Chapter 5

NOZZLES & COMBUSTION CHAMBERS

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- Nozzle construction and operation
- Air-oil mixing and flame patterns
- Solving after-drip problems
- Combustion chambers


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Chapter 5

Nozzles and Combustion Chambers

Part 1: Nozzles

Proper nozzle selection is the key to efficient, clean combustion. By knowing how to determine the proper firing rate, the right spray angle, and the appropriate spray pattern, you can ensure good reliable combustion.

Construction of the nozzle

The oilburner nozzle is a precisely engineered product, manufactured to the very close tolerances necessary to atomize and meter fuel in the spray patterns and angles required of today's oilheating equipment.

Nozzles are made of either stainless steel or a combination of stainless steel and brass, allowing them to withstand the temperatures, pressures, and variety of fuels found in combustion environments.

Nozzle function

The nozzle performs three vital functions for an oilburner:

1. Atomizing: Heating oil must be vaporized to burn. Although the vaporization is actually accomplished with heat, the oil must be 'broken down' into tiny droplets first. This is called 'atomization' and allows the oil to vaporize quickly and evenly for fast and quiet ignition. See Figure 5-1.

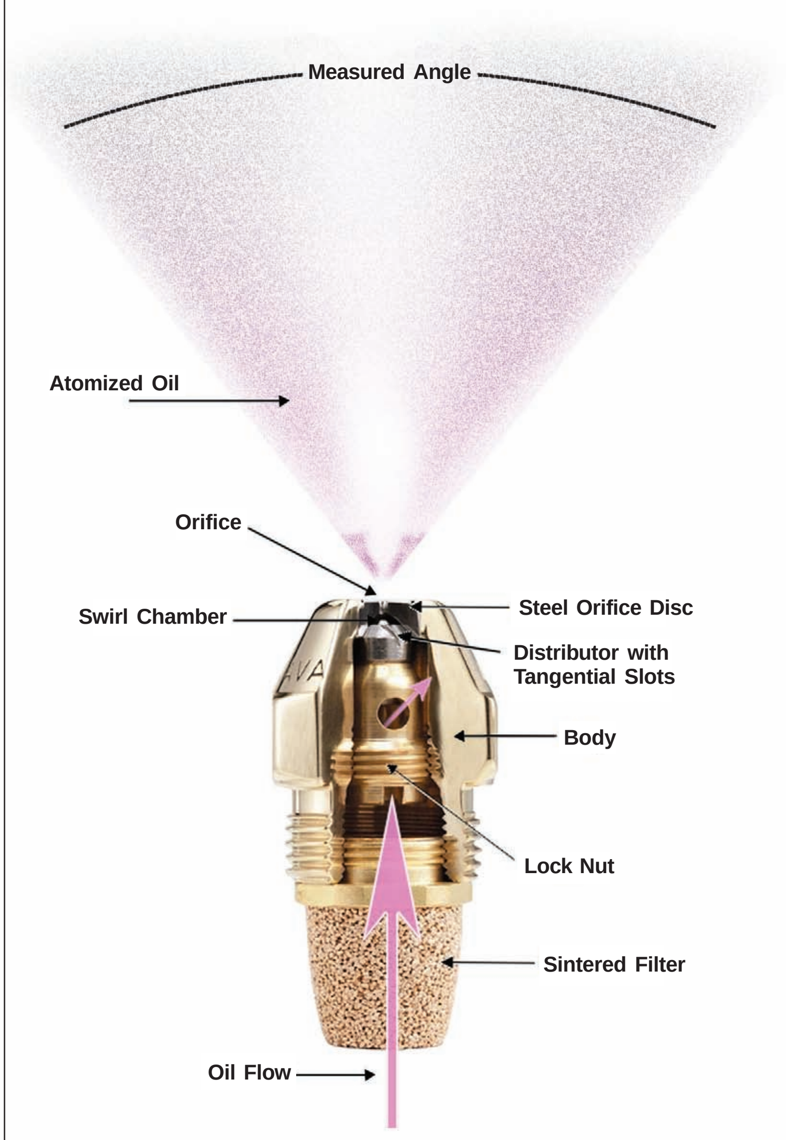
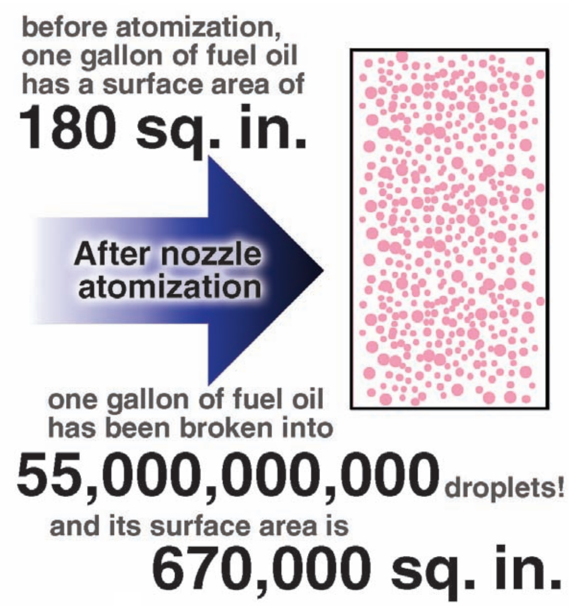


Figure 5-1: Nozzle; cutaway view



pattern and angle best suited to the requirements of each specific burner and combustion area.

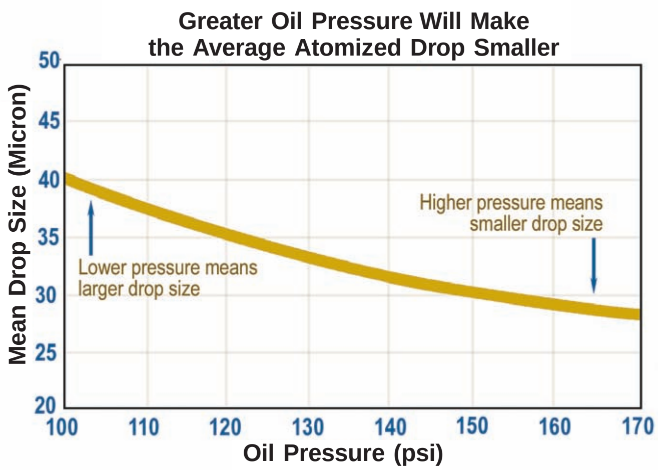
Effects of pressure on nozzle performance

Historically, 100 PSI was considered satisfactory for the fixed oil pressure supplied to the nozzle, and all nozzle manufacturers calibrate their nozzles at that pressure. Many burner and appliance (boilers, furnaces, and water heater) manufacturers are recommending higher pressures for their products. Higher pressures create better atomization, i.e. smaller droplets. See Figure 5-2.

2. Metering: A nozzle delivers a fixed amount of atomized fuel to the combustion chamber. The amount of fuel is measured in gallons-per-hour (GPH) at 100 pounds pressure. For burning rates below five GPH, there are more that 25 different flow rates each in 6 different spray angles and six or more spray patterns.

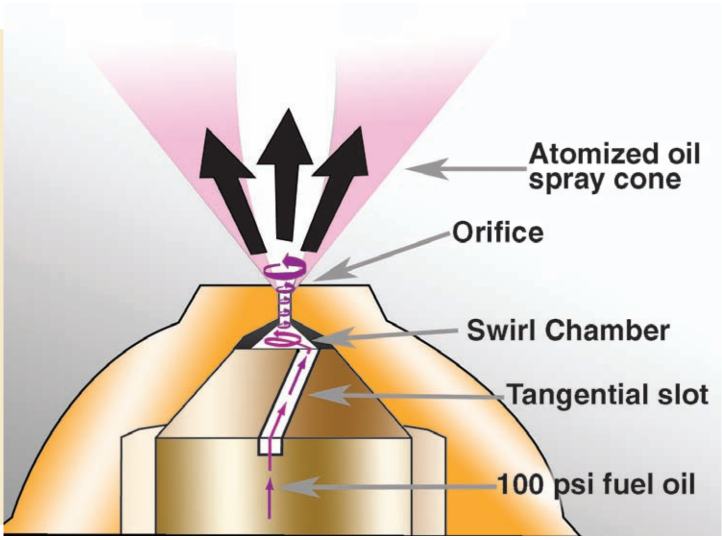
3. Patterning: A nozzle is expected to deliver the fuel to the combustion area in a uniform spray

Figure 5-2: Fuel pressure vs. droplet size



How a nozzle works

Heating oil, under pressure (100 psi) passes through the strainer to remove contamination, then through a set of slots, cut at an angle into the swirl chamber. The angle of the ejected oil creates a high velocity swirl, like a tornado. As the oil swirls against the swirl chamber walls it creates an area of low pressure in the center. This pressure differential moves the oil out through the orifice in a hollow tube shape where it spreads into a film that stretches until is ruptures into billions of tiny droplets.



In Figure 5-3 we can see how the spray from a nozzle changes as the pressure increases. At low pressure, the cone shaped film is long and the droplets are large and irregular. As the pressure increases, the spray angle becomes better defined. Once a stable pattern is formed, any increase in pressure does not affect the spray angle directly in front of the orifice. However, at higher pressure, the angle of spray further away from the orifice does start to narrow by one to two degrees. This is because the droplets are starting to slow down due to air resistance and the air the spray draws in moves the droplets inward. This is the same effect that causes a shower curtain to be drawn into the shower spray.

As you might expect, pressure increases cause a corresponding increase in the amount of oil flowing through the nozzle. A nozzle rated at one gallon-per-hour at 100 PSI will deliver about 1.23 gallons-per-hour at 150 PSI. Increasing pressure also reduces the size of the droplets in the spray. For example, an increase from 100 to 300 PSI reduces the droplet diameter by about 28%. Lower pressure means larger droplets that are much harder to vaporize and burn. While pressures greater than 100 PSI are sometimes desirable, never operate at less than 100 PSI. See Table 5-1 on following page.

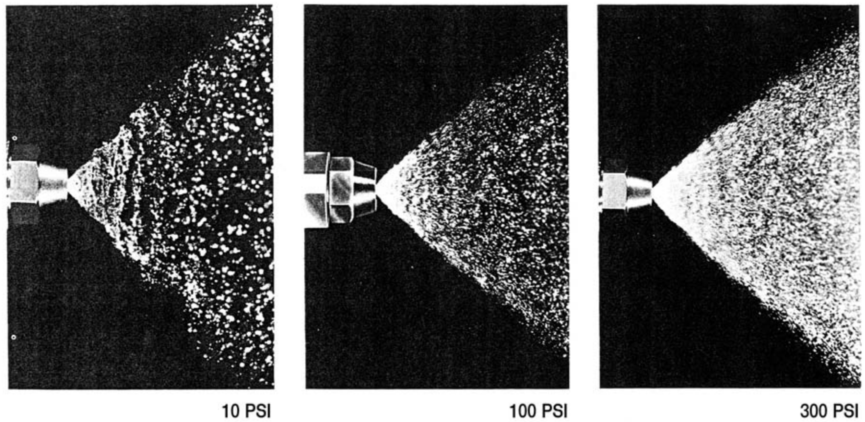


Figure 5-3: Nozzle spray droplets

Spray pattern

There are many different spray patterns offered by manufacturers. Although all spray patterns are hollow to some degree, nozzles are grouped into three general classifications—solid, hollow, and semi-solid. See Figure 5-4.

Hollow cone: As the name implies, the greatest concentration of droplets is at the outer edge of the spray, with little or no distribution in the center. Generally, hollow cone nozzles are used on low firing rate burners, particularly those firing less than 1 GPH. This is an important advantage in fractional gallonage nozzles, such as those used in mobile home furnaces, where cold, high viscosity oil may cause a reduction in spray angle and increases in droplet size. Hollow flames also tend to be quieter.

Solid cone: Here the distribution of droplets is more uniform throughout the pattern. These nozzles work best when the air pattern of the burner is heavy in the center or where long fires are required. They provide smoother ignition for burners

Oil Nozzle Type A Ordering Table

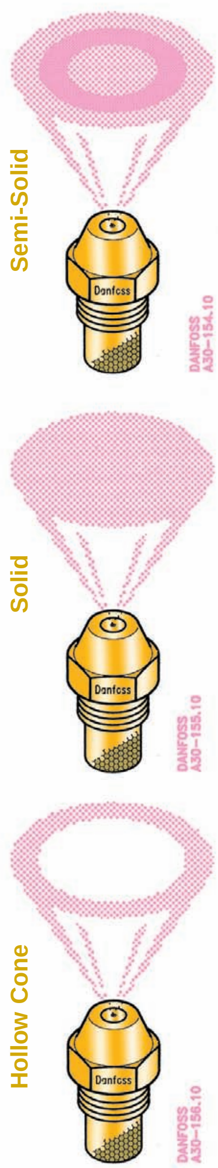


Figure 5-4: Nozzle spray patterns

**Table 5-1:
Nozzle capacities
US gph**

Nozzle Flow Rate vs. Pressure (Approx.)

Flow Rating USGPH @ 100 PSI	Flow Rates in US GPH Pressure PSI					
GPH	125	145	175	200	250	300
0.40	0.45	0.48	0.53	0.57	0.63	0.69
0.50	0.56	0.60	0.66	0.71	0.79	0.87
0.60	0.67	0.72	0.79	0.85	0.95	1.04
0.65	0.73	0.78	0.88	0.92	1.03	1.13
0.75	0.84	0.90	0.99	1.06	1.19	1.30
0.85	0.95	1.02	1.12	1.20	1.34	1.47
1.00	1.12	1.20	1.32	1.41	1.58	1.73
1.10	1.23	1.32	1.48	1.56	1.74	1.91
1.20	1.34	1.44	1.59	1.70	1.90	2.08
1.25	1.40	1.51	1.65	1.77	1.98	2.17
1.35	1.51	1.63	1.79	1.91	2.13	2.34
1.50	1.68	1.81	1.98	2.12	2.37	2.60
1.65	1.84	1.99	2.18	2.33	2.81	2.86
1.75	1.96	2.11	2.32	2.47	2.77	3.03
2.00	2.24	2.41	2.65	2.83	3.16	3.46
2.25	2.52	2.71	2.98	3.18	3.56	3.90
2.50	2.80	3.01	3.31	3.54	3.95	4.33
2.75	3.07	3.31	3.84	3.89	4.35	4.76
3.00	3.35	3.61	3.97	4.24	4.74	5.20
3.25	3.63	3.91	4.30	4.60	5.14	5.63
3.50	3.91	4.21	4.63	4.95	5.53	6.06
3.75	4.19	4.52	4.96	5.30	5.93	6.50
4.00	4.47	4.82	5.29	5.66	6.32	6.93
4.50	5.03	5.42	5.95	6.36	7.12	7.79
5.00	5.60	6.00	6.60	7.10	7.91	8.66
5.50	6.10	6.60	7.30	7.80	8.70	9.53
6.00	6.70	7.20	7.90	8.50	9.49	10.39
6.50	7.30	7.80	8.60	9.20	10.28	11.26
7.00	7.80	8.40	9.30	9.90	11.07	12.12
7.50	8.40	9.00	9.90	10.80	11.86	12.99
8.00	8.90	9.60	10.60	11.30	12.65	13.88
8.50	9.50	10.20	11.20	12.00	13.44	14.72
9.00	10.10	10.80	11.90	12.70	14.23	15.59
10.00	11.20	12.00	13.20	14.10	15.81	17.32
11.00	12.30	13.20	14.80	15.60	17.39	19.05
12.00	13.40	14.40	15.90	17.00	18.97	20.78
13.00	14.50	15.70	17.20	18.40	20.55	22.52
14.00	15.70	16.90	18.50	19.80	22.14	24.25

NOZZLE MANUFACTURERS AND SPRAY PATTERNS

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

Figure 5-5: Manufacturers use different designations for their spray patterns

firing over 2 GPH. An interesting characteristic of solid cone patterns is that they become more and more hollow as flow rates increase, particularly above 8 GPH. In addition, increased pump pressure tends to make both hollow and solid patterns more hollow.

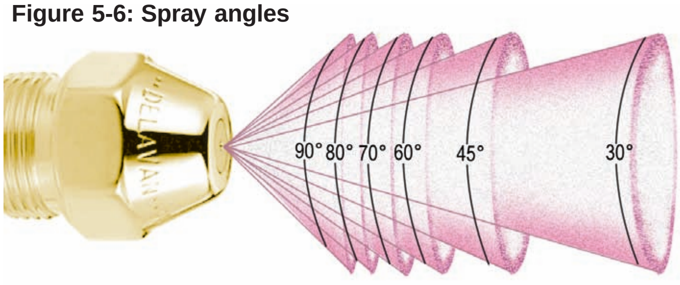
Semi-solid: Many burners perform well with solid or hollow spray patterns. To accommodate these designs, nozzle manufacturers have developed patterns that are a compromise between solid and hollow. We call these semi-solid patterns.

Your job as a technician is to select the nozzle that puts the oil spray where the air velocity delivered by the burner is greatest. In most modern equipment, the appliance manufacturer designates the nozzle to use. Figure 5-5 describes the manufacturers' different designations for their spray patterns.

Spray angle

Spray angle refers to the angle of the cone of spray from the nozzle. Spray angles are available from a 30-degree angle to a 90-degree angle to meet the wide variety of burner air patterns and chamber shapes. Generally, round or square chambers are fired with 70 to 90-degree nozzles. Short wide chambers need a short fat flame. Long narrow chambers usually require 30-degree to 70-degree solid cone nozzles. The spray pattern and angle must be such that all the droplets burn completely in suspension in the combustion area. Unburned oil must not strike (impinge) on any cold surface such as the chamber walls or floor, the crown sheet of the heat exchanger, or the burner end cone. Impingement of unburned drops will cause high smoke and will lead to future service calls. The correct spray pattern and angle depends on the air-oil mixing design of the burner and the shape of the combustion chamber. See Figures 5-6 and 5-7.

Figure 5-6: Spray angles



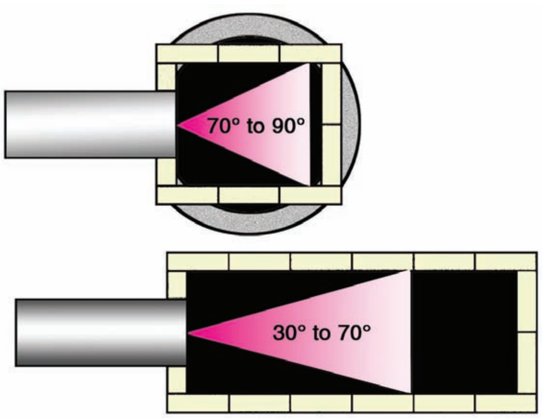


Figure 5-7:
Spray angles based on chamber design

Flow rate

Atomizing nozzles are available in a wide range of flow rates. Generally, with hydronic and warm air heating systems, the smallest firing rate that will adequately heat the building on the coldest day of the year is the proper size to use. Another guideline is to select a flow rate that provides a reasonable net stack temperature regardless of the connected load. This avoids acid condensing in the stack, which occurs at about 150 to 200°F. If the appliance is undersized for the load (highly unlikely), it may be necessary to fire to the load and ignore the efficiency. A nozzle that is too small will not produce adequate heat and hot water. A nozzle that is too large will cause the unit to short cycle, reducing efficiency and wasting fuel. Whenever it is possible, determine the manufacturer's recommendations on nozzle selection and *never overfire the rating* of a heating appliance.

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Dual filtration

Double filtration nozzles are available for mobile home installations and other units with very low firing rates. In addition to the standard nozzle filter, these nozzles have a secondary internal filter located immediately before the metering slots. This extra filter gives the nozzle 35% more nozzle filtration. The internal filter does not change the nozzle's performance; it just increases its longevity.

There is also a nozzle available from Delavan Spray Technologies for low firing rates that uses two swirl chambers and short metering slots, keeping the oil contaminants in suspension and flushing them from the orifice. Particles are not allowed to collect or stick together, limiting buildup and plugging.

Burner air patterns

Burner air patterns are much like nozzle spray patterns in that they fall into solid and hollow classifications.

Burners with solid air patterns are often referred to as open-end burners. There is no restrictive air cone in the end of the air tube to direct the air effectively in any desired pattern. This produces high velocity air down the middle of the air pattern and works best with a solid nozzle and narrow spray angles. This situation does not apply to flame retention burners.

Flame retention burners are equipped with air handling devices in the air tube that afford better mixing of air and oil vapor in the combustion area. Many flame retention burners can fire both solid and hollow nozzles with good results because of the strong recirculation air pattern they produce. This recirculation of air and oil in the chamber also affects the fire box pressure.

In the flame retention burner, the flame front is held very near the burner head. It creates a flame that is less likely to pulsate or produce soot. Nozzle selection for these burners should follow manufacturer's recommendations and the following general guidelines:

- **Burners with flow rates up to 2 GPH:** Hollow nozzles can be used successfully for most applications, even on burners with most of the air down the middle. Hollow nozzles in lower firing rates produce the quietest operation. It is often better, especially in furnaces, to sacrifice 1 or 2 points in efficiency for quiet operation.

- **Burners with flow rates between 2 and 3 GPH:** You may use hollow or solid nozzles depending upon the burner air pattern. At this higher firing rate, spray patterns are not as critical.

• **Burners with firing rates above 3 GPH:** Here it is advisable to standardize on solid nozzles which produce smoother ignition in most burners. Burners with hollow air patterns are the exception. Check the manufacturers' recommendations.

Nozzle brand interchange

Replacing nozzles of one brand with those of another can sometimes present problems. There are subtle differences between manufacturers because they use different methods of production and evaluation.

The burner manufacturers test their burners in different appliances and determine what type nozzle, from which nozzle manufacturer, works best in that particular application. Burner manufacturers publish nozzle recommendations called OEM Specification Guides. Be sure to have this information at hand.

If you are working on a unit not listed in the Specification Guide, you will find that generally, all hollow nozzles have similar spray patterns and may be interchangeable. The variation shows up mainly in the solid nozzles, and if you must change brands, you will have to do some testing to determine the best nozzle for that application. Check with your supply house to secure a nozzle interchange chart to help you in your testing.

Nozzle care and service suggestions

Never, under any conditions, interchange the inner parts of a nozzle with those of another nozzle. Each nozzle component is matched exactly to all the other components of that nozzle. In fact, you should leave a nozzle in its original container until you install it. You should store all your nozzles in a proper nozzle box. They are available from the nozzle manufacturers.

Handle nozzles carefully. Pick them up by the hex flats only. Do not touch the strainer or orifice. Even clean hands have enough dirt on them to plug up the tiny slots inside the nozzle. Obviously, you should never disassemble a nozzle you plan to use.

Only install nozzles with clean tools to reduce the possibility of contamination. If possible, use a nozzle changer or nozzle wrench when changing a nozzle. Most open-end wrench handles are too long and increase the possibility of stripping the nozzle adapter threads. Before installing a new nozzle, flush out the nozzle line and adapter with clean oil, kerosene, or a solvent.

Before you install the nozzle in the adapter, be sure the inside of the adapter is clean and free of carbon or contamination. Carefully examine the sealing surface of the adapter to be sure there are no scratches or nicks. These can be caused by careless handling, or just wear and tear. If it is scratched or nicked, then replace the adapter. Do not take a chance here. A leak between the nozzle and the adapter can cause serious problems. Do not put anything on the nozzle threads! Screw the nozzle into the adapter one-eighth to one-quarter turn past hand tight (about 88 to 138 pounds of torque).

The nozzle orifice face is polished to a mirror finish. Do not ruin it with a wire or pin, or by bumping it with a wrench. This will ruin the spray. If a nozzle is dirty, or plugged, change it. It is impossible to clean it out properly. It is tempting, especially in the middle of the night to try to clean out the orifice with a pin or tooth pick. It will not work. Replace it!

A good quality nozzle should last at least two heating seasons. Contamination

Figure 5-8

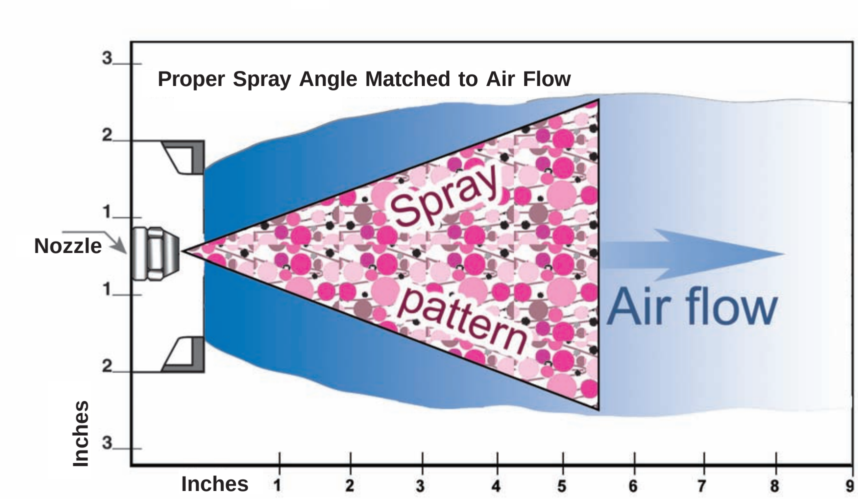
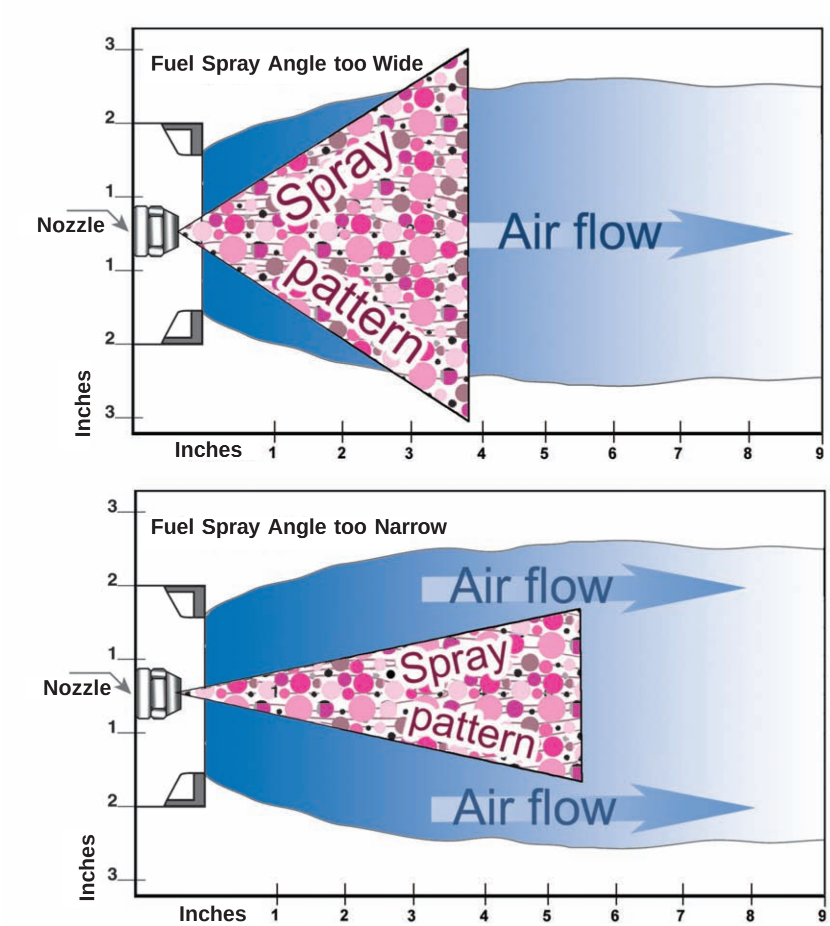


Figure 5-9



and excessive heat are the main causes of nozzle failure. Contamination can be limited by installing a good oil filter in the supply line. If there are excessive tank bottom sediments in the tank, you may need to clean the tank and adopt a fuel additive program. For severe cases, replace the tank.

Nozzles should not be very hot when operating because of the amount of air and fuel traveling past them. Nozzles overheat from poor or no over-fire draft. Over-fire draft should be at least -.01" to keep nozzles cool. There are some exceptions to this rule. As usual, manufacturer's instructions take precedence. Be sure the end of the burner air tube does not extend into the chamber. The face of the end tube should be flush with the face of the chamber, or recessed about one quarter inch.

Air-oil mixing and flame patterns

What constitutes a perfect oilburner flame? Theoretically, each droplet of oil that leaves the nozzle orifice should be completely surrounded by air. It should be vaporized and then burst into flame—totally burning all the hydrogen and carbon atoms in the fuel. This air volume, generated by the burner fan, and, in most applications, aided by the draft-over-the-fire, should be adjusted to deliver the exact amount of air required by the fuel being fed through the nozzle, see Figure 5-8.

It is impossible to reach this perfect state in the field, but it is a good target to shoot for. The closer you come to this perfect air-oil match, the cleaner, quieter, more efficient and odor free the flame will be.

There are six elements for the perfect air-oil match. They are: air volume, oil volume, oil pressure, oil spray pattern, oil spray angle, and the air pattern of the burner. The air pattern of the burner is the most important factor. This is unfortunate, because you cannot control or adjust air pattern; it is fixed by the burner design. Also, you cannot see the burner air pattern; you must rely on trial and error in our quest for perfection. See Figure 5-9.

Your tools in your search for the perfect flame are: the smoke tester, stack thermometer, draft gauge, pressure gauge, CO_2 or O_2 tester, the manufacturer's recommendations and the experience of the person who was there before you. Always use the condition of the unit as you found it as your best guide to what needs to be done. If you find the unit running well and reasonably clean, the nozzle installed in the unit is probably pretty close to being the right one. However, if the unit is not running well, it may be time for some changes. The single greatest factor in combustion inefficiency is excess air. It absorbs large quantities of heat and carries it wastefully up the chimney. It also reduces the flame temperature, decreasing the rate of heat transfer to the heat exchanger. Both of these raise stack temperatures, which lower efficiency.

The best burner adjustment is one that allows a smokeless, sootless operation with a minimum of excess air. We determine excess air by measuring the percentage of oxygen (O_2) in the flue gases. You will learn more about this in the combustion chapter.

Nozzle application procedure

If the manufacturer's recommendations are not available, or if you are upgrading an old unit with a new burner, the following is a step-by-step procedure you may use for selecting the best nozzle.

1. Set the over-the-fire draft to -.02", check the oil pressure, and install a nozzle that does not exceed the rating of the appliance.

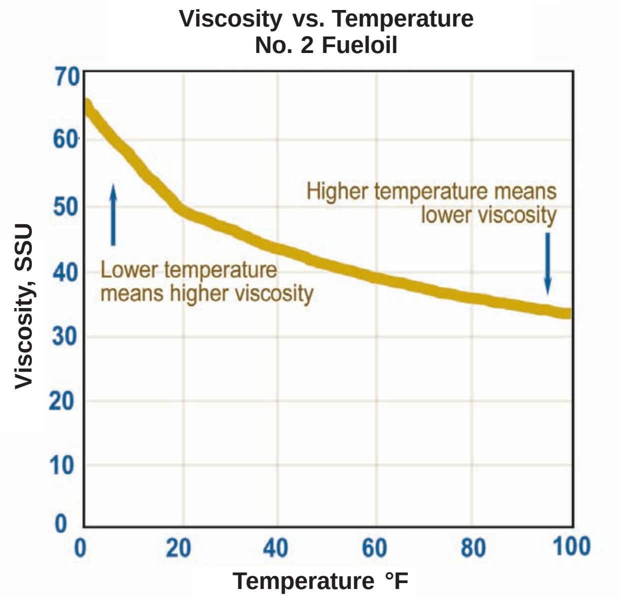


Figure 5-10: Viscosity vs. temperature change

2. Start with an 80-degree hollow nozzle, and adjust for a 1 smoke and mark the air band opening.

3. Try an 80-degree solid nozzle and take another smoke test. If it is lighter, you have a solid air pattern; if the smoke is heavier, it is hollow.

4. Try a 60-degree hollow or solid nozzle as indicated by the previous two tests.

5. Select the nozzle that creates the lowest smoke and highest efficiency.

6. Once the tests are completed, record the results. Post the results near the burner and report them to the office where they should become a permanent part of the customer's service history.

Effects of viscosity on nozzle performance

One of the important factors affecting nozzle performance is the viscosity of the fuel. Viscosity is the resistance to flow—the thickness of the fuel. Thus, gasoline is "thin", having a lower viscosity, while *grease* is "thick", having a higher viscosity.

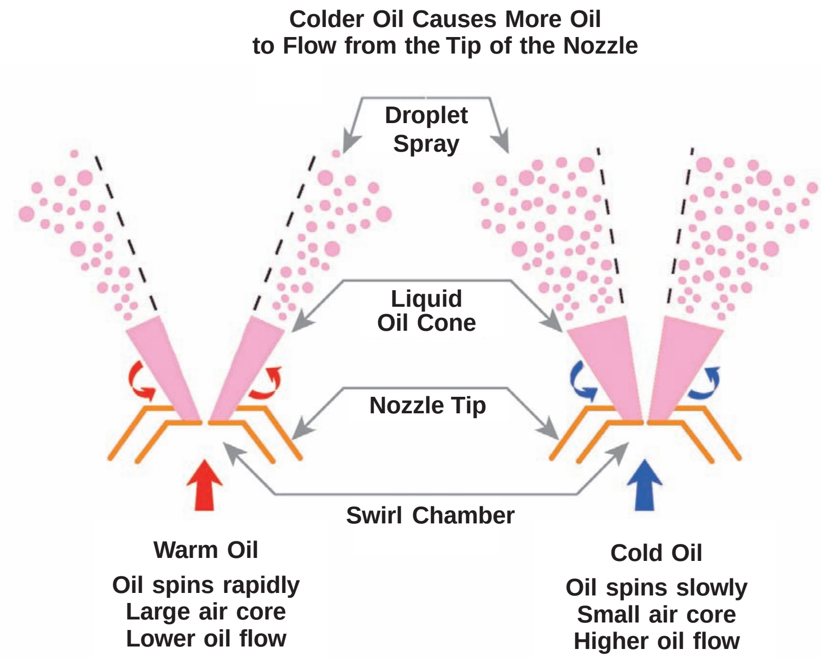


Figure 5-11: Comparison of warm vs. cold oil on nozzle flow rates

What makes the viscosity of oil increase? Temperature is the main factor in changing oil viscosity. As the temperature of the oil goes down, the viscosity goes up. The viscosity of No.2 oil is 35 SSU (seconds saybolt universal) at 100°F. When the temperature drops to 20°F, the viscosity goes to 65 SSU. See Figure 5-10 on previous page.

The effects of increased viscosity can be confusing. As the viscosity of the fuel flowing through a nozzle increases, so does the flow rate. Here is how it happens. As higher viscosity oil passes into the nozzle through the tangential slots and into the swirl chamber, the rotational velocity slows down. As a result, the walls of the tube of oil leaving the nozzle orifice are thicker—more oil enters the chamber and the oil droplets are bigger. The result is that the flame front moves out into the chamber and the angle of the spray becomes narrower. The flame is longer, thinner, bigger, and less stable. This creates incomplete combustion that means increased smoke and soot. It is also harder to light cold oil, so ignition is delayed, and if the viscosity is very high, flame out and no heat result. See Figure 5-11.

Outside, above-ground storage tanks suffer most dramatically from the problems of cold oil. Let's say you do a tune up on a sunny hot summer day. The temperature of the oil in the tank is 80°F. You adjust the burner to run clean at that viscosity. As the temperature drops, the oil becomes much thicker and the amount of oil flowing out of the nozzle increases, causing the burner to over-fire. Not enough air is delivered and smoke increases. The angle of the spray decreases and the fire gets longer and

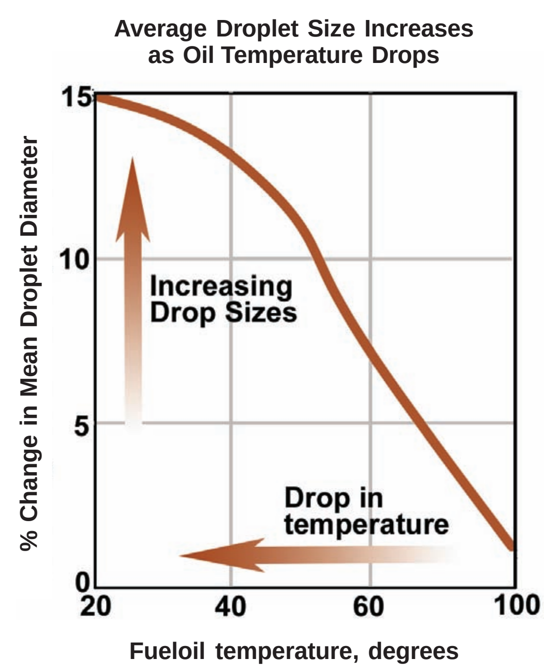


Figure 5-12: Nozzle droplet size in relation to temperature

hits the back wall, which also increases smoke. The thick stream of oil makes for larger droplets that result in delayed ignition and smoke. Suddenly, the appliance is full of soot. Fortunately, as the oil gets colder, so does the air. This increases draft. The stronger draft draws in more combustion air and helps accommodate the increased volume of combustion gases.

This can happen to a lesser degree to underground tanks that are normally at about 50 to 55° F, and even to indoor tanks that are at room temperature. As oil trucks are not heated, it takes several days for a fresh load of cold oil to warm up in an underground or indoor storage tank. Until the oil warms, you can have viscosity problems. See Figure 5-12.

The easiest way to cut down on the effects of cold oil is to increase pump pressures. This decreases droplet size and better defines the spray angle, which makes burners less susceptible to high viscosity oil. Remember, it also increases the flow rate, so size the nozzle correctly. Another solution to cold oil is to install a nozzle line pre-heater. This simple, strap-on device increases the temperature of the oil arriving at the nozzle to about 100 to 120° F. See Figures 5-13 and 5-14.

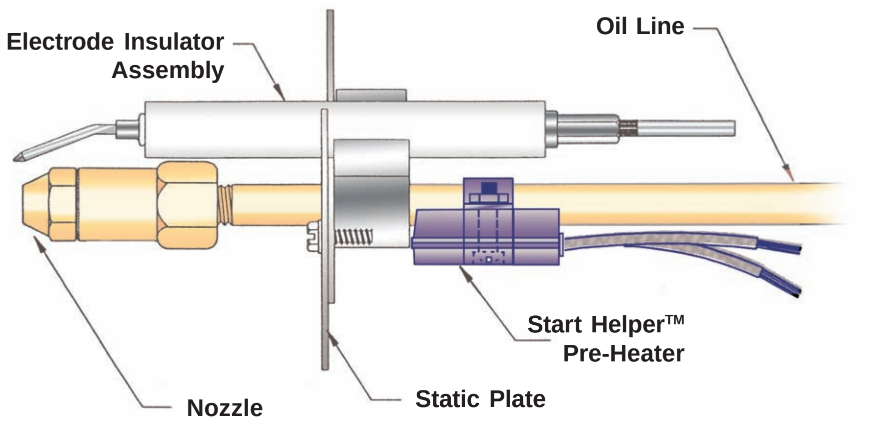


Figure 5-13: Nozzle line pre-heater

The nozzle line heater is wired in parallel with the limit control so it is energized whenever there is power to the heating system. It works on electrical resistance. When the resistance gets too high, it stops heating. As the unit cools, the resistance drops and it heats up again. Pre-heaters draw about one amp and only heat the fuel to about 80 degrees above the ambient temperature—between 120 and 130°F—during stand-by. When the burner is running, the cold oil brings the temperature well below

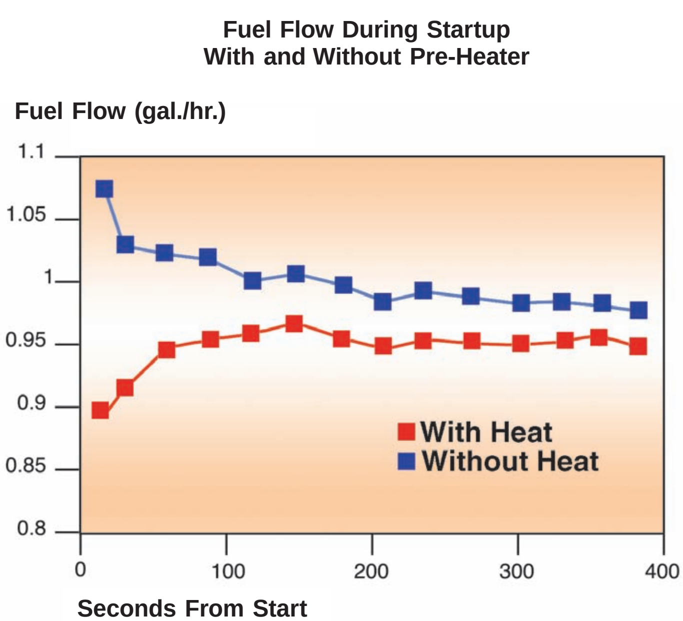


Figure 5-14

120°. Yet another way to help with this problem is to blend kerosene or additives with heating oil.

Thermal stability

If you find a fuel failure but the filter and strainer are clean and the nozzle is plugged with coke (a dull black substance), the problem is probably thermal stability. Oil can become unstable in the prolonged presence of heat, particularly when in contact with copper and other "yellow" metals. As the oil sits in the nozzle and drawer assembly and its temperature rises, it can form coke. This is more of an installation issue than a fuel issue.

There are three basic causes of after-drip—a defective pump shut off valve, air entrapped in the nozzle line, and oil expansion in the nozzle line caused by excessive radiated heat at shut down.

Nozzles should not get hot. If the nozzle is hot enough to overheat the oil, you probably have either a bad draft situation, an old hard brick chamber reflecting excessive heat back on the nozzle after shut down, an after-drip problem, or a draw assembly and end cone sticking into the chamber. There are good mechanical fixes for these problems—i.e. post purge, draft inducers, interrupted ignition, ceramic chamber liners, and end cone amulets, to name a few.

If you encounter a thermal stability problem, find out what is causing the nozzle to get hot. The problem is most likely to occur after burner shutdown. Check the over-fire draft after shut-down. Check to see if the draft regulator closes after shutdown. If it stays open, it will reduce draft over-the-fire needed to cool the nozzle. Check electrode settings and the type of chamber. Check to be sure that the end-cone is flush or slightly recessed from the chamber face. Check for after-drip. Any of these problems could be the cause of your thermal instability.

Another cause of overheating is a hard brick chamber. When replacing an old non-flame retention burner with a new flame retention burner, it is tempting to leave the old chamber in place. The problem is, new burners have much higher flame temperatures than the old burners. It did not matter with the old burner's cool flame that the hard brick chamber held its heat for hours. The white-hot flame from the new burners, however, heats the chamber to very high temperatures. When the burner shuts off, the old chamber reflects all this heat back and overheats the nozzle.

The solution is to replace the old chamber or line it with a ceramic liner. In some cases, with big old dry base boilers, you can fill in the old chamber and install the new burner in the clean-out door, firing against a target wall—essentially creating a wet base boiler.

Many units are very tight or operate without a chimney and offer little or no over-fire draft. The best way to avoid nozzle overheating in these situations is motor-off-delay (commonly called post-purge.) Using a solenoid valve, the primary control shuts off the flow of oil but keeps the burner running for a few minutes, blowing air from the burner air intake through the air tube and past the nozzle—keeping it cool.

Nozzle after-drip

The quickest way to soot up a heat exchanger is nozzle after-drip. This happens when oil drips from the nozzle orifice after the burner shuts down. If the combustion area is still hot, this oil burns with a smoky fire. If the combustion area is not hot enough, the oil drips out and collects in the bottom of the chamber. When the burner comes back on, all this extra oil lights and results in smoke, soot and rumbles.

There are three basic causes of after-drip—a defective pump shut off valve, air entrapped in the nozzle line, and oil expansion in the nozzle line caused by excessive radiated heat at shut down. The first is easy to check. Install a reliable pressure gauge in the nozzle discharge port of the fuel unit. Start the burner and let it run for the duration of the safety timing cycle. When it locks out, the pressure should drop about 20% and hold indefinitely. If it fails to stabilize and slowly descends to zero, you know the pressure-regulating valve in the pump is no good and the pump should be replaced.

If air is trapped in the nozzle line or adapter, it will cause an after-drip. See Figure 5-15. A bubble of trapped air will be compressed to 1/7th its original volume by the 100 PSI pressure of the oil. When the burner shuts off, the pressure eases back to normal and the air bubble expands back to its original volume. This rapid expansion pushes oil out of the nozzle, causing an after-drip for several seconds. This can lead to delayed ignition, sooted heat exchangers and the smell of fumes.

This condition is diagnosed by looking into the combustion chamber at burner shut down. If there is no view port, you can perform the same check by tilting the transformer back and looking through the combustion head. If air is present, check for air leaks using the procedure described in the Chapter on Fuel Units.

Expansion of oil in lines can also cause after-drip. For every degree F of temperature rise, there is a .04% expansion of volume. After-drip occurs when the burner shuts down and the temperature of the oil in the nozzle line and adapter rise because of the heat from the appliance. Hard refracto-

Figure 5-15: Air trapped in nozzle line

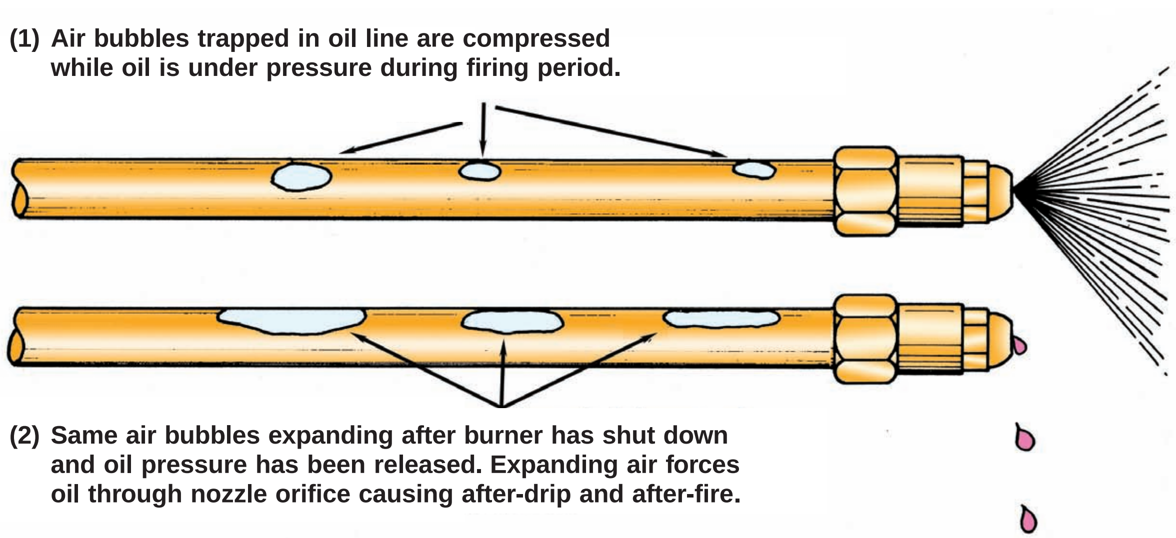


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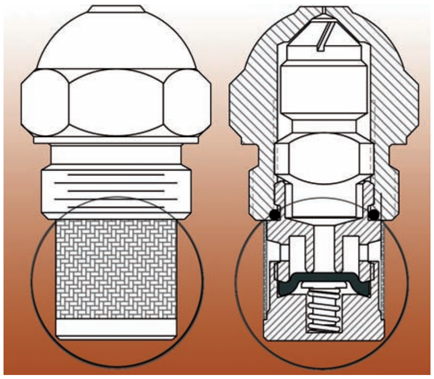
Figure 5-16:
Hago Ecovalve



ries, such as firebrick, tend to radiate more heat after shut down and thus are more likely to have this type of after-drip. To prevent this, line old refractory with ceramic.

Oilburner nozzle anti-drip valves

Another solution is the use of nozzles with check valves. These nozzles are designed to cut-off fuel flow from the nozzle quickly. See Figures 5-16 and 5-17.

Nozzle check valves also eliminate the incomplete atomization that can occur on start up and shut down of the oilburner. They also eliminate after-drip associated with air bubbles in the nozzle line or expansion of the oil caused by reflected heat from the combustion chamber. Figure 5-18 shows how these valves reduce hydrocarbon (smoke) emissions.

These check valves are built into the nozzle strainer assembly and must be installed or changed at the time the nozzle is changed. The check valve is calibrated to open and close within a very tight tolerance of the burner operating pressure. For this reason, different nozzle check valves are manufactured to match different operating pressures. If you are about to change the operating pressure of a burner, you should first check to see if it has a check valve installed. If it does, be sure to install the right check valve for the new operating pressure.

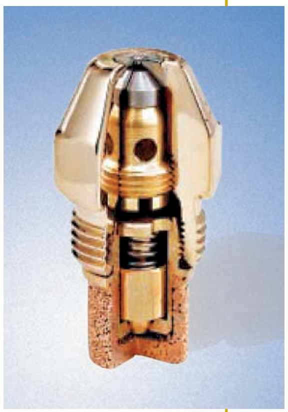
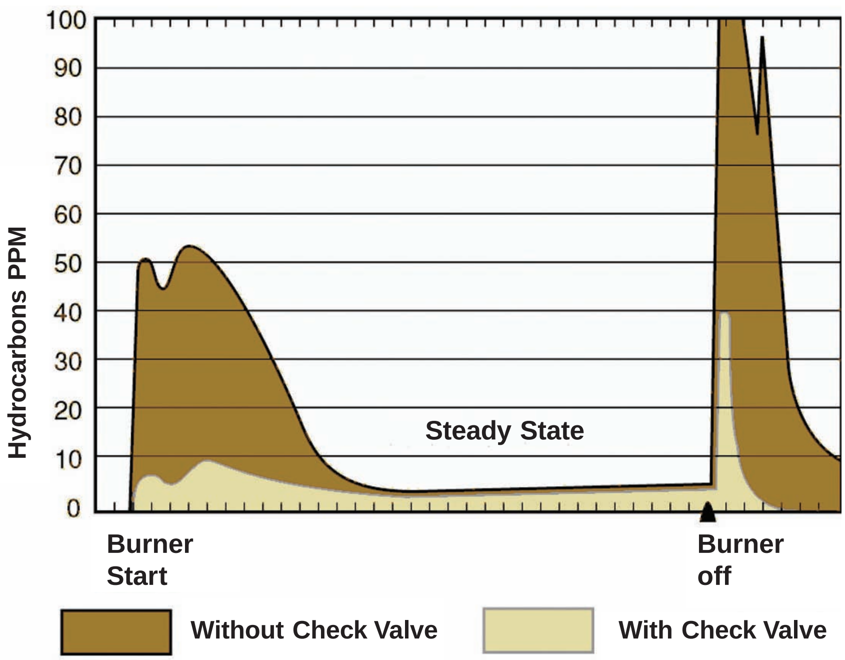


Figure 5-17:
Delavan
ProTek valve

Figure 5-18: Standard vs. anti-drip valve; emissions chart.
Dark tint area is a standard nozzle,
light shaded area is with a nozzle check valve.



Part II: Combustion Chambers

Introduction

The flame from the oilburner is contained in the combustion chamber. A chamber must be made of the proper material to handle the high flame temperatures. It must be properly sized for the nozzle-firing rate and it must be the correct shape and the proper height. Combustion chambers have a profound effect on the first three of the four rules for good heating oil combustion:

1. The oil must be completely atomized and vaporized.
2. The oil must burn in complete suspension.
3. The mixture of air and oil vapors will burn best in the presence of hot refractory.
4. A minimum amount of air must be supplied for complete, