Energy, Mines and Resources Canada | Énergie, Mines et Ressources Canada

EFFICIENT RESIDENTIAL OIL-HEATING SYSTEMS

A Manual for Servicemen, Designers and Builders

Report SP 88-1E

Canada

EFFICIENT RESIDENTIAL OIL-HEATING SYSTEMS

energy conservation
petroleum
oil-heating
efficiency

A Manual for Servicemen, Designers and Builders

Report SP 88-1E
(Revised Reprint of EI 79-8)

A.C.S. Hayden
R.W. Braaten

Canadian Combustion Research Laboratory
Energy Technology Branch
Canada Centre for Mineral and Energy Technology

Available in Canada through

Associated Bookstores
and other booksellers

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Ottawa, Canada K1A 0S9

Catalogue No. M38-15/88-1E
ISBN 0-660-12865-9

Price subject to change without notice

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Acknowledgements

The effort of Dr. T.D. Brown in the joint development of the original seminars on which parts of this manual are based is gratefully acknowledged.

First draft manuscripts were prepared with the co-operation of Mr. J. Foxx, technical writer.

CHAPTER 1

INTRODUCTION

The rising cost of oil, along with the realization that oil reserves in Canada and the world are running out, has promoted research on the efficient use of this valuable resource in stationary source heating, in transportation and in industrial processes. In particular, work at the Canadian Combustion Research Laboratory in Ottawa has shown that the conventional domestic oil heating system can be improved substantially and fuel consumption reduced accordingly.

This book is intended as a guide to improve the efficiency of domestic oil-fired systems, both by changing or expanding the emphasis of periodic maintenance and by actual physical modifications to the heating system.

In the past, when energy was cheap and apparently plentiful, the serviceman had two criteria in order to perform his task well. The furnace had to supply heat to the house and it had to do this safely. In general, both of these terms were complied with and the homeowner was satisfied; the job was indeed done well under these conditions.

Today the cost of heating a home has increased drastically, and the homeowner, justifiably concerned with getting the most for his or her money, is becoming aware that an efficient heating system is important. Thus, the role of the serviceman must also change in order that he become an expert on energy efficiency. This book will provide the basic knowledge and is aimed at the working, experienced tradesman. Although the information on conventional servicing will be familiar to some, the main portion of the book should interest everyone concerned with this field. It explains the different aspects involved in real-life furnace efficiency and measurement and gives the ways and means of upgrading this efficiency considerably.

Armed with the knowledge, you can indeed become the system expert the homeowner is seeking. With these abilities to help achieve optimal use of our liquid fuels, you can make an important contribution to Canada's national energy strategy.

CHAPTER 2

EFFICIENCY

Getting the Facts Straight

In the past, the efficiency of the home heating system was given relatively little emphasis, and little effort was given to close study of the subject. As a result, there were a number of areas where heating engineers didn't know the right answers. In the trade, many practices became accepted which were based on wrong or incomplete information.

The Canadian Combustion Research Laboratory (CCRL) of Energy, Mines and Resources Canada set out to develop a foundation of real data on home heating maintenance and operation. To do this, CCRL conducted lengthy and careful studies of a wide range of heating equipment for what was then the Oil Heating Association of Canada, as well as for individual oil companies, manufacturers and users. Over several winters, detailed studies were carried out in a large number of oil-heated houses in the Ottawa area, measuring such things as fuel consumption, number of cycles, and hours of operation. The results were correlated with such factors as outside temperature and weather conditions, thermostat settings and house insulation.

Thermostat settings and firing rates were varied, as were circulating fan speeds and cycles. Burner performance was modified significantly and draft losses reduced. In short, the "what ifs" were tried and the results carefully recorded under real-life conditions. From these studies, it is possible to say with relative certainty, "If you do this, then the fuel consumption will change in this manner." With this kind of information available, the serviceman is better able to judge how a system is performing and how it can reasonably be improved.

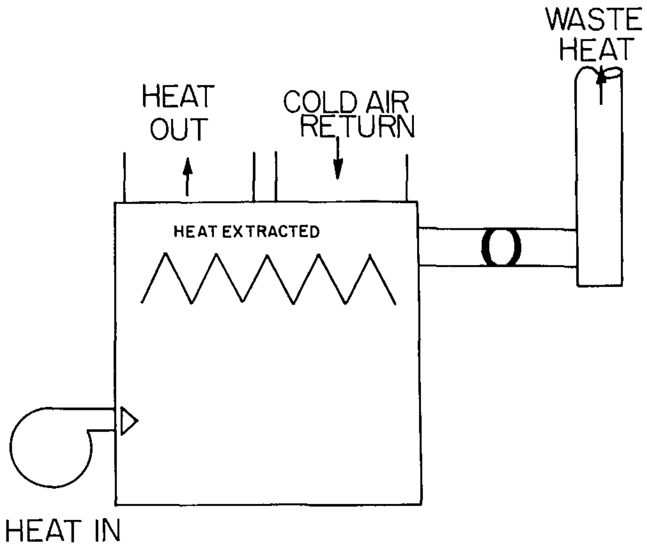
One result of the CCRL studies is that a lot of myths about heating systems are being put to rest. Some things are going to take a bit of getting used to, since they are contrary to common practice. For example, the notion that "bigger is better" must give way. An over-fired furnace does a fine job of keeping the house warm; however, it wastes a large amount of fuel. In most cases, the firing rate can be reduced and a comfortable temperature maintained. In the bargain, fuel usage can be reduced significantly. Another common belief that is gradually being put to rest is that there is no appreciable fuel saving to be had by turning down the thermostat. In fact, this is one of the simplest and most effective ways to reduce fuel consumption. Throughout this manual, many commonly accepted ideas about furnace maintenance and operation will be shown to be simply not correct.

What is Furnace Efficiency?

In the simplest terms, furnace efficiency is a measure of how much of the heat energy in the fuel is actually available for heating the house. Efficiency is usually measured as a percentage. For example, an efficiency of 60% means that for every 100 units of heat energy available in the fuel, 60 units are extracted to meet the energy demand of the house; the rest leaves the stack in the form of waste heat, as shown in Figure 2.1. Before discussing efficiency in detail, it may be useful to get a picture of how the house and heating system interact. Table 2.1 summarizes the factors that affect fuel consumption. On the left-hand side are the demand factors – why heat is required from the heating system. On the right hand are the performance factors – the ability of the heating system to supply the heat.

The first factor in demand is the inside temperature requirement of the house – the thermostat setting. The higher the temperature, the greater the demand.

At the same time, the house is constantly losing heat to the outside. This loss can be broken down into two basic areas, transmission loss and ventilation loss. **Transmission loss** is heat loss directly through the physical fabric of the structure – the walls, window glass, roof, etc. This loss is directly affected by insulation. The more insulation, the lower the transmission loss. **Ventilation loss** is heat loss due to a passage of heat directly through holes in the building envelope. This loss can in turn be broken down into two areas. The first is the heat loss due to infiltration/exfiltration of air through cracks around doors, windows, foundation, etc. This loss can best be reduced by caulking or weatherstripping. A second type of ventilation loss is directly associated with the heating



$$\text{Efficiency} = \frac{\text{Heat Extracted}}{\text{Heat In}} \times 100$$

$$= \frac{\text{Heat In - Waste Heat}}{\text{Heat In}} \times 100$$

Figure 2.1 Heat flows and furnace efficiency

system. Whenever the burner is off, there is a large direct opening to the outside via the chimney, by which warm air can leave the house, or cold air can enter in a downdraft situation.

A given house will lose more or less heat from these factors, depending on the difference between the inside and the outside temperatures. Thus, the thermostat setting becomes an important demand factor, as does the outside temperature. Obviously, the lower the outside temperature, the greater the amount of heat required.

The **performance factors** are a measure of how well the heating system is able to supply the demand for heat. For any oil-fired heating system, there are two basic aspects of its performance which must be considered: the steady state efficiency and the efficiency during transient operation. The first is the one to which most technicians are accustomed. It takes between 10 and 15 minutes from the time the burner comes on, for a system to reach equilibrium (i.e. steady state) as shown in Figure 2.2. Until that time, the furnace is operating under the second condition, that is, in a transient state. No physical system performs as efficiently in transient operation as when it is in equilibrium with its surroundings. An analogy is someone driving a car. He or she uses more gasoline accelerating from 0 to 100 kilometres per hour than is used when a steady or constant rate of speed has been attained.

Steady State Efficiency

The method used to measure steady state efficiency is called the indirect or heat loss method. The percentage of heat lost up the stack is determined after the system has come to equilibrium and the stack temperature has leveled off; this loss is then subtracted from 100 to determine how much heat is being delivered to the house. This method has the advantage that only two fairly easy measurements must be made in order to determine an efficiency – the amount of excess air in the flue gases as measured by either their carbon dioxide (CO_2) or oxygen (O_2) content, and the stack temperature.

While other values must be known to determine efficiency, they have already been measured elsewhere. For instance, the heat energy contained in the fuel, called the gross calorific value (higher heating value), is determined in a laboratory with great precision. Although it does not appear as a number during a steady state efficiency test, it is used in making the special slide rule or table for finding the efficiency percentage.

It must always be remembered that steady state efficiency is only one part of the measure of heating system performance. The transient and off-cycle losses through the unit also play a major role in the fuel consumption of the heating system.

Combustion Parameters

To gain understanding and control of furnace efficiency, it is important to know what goes into the burner, what goes into the house and what goes up the chimney. The burner is the means by which a controlled mixture of oil droplets and air is ignited and burned in the combustion chamber. The hot gases from the resulting flame pass through the heat exchanger of the unit and then up the chimney. Some of the heat from the flue gases is extracted by the heat exchanger and supplied to the house in the form of warm air or hot water, and the rest of the heat goes up the chimney in the form of waste heat and is lost, as shown in Figure 2.1. The ability of the system to function efficiently is primarily dependent on the ability of the burner to combust the fuel with as little excess air as possible, and for the resulting flame to transmit as much heat as possible to the heat exchanger.

TABLE 2.1

Factors affecting fuel consumption

Demand Factors (House)		Performance Factors (Heating System)
Heat Requirements	Heat Losses	Steady State Efficiency
Thermostat	Transmission	Transient Operation
	Infiltration	Dilution Air
	Downtime Losses	

Excess Burner Air

When the burner is firing, fuel oil is sprayed into the combustion chamber in a prescribed pattern at a constant flow rate. To burn that fuel completely requires a certain rate of air flow supplied from the burner blower (squirrel cage). If there is not enough air, the flame is orange, sluggish and smoky, and produces large quantities of soot. The right amount of air, or a slight excess, produces a bright, clean-burning flame.

Although providing even more air may not cause any appreciable change in the appearance of the flame, it does make a significant difference by lowering furnace efficiency. This is because the excess air is mixed with the hot flue gases and is heated to their temperature by the time it leaves the furnace. To heat the house air, some fuel oil must be burned. If there is excess air going through the furnace, then some of the oil is being used merely to heat that excess air. In other words, some of the fuel is heating unneeded air going up the chimney. The more excess air that goes through the burner, the lower the efficiency. Air is controlled primarily by the air band on the burner, with the draft (governed by the barometric damper) also having a small effect. A result of higher excess air is a higher stack temperature, due to increased mass flow through the system; this higher stack temperature results in less efficiency.

Effect of Draft

To isolate the furnace from changes in chimney draft, a barometric damper is installed in the flue pipe between the furnace and the chimney. The flap of the damper pivots to admit more or less room air as the chimney draft increases or decreases, keeping the furnace draft effectively constant as long as the chimney draft is within the range of the damper. Once the draft is stabilized in this fashion, the air control band on the burner determines how much air is used for combustion.

Since the setting of the air control is critical to the furnace efficiency, the adjustment should always be made with a smoke tester, usually to a smoke number of 1 or 2, unless it is a blue flame burner, in which the smoke should be zero.

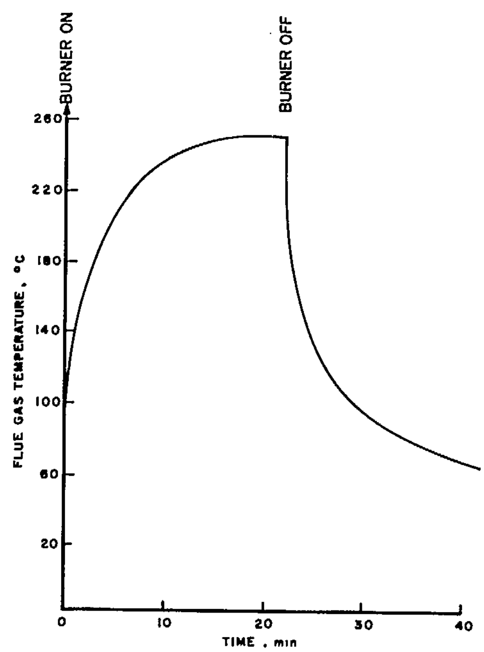


Figure 2.2 Flue gas temperature change during transient furnace operation, 0.85 USgph nozzle

There are two ways to measure excess air. Usually the concentration of carbon dioxide (CO_2) in the exhaust gas is measured. Furnaces and boilers are usually found to operate in the range of 6% to 11% CO_2, where the higher number represents lower excess air. Alternatively, the oxygen (O_2) concentration in the flue gas may be measured. In this case, the normal range of operation would be from 13% to 6% O_2, with the lower number representing lower excess air. Figure 2.3 shows how carbon dioxide and oxygen concentrations are related to the actual percentage of excess air, for a typical Canadian No. 2 heating fuel.

Stack Temperature

The temperature of the flue gases leaving a domestic furnace or boiler should not be higher than 400°C (750°F), otherwise a potential fire hazard exists, and the system is extremely inefficient. At the other extreme, on conventional systems the stack temperature should be at least 175°C (350°F) to prevent condensation and corrosion on the inside of the chimney and perhaps on the tail end of the heat exchanger. With current technology, the working range lies between these two temperatures.

The temperature of the flue gases leaving the heat exchanger depends on the amount of heat extracted from the gases and transferred to the heating medium (air or water). The more heat extracted, the lower the stack temperature. In any furnace, there are three things that affect the heat transfer through the heat exchanger: the rate at which heat is supplied to the furnace, the resistance to heat flow across the heat exchanger, and the rate at which heat is removed by the circulation of air or hot water.

The nozzle size determines the rate at which heat is supplied to the furnace and is usually expressed in U.S. gallons per hour. A size or range of sizes is specified for a given furnace.

Resistance to heat flow across the heat exchanger is lowest when the heat exchanger is perfectly clean. When a coating of soot begins to build up on the surfaces, the soot acts as an insulating layer; this causes the resistance to heat flow to go up and the amount of heat extracted from the hot gases to go down. Consequently, the stack temperature goes up and the efficiency goes down.

The rate at which heat is extracted from the heat exchanger depends on how fast the circulating air removes heat from the bonnet side; the greater the velocity, the more rapid the heat exchange. If the circulation is slowed down by a loose fan belt, clogged filter, blocked registers, etc., then the heat will not be removed as quickly and the heat flow will drop. Again, the stack temperature will be higher and the efficiency will be lower.

Incomplete Combustion

Although any fuel that does not burn completely is a waste of energy, the combustion efficiency (the measure of completeness of combustion) of an oil burner is usually better than 99.9%. Effectively no energy is wasted in this fashion. The combustion efficiency will become important only if the burner is grossly out of adjustment or is misaligned in some way. Insufficient air tends to produce soot and carbon monoxide (CO).

A large excess of air may produce quantities of unburned fuel in the exhaust. The only real combustion efficiency losses are from unburned fuel. The actual loss from producing smoke – even at a high number – is insignificant, since it represents such a small amount of fuel.

While there is no appreciable direct energy loss due to producing soot, the accumulation on the heat exchanger obviously causes the efficiency of the furnace to drop from the time it is cleaned until it is cleaned again.

Putting It All Together

Three things affect steady state furnace efficiency: excess air, stack temperature and smoke production. The first two have an immediate and direct effect on efficiency, while the third has a slight and only gradual effect over a period of time. However, it is not possible to change any one of these things independently of the other two, since they are all inter-related. For example, decreasing excess air will lower stack temperature and tend to increase smoke number.

Figure 2.4 shows the results of actual measurements made on a furnace as the burner air control band was gradually adjusted to vary the excess air between CO_2 levels of 8% and 13%. It can be seen on the left side of the graph that when the CO_2 level is low – a high level of excess air – the stack temperature is high and the efficiency is low. At this point the smoke number is zero because of the high excess air level. As the air is reduced, the stack temperature falls and the efficiency rises. Not until the CO_2 level rises to about 11% does smoke begin to appear, and as the smoke number rises, the efficiency continues to increase. As will be discussed later, the optimum setting to obtain

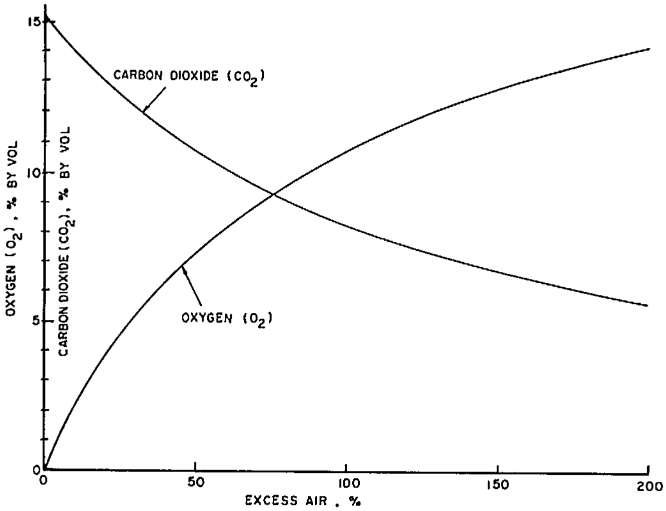


Figure 2.3 Variation in carbon dioxide and oxygen in flue gas with excess air level

best furnace efficiency over the longest period of time is a smoke number of 2.

The measurement of these conditions is detailed in Chapter 3.

Transient vs. Steady State Operation

The previous discussion was concerned with a furnace or boiler operating with stabilized temperatures in steady state. That is, the combustion chamber, heat exchanger, flue pipe and chimney were all as hot as they were going to get. However, it is important to consider what happens in the time between start-up and final running temperature. Figure 2.2 shows how the flue gas temperature rises in a typical furnace, from a cold start until operating conditions are stabilized. During this time, operating conditions are far from ideal. The average time to reach a reasonable approximation of the final temperature in the stack is at least 10 minutes.

Smoke Production

During the first minute or two of operation, the flame produces a great deal of soot, as shown by the first peak in Figure 2.5. After 1 to 1 1/2 minutes the smoke level stabilizes to a normal smoke number (in this case, 1) until the burner switches off. At this point the burner blower stops, but a small amount of oil continues to dribble out of the nozzle in a syphoning action. The effect of this oil running over the hot nozzle is to cause coking, particularly because of inadequate air supply at this time; hence, the second peak of smoke number is produced. The net result is that most of the soot deposited on the heat exchange surfaces results from this massive soot production each time the burner goes on and off. Fortunately, most of this soot can be avoided by fitting a delayed action solenoid valve to the burner. (See Solenoid Valve section in Chapter 5.) Another piece of equipment, the clutch coupling, also works at reducing this soot formation on cycling, though it sometimes results in problems due to slippage from oil vapours on the parts.

One point that most people do not realize is that a typical furnace without the delayed action solenoid or the clutch coupling, produces more smoke at start-up and shut-down than during steady running at a smoke number of 2.

Table 2.2 gives the results of a survey of furnace efficiencies for a large number of homes over a heating season. This indicates that even without a solenoid fitted, the homeowner is better off if the furnace is set to a no. 2 smoke than a zero smoke number. Even at the end of the year, the furnace has about 3.5% greater efficiency on average than the one set at zero smoke. The rate of deterioration at a no. 2 smoke is no greater than at a zero smoke. Only with the smoke number in the range 4.9 does the steady state smoke production begin to dominate the start-up, shut-down production.

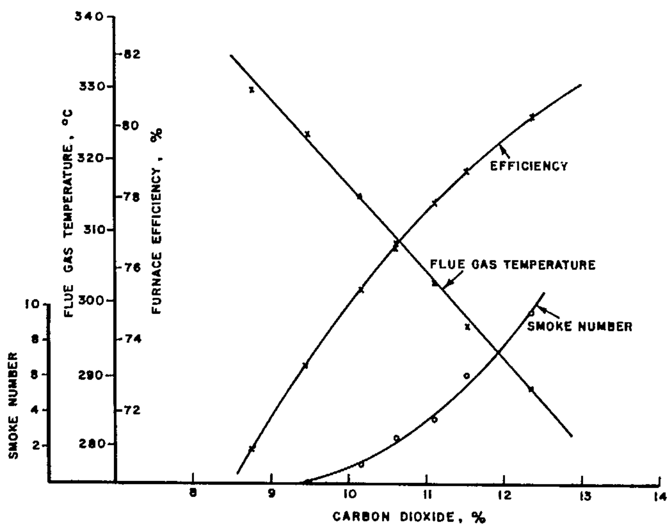


Figure 2.4 Effect of excess air on furnace performance

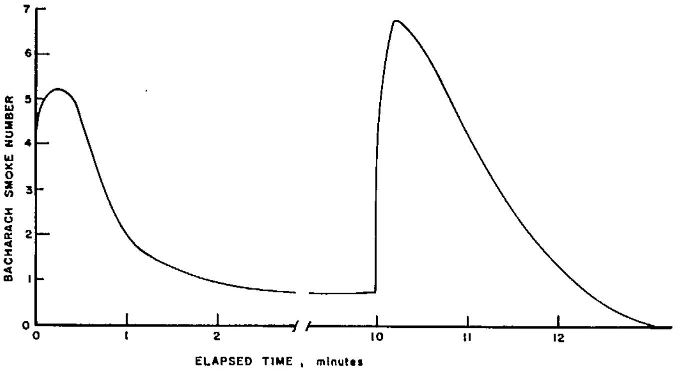


Figure 2.5 **Typical start-up and shut-down smoke characteristics for a steady state smoke no. 1**

Circulating Fan Operation

When the furnace starts up it runs for a period of time until enough heat is built up to switch on the circulating fan. This fan continues to operate for a certain time after the burner shuts off, until the bonnet temperature reaches the cut-out setting. The standard cut-in and cut-out temperatures of the circulating fan, 65.5°C (150°F) and 49°C (120°F) respectively, are quite close. Therefore, when the fan cuts out there is still almost as much heat in the furnace as the burner delivered before the fan started. What becomes of this heat? For the most part, it goes straight up the chimney. This is a loss that occurs every time the furnace cycles on and off. It accounts for a significant difference between the steady state efficiency and the actual efficiency of the furnace in normal operation. Savings can result from lengthening the on-cycle, lowering the cut-in and cut-out temperatures to 49°C (120°F) and 32°C (90°F), respectively. (For a more detailed description see Chapter 4.)

