Appleton	-14	-9
	Eau Claire AP	-15	-11
	Green Bay AP	-13	-9
	La Crosse AP	-13	-9
	Madison AP	-11	-7
	Milwaukee AP	-8	-4
	Racine	-6	-2
	Wausau AP	-16	-12

AP = Airport AFB = Military Air Base
Co = Office locations within an urban area that are affected by the surrounding area.

Courtesy of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., and Brookhaven National Laboratory.

* Design temperatures are based on the assumption that the frequency level of a specific temperature over a suitable time period will repeat in the future. The selected winter frequencies of 99% and 97.5% enable the engineer to match the risk level desired for the problem at hand. At many locations, meteorological evidence indicates that the temperatures at the 99% level may vary in the order of 2 to 4°F in any 15-year period from the previous 15-year period, and even more in any single year from the previous one. The proximity of the 99% level to the median of the annual extreme minimum temperatures indicates that extremely low temperatures occur in rare extended episodes rather than in long-term summations (Ecodyne Cooling Products 1980, Snelling 1985, Crow 1963).

NOZZLE MANUFACTURERS AND SPRAY PATTERNS

DANFOSS	DELAVAN	HAGO	MONARCH	STEINEN
AS-SOLID	**A**-HOLLOW	**ES**-SOLID	**R**-SOLID	**S**-SOLID
AH-HOLLOW	**B**-SOLID	**P**-SOLID	**NS**-HOLLOW	**SS**-SEMI-SOLID
AB-SEMI-SOLID	**W**-ALL PURPOSE	**SS**-SEMI-SOLID	**AR**-SPECIAL SOLID	**H**-HOLLOW
	SS-SEMI-SOLID	**H**-HOLLOW	**PLP**-SEMI-SOLID	
			PL-HOLLOW	

NOZZLE CAPACITIES

U.S. Gallons per Hour No. 2 Fuel Oil

rate gph @ 100 psi	**Operating Pressure:** pounds per square inch							
	125	140	150	175	200	250	275	300
.40	.45	.47	.49	.53	.56	.63	.66	.69
.50	.56	.59	.61	.66	.71	.79	.83	.87
.60	.67	.71	.74	.79	.85	.95	1.00	1.04
.65	.73	.77	.80	.86	.92	1.03	1.08	1.13
.75	.84	.89	.92	.99	1.06	1.19	1.24	1.30
.85	.95	1.01	1.04	1.13	1.20	1.34	1.41	1.47
.90	1.01	1.07	1.10	1.19	1.27	1.42	1.49	1.56
1.00	1.12	1.18	1.23	1.32	1.41	1.58	1.66	1.73
1.10	1.23	1.30	1.35	1.46	1.56	1.74	1.82	1.91
1.20	1.34	1.42	1.47	1.59	1.70	1.90	1.99	2.08
1.25	1.39	1.48	1.53	1.65	1.77	1.98	2.07	2.17
1.35	1.51	1.60	1.65	1.79	1.91	2.14	2.24	2.34
1.50	1.68	1.77	1.84	1.98	2.12	2.37	2.49	2.60
1.65	1.84	1.95	2.02	2.18	2.33	2.61	2.73	2.86
1.75	1.96	2.07	2.14	2.32	2.48	2.77	2.90	3.03
2.00	2.24	2.37	2.45	2.65	2.83	3.16	3.32	3.46
2.25	2.52	2.66	2.76	2.98	3.18	3.56	3.73	3.90
2.50	2.80	2.96	3.06	3.31	3.54	3.95	4.15	4.33
2.75	3.07	3.25	3.37	3.64	3.90	4.35	4.56	4.76
3.00	3.35	3.55	3.67	3.97	4.24	4.74	4.97	5.20
3.25	3.63	3.85	3.98	4.30	4.60	5.14	5.39	5.63
3.50	3.91	4.14	4.29	4.63	4.95	5.53	5.80	6.06
3.75	4.19	4.44	4.59	4.96	5.30	5.93	6.22	6.50
4.00	4.47	4.73	4.90	5.29	5.66	6.32	6.63	6.93
4.50	5.04	5.32	5.51	5.95	6.36	7.11	7.46	7.79
5.00	5.59	5.92	6.12	6.61	7.07	7.91	8.29	8.66
5.50	6.15	6.51	6.74	7.27	7.78	8.70	9.12	9.53
6.00	6.71	7.10	7.35	7.94	8.49	9.49	9.95	10.39
6.50	7.26	7.69	7.96	8.60	9.19	10.28	10.78	11.26
7.00	7.82	8.28	8.57	9.25	9.90	11.07	11.61	12.12
7.50	8.38	8.87	9.19	9.91	10.61	11.86	12.44	12.99
8.00	8.94	9.47	9.80	10.58	11.31	12.65	13.27	13.86
8.50	9.50	10.06	10.41	11.27	12.02	13.44	14.10	14.72
9.00	10.06	10.65	11.02	11.91	12.73	14.23	14.93	15.59
9.50	10.60	11.24	11.64	12.60	13.44	15.02	15.75	16.45
10.00	11.18	11.83	12.25	13.23	14.14	15.81	16.58	17.32
10.50	11.74	12.42	12.86	13.89	14.85	16.60	17.41	18.19
11.00	12.30	13.02	13.47	14.55	15.56	17.39	18.24	19.05
12.00	13.42	14.20	14.70	15.88	16.97	18.97	19.90	20.79

FIGURE 71 Nozzle manufacturers' codes and nozzle capacities

Call the Beckett Service Hotline

1-800-OIL-BURN

(1-800-645-2876)

Beckett

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