Other Areas to Improve Efficiency

There is one more loss associated with the furnace which is practically independent of whether or not the furnace is running. This is the loss of heated basement air through the barometric damper as shown in Figure 3.13. Warm air is constantly drawn out of the house by way of the barometric damper and the chimney as long as there is enough draft to open the damper. The air that is lost is constantly replaced with cold air from outside. A partial solution is to install a certified positive chimney damper in the exhaust breeching to stop the escape of air during the time when the furnace is off. (See Positive Chimney Damper in Chapter 5.)

By reducing the firing rate, the furnace or boiler must run longer to supply the same amount of heat; hence, the heating unit will be running more often in equilibrium over the heating season and will thus be more efficient. At the same time, the amount of off-cycle losses of warm air up the chimney will also be reduced, because the down-time will be less. (For more details see Nozzle Downsizing in Chapter 4.)

TABLE 2.2

Deterioration in stack temperature and furnace efficiency over heating season for large-scale field sample, at different smoke numbers

Smoke Number	Parameter	November	April	Seasonal Deterioration
0	Temperature, °C Efficiency, %	326 74.0	341 73.0	14 1.0
1 - 3	Temperature, °C Efficiency, %	291 77.4	307 76.5	15 0.9
4 - 9	Temperature, °C Efficiency, %	306 77.8	333 76.3	27 1.5

CHAPTER 3

ANNUAL SERVICING

A complete servicing job is usually done on the customer's heating system every year. Since the serviceman is, or at least should be, concerned with the entire heating system, a visit means more than just a cleaning and tune-up of the furnace. All parts of the system should be checked and serviced as necessary. It is a mistake to consider any part to be a "minor" part if its improper operation causes the customer discomfort or loss of money, or the technician a costly call-back.

"The Billpayer's Guide to Heating Systems" (Reference 8) gives an outline of what a conventional annual servicing should involve.

Inspections

With very little effort, you can do a visual inspection of several important points while you are carrying your tools from the truck to the basement. Most servicemen probably do these inspections without even thinking about them.

1. Filling and Vent Pipe – Have a look for leaks or damage.

2. Check to see if the fuel gauge appears to be working.

3. Oil Lines – Again, a quick check for leaks or damage.

4. Flue Pipe – Check for corrosion of the flue pipe from the furnace exit to the chimney. If it is in bad condition, as in Figure 3.1, then the customer should be told about it. You can't force the customer to have it repaired, of course, but you must certainly try to convince him or her. In addition to the risk of fire, remember that corroded pipes will allow air to be drawn into the flue pipe. This will interfere with the draft control and also will make any servicing measurements wrong if the corrosion is upstream of the measurement point.

5. Furnace Casing – Check the outside of the furnace casing for soot. This could indicate draft problems or, possibly, incorrectly positioned electrodes causing delayed ignition and backpuffing on start-up.

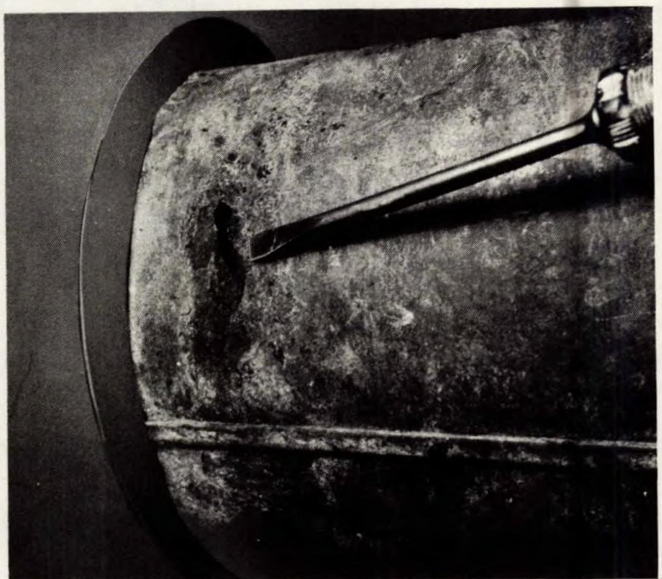


Figure 3.1 Examine flue pipe for corrosion

6. Warm Air Ductwork – Do a quick check of the ductwork in the basement, particularly around the humidifier for signs of leaks or corrosion.

7. Hot Water Pipes – If the house has a hot water heating system, check the pipes for signs of leakage.

8. Furnace Operation – Start the furnace and let it run for a short time. While it is running, open the inspection door and have a look at the flame and the inside of the combustion chamber with a flame mirror, as in Figure 3.2. You can see the shape and colour of the flame and get some idea of how the burner is working, while also seeing if there are any major defects in the combustion chamber. Any really serious problems with the furnace should show up during this short run.

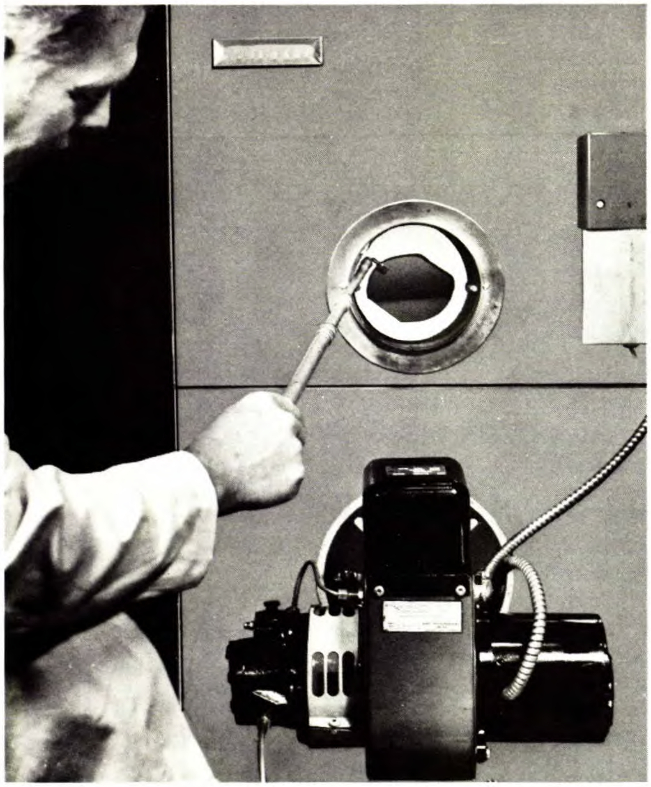


Figure 3.2 Examine condition of flame with mirror

Cleaning and Tune-up

Furnace cleaning is a dirty, unpleasant job no matter how it is done. However, it is also an essential job for efficient and reliable operation of the heating system. Anything less than a thorough cleaning job means starting off the heating season with a second-class furnace, and it's downhill from then on. In effect, it can mean cheating the customer out of a lot of heating dollars. The basic steps are as follows:

1. Flue Pipe – If the flue pipe seems to be in good condition, remove it from the furnace exhaust and have a look at the inside. Clean out any soot that might have accumulated.

2. Barometric Damper – Check that the barometric damper moves freely. Clean off any soot or dust with a brush, especially around the pivots.

3. Stack Controller – Some furnaces are fitted with a stack controller, which senses flue gas temperature in the flue pipe and shuts off burner ignition if the temperature is not within a certain range. These units usually are designed to operate at stack temperatures between 150°C and 400°C (300°F-750°F). Soot accumulates on the stack controller and eventually will act as an insulating blanket, slowing down the response time significantly. Carefully clean off the soot with a soft brush and inspect the controller for corrosion or other damage (see Figure 3.3).

4. Chimney Base – Clean out the accumulated deposits from the chimney base, using a brush and a vacuum cleaner. Using a mirror, check the chimney base for visible signs of damage.

5. Heat Exchanger – Whether it is easy, difficult, or just about impossible to clean the heat exchanger depends on the furnace manufacturer. In some cases, particularly in furnaces with horizontal tube heat exchangers, as in Figure 3.4, removable end covers are provided which allow you to go straight into heat exchanger passages with a brush and vacuum cleaner with little difficulty. Other furnaces are made so that all the cleaning must be done through the exhaust opening, and there is just no way that a brush can be made to get into all of the passages. In particular, concentric tube heat exchangers such as shown in Figure 3.5 are usually the most difficult to clean completely. It is important to clean the heat exchanger as well as possible because accumulated soot is a prime contributor to inefficiency, as well as a cause of significant pressure drop in the system. However, at the same time, be realistic about the heat

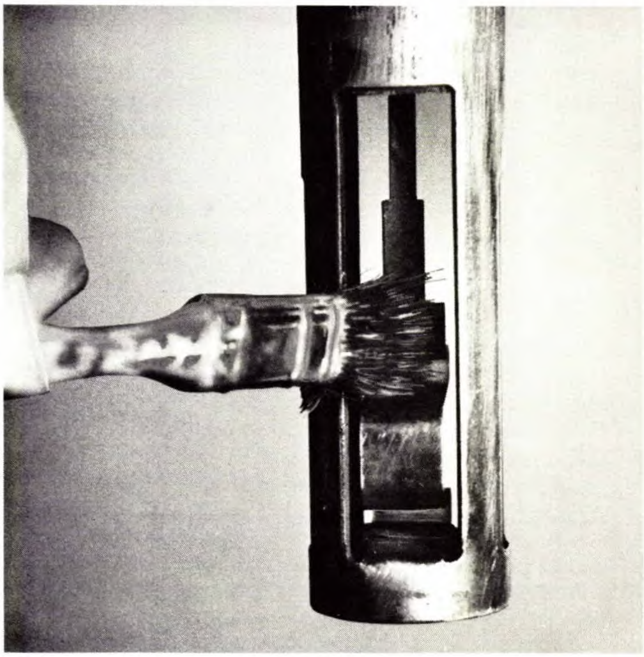


Figure 3.3 Clean stack controller with a soft brush

exchanger. If the design of the furnace prevents thorough cleaning, this should be taken into account if you are looking for ways to improve efficiency. More is said about this in the section on Adjustments to Improve Efficiency.

Because heat exchanger cleaning is a messy job, or because a particular furnace design makes the job very difficult, servicemen sometimes resort to **chemical cleaners.** These are put into the combustion chamber while the fire is burning and are supposed to remove soot by chemical action. A number of these products have been examined and NONE has appeared to be very effective. Some will loosen a bit of soot simply by producing great billowing flames which force large quantities of gases through the heat exchanger under slight pressure. However, many of these chemical cleaners contain substances that can damage the lining of the combustion chamber or corrode the heat exchanger. As a rule, **stay away from chemical cleaners.**

6. Fan and Filters (Warm Air Furnace) – Check the fan bearings and drive belt for wear and tension. Lubricate the fan and motor bearings with a few drops of oil (unless they are sealed bearings). Inspect the fan blades for dirt, sawdust, lint, etc., and clean if required. These deposits in the hollow part of the fan blades, change their contour as shown in Figure 3.6, reducing the amount of air they can handle, and hence lowering furnace efficiency.

   These deposits seriously reduce the ability of the circulating fan to move air and take heat from the furnace, reducing efficiency. At intervals of about three years, or sometimes less, it will be necessary to remove the entire fan assembly from the furnace for a complete cleaning.

7. Air Filters – Check and either clean or replace as required. A clogged filter will reduce air flow and circulation, lowering efficiency.

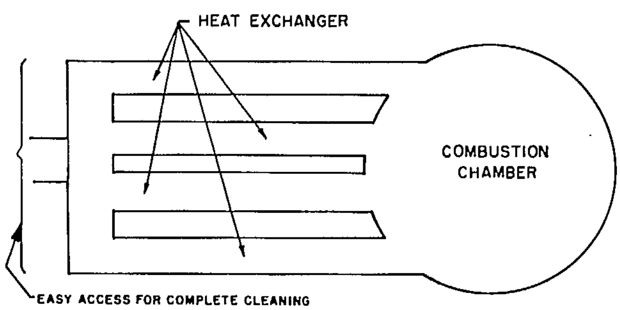


Figure 3.4 **An easy-to-clean heat exchanger (horizontal tube)**

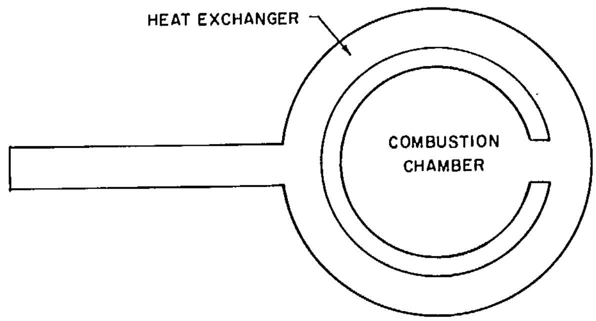


Figure 3.5 **A difficult-to-clean heat exchanger (concentric tube)**

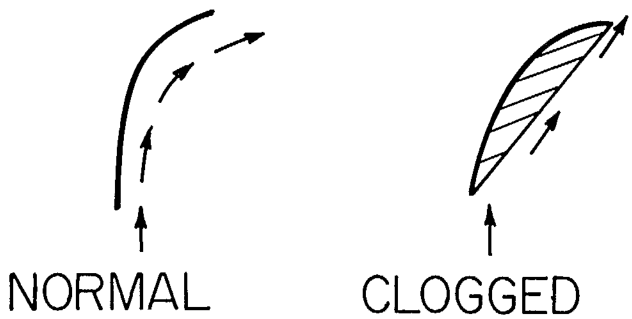


Figure 3.6 **Reduced air flow from fan/blower due to dirt build-up on vanes**

8. Water Circulating Pump (Hot Water Heating Systems) – Examine the circulating pump and motor and lubricate as required.

9. Reinstall the flue pipe onto the furnace and replace the fan access door. Ensure that the barometric damper is installed with the face absolutely vertical and that the pivots are on a horizontal line. Check that the damper swings freely without sticking or binding.

Servicing the Oil Filter

The oil filter bowl should be cleaned and the cartridge replaced periodically (Figure 3.7). There is no set interval for this since there are a number of governing factors. If the tank is fairly new and there are no problems with fuel contamination, there may be no need to touch the filter for three

Figure 3.7 Servicing the oil filter

years or more. If the tank and filler pipe are likely to be a bit rusty inside, then it may be necessary to service the filter more often. When significant amounts of burner ignition failure occur, the filters often can indicate if the problem is due to fuel quality. In such a case, the filter on the oil nozzle should also be examined. The servicing procedure for the filter is as follows:

1. Close the stop valve at the tank.

2. Remove the filter bowl and dump the contents into a waste container.

3. Remove and discard the cartridge and gasket.

4. Clean out the bowl with a clean, lint-free rag.

5. Install a new cartridge and gasket.

6. Replace the bowl on the holder, taking care to position the gasket properly.

7. Open the stop valve and check for leaks.

It is possible to fill the filter bowl before tightening it down by opening the stop valve slightly. This will prevent air from getting into the oil line, so that there is no need to bleed the pump later.

Servicing the Oil Burner

The oil burner is the most important component of the system from the point of efficiency. There are several basic steps to be followed when servicing the burner. Details of servicing will vary slightly because of differences in design. The following steps should be followed in general:

1. Open the burner to get access to the interior.

2. Check the wiring inside for loose connections, frayed insulation, etc.

3. Remove the nozzle and electrode assembly, after marking the fore- and aft-positions if the assembly is adjustable (see Figure 3.8).

4. Check the condition of the electrodes and insulators. Remove any deposits from the electrodes and replace any cracked or damaged insulators.

5. Remove the nozzle and replace it with a new CSA approved one, of the correct firing rate and spray pattern, as in Figure 3.9. To give the correct flow rate and to produce an exactly shaped spray pattern of fine droplets, the nozzle is machined to a very high tolerance. In use, the oil spray gradually wears away the edges of the orifice and a hard film is deposited around it. The size of the droplets slowly increases and the shape of the spray changes. There is no practical way to restore a nozzle and any attempt to clean it is likely to make it worse. It is good practice to change the nozzle annually, as well as to size the nozzle to the house requirements. (See Nozzle Downsizing in Chapter 4.)

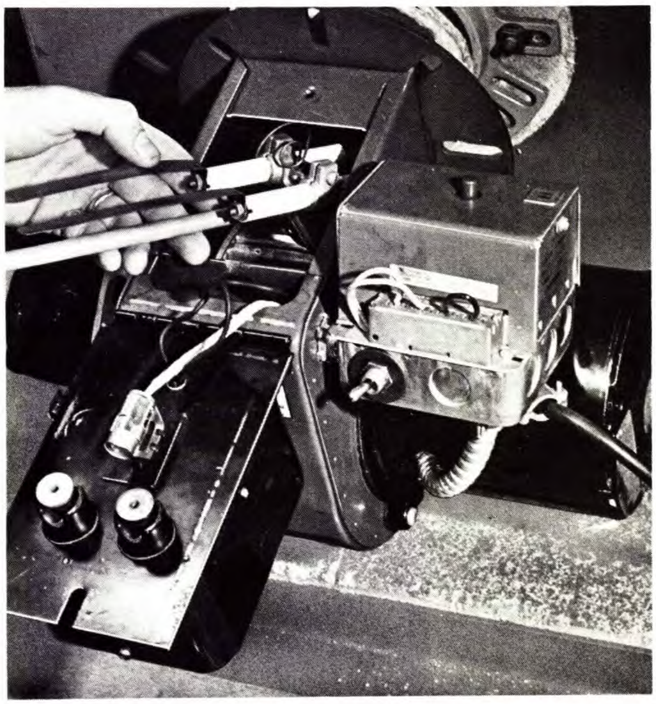


Figure 3.8 Servicing the oil burner

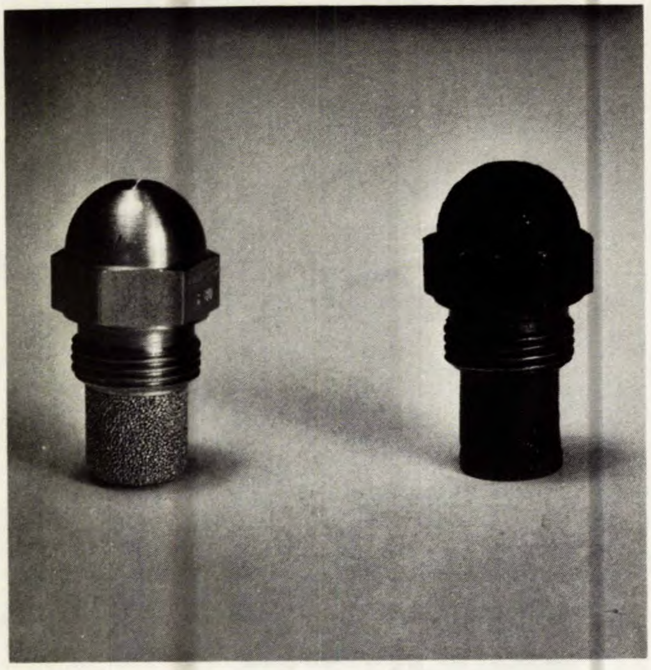


Figure 3.9 Clean and dirty nozzles

6. The threaded fitting that holds the nozzle will stretch and wear a little each time the nozzle is changed. After a number of years it may begin to leak and must be replaced; check this fitting and replace if necessary.

7. Check that the electrodes are positioned correctly according to the manufacturer's instructions, where available.

8. Install the nozzle and electrode assembly in the burner.

9. Clean the burner fan, housing and motor. Dirt on the vanes of the burner fan will seriously reduce the ability of the fan to supply combustion air and can be a reason that smoke numbers cannot be brought into an acceptable range. Lubricate the motor with a few drops of oil, unless the motor is fitted with sealed bearings.

10. If air was introduced into the oil supply line when the oil filter was being serviced or at any other time, then the pump must be bled if it is a one-pipe system. If the bleed valve is on top of the pump and the oil tank fairly full, air can be released from the pump simply by opening the valve. Otherwise fit a short length of flexible tubing over the bleed nipple, open the bleed valve, switch on the burner, and allow oil to flow into a waste container until it is free of air bubbles. Switch off the burner, close the bleed valve, and remove the flexible tubing (see Figure 3.10).

11. Remove the plug in the pressure port and install a suitable oil pressure gauge. Switch on the burner and check that the gauge reads 7.0 kg/cm^2 (100 psi), as in Figure 3.11. This is the standard operating pressure for gun-type burners. A lower pressure will result in poor atomization, poor air-fuel mixing and hence greater excess air and lower efficiency. A higher pressure gives greater oil throughput than required, which increases fuel consumption. Readjust the pressure if necessary by turning the adjusting screw. Remove the pressure gauge and replace the plug.

12. Check the operation of the safety timer. To do this, disconnect power to the burner motor, switch on power to the furnace, and note the time that it takes for the flame failure relay to trip. The time for a photocell should be 20 to 50 seconds and for a stack controller 60 to 120 seconds. If the timing is outside these limits, then the relay or controller should be replaced. Reconnect the motor after the test is completed.

13. Check the pump and all oil fittings for leaks.

14. Close the burner.

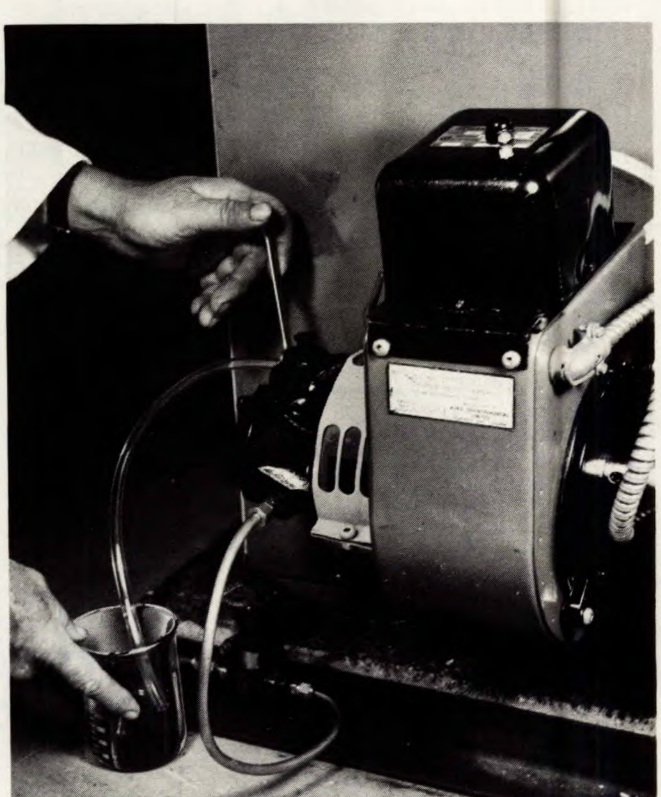


Figure 3.10 Bleeding air from the pump and oil lines

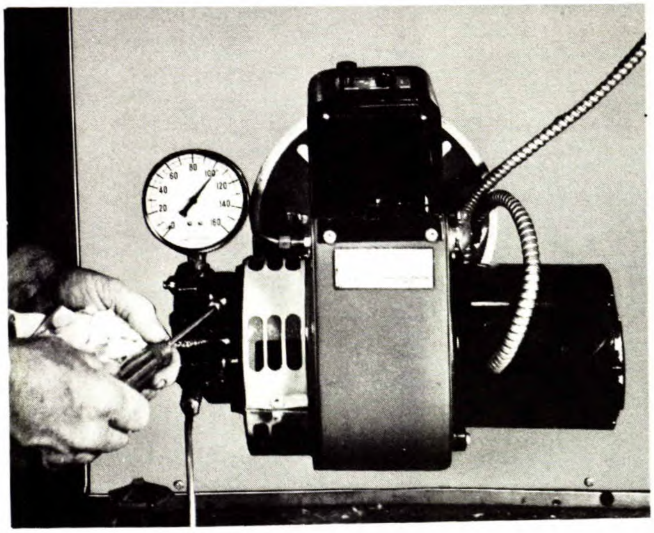


Figure 3.11 Adjusting the pump pressure

Burner Adjustment

After the oil burner is cleaned and overhauled it must be adjusted. The object of this, of course, is to achieve efficient burning with a minimum of smoke. While visual adjustment is useful for obtaining initial draft and air band settings, unfortunately using only this can result in the furnace performing well below its potential efficiency. The furnace will probably still work with incorrect draft, and the flame will look almost the same both with the right amount of air and with twice that amount. To adjust the burner correctly it is absolutely necessary to use good instruments, well maintained.

Four basic measurements are made on a furnace. For burner adjustment the draft and the smoke are measured and for an efficiency test CO_2 (or O_2) and stack temperature are measured. All of these measurements are usually made through a 0.6 cm hole drilled in the flue pipe upstream from (i.e. before) the barometric damper. Preferably, the hole should be located towards the middle of a straight run. If it is desired to conform with CSA test results, the hole should be 45.7 cm from the furnace exit. Very often, you will find this location impractical because of the layout of the flue pipe. In such a case, you will have to make a hole where you can, somewhere between the furnace exit and the barometric damper. If it must be on a bend, it should be located as in Figure 3.12.

The only places where the hole should never be located is immediately beside the barometric damper, or between the barometric damper and the chimney. If the hole is located there, the measurements on which the burner set-up is based will be in

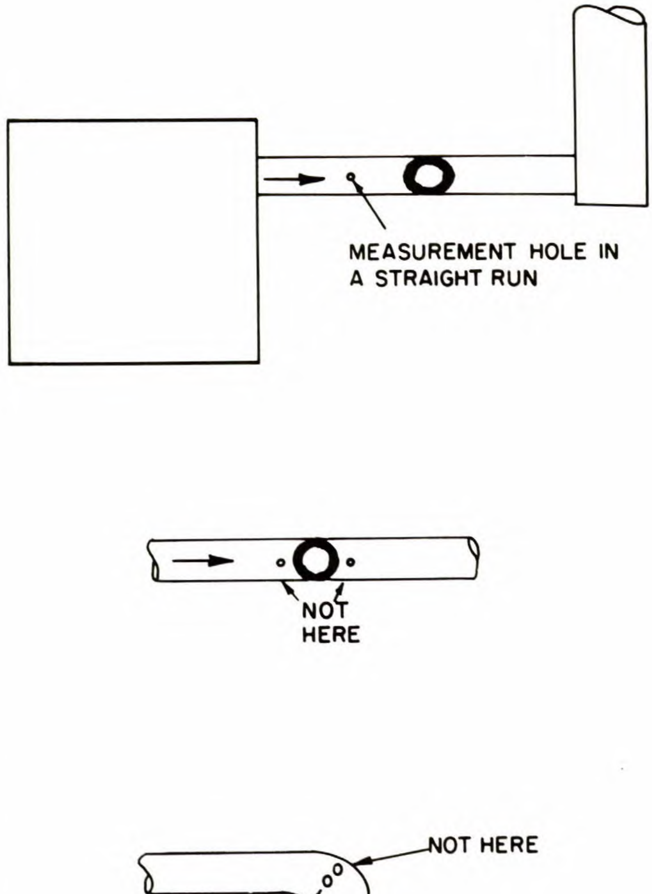


Figure 3.12 Location of sampling hole for furnace performance measurements

error, because of basement air entering the barometric damper and mixing with the flue gas. Figure 3.13 shows the actual measurements of the cooling and dilution of flue gas in this way.

The technique for performing the measurements is as follows:

1. Run the furnace for at least one minute.

2. Before using the draft gauge, check that the pointer reads zero. Readjust if necessary (see Figure 3.14). Insert the probe of the draft gauge, following the manufacturer's instructions for inserting the probe and aligning it across the direction of gas flow. A number of different draft gauges are in use in the field,

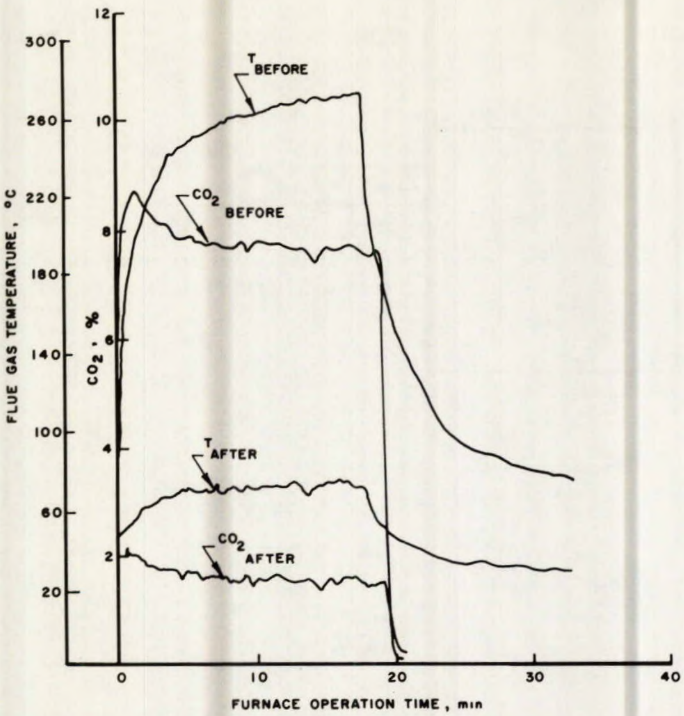


Figure 3.13 Dilution effect of barometric damper

but all are basically similar. To use the draft gauge insert the tip of the probe through the 0.6 cm hole in the flue pipe for a distance of about 0.6 cm. It is important to hold the probe at right angles to the gas flow, no matter where the hole is located. If the probe is inclined upstream or downstream in the gas flow, then it can produce a false reading. Some furnaces call for setting draft using an overfire reading. Provision is made for inserting the probe in the combustion chamber of these furnaces.

3. Adjust the counterweight on the barometric damper until the draft gauge shows the reading specified by the furnace manufacturer. The required draft for the furnace is often marked on the nameplate. In most cases it should be between .02 and .04 inch water gauge. On some furnaces the required draft is not indicated. In this case set the draft to .03 for a start, and check for backpuffing on start-up. If any problems appear, increase the draft to .04 inch. If this does not cure the problem, check for other causes. When the draft is set, lock the counterweight in place.

4. While watching the flame, adjust the air control band on the burner until the smoke just disappears.

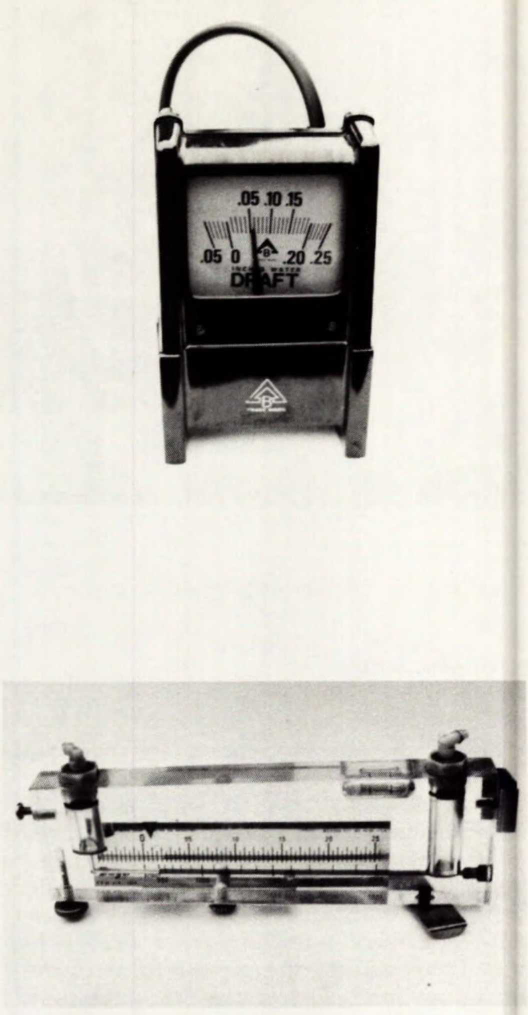


Figure 3.14 Draft measurement devices

5. Take a reading of smoke using the smoke tester (see Figure 3.15). Be sure to follow the manufacturer's instructions for its use carefully. One major source of error is not taking the number of pulls required by the manufacturer. The Shell Bacharach smoke spot tester is the most commonly used instrument to measure the amount of soot in the flue gas. To use the tester, the probe is inserted through the 0.6 cm hole in the exhaust breeching and the pump is operated through ten full strokes to force a gas sample through a piece of special filter paper. The filter paper is then removed and the stain produced by the soot is compared with a standard card showing a range of stains numbered from 0 to 9. Other smoke gauges are in use which are operated slightly differently although the Bacharach smoke number is generally the standard. Always check the

Figure 3.15 Using a smoke tester in a flue pipe

instructions before using an unfamiliar instrument. One problem sometimes encountered with smoke measurements, especially at or downstream from a bend, is the layering or stratification of the soot particles. If this occurs, the smoke reading could vary all the way from 0 to 9, depending on the depth and angle of insertion. When this happens, the maximum reading obtained is the one to use. Note that care must be taken not to pick up soot deposited on the walls of the flue pipe. Readjust the air band as in Figure 3.16 until a smoke number of 1 or 2 is achieved. (This does not apply to blue flame burners, in which the smoke number should be zero.)

Efficiency Measurements

Two other conditions are needed to determine steady state efficiency: excess burner air and stack temperature. Excess air actually takes no part in the combustion process but only mixes with and dilutes the combustion products, and hence the CO_2 produced by burning. Thus, the concentration of carbon dioxide (CO_2) in the flue gas can be related to the amount of excess burner air.

Alternatively, the concentration of oxygen (O_2) in the flue gas can also be related to excess air. Different instruments are available which measure the concentration of either CO_2 or O_2; any one can be used with the appropriate calculations to determine efficiency.

A number of measuring instruments are now in use in the industry. Some have been around for years, whereas others have only recently been introduced. All-electronic instruments are slowly replacing many of the conventional instruments because they are easier to use, and are potentially more accurate. The older instruments require much more care to obtain accurate readings. However, with nearly all the instruments in the field today, it is possible to measure steady state efficiency to within 2% or better, providing the instrument is properly maintained and used. Figures 3.17 and 3.18 show some typical measuring instruments.

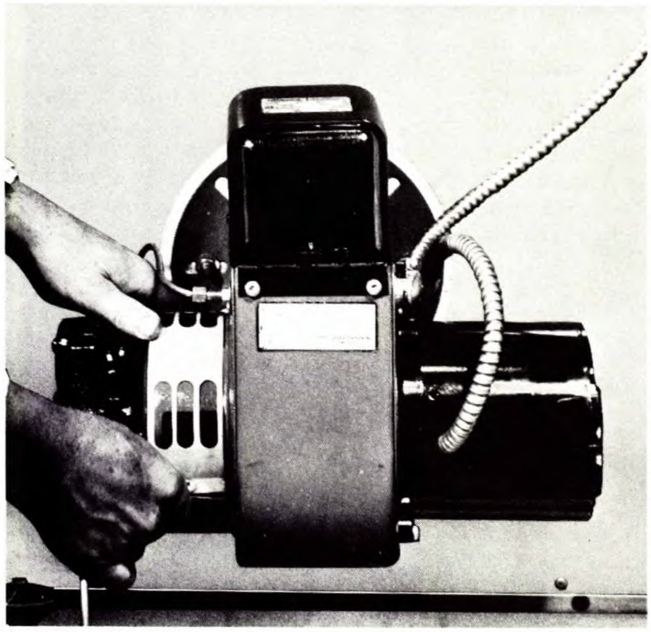


Figure 3.16 Adjust air band setting to 1-2 smoke number (except for blue flame burner)

Annual steady state efficiency measurements provide many benefits. First, they indicate how well the system is performing when set properly. Second, a comparison of year-to-year efficiency figures will show any significant change in performance and might point out maintenance problems that otherwise might not be apparent. As well, comparison of similar systems from house-to-house is useful. Although some variations can be expected due to differences in installation, large differences are a good indication of problems. Finally, it indicates if the system can benefit by retrofitting, as described in Chapter 5.

If the efficiency measurement is going to be worth the trouble, it must be done correctly and carefully from beginning to end.

The instructions that come with each instrument must be read, understood and followed exactly. For instance, if instructions say to squeeze the bulb 18 times to draw the gas sample into the CO_2 gauge, then that is the number of times the bulb must be squeezed.

Some dial thermometers take much longer than others to reach their final temperature. The variation between different types can be from 2 to 30 minutes. If the 30 minutes is too long to wait, which it most assuredly is in most cases, a faster acting thermometer must be obtained. If the thermometer is not used correctly, then the temperature reading is wrong, the efficiency calculated is wrong, and the whole exercise is a waste of time.

The problem in reading stack temperature is compounded by the fact that it takes the stack a fair length of time to reach equilibrium after the burner comes on, as shown in Figure 3.19. Only after at least 10 minutes of operation does the stack temperature start to level out.

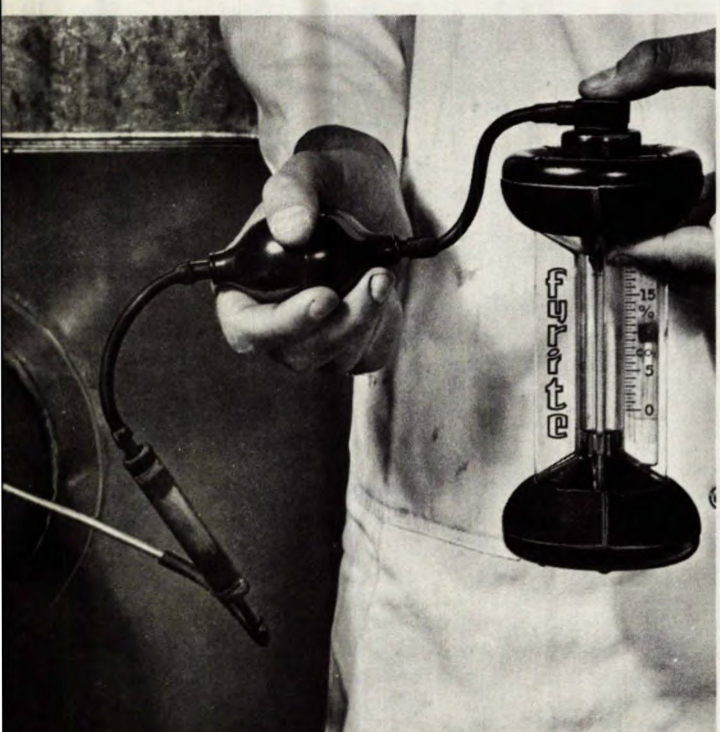


Figure 3.17 Carbon dioxide measurement in flue pipe

For a dial thermometer, the time required for the thermometer to stabilize must also be taken into account. That time depends on how far the reading has to rise to reach stack temperature. If the stack temperature is stabilized before the thermometer is placed in the exhaust breeching, then it will take a certain length of time before it reaches that temperature. However, if the stack temperature is still rising when the thermometer is inserted, then the reading is chasing a moving target. These two lags can combine to give significantly lower-than-actual stack temperatures, and artificially high efficiencies, if the serviceman does not wait for the furnace to stabilize. Figure 3.20 shows how measured temperatures lag behind the real stack temperature.

Figure 3.18 Stack temperature measurement

Maintaining the test instruments is just as important as using them properly. Again, the maker's instructions must be read and followed. The liquid CO_2 gauge is the one instrument that should be mentioned in particular, since it is most likely to be neglected. The manufacturer will recommend changing the fluid after a certain number of uses. In actual use the fluid gets spilled and topped up with water a few times and nobody knows how many times it has been used. The gauge should be checked periodically by taking a reading twice, that is, by making two more inversions than the manufacturer calls for. If the second reading is 0.50% higher or more, then it is time to change the fluid. A good rule-of-thumb is to start checking the fluid in this fashion after every 25 readings.

Any instruments employing flexible rubber tubing must be checked for leaks frequently. The tubing tends to become brittle and to crack with age, and will require periodic replacement. This applies particularly to smoke and gas analysis (CO_2 or O_2) measurement, where the gas samples are pulled down the tubing.

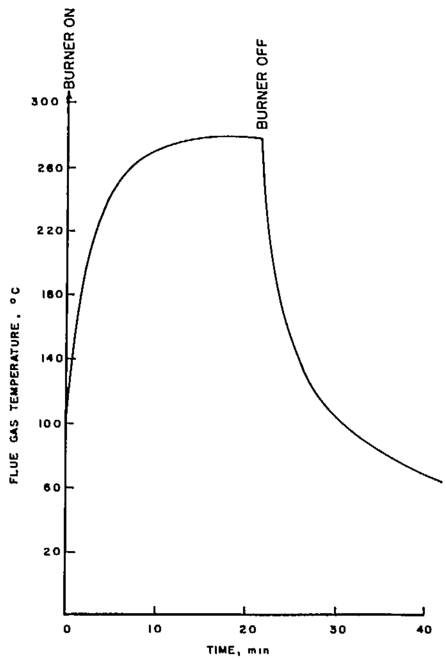


Figure 3.19 Flue gas temperature change during transient operation of furnace, fired at 1.0 USgph

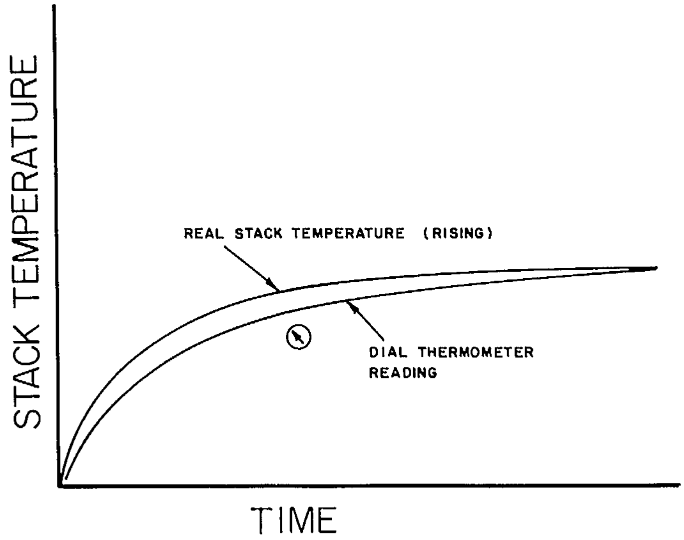


Figure 3.20 Stack temperature measurement error due to lags in real temperature and in measuring thermometer

The efficiency test will usually be made right after adjusting the burner during the annual service call. The normal sequence and timing of the steps is as follows (see the section on servicing for details of draft and air control band adjustment):

1. Fire up the furnace.

2. Set the draft after at least 30 seconds of operation.

3. Adjust the air control band to give a flame that looks about right. Take a smoke reading and then fine tune the air control to about a no. 2 smoke. This is done after about 2 minutes of operation. If the smoke number is in the zero range, close down the air control band slightly. If the smoke number is above 3, open the air control band slightly. As explained in the section on furnace efficiency, the best efficiency setting usually corresponds to a smoke number between 1 and 3. Therefore, a no. 2 smoke is your target.

4. Take a CO_2 (or O_2) reading immediately after the air control band is adjusted.

5. Measure the stack temperature after at least 10 minutes of operation. Remember that the thermometer must be left in for 2 to 10 minutes before it comes up to temperature, depending on the response time of the thermometer.

The final calculation of efficiency is made using the measured CO_2 or O_2 concentration and the stack temperature. Whether you use the slide rule supplied by the instrument manufacturer, or a chart to calculate the efficiency does not make a great deal of difference. The efficiency figure will vary only slightly from one method to another. This difference is due mainly to the fuel on which the slide rule is based. The manufacturer's rule is often a light fuel commonly used in the United States.

The important thing is to make the readings carefully and always keep the instruments in good operating condition. Then the efficiency measured from year to year will be an accurate, meaningful indicator of the performance of the furnace. In short, it takes away some of the guesswork and puts authority in your judgement.

The question is often asked, "Can the tune-up and efficiency measurement of a furnace be done accurately in the summer?" In other words, if a furnace is serviced in July and the measured efficiency is 75%, what happens to the efficiency in

January? The answer is simple – nothing. Figure 3.21 shows actual efficiency measurements made on a furnace at different times of the year. The dots represent the actual measured percentages and the solid line is the average of the readings. The result – no measurable effect.

You might sometimes be tempted to improve the furnace efficiency by simply changing the test results. This is unfair to the customer and unfair to other servicemen as well.

If the efficiency of the furnace is low, it shows the customer that there is some room for improvement. Also, it shows you that there may be a problem which you may have the potential to fix. It could mean a retrofit head, a new furnace or merely taking a couple of minutes to explain why the registers should not be covered with carpets.

Every serviceman is encouraged to leave a completed check list of the items covered during an annual servicing, including the installed nozzle size. There are at least three benefits which can accrue from this action. It tends to encourage thoroughness on the part of the serviceman, lets other servicemen in future years know if particular areas have been examined recently and also encourages the consumer to review what has been done from year to year, developing a greater awareness of what is required for proper maintenance.

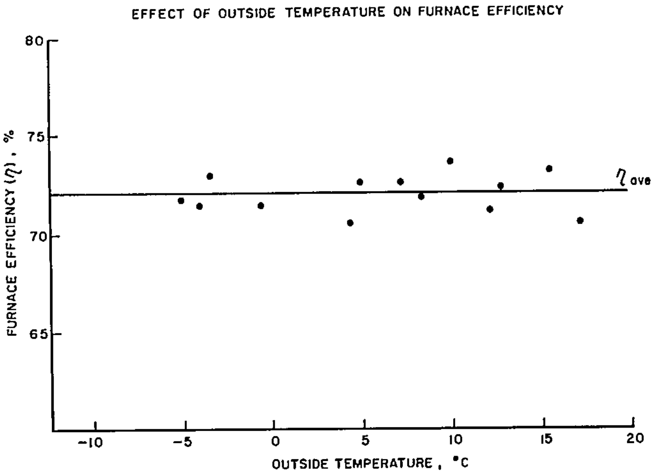


Figure 3.21 Effect of outside temperature on furnace efficiency

If performance measurements have been made, they also should be left with the homeowner, both for the above reasons and to enable the homeowner to decide if his or her system may be suitable for retrofitting, or indeed, might require total replacement.

CHAPTER 4

WAYS AND MEANS OF REDUCING FUEL CONSUMPTION

Various things can be done to improve heating system efficiency without making basic changes to the furnace or boiler. Most of these require very little extra effort from the serviceman, except perhaps, a little patience in explaining things to the customer. On the other hand, the payoff to the customer in terms of savings in heating costs can be quite large. The payoff to you? Satisfaction in a job well done, enhancing your position in the eyes of the homeowner, and general improvement in customer relations.

There is usually little argument with the suggestion that fuel consumption goes up when the outside temperature goes down. Figure 4.1 is a graph of actual measurements of fuel consumption for one test home (Reference 12) at different outside temperatures, while the indoor temperature was held constant. The results were then plotted on a graph to form a straight line indicating a fuel consumption of about 0.0066 gallon (0.03 L) per hour for every degree Celsius of outside temperature below indoor temperature. In fact, in this and nearly every other house in Canada, the rate of fuel consumption and the indoor/outdoor temperature differences are in constant proportion.

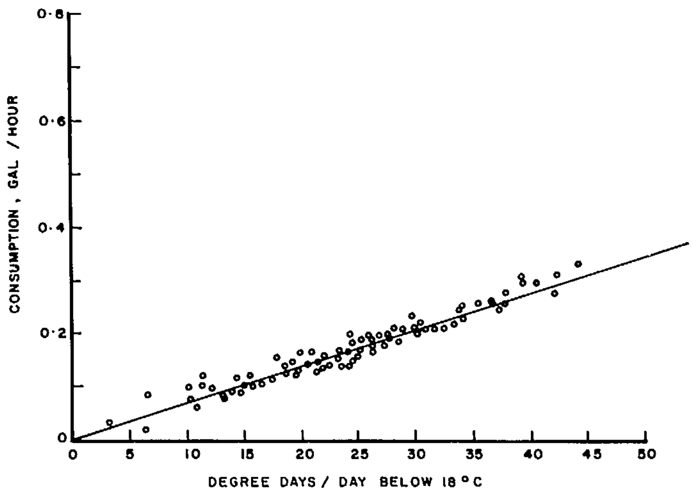


Figure 4.1 Effect of outside temperature on fuel consumption

Thermostat Cutback

Since there is obviously no way to raise the outside temperature to reduce the heat loss, the next best thing is to reduce the inside temperature, either all the time or overnight. There are limits to how far this can be carried, particularly from the comfort point of view, but the homeowner must realize that a difference of a few degrees in the thermostat setting is an expensive luxury in terms of the fuel that can be saved. By cutting the thermostat back 5°C overnight, savings of as much as 14% have been measured in tests done by CCRL. Figure 4.2 shows the effect of this cutback of 5°C overnight on a test home.

Even greater savings can result if the thermostat is lowered during the day as well. In general, each degree Celsius of cutback overnight will save nearly 2% on the heating bill; if the cutback is on a 24-hour basis, each degree Celsius of cutback will save 5%.

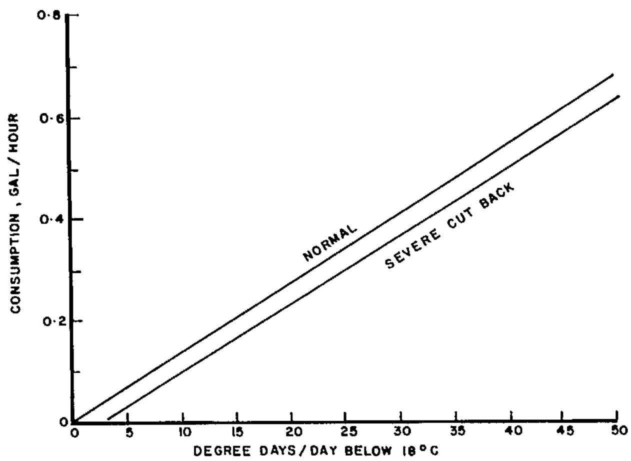


Figure 4.2 Effect of severe (5°C) overnight thermostat cutback on fuel consumption

The overnight cutback can be done manually at no cost to the homeowner. However, for those people wishing to have a warm house when they get up in the morning, automatic thermostat setback devices can be readily purchased.

Nozzle Downsizing (Reduced Firing Rate)

In general, the furnace is off for a considerable period of the heating season. In fact, nearly all furnaces run less than 50% of the time even at their nominal design temperatures (see Appendix E). As well, it takes up to 15 minutes for the furnace to come to equilibrium. With the general degree of furnace oversizing in Canada, this means that furnaces rarely run long enough to get to their efficient equilibrium condition.

By reducing firing rate merely by changing nozzle size, the furnace will run longer to satisfy any given thermostat demand. The overall off-cycle time will be reduced and the time that the furnace will be operating in equilibrium over the heating season will be increased. Both of these changes will result in more efficient heating system operation, and reduced fuel consumption.

The available savings are clearly indicated in Figure 4.3. The fuel savings get larger and larger as the outside temperature gets colder. In this particular example, a field trial carried out under actual living conditions, the firing rate was reduced from 1.0 USgph to 0.85 USgph. This firing rate reduction actually resulted in a decrease in steady state furnace efficiency from 79.1% to 78.3%. Even so, a real fuel saving of 9% was experienced in the house over the heating season, for the reasons described in the previous paragraph.

In general, downsizing always reduces stack temperature, and nearly always increases excess air (lowers CO_2). When reducing firing rate one size, steady state efficiency will not change in about half the cases, it will decrease slightly one third of the time and will increase slightly in other cases. IN ALL CASES, IT WILL SAVE FUEL OVER A HEATING SEASON.

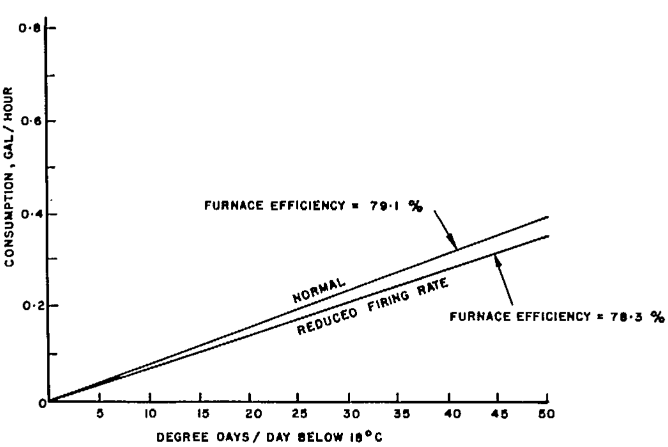


Figure 4.3 Effect of reduced firing rate on fuel consumption

One limitation to this technique to save fuel with many conventional oil burners is imposed because of poor air-fuel mixing when downsizing more than one size below the rating on the CSA certification label. In extreme cases, the excess air can increase to the point where it overbalances the savings from reduced stack temperature and off-cycle losses. This is much less a problem for retention head burners, as outlined in Chapter 5.

A second limitation is imposed by the maximum heat requirements of the individual home under consideration, since reductions in firing rate necessarily reduce the output capacity of the furnace. However, as mentioned previously, most furnace sizing is more than generous.

Remember when downsizing to keep the oil pressure at the design pressure of 100 psig. The misguided conventional wisdom of upping the pressure when lowering the nozzle size will result in no real reduction in firing rate, and the potential savings will be lost.

Figure 4.4 shows the effect of outside temperature on furnace running frequency. Houses C, D and E have already been downsized one size, and still show less than 50% running time at 40 degree days Celsius, while home A, grossly oversized, operates for less than 40% of the time at this temperature. All these units have significant downsizing potential. Only home B, whose furnace runs 70% of the time at this temperature can be considered to be at a proper size.

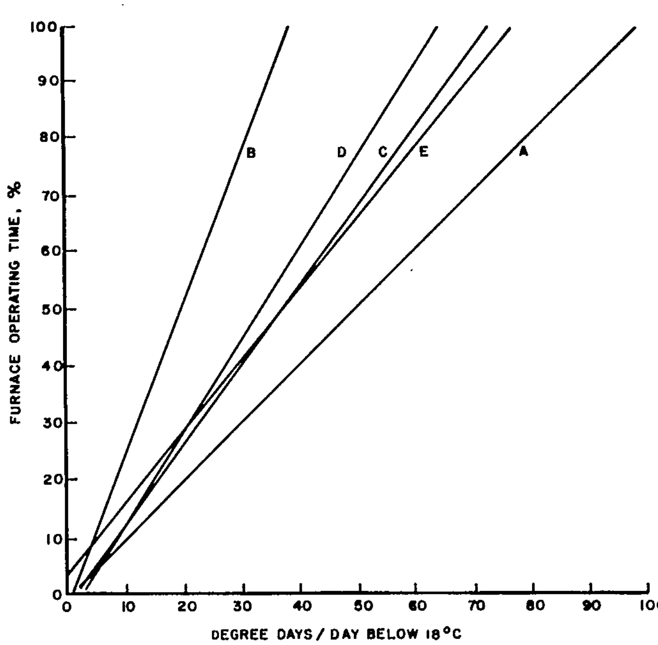


Figure 4.4 Effect of external temperature on furnace running frequency

Speedup of the Circulating Fan

The circulating fan forces the house air over the surface of the heat exchanger, constantly scrubbing away the warmed-up layer of air with a steady stream of cool air. The rate at which this heated layer is removed is the rate at which heat is extracted from the hot combustion gases. The faster the heat is removed from the combustion gases, the less heat goes up the chimney. Thus, there is energy to be saved by increasing the speed of the circulating fan.

Any significant increase in fan speed will be immediately noticeable to the homeowner. The air coming out of the registers might feel a little cooler because it is moving faster, but in fact, more heat is being put into the room and energy is being saved.

Before increasing the fan speed, talk it over with the homeowner to ensure that he or she is agreeable. Be sure the customer is satisfied with the change before you leave the house.

Many circulating fans are fitted with adjustable pulleys, making it simple to vary the fan speed over a wide range. If the pulley cannot be adjusted, it can be changed. The limits on fan speed are at the point where circulation noise becomes objectionable, the blast of air from the registers is uncomfortable, or when the fan motor becomes excessively loaded.

Increasing Circulating Fan Operating Cycle

The bonnet temperatures at which the circulating fan starts and stops are adjustable. Usually the set points are 65.5°C (150°F) and 49°C (120°F). Warm air temperatures for this condition are shown in Figure 4.5.

In nearly all cases, it will be possible to lower the cut-in and cut-out temperatures to 49° and 32°C (120° and 90°F) respectively, in order to squeeze more heat out of the furnace at the beginning and end of the operating cycle.

The air from the registers will be slightly cooler at the beginning and end of the cycle than during the middle. This is another point to discuss with the customer. If it is explained properly, he or she will usually accept this, in order to gain the extra fuel economy.

The obvious extension of this is to run the circulating fan continuously. From the point of view of extracting heat from the furnace, there is some advantage to forcing air through the heat exchanger when the burner is not running. In some houses, the constant circulation may improve comfort by making a more uniform heat distribution, especially where systems are balanced.

However, the majority of homes have poor heat distribution systems and it is very difficult to balance them. In these cases, operating the standard single-speed circulating fan when the furnace is off causes cold drafts in the house in the major living areas, and the homeowner compensates by turning up the thermostat and using more energy. Another thing that must be considered is that the circulating fan motor uses electrical energy, a very expensive form of derived energy. In general, it will cost more to run the fan continuously in terms of the electrical energy used, than can be saved in terms of fuel.

Using a two-speed fan will lessen the above problems, and can make continuous running applicable to some homes. If there is a supplementary source of heat in the house, such as a wood stove or passive solar gain, the low speed can aid in distributing this localized heat to the rest of the house.

In general, the best solution is merely to lower the set point temperatures.

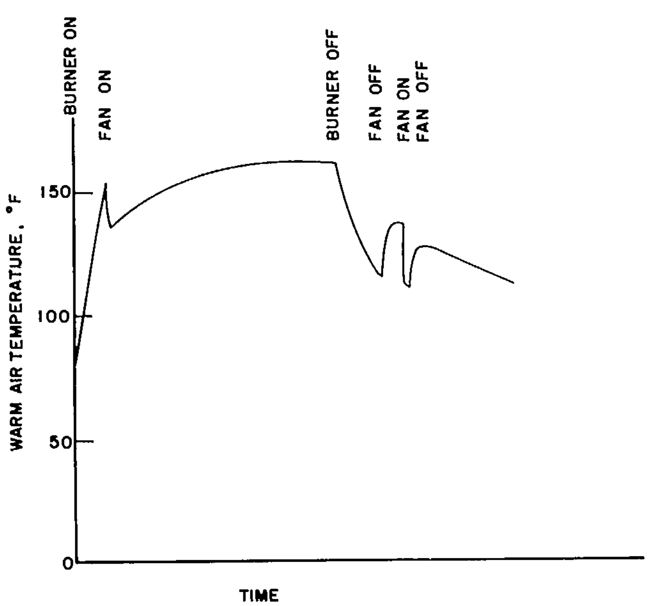


Figure 4.5 Warm air temperature for cut-in and cut-out controls at 150°F and 120°F (65.5° and 49°C)

Heat Distribution Systems

When a heating system is designed for a house, the duct runs should be laid out to take the heat where and when it is needed. If any of the heat ends up somewhere else, then it is effectively wasted.

This often happens when heat is lost through the walls of a distribution duct, with the duct acting as a heat exchanger. Where ducts are run within closed inside walls or ceilings, the heat loss is usually not significant. On outside walls, it can be important; in both cases, however, it is usually very difficult and often impractical to do anything about it.

However, where warm air ducts have long, exposed runs in basements, storage areas, or other similar locations, significant losses occur which can be reduced. Often an "unheated" basement becomes one of the warmer areas in the house due to heat losses from such ducts.

This loss of heat used to be dismissed by assuming that since it was going into the basement, it was going to make its way into the house anyway. Unfortunately, this is often not so. In fact, most of this heat often ends up passing through the commonly uninsulated walls and joist spaces to the outside air and the cold ground. The only purpose this serves is maybe to have flowers blooming a little earlier in the spring around the house – this is certainly not the most efficient way to grow flowers or to save energy! **All exposed warm air ducts over 1.8 m long should be insulated.**

Another practice that is recommended as a first defence against this loss is the **taping of all warm air duct joints.**

The problem with long basement duct runs is often aggravated by many unnecessary right angles to bypass horizontal or vertical building structural supports. Each directional change causes a pressure drop and makes it that much harder to push heat in that particular direction. Tell the howeowner where you see obvious faults.

Taping and insulating the exposed ducts will definitely save fuel. At the same time, it can have the added benefit of allowing the heating systems to be much more readily balanced, and hitherto hard-to-heat rooms distant from the furnace can now be heated comfortably, while using less fuel.

Combustion Air Supply

Occasionally, the homeowner may create a situation where the air supply to the burner may be choked off, causing burner air starvation. One reason why this occurs is that the homeowner builds a tight furnace room, contrary to the building codes, which require 180.6 cm^2 of opening per US gallon firing rate. Another more common reason is competition from other air users in the house – clothes dryers, exhaust fans and, worst of all, open fireplaces.

Air starvation will have the same effect on the burner as closing down the air control – increased smoke and sooting.

The possibility of this condition should be considered in houses where the furnace is enclosed in a tightly built room or small basement where ventilation is limited. If such a condition exists, the installation of an air supply to the furnace room should be recommended. However, connecting a duct from the outside to the cold air return will not help the specific problem of burner air, since the air is going to be distributed throughout the house, and the ducts in the basement should be tightly sealed, unless a specific opening is made in the warm air duct within the furnace room.

If outside air must be brought in to counter burner air starvation, an alternative is to connect a duct to the outside and bring it in to open about 0.9 m from the burner.

IT IS NOT A GOOD IDEA TO ENCLOSE THE BURNER! The reasons are as follows:

1. Combustion air accounts for only 1-2% of the heat requirements of the house, so that tying outside air directly to the burner can result in little potential energy saving.

2. The burner is nearly always set up for best running in the summer. During the winter, with cold outside temperature, the net effect will be to have the burner run at a higher excess air level, and hence, less efficiently.

3. Pressure variations at the outside air intake can give variations in burner air supply, producing soot, and possibly even losing the flame off the burner.

The diluted air allowed through the barometric damper accounts for a much greater air requirement and heat loss from the house than does the combustion air. However, bringing air from the outside is definitely **not** suited to the Canadian climate. If cold outside air is drawn through the barometric damper, it can chill the flue gas. This can cause draft problems, potentially severe corrosion, and possibly, icing in the chimney with potentially catastrophic results.

Again, if air supply to the burner and the barometric damper is a problem, bring it in with sufficient length of ducting to allow some warming and then open the duct into the furnace area at least 90 cm from the burner.

Basement Insulation

As mentioned previously, inadequate or no basement wall insulation can account for a large part of the heat loss from the house, particularly heat directly from the furnace and surrounding ductwork. The insulating effect of wall-to-wall carpets and thick underpads has probably enhanced this loss in recent years, as has the increasingly poor design of the distribution systems and furnace location.

Insulating the basement joist space and the basement walls to at least 0.9 m below grade can make an important contribution to energy conservation. The federal government booklet "Keeping the Heat In" (Reference 9) gives many valuable tips on how to go about insulating this neglected area.

Gravity Heat Distribution Systems

Significant fuel savings can be realized by converting gravity heat distribution systems to forced convection systems, be they warm air or hot water. In the case of hot water systems, inefficiencies can still arise, because a much larger than normal boiler is needed to handle the return water capacity. This problem can often be overcome by the insertion of a bypass system for most of the water, and continuously circulating this bypass flow through the distribution system, as shown in Figure 4.6. This enables the installation of a boiler more properly sized to the house heat demand.

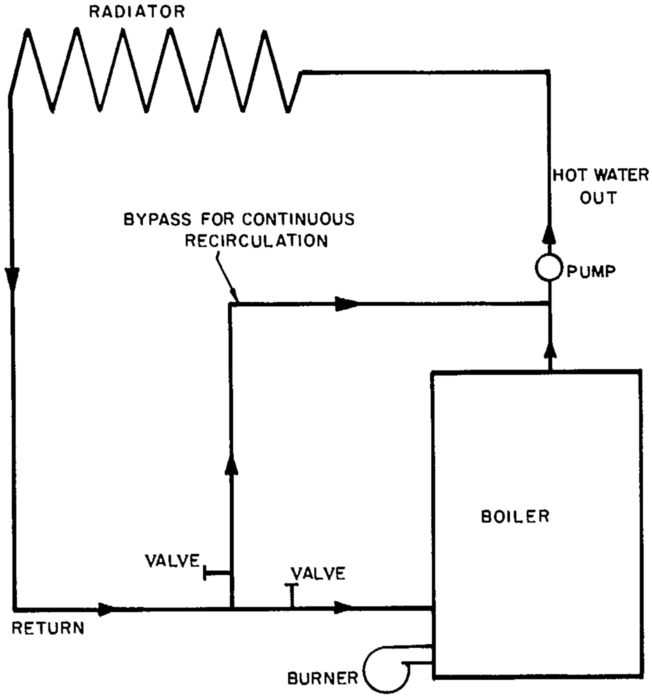


Figure 4.6 Installation of bypass system for forced convection system in what was originally a gravity hot water heating system

CHAPTER 5

RETROFITTING FOR IMPROVED EFFICIENCY

If an efficiency test shows that the performance is poor, there are some adjustments that can be made to bring about an improvement. These are described in Chapter 4. However, if these adjustments do not bring the efficiency of the system up to its now realizable potential, then the possibility of retrofitting existing hardware, or adding new equipment, should be considered.

Retention Head Burner

The retention head burner (Figure 5.1) is designed to mix the air and the oil spray in a vigorous, turbulent action. In particular, the opening for the air around the nozzle is much smaller than for a conventional burner head, such as shown in Figure 5.2. This smaller opening imparts greater momentum to the combustion air, promoting better mixing between the oil and the air. In this way, the retention head (Figure 5.3) allows the burner to achieve complete combustion of the oil with considerably less excess air than is the case with the conventional head burner.

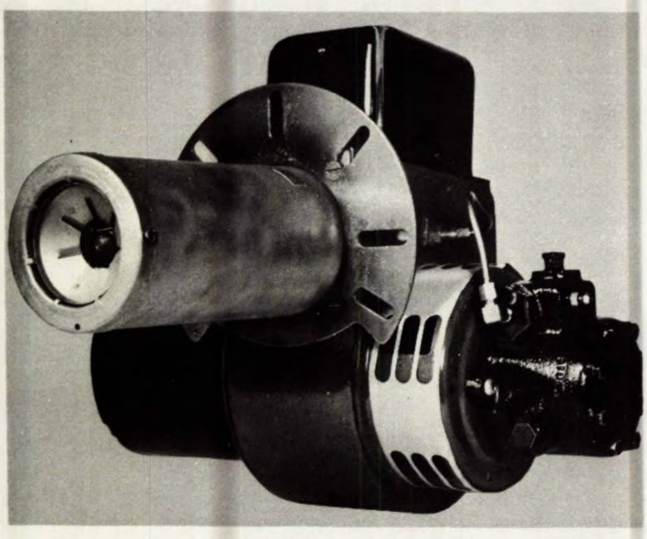


Figure 5.1 Retention head oil burner

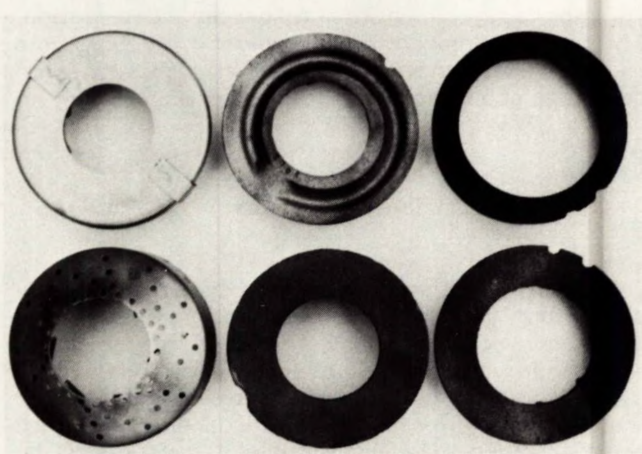


Figure 5.2 Typical conventional burner heads

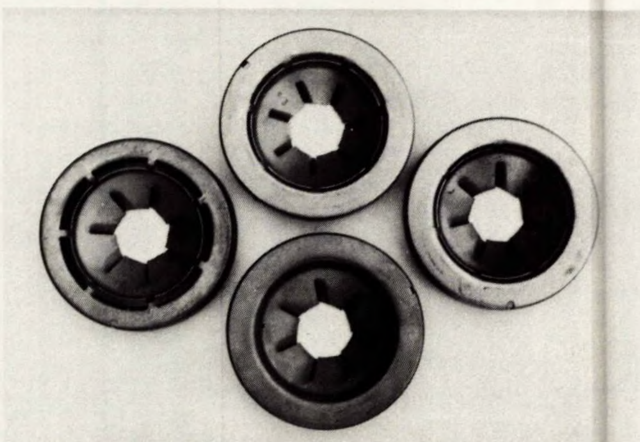


Figure 5.3 Retention heads for different firing rates

Figure 5.4 shows two sets of performance curves for the same furnace, one with a conventional cast iron head burner and the second with the same basic burner retrofitted with a retention head. A comparison of the two demonstrates that with the retention head, the entire range of operation is shifted to the right – that is, to levels of lower

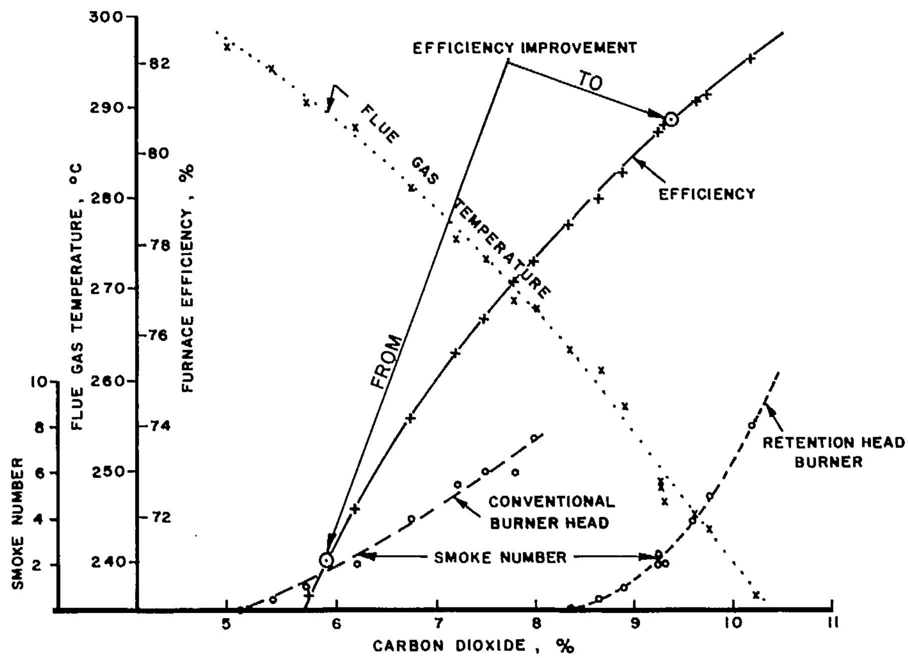


Figure 5.4 Efficiency improvement of domestic oil burner when retrofitted with a retention head

excess air. With the retention head, the onset of smoke occurs at an excess level equivalent to 8.5% CO_2, a point at which the smoke number is at an intolerable level of above 9 for the conventional head. Because of this inherently lower excess air, the efficiency range of the retention head burner starts at a point higher than the maximum for the cast iron head. In this case, for a smoke number of 2, the retention head gives a steady state efficiency of over 81%, while the conventional head yields an efficiency of only 73%.

Along with higher efficiencies, the retention head burner also operates at higher flame temperatures than a cast iron head burner at the same firing rate, although the stack temperatures are reduced significantly, due to the lower mass flow through the system.

The flame temperatures are higher because with less excess air there is less chilling of the flame. For this reason, it is **required that the firing rate be reduced by at least one standard nozzle size when a burner is fitted with a retention head,** to protect the combustion chamber and the primary heat exchanger. This reduced firing rate gives approximately the same input to the house as before, since the efficiency is improved.

In addition, if the combustion chamber is made of stainless steel or firebrick, it must be fitted with a ceramic fibre lining. If this is not done, the higher flame temperatures achieved with a retention head may exceed the temperature that stainless steel or firebrick can withstand, leading to burn-out of the combustion chamber.

Figure 5.5 shows the field result of retrofitting a retention head on heating system performance. The consumption has been reduced considerably, in the same general fashion as if the demand had been lowered. In this particular case, steady state efficiency was increased from 68% to over 82%, with fuel savings of more than 20%.

The retention head, with its superior air-fuel mixing, allows a significantly greater degree of downsizing than do conventional heads, while still maintaining superior excess air performance. The discussion on nozzle downsizing in Chapter 4 explains that reducing the firing rate saved fuel even at slightly lower steady state efficiency. Hence, a retention head retrofit, coupled with a significant firing rate reduction, yields the combined large fuel savings available from both steady state efficiency improvement and firing rate reduction.

Many existing burners with various designs of conventional heads may be retrofitted with a retention head at a fairly low cost, giving almost the same performance as a new retention head burner. Kits will be available to fit many common types of burners, making the modification jobs fairly straightforward. These kits must be CSA certified for specific burner makes and models (Reference 6). In some cases, some cutting and fitting may be necessary to reposition the nozzle.

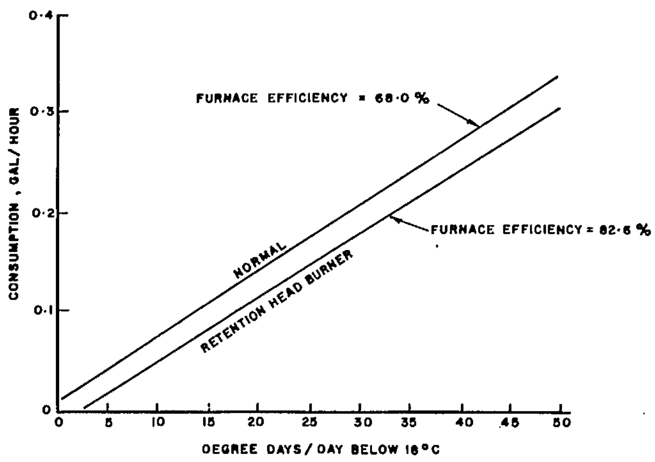


Figure 5.5 Effect of improved burner performance on fuel consumption

Replacing a conventional burner head with a retention head is not a simple ten-minute task with a screwdriver. Nor is it so complicated a task that you should try to avoid it. However, you must understand how to do the job and be aware of possible problems before starting.

In general, there are four parts to the job:

1. Decision
2. Selecting firing rate
3. Selecting new head
4. Installation

Each of these parts can be broken down into a series of steps. The entire procedure is shown in Figure 5.6 in flow chart form, and can be described as follows:

Decision

1. Examine the furnace and burner carefully. If it is very old or shows serious signs of corrosion, a retrofit is probably not justified. Carry out normal servicing and if the condition or efficiency results are poor, suggest to the homeowner that he or she consider replacing the unit.

2. If the furnace is in reasonable condition, determine whether a CSA certified retention head kit is available for the burner. Some odd-sized blast tube diameters or unusually designed burners cannot be matched to available retention heads. If no CSA certified kit is available, retrofitting the burners is not permitted.

3. Carry out an efficiency test. If the efficiency is greater than 77%, there is little to be gained by retrofitting, although, if the furnace is considerably oversized for the house, a retention head in conjunction with significant downsizing might be desirable. However, the need to maintain a stack temperature above 175°C (350°F) and the small potential savings must be weighed against the cost of a retrofit.

4. If the efficiency is less than 77%, a retention head is indicated, and such a conversion becomes more desirable if the efficiency is significantly below this value. The next step is to determine the new firing rate.

Selecting the New Firing Rate

The lower the firing rate, the more efficiently the furnace will operate over the heating season. Two things place a limit on the extent to which a furnace can be downsized, however. The steady state stack temperature must not be below 175°C (350°F), to prevent condensation in the chimney, and the furnace must be capable of heating the house during the coldest time of the year.

In practice, most furnaces have stack temperatures well above the minimum figure, and furnaces tend to be considerably oversize. As well, the addition of insulation in many homes has made furnaces even more oversize.

The optimum firing rate for a given home can be determined using one of a number of standard reference procedures. In particular, Appendix B contains a simplified method for use where past fuel consumption is known. Keep in mind that many of the accepted methods of calculation are excessively conservative, and may indicate nozzle sizes considerably above what is actually required. However, when combined with experience, they are a guide to the range in which to work.

Once the desired firing rate is known, an estimate can be made of the stack temperature. Switching from a conventional to a retention head will lower the stack temperature approximately 30°C (70°F), and each drop of one nozzle size will drop stack temperature roughly 25°C (50°F). These numbers are approximate but give some guideline to initial nozzle selection. If moving to the desired nozzle size seems likely to result in too low a stack temperature, a nozzle one size larger may have to be used.

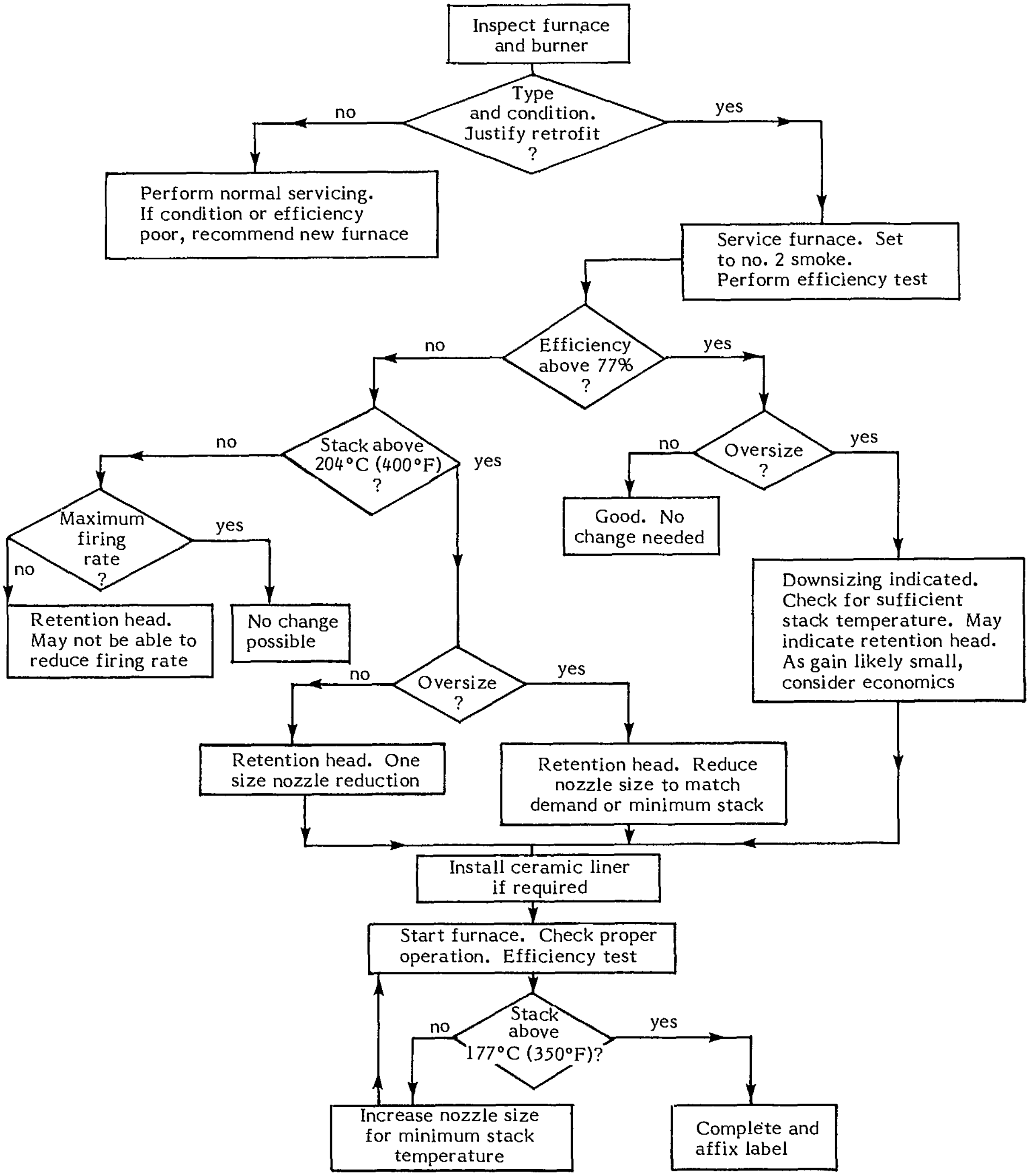


Figure 5.6 Flow chart for retrofitting retention head on conventional burner

Selecting the New Head

The manufacturers of retention heads provide selection charts for matching retention heads and nozzles. In some cases, there is an overlap where two retention heads could be used for a particular nozzle. Where there is a choice, always use the smaller rated retention head to achieve the greatest efficiency.

Installation

1. Read the installation instructions in the kit and follow them precisely.

2. Tolerances are critical since the opening in the head is much smaller than before. Ensure that the nozzle and oil line are exactly centred. Any off-angle will cause the spray to hit the head and coke up rapidly.

3. Most retention heads require a distance of 2.8 cm (1 1/8 inch) between the face of the head and the tip of the nozzle.

4. Check that the electrodes are not too close to the head. Bend or change the electrodes as necessary to give sufficient clearance. The settings of the electrodes are 0.3 cm apart, 0.15 cm ahead of the nozzle and 1.1 cm above the centre of the nozzle (1/8, 1/16, 7/16 inch) unless otherwise indicated by the manufacturer (see Figure 5.7).

5. Check that the oil line support in the blast tube is snug. If it allows sideways movement of the nozzle, then it must be changed.

6. Ensure that the cadmium (cad) cell on burners equipped with these devices has an unobstructed view of the flame area. It may be necessary to reposition the cell since the opening at the retention head is normally much smaller than that of a standard head.

7. If a ceramic liner is not already fitted, **or the combustion chamber is in direct contact with the metal walls of the primary heat exchanger,** a ceramic liner must be installed. This is because a retention head produces a hotter flame than a conventional head, and could burn through many materials that were adequate at lower temperatures.

8. If the furnace has a corbelled combustion chamber (that is, a true corbel where the area of the top of the chamber is significantly less than the area of the chamber), there is a possibility of getting a large amount of heat reflected back on the nozzle and head. This can result in rapid coking of these components, or in some cases, burning out of the combustion chamber. To avoid this problem, if the combustion chamber is a ceramic type, cut off the corbelled top of the chamber. If a firebrick or stainless steel chamber has been used to form a corbel, intall a ceramic liner **without** a corbel in the chamber.

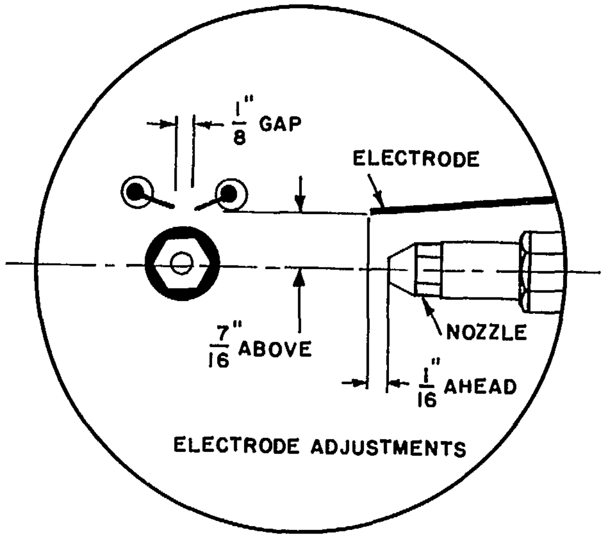


Figure 5.7 Typical electrode settings with retention head

9. Reinstall the burner in the furnace and proceed with the normal set-up and adjustments previously described.

10. Conduct an efficiency test on the retrofitted furnace. Note that the stack temperature should remain above 175°C (350°F). If the nozzle size has been reduced to the point where the stack temperature falls below this level, then the nozzle size should be increased, or the air band opened up slightly to bring the stack temperature up to the minimum.

11. Complete the appropriate warning labels and attach them to the furnace. Include the efficiency test results and the installed nozzle size. Note also the new maximum firing rate of the furnace, as this will be less than the original furnace rating.

Delayed Action Solenoid Valve

When a conventional burner starts up, the oil begins to spray into the combustion chamber before the pump reaches its design pressure of 100 psig. At the same time, the air pattern is not completely established. On ignition, the result is an extremely smokey flame, as shown in Figure 2.5.

This only lasts for a short time but produces an inordinate amount of soot. If delayed ignition occurs, then the problem is compounded and soot and fumes may enter the house.

A similar situation occurs at the end of the burning cycle. When the burner shuts down and the flame goes out, the pressure at the outlet of the pump does not immediately disappear. In fact, a syphoning action occurs, and a weak oil spray continues for a short time over the still-hot nozzle. This produces severe coking of the fuel and a large amount of carbon. Also, the rest of the oil burns with very little air, the blower having stopped. This also results in a large amount of soot, which is deposited on the burner head and the heat exchanger. It is conceivable that, over time, weakening of the shut-off spring and wear in the pump could accentuate the problem. Figure 2.5 shows a typical shut-down soot formation for a conventional burner.

The **delayed action solenoid valve** minimizes all of the problems described above. It is fitted into the oil line between the pump outlet and the nozzle. When the burner is switched on, the solenoid valve prevents the oil from reaching the nozzle for about 10 seconds. By this time, the blower is up to full speed and the pump at design pressure. When the burner shuts off, the solenoid valve immediately closes off the oil line completely, preventing any more oil from reaching the nozzle. This results in a significant reduction in soot formation so that less deterioration in heat exchange efficiency can be expected over a heating season, and the burner can be run at a lower excess air level and a higher steady state smoke number (1-3) resulting in greater efficiency. Further benefits are that call-backs due to furnace puffs, sooting or odour on ignition are reduced significantly.

Another means of attacking this problem is with a **clutch coupling** fitted between the blower shaft and the pump. It has a slip clutch which lets the blower come up to speed before the pump starts, and allows run-on of the blower after the burner shuts down, continuing to supply combustion air for the oil which is being syphoned onto the nozzle.

Performance improvements when the clutch coupling is in good condition are similar to those offered by the delayed action solenoid valve. However, the clutch coupling must operate in a dirty, oily environment. Thus, it sometimes has significant reliability problems, particularly where oil vapours are deposited on it, resulting in slipping of the clutch. If this happens, performance is worse than if no device at all were used.

At this time, it appears that the delayed action solenoid valve offers overall performance advantages and should be fitted to all gun-type domestic burners. For best results, the solenoid should be fitted as close to the burner oil tube (and hence nozzle) as possible, according to the manufacturer's instructions. Also remember that open wiring is not allowed in most provinces, so that metal sheathing should be used to cover the wires.

Positive Chimney Damper

When the burner switches off, the chimney draft will continue to draw heated air from the house through the burner and furnace as well as through the barometric damper. This results in two distinct heat losses. First, heat remaining in the combustion chamber and heat exchanger is carried up the chimney along with the warm air passing through the burner. This becomes a slightly greater loss for hot water systems than for warm air ones, since the water in the heat exchanger stores a considerable amount of heat. Second, the flow of heated room air through both the burner-furnace and barometric damper to the chimney constitutes another significant heat loss; this air must be replaced by an equal amount of cold outside air.

To reduce the heat loss up the chimney when the furnace is not operating, a positive chimney damper may be fitted onto the flue pipe downstream of the barometric damper, as shown in Figure 5.8. The damper is designed to close the flue when the furnace is off and to open it again before the furnace starts. An interlock switch must prevent the burner from starting if the damper is not fully open. In Canada, only a chimney damper for oil-fired appliances which has been approved by CSA (Reference 4), as well as by the local authority having jurisdiction, should be installed in strict accordance with manufacturer's instructions.

Figure 5.9 shows a comparison of fuel consumption in a house with and without a positive chimney damper. Depending on the particular installation, oil savings of 3% to 9% can be expected. It is interesting to note the shape of the consumption profile with the damper. Savings are greatest in mild weather and decrease rapidly as the temperature gets colder, when the furnace runs longer and the off-cyle time is reduced. Hence, savings are greatest on over-fired systems operating in generally mild climates. The greater the degree of nozzle downsizing practised, the less the available savings from a chimney damper.

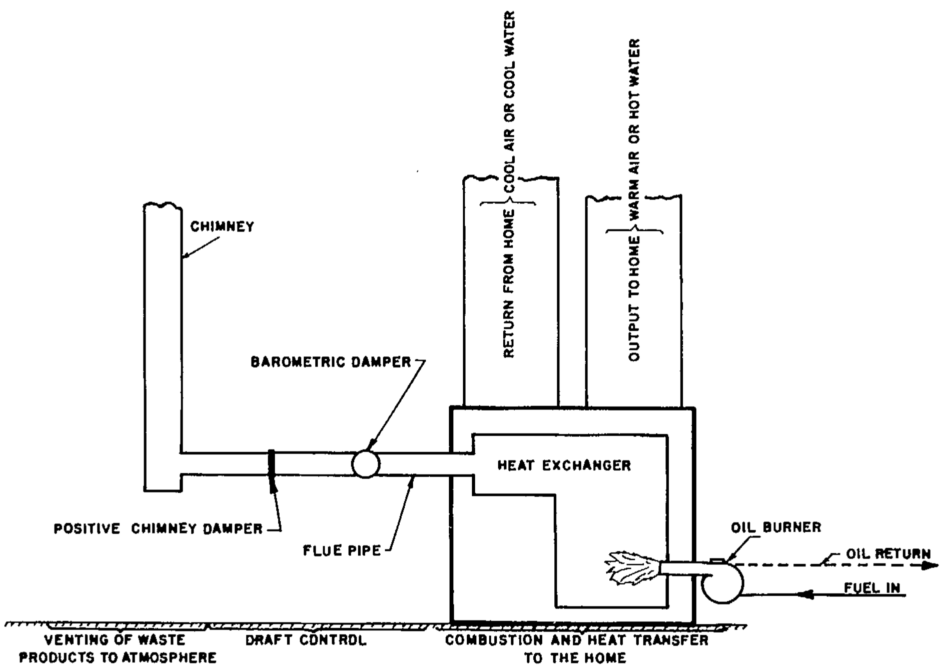


Figure 5.8 Oil furnace/boiler schematic showing location of positive chimney damper

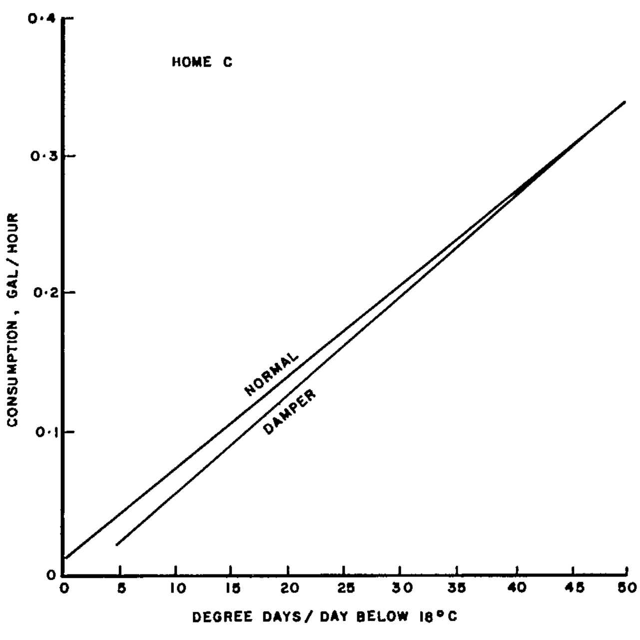


Figure 5.9 Effect of positive chimney damper on fuel consumption

CHAPTER 6

ADVISING THE CUSTOMER

As the cost of home heating increases, the need for more efficient home heating systems becomes greater. Homeowners are increasingly seeking means of reducing their annual oil consumption. They are starting to ask questions and expect you to have the answers. The serviceman who can't give the right answers is in trouble.

Air Filters

Clogged air filters slow down the flow of air through the heat exchanger and reduce the efficiency of the furnace. However, you are present only once a year to change the filters. Take the time to show the customer where the filters are and how to clean or change them. Explain that vacuuming can extend the life of disposable filters by 2 or 3 times. Make the customer realize that a regular habit of changing or cleaning the filters monthly will pay off.

Stack Thermometers

Many customers will take a close interest in the steady state furnace efficiency test. Suggest the purchase of a thermometer in order to measure the stack temperature at intervals throughout the season. In this way, he or she can monitor at least one aspect of efficiency and can call you back when the temperature rises significantly. Good thermometers are available which are not too expensive, and a few minutes of explanation will be all that is required for its use.

Registers and Radiators

Registers or radiators that are covered with mats or furniture or are choked with dust and debris will not permit proper circulation of air. Homeowners often don't realize the importance of keeping registers free.

Thermostat Cutback

This is the easiest and most effective way to save fuel. Just tell the customer to lower the house temperature a bit during the day and a lot at night. There is no measuring or cutting, nothing to buy – he or she just has to do it and the fuel saving will be significant. (Refer to Chapter 4.)

Insulate and Seal the House

Heat is lost from a house by conduction through the walls, floor, roof, windows and doors. Heat is also lost by convection or drafts around doors and windows, through cracks, and through other openings such as fireplace flues. Make the homeowner understand that insulation, caulking, and weather-stripping are as important to keeping fuel consumption down as furnace efficiency, and advise him or her to get the booklet "Keeping the Heat In" (Reference 9). Even if the house is fairly new, there may still be room for improvement.

For example, if the basement walls are not insulated to at least R-7 (RSI 1.23) down to the floor, they could account for as much as 20% of the heat loss from the house. The point where basement joists meet the outside wall is another major source of heat loss and should be insulated to at least R-12 (RSI 2.1).

In calculating steady state efficiency, people have rationalized the radiation loss from the furnace casing, saying the heat goes into the house. In fact, it is more likely to go directly outside, through uninsulated basement walls, and even more so today because of thick wall-to-wall rugs and insulating underpads upstairs in the major living area. Just look outside in the winter and watch the snow melt away beside the house. Thus, advise homeowners to insulate their basement walls and joist spaces.

Fireplaces and Wood Stoves

One thing often overlooked and misunderstood is the fireplace. The net heat benefit from most built-in fireplaces is very small and often actually causes a net heat loss. This is because the enormous amount of excess air pumped up the chimney by the fire draws an equally enormous amount of cold air into the house from outdoors.

The flue damper is often forgotten and left open for long periods after the fire is out (or even the whole winter) and still more cold air is drawn into the house. Measurements have shown that the use of a fireplace actually increases the oil consumption in some cases. Thus, tell the homeowner to at least close the damper when the fireplace is not being used – better still, to close it up completely.

On the other hand, an airtight wood stove can be an effective complement to a conventional central heating system. Field tests by CCRL have shown that well-designed stoves of either sidedraft or horizontal baffle type, when located in a major living area, can be as efficient as an oil or gas furnace.

CHAPTER 7

FUTURE TECHNOLOGY

Low Firing Rate Burner

In Chapter 4, under Nozzle Downsizing, it was explained how a reduced firing rate leads to longer on-cycles, which in turn lead to the furnace running in the more efficient steady state mode for longer periods, at the same time reducing the off-cycle loss. Oil burner nozzles for domestic furnaces are presently not available for less than 0.5 US gallon per hour. However, work is being carried out to develop burners that can fire at significantly lower rates, making longer on-cycles possible. It is anticipated that other advanced high-efficiency burners will appear on the market in the near future. An alternative is combining space and tap water heating, as discussed below.

Modulating Burner

An approach to continuous firing is also being studied. This involves a modulating burner capable of being fired at a continuously variable rate from 0.2 gph up to at least 0.8 gph. This type of system has the potential of increasing efficiency considerably, in comparison with existing systems, although problems can result from condensation in the heat exchanger at the lower firing rates.

Advanced Heat Reclaimers

There are instances where the stack temperature is high, and there is no straightforward way to reduce waste heat up the chimney by burner modifications, as previously described. In such cases, a heat reclaimer designed to extrct heat from the flue gases may be a solution. These devices are made in a variety of designs, but are usually mounted in the flue pipe after the furnace.

Sooting is one major problem with any heat reclaimer that really does extract significant amounts of heat without creating an undesirable pressure drop. This tends to reduce the heat output of most good performers fairly quickly. However, improvements in design and materials may have solved this problem. Generally, however, it is more energy- and cost-effective to reduce stack temperature by improving burner performance, and hence lowering excess air requirements, and by nozzle downsizing, than by adding on an additional heat exchanger, unless the latter is incorporated in the furnace system, as in the furnaces described below.

Advanced Furnace Designs

New developments are yielding more efficient oil furnaces, often with positive venting of combustion products and no dilution air requirement. Many of the new designs may be safer and more appropriate for tight housing, while being from 10 to 20% more efficient than even the flame retention head burner systems, or as much as 37% more efficient than conventional oil or gas furnaces.

Mid Efficiency Oil Furnace

The mid efficiency oil furnace is one which eliminates the need for the dilution device (barometric damper, which requires huge amounts of air), without condensing the flue gases. This may be accomplished in one of two ways:

1. by using an induced draft fan downstream of the furnace heat exchanger, which pulls the combustion gases through the furnace and propels them up the stack;
2. by using a forced draft system with a high pressure drop burner, with some restriction within the furnace to isolate the burner from outside pressure fluctations.

Both techniques also make off cycle losses negligible.

Eliminating the dilution device with its large yet variable air requirement, allows an exact knowledge of the quantity of flue gases the venting system must handle. In turn, the venting system may then be sized and insulated exactly, allowing a further increase in steady state efficiency in the furnace, reducing the Dry Flue Gas Loss (sensible heat). The transient losses are also minimized. The seasonal efficiency of this furnace type is almost the same as the steady state value.

Fuel saving relative to conventional furnaces would be from 19% to 31%, depending on the furnace design, with seasonal efficiencies up to 88%.

Compared to a flame retention head-equipped furnaces, savings could be at least 10%, even though the steady state efficiencies might be the same.

Additional benefits are reduced reliance on natural draft, much lower total air requirements and a safety shutoff in the event of flue blockage or reversal. Knowing the exact quantity and temperature of flue gas to be delivered to the chimney base allows proper sizing of the chimney to ensure adequate capacity, with little danger of condensation in the system.

Combined Space and Tap Water Heating System

A mid efficiency unit, combining space and tap water heating requirements with energy storage in the form of a tap water tank, would allow the efficient use of oil in very low energy housing, even with the present firing rate limitation of 0.4–0.5 USgph. In this case, the furnace would continue to run in its most efficient mode after the thermostat has been satisfied, supplying heat to the tap water storage tank, to be utilized later.

Condensing Furnace

Number 2 oil and natural gas both contain hydrogen which, on combustion, forms water vapour, which is "boiled" in the flame, tying up energy in the form of latent heat. In comparison to oil, natural gas has twice the hydrogen content, making its flue gases much more moisture-laden than oil. This results in the fixed "hydrogen loss" of about 12% for conventional gas-fired units. A similar oil-fired unit, with much less water vapour in the flue gas, has a hydrogen loss of only about 6%. The condensing oil furnace makes a conscious effort to recover some of the latent heat described above, by condensing some of the moisture from the flue gases in an additional heat exchange section. Because the flue gas temperature is so low with any condensing furnace, no chimney is required. Combustion products are merely vented through an outside wall via a plastic pipe and condensate sent to the drain.

With oil containing much less hydrogen than does natural gas, the potential for efficiency improvements with oil by condensing the flue gas is poorer – the dewpoint is lower, so one must work harder to condense less. Also, with much higher sulphur levels, the condensate is more corrosive, so that any condensing heat exchanger for oil must be even more corrosion resistant. The fact that oil combustion also produces a certain amount of soot, which can concentrate the acidic condensate at certain points on the heat exchange surface, makes things even more difficult.

This furnace can be 5–10% higher in terms of efficiency than the mid efficiency type described previously, if it can eliminate the need for a dilution device. However, some of the water spray condensing designs require a barometric damper, and even leave the conventional chimney connection open, along with using the plastic vent pipe out the side wall. In this case, much of the flue gas may go up the chimney without passing through the condensing section. The seasonal efficiency with such units is not nearly as high as the steady state. Indeed, it can actually be lower than for the mid efficiency furnace.

Both the mid efficiency and condensing oil furnaces offer major efficiency advantages over conventional existing appliances, much more than can be seen merely by the differences in their steady state efficiencies. However, the condensing furnace may be much less attractive for oil than for gas, because of all the potential problems and costs. On the other hand, the mid efficiency oil furnace offers nearly the same efficiency advantage, without the drawbacks of condensing.

Table 7.1 presents the steady state and seasonal efficiencies for the different oil technologies discussed in this manual.

Table 7.1 Efficiency of various oil furnace technologies.

Furnace Type	Steady State Efficiency	Fuel Savings re Conventional	Seasonal Efficiency
Conventional	73%	base	60%
Chimney Damper	73%	3–11%	62–68%
Flame Retention Head Burner	78–84%	10–20%	67–75%
Mid Efficiency Furnace	75–88%	19–31%	74–87%
Condensing Furnace	90–96%	29–37%	85–95%

REFERENCES AND BIBLIOGRAPHY

1. Brown, T.D., Comparative Performance Characteristics of Typical Oil-Fired Domestic Space and Water Heating Appliances; compendium of reports produced by CCRL for Ontario Petroleum Association, 1975.

2. Brown, T.D., Performance of Vane Swirlers in Domestic Oil Burners; FRC 72/59, 1972.

3. Burkhardt, C.H., Domestic and Commercial Oil Burners; McGraw-Hill, 1969.

4. Canadian Standards Association, Automatic Flue Pipe Dampers for Use with Oil-Fired Appliances; CSA Standard B140-14, 1979.

5. Canadian Standards Association, Installation Code for Oil Burning Equipment; CSA Standard B139, 1979.

6. Canadian Standards Association, Replacement Combustion Heads for Residential Oil Burners; CSA Standard B140-2.3-M, 1979.

7. Don, W.A., The Efficiency of Domestic Oil Burning Boilers at Reduced Load; Energy World, January 1976.

8. Energy, Mines and Resources, The Billpayer's Guide to Heating Systems; M-27-10/1983E.

9. Energy, Mines and Resources Canada, Keeping the Heat In – How to Reinsulate Your Home; Office of Energy Conservation, M92-1/1983, 1983.

10. Friedrich, F.D., Combustion Handbook for Canadian Fuels – Fuel Oil; Volume I, Mines Branch Monograph 877, 1969.

11. Hayden, A.C.S., Braaten, R.W., Brown, T.D., Emissions and Energy Conservation in Residential Oil Heating; Journal of the Air Pollution Control Association, v.28, No. 7, July 1978.

12. Hayden, A.C.S., Braaten, R.W., Brown, T.D., Oil Conservation in Home Heating; ASME Journal of Engineering for Power, January 1977 and ASME Paper No. ASME 76WA/Fu-8, 1976.

13. Hise, E.C., Seasonal Fuel Utilisation of Residential Heating Systems; ORNL-NSF-EP-82, April 1975.

14. Janssen, J. and Bonne, U., Improvement of Seasonal Efficiency of Residential Heating Systems; ASME Paper 76-WA/Fu-7, December 1976.

15. Katzman, L. and Weitzman, D., A Study to Evaluate the Effect of Reducing Firing Rates on Residential Oil Burner Installations; ABCOR, Contract 6-35738, NBS Center for Building Technology, U.S. Dept. of Commerce, 1977.

16. Rasmussen, P.H., Operational Efficiency and Hot Water Capacity of Oil-Fired Domestic Boilers; Royal Institute of Technology, Department of Heating and Ventilating, Stockholm, Sweden, 1979.

17. United States Environmental Protection Agency Guidelines for Residential Oil-Burner Adjustments; EPA-600/2-75-069-a, 1975.

APPENDIX A

DETERMINING EFFICIENCY

The basic principle for determining efficiency is fairly simple. The heat energy content of the fuel is known. What goes up the chimney is lost. The difference between the two is the useful heat output of the furnace. Expressing this as a mathematical formula:

$$\text{efficiency} = \frac{(\text{heat in (fuel)} - \text{heat lost}) \times 100}{\text{heat in (fuel)}}$$

Three components go up the chimney when the furnace is running: dry flue gas in the form of superheated steam formed from the combustion of hydrogen in the fuel, and products of incomplete combustion consisting of carbon monoxide and soot (carbon) particles.

Dry Flue Gas Loss

A quantity of air in excess of that needed to burn the oil is drawn into the furnace. This excess air is mixed with the combustion gases and is heated to the stack temperature. The sensible heat energy in the combustion gases and excess air at the stack temperature is the dry flue gas loss. The amount of energy lost in heating dry flue gas depends directly on the quantity of excess air and the stack temperature.

Hydrogen Loss

When oil is burned, a quantity of hydrogen is produced which combines with oxygen to form water. The heat of the fire converts the water to steam and then heats the steam to the stack temperature. The heat energy required to convert the water to steam and then to raise the temperature of that steam from the boiling point to the stack temperature is the hydrogen loss.

Since the hydrogen loss depends only on the quantity of fuel burned, and not on excess air, the amount of energy lost depends only on stack temperature.

Loss Due to Incomplete Combustion

Carbon monoxide produced in the flue gas due to incomplete combustion has greater heat content than the completely burned carbon dioxide. That is, carbon monoxide can be burned in oxygen to produce carbon dioxide plus heat. That amount of heat that remains locked in the carbon monoxide is the heat loss due to incomplete combustion.

The same consideration applies to soot particles in the flue gas. However, unless a furnace is grossly out of adjustment or otherwise defective, these losses will be less than 0.1%, and can be ignored. Typical carbon monoxide production for domestic burners is 40 ppm.

Measurement

A laboratory measure of the steady state efficiency of an oil furnace consists of determining the dry flue gas loss, hydrogen loss and incomplete combustion loss. The total heat losses and the heat content of the fuel burned are then used in the formula to calculate the efficiency. More complete descriptions of how these are determined, in concert with Figures C. 3, C. 4, and C. 5 in Appendix C, are given in Reference 10.

APPENDIX B

CALCULATION OF OPTIMUM NOZZLE SIZE

The following formulae allow calculation of optimum nozzle size for a house where records of previous fuel consumption are known. Optimum size is determined in two steps:

A. Nozzle size (USgph):

$$\frac{18 - \text{design temperature (°C)}}{20K}$$

where

$$K = \frac{\text{degree days for a given period (°C)}}{\text{fuel consumption over same period (imp. gal.)}}$$

For fuel consumption in litres the K factor can be calculated as

$$K = \frac{\text{degree days for a given period (°C)}}{.22\ (\text{fuel consumption over same period (L)})}$$

B. Efficiency change correction:

Optimum nozzle size =

$$\frac{\text{(nozzle size from A)(\% efficiency as found)}}{80}$$

The graphs on the following pages allow determination of nozzle size without the need for mathematical calculation.

Example 1:

Winter design temperature: -18°C

Oil consumption Nov. 16 fillup to Feb. 10 fillup: 5800 litres

Degree days C over this period: 3850

Measured furnace efficiency: 73%

If this furnace is to be fitted with a retention head, what would the optimum size nozzle be?

Using the chart at the top of page 37, draw a line up from 3800 degree days and across from 5800 litres. The intersection point is on the K factor of 3 line. Draw a line up from this K factor on the chart on page 38 and across from the winter design temperature of -18°C. The intersection point is on the line for a 1.2 USgph nozzle. If the furnace efficiency was unchanged, this is the size of nozzle which would be optimum for this furnace and home.

However, the efficiency will hopefully be improved, which will allow the use of a smaller nozzle. If the new efficiency is assumed to be at least 80%, the chart on page 39 can be used to determine the final nozzle size required. Draw a line upward from the 1.2 USgph figure, and across from the measured as-found efficiency of 73%. The intersection point is just below the 1.1 USgph line. Thus the optimum size nozzle for this unit after retrofitting will be **1.1 USgph.**

Example 2:

Over a heating season of 4200 degree days C a home used 950 imperial gallons of oil. The winter design temperature for the area in which this home is located is -10°C. The furnace steady state efficiency was 69%. What size nozzle should be used in retrofitting this furnace?

For fuel consumption in imperial gallons use the chart on the bottom of page 37 to determine the K factor. A line drawn up from 4200 degree days and across from 950 gallons intersects midway between the 4 and 5 K factor lines. So use a K factor of 4.5. Using this value in the chart in Figure B.3, a line drawn up from 4.5 and across from the design temperature of -10°C intersects between the .6 and the .65 USgph nozzle lines. Using a value of .63 in the chart on page 39, a line drawn up from this value and across from 69% intersects midway between .5 and .6 USgph nozzle lines. Use the larger nozzle size, in this case **.6 USgph,** as the optimum size for this furnace.

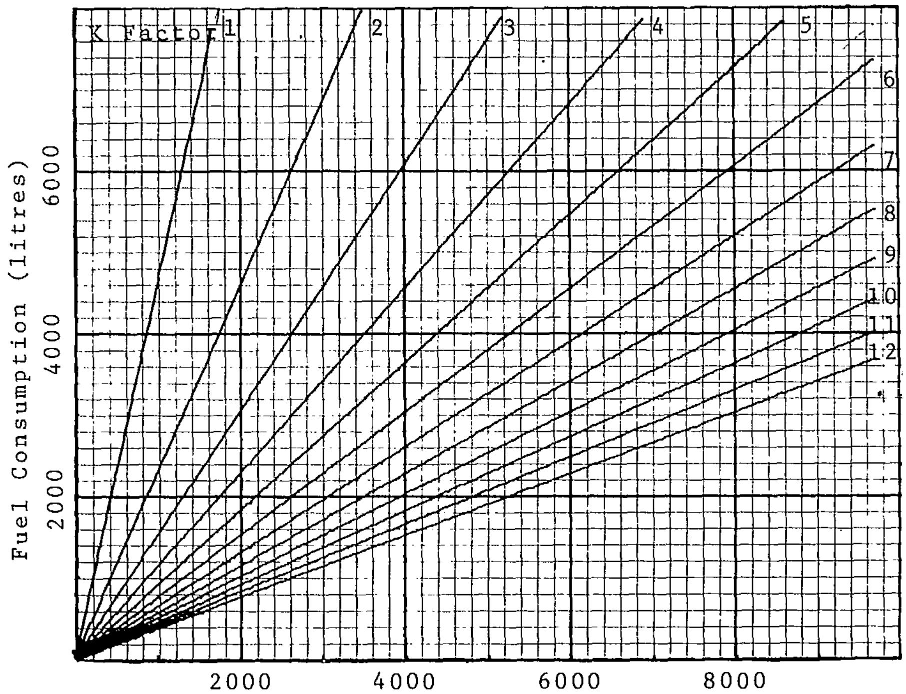


Figure B.1 K factor determination using degree days (C) and fuel consumption in litres

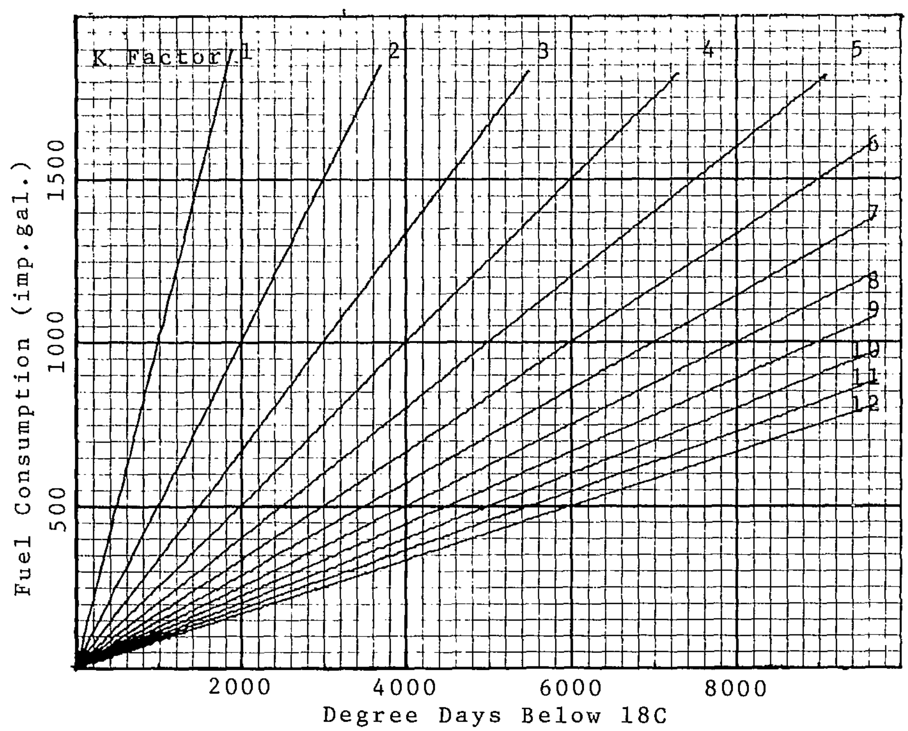


Figure B.2 K factor determination using degree days (C) and fuel consumption in gallons

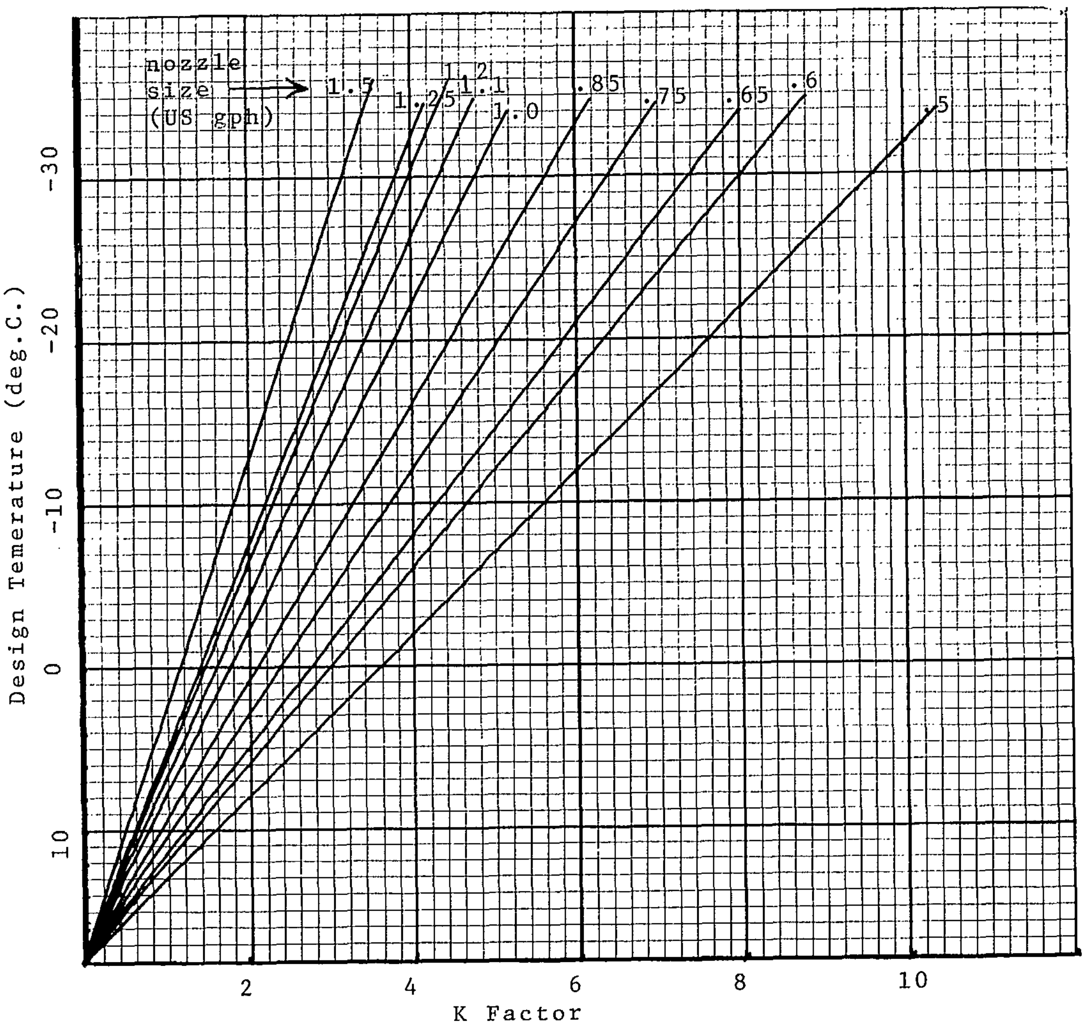


Figure B.3 Selection chart for nozzle size based on K factor and design January temperature

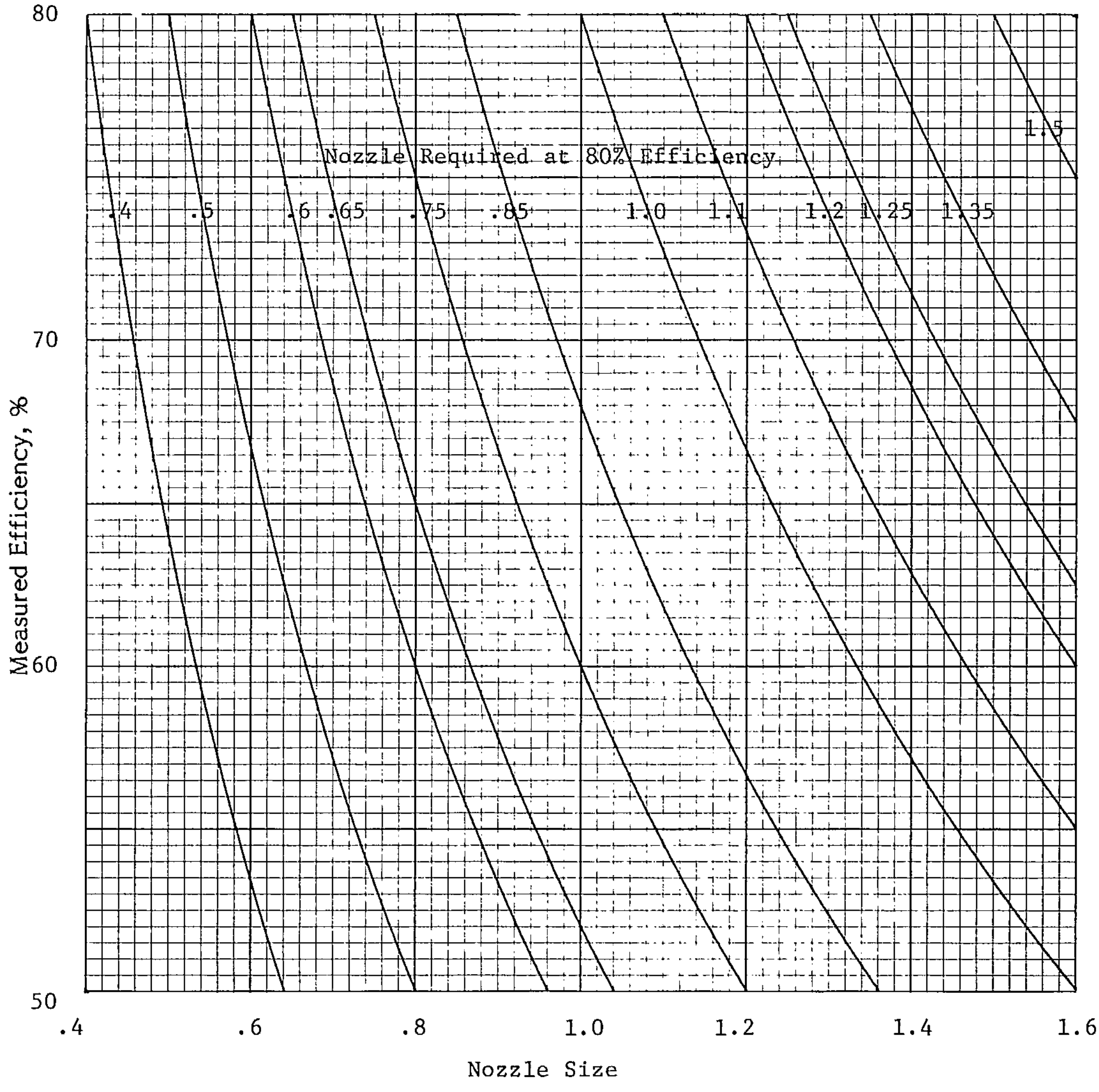


Figure B.4 **Optimum nozzle size (USgph) at measured steady state efficiency and at 80% efficiency**

APPENDIX C

COMBUSTION CURVES – NO. 2 FUEL OIL

Ultimate analysis, kg/kg:

Carbon	0.8642
Hydrogen	0.1331
Sulphur	0.0027
TOTAL	1.0000

Specific gravity: 0.846

Higher heating value: 45.5 megajoules/kilogram (19 570 Btu/lb)

38.4 megajoules/litre (165 600 Btu/Ig)

For an explanation of the derivation and of the charts, see Reference 10.

Example:

A domestic furnace is fired with a nozzle rated at 1.1 USgph. Steady state flue gas temperature is 335°C (635°F) and the carbon dioxide (CO_2) content in the flue gases is 7.5%. Room temperature is 16°C (60°F).

What is the excess air level, the equivalent oxygen level, the mass and volume of the combustion air required and the total flue gas produced, and the steady state efficiency?

Solution:

Oil firing rate = 1.1 USgph = $\frac{1.1}{1.2}$ = 0.9167 imperial gal/hr (4.167 L/hr)

For a specific gravity of 0.846, oil density = 8.46 lb/gal (0.83 kg/L)

Thus, oil firing rate = 0.9167 x 8.46 = 7.755 lb/hr (3.49 kg/hr)

From Figure C.1, for CO_2 = 7.5%: total combustion air = 198%
excess air = 198% – 100% = 98%
equivalent oxygen = 10.7%

Similarly, from Figure C.1: mass of dry air = 28.5 lb/lb oil (12.8 kg/0.45 kg oil)
mass of total flue gas = 29.7 lb/lb oil (13.4 kg/0.45 kg oil)

At a firing rate of 7.755 lb/hr, mass of combustion air (dry air) = 28.5 x 7.755 = 221 lb/hr;
mass of total flue gas = 29.7 x 7.755 = 230 lb/hr.

From Figure C.2, for CO_2 = 7.5% and stack temperature = 335°C (635°F):

volume of combustion air (dry air) = 380 ft^3/lb (10.76 m^3/0.45 kg)
= 380 x 7.755 = 2950 ft^3/hr (83.5 m^3/hr)

volume of total flue gas = 820 ft^3/lb (23.2 m^3/0.45 kg)
= 820 x 7.755 = 6360 ft^3/hr (180 m^3/hr)

Heat losses:

ΔT = stack temperature – combustion air temperature = 335°C (635°F) – 16°C (60°F) = 302°C (575°F)

From Figure C.3, for CO_2 = 7.5% and ΔT = 302°C (575°F): dry flue gas loss = 20.2%

From Figure C.4, for stack temperature = 335°C (635°F) and air temperature = 16°C (60°F): hydrogen loss = 8.1%

Thus, heat losses = 20.2% + 8.1% = 28.3%

Steady state efficiency = 100% – 28.3% = 71.7%

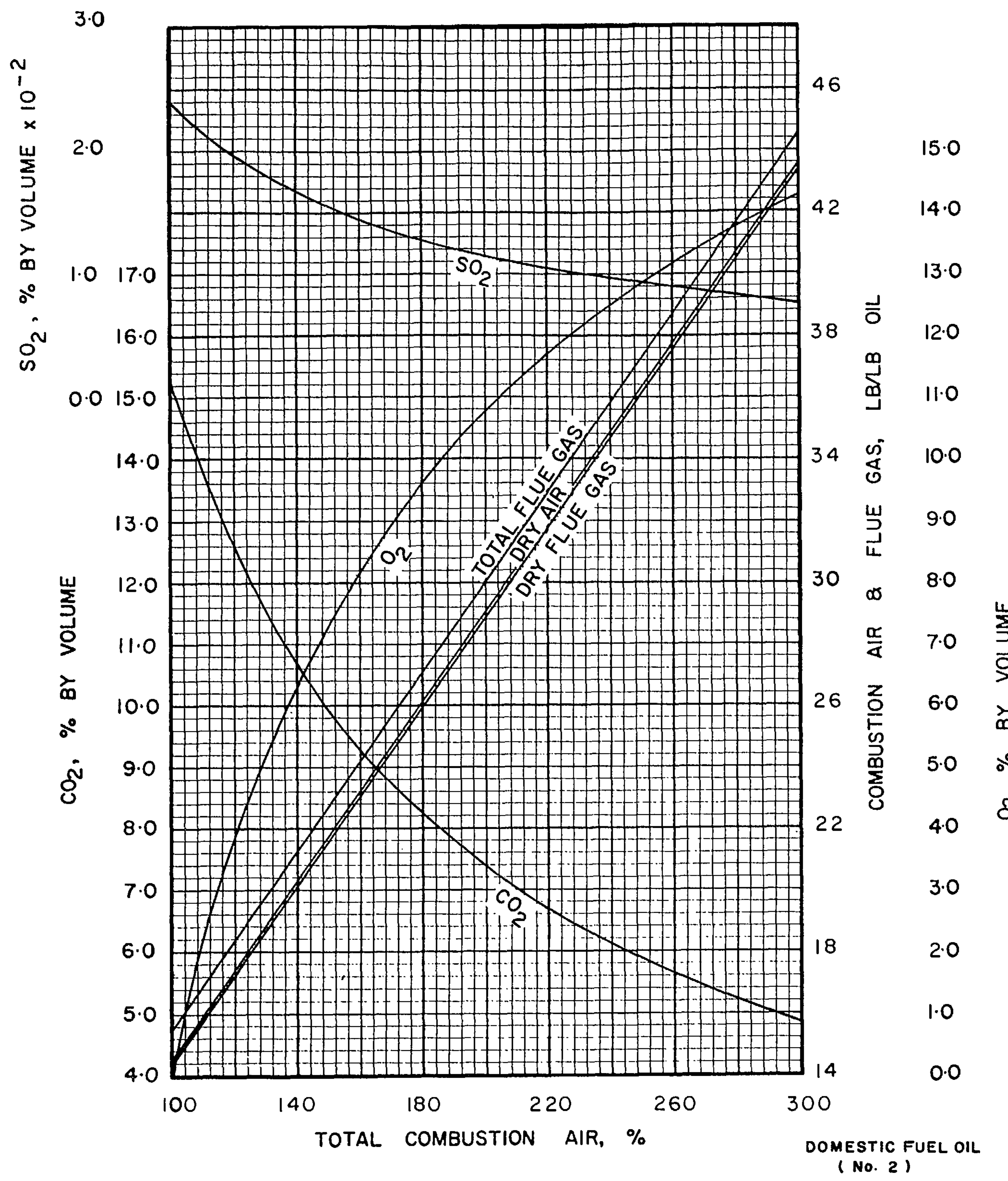


Figure C.1 Combustion data, weight basis

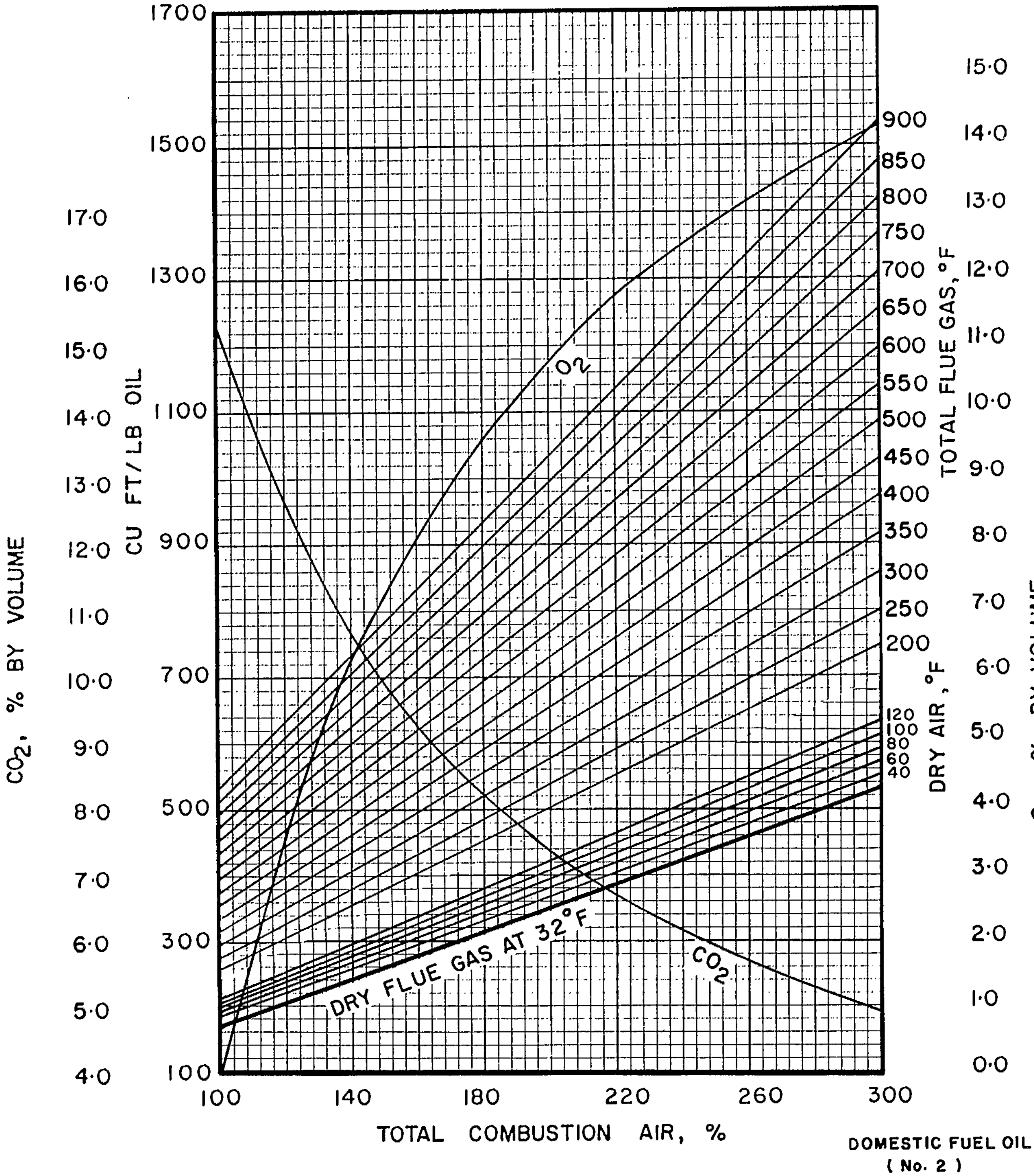


Figure C.2 **Combustion data, volume basis**

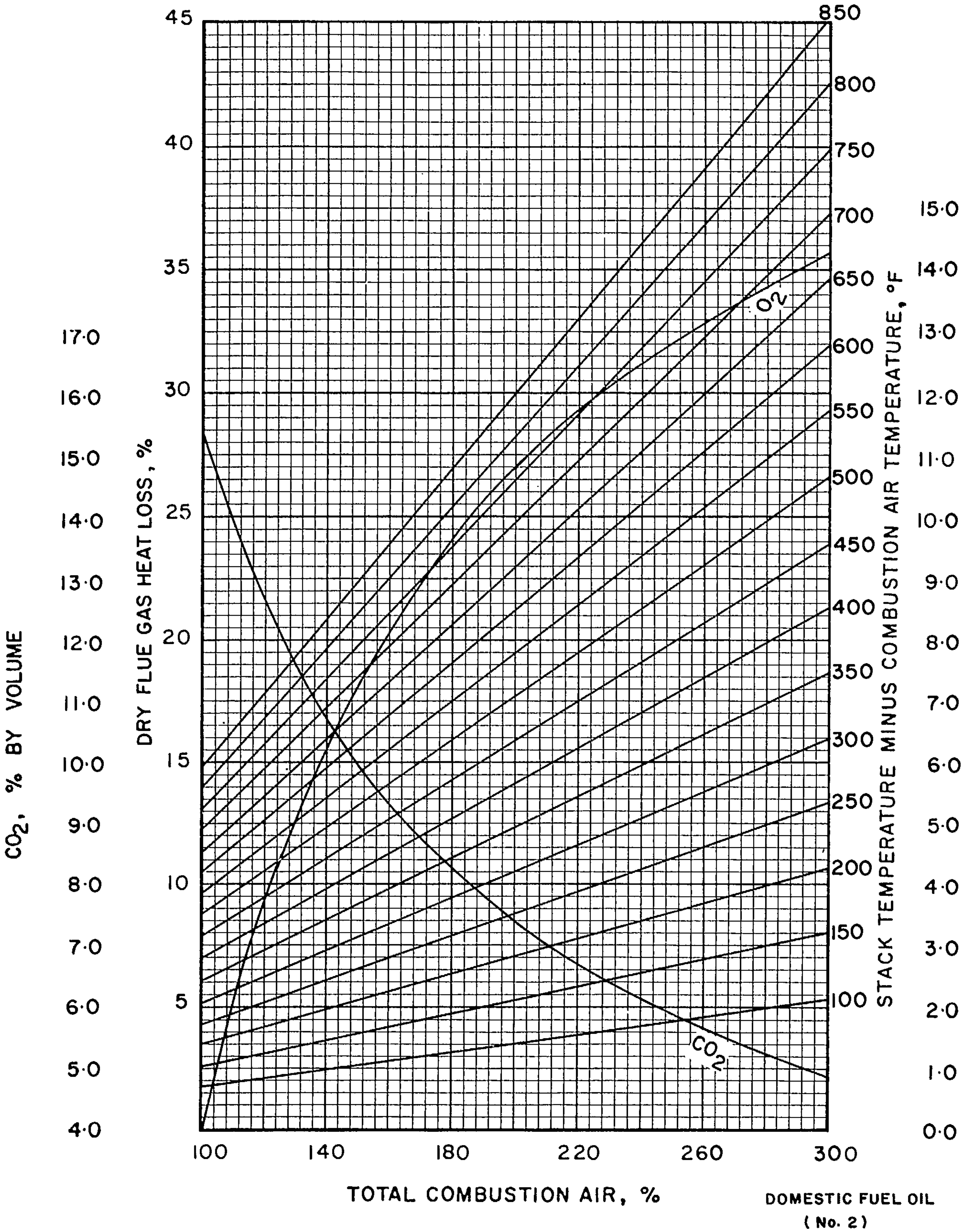


Figure C.3 Dry flue gas loss for a range of temperature differentials

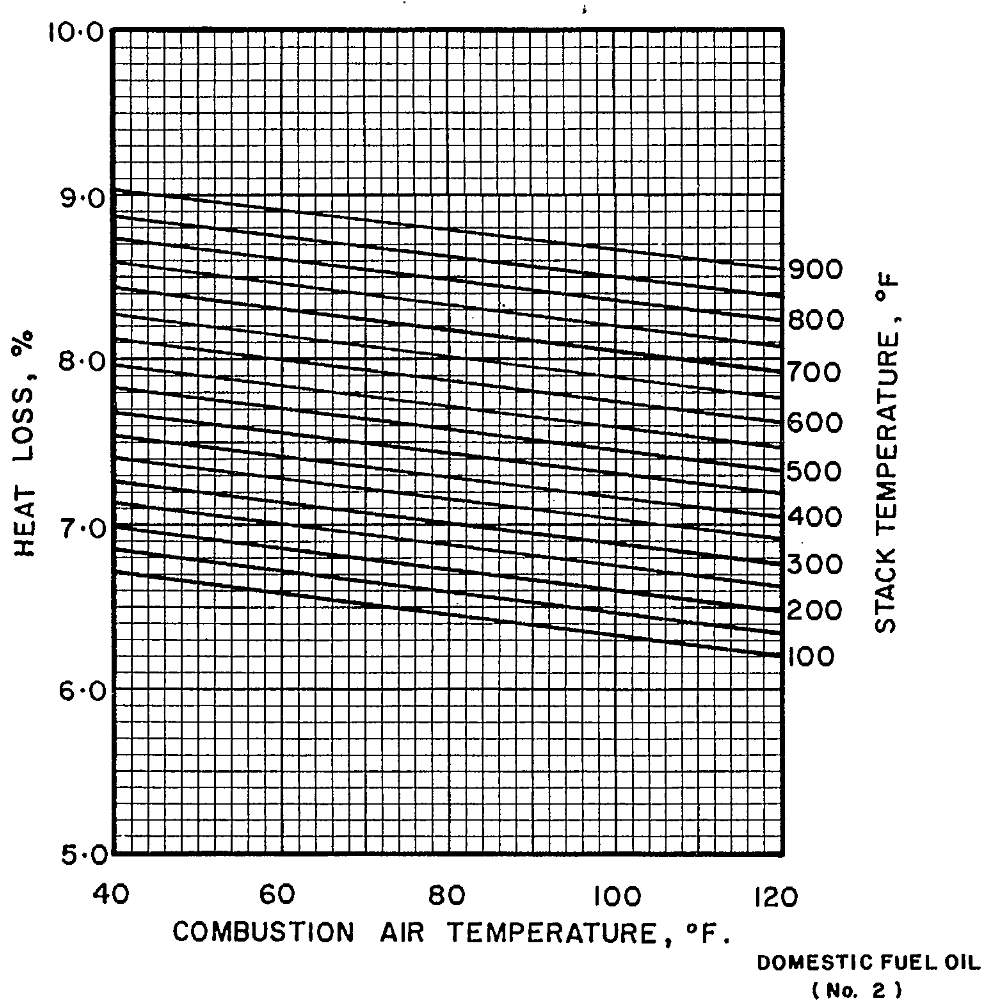


Figure C.4 Hydrogen loss for a range of stack temperatures

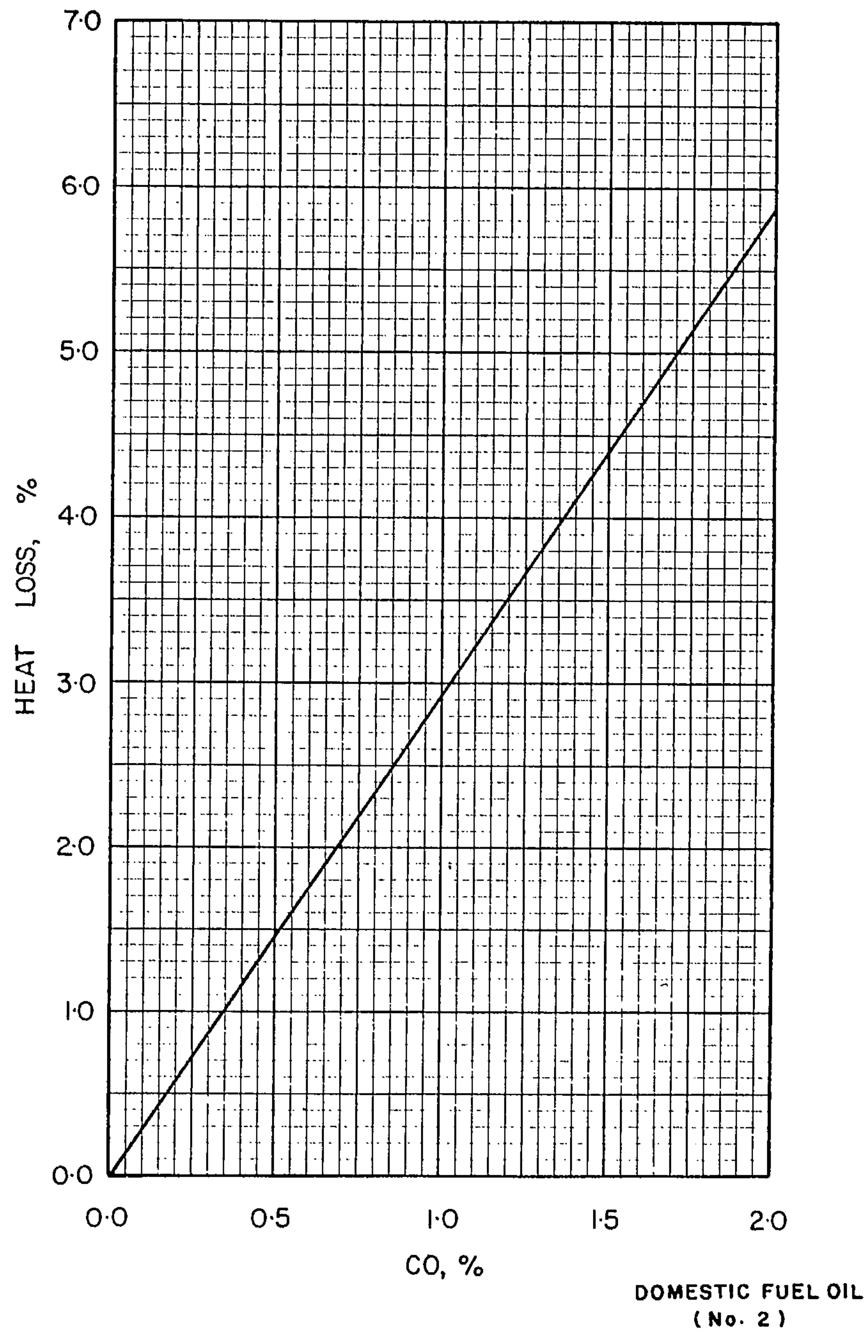


Figure C.5 Heat loss for a range of CO concentrations, assuming negligible excess air

APPENDIX D

CONVERSION FACTORS – IMPERIAL TO METRIC

Temperature:	To convert from Fahrenheit to Celsius, subtract 32 and multiply by 5/9
Example:	If temperature is 600°F, temperature in Celsius = (600 – 32) x 5/9 = 315°C
	To convert from Celcius to Fahrenheit multiply by 9/5 and add 32.
Example:	If temperature is 400°C, temperature in Fahrenheit = $\frac{9 \times 400}{5} + 32 = 752°F$

Other Conversion Factors

	from:	to:	multiply by:	reciprocal:
length	inch	mm	25.4	0.039 37
	inch	cm	2.54	0.393 70
	ft.	m	0.304 8	3.280 84
	yd.	m	0.914 4	1.093 61
	mile	km	1.609 34	0.621 37
	int. naut mile	km	1.852	0.539 96
	micron	µm	1	1
	millimicron	nm	1	1
	angstrom	nm	0.1	10
	x-unit	pm	0.1	10
area	sq. inch	cm^2	6.451 6	1.155 00
	sq. ft	m^2	0.092 90	10.763 91
	sq. yd.	m^2	0.836 13	1.195 99
	acre	ha	0.404 69	2.471 05
	sq. mile	km^2	2.589 99	0.386 10
volume	cu. inch	cm^3	16.387 06	0.061 02
	cu. ft.	m^3	0.028 32	35.314 67
	cu. yd.	m^3	0.764 55	1.307 95
	register ton	m^3	2.831 68	0.353 15
	acre ft.	m^3	1233.482	8.107×10^{-4}
capacity Imp. measure	minim	mL	0.059 19	16.893 60
	fluid oz.	mL	28.413 06	0.035 20
	pint	L	0.568 26	1.795 75
	quart	L	1.136 52	0.879 88
	gallon	L	4.546 09	0.219 97
	bushel	hL	0.363 69	2.749 62

	from:	to:	multiply by:	reciprocal:
weight or mass	grain	mg	64.798 91	0.015 43
	dram	g	1.771 84	0.564 38
avoirdupois	oz.	g	28.349 52	0.035 27
	lb.	kg	0.453 59	2.204 62
short	cwt.	kg	45.359 24	0.022 05
	ton	t (metric)	0.907 18	1.102 31
troy or apothecary	oz.	g	31.103 48	0.032 15
	lb.	kg	0.373 24	2.679 23
frequency	cps	Hz	1	1
velocity	ips	m/s	0.025 4	39.370 1
	fps	m/s	0.304 8	3.280 84
	fpm	m/s	0.005 08	196.850
	mph	m/s	0.447 04	2.236 94
	mph	km/h	1.609 34	0.621 37
acceleration	in/s^2	m/s^2	0.025 4	39.370 1
	ft/s^2	m/s^2	0.304 8	3.280 84
magnetic flux	maxwell	weber (Wb)	10^{-8}	10^{8}
	maxwell	nanoweber (nWb)	10	0.1
mag. flux density	gauss	tesla (T)	10^{-4}	10^{4}
	gauss	mT	0.1	10
force	ounce-force	N	0.278 01	3.596 94
	pound-force	N	4.448 22	0.224 81
	kip	kN	4.448 22	0.224 81
	poundal	N	0.138 25	7.233 01
	dyne	µN	10	0.1
	kilogram-force (kp)	N	9.806 65	0.101 97
pressure	psi	kPa	6.894 76	0.145 04
	pound-force/ft^2	Pa	47.880 26	0.020 89
	ksi	MPa	6.894 76	0.148 04
	short ton-force/in^2	MPa	13.789 49	0.072 52
	kp/m^2	Pa	9.806 65	0.101 97
	kp/cm^2 technical at.	kPa	98.066 5	0.010 20
	dyn/cm^2	Pa	0.1	10
	bar	Pa	10^{5}	10^{-5}
hydrostatic units	mm of mercury (torr)	mbar	1.333 22	0.750 06
	normal atmosphere	bar	1.013 25	0.986 92
	inches of mercury	mbar	33.863 9	29.530 0
	mm of water (4°C)	Pa	9.806 65	0.101 97
	in. of water (conv.)	mbar	2.490 89	0.401 46

	from:	to:	multiply by:	reciprocal:
energy	ft.-lb.-force	J	1.355 82	0.737 56
	Btu (int.)	kJ	1.055 06	0.947 82
	therm	MJ	105.506	9.478×10^{-3}
	horsepower-hour	MJ	2.684 52	0.372 51
	calorie (int.)	J	4.186 8	0.238 85
	erg	J	0.1	10
	kgf-m	J	9.806 65	0.101 97
	kWh	MJ	3.6	0.277 78
	watt-hour	kJ	3.6	0.277 78
	electron-volt	aJ	0.160 21	6.242
power	Btu/h (int.)	W	0.239 07	3.412 14
	Btu/s (int.)	kW	1.055 06	0.947 82
	ft.-pound-force/h	mW	0.376 62	2.655 22
	HP metric	kW	0.735 50	1.359 62
	HP electr.	kW	0.746	1.340 48
	HP mech. (UK)	kW	0.745 70	1.341 02
	HP boiler	kW	9.809 5	0.101 94
	kp•m/s	W	9.806 65	0.101 97
conductance	mho	siemens (S)	1	1

APPENDIX E

DESIGN DATA FOR SELECTED LOCATIONS IN CANADA

City	Design Temperature °C 2.5% January	Degree Days (C)
British Columbia		
Victoria	-5	3033
Vancouver	-7	2997
Kelowna	-18	3698
Prince Rupert	-35	5353
Prince George	-9	3838
Fort Nelson	-41	7032
Nanaimo	-7	3019
Alberta		
Edmonton	-32	5638
Calgary	-32	5324
Fort MacMurray	-36	6318
Lethbridge	-31	4736
Saskatchewan		
Regina	-34	5937
Saskatoon	-34	5964
Prince Albert	-37	6394
Estevan	-32	5461
Manitoba		
Winnipeg	-32	5866
Brandon	-32	5949
Churchill	-39	9227
Ontario		
Thunder Bay	-31	5714
Timmins	-33	6267
Sudbury	-26	5267
Windsor	-14	3588
Toronto	-17	3726
Peterborough	-23	4489
Ottawa	-25	4763
Québec		
Montréal	-23	4491
Ste-Agathe	-27	5417
Sherbrooke	-25	4650

City	Design Temperature °C 2.5% January	Degree Days (C)
Thetford Mines	-14	5387
Québec	-25	4898
Chicoutimi	-29	5547
Mont Laurier	-29	5374
Drummondville	-25	4767
Rimouski	-24	5433
New Brunswick		
Fredericton	-23	4751
Edmundston	-27	5376
St. John	-14	4629
Chatham	-23	4969
Sackville	-21	4611
Moncton	-14	4622
Prince Edward Island		
Charlottetown	-19	4648
Summerside	-19	4622
Nova Scotia		
Halifax	-16	4023
New Glasgow	-21	4600
Kentville	-18	4262
Sydney	-15	4405
Newfoundland		
St. John's	-14	4928
Corner Brook	-21	4921
Grand Falls	-14	4588
Labrador City	-36	7822
Port aux Basques	-14	4822
Goose Bay	-32	6537
Yukon		
Whitehorse	-41	6864
Northwest Territories		
Yellowknife	-44	8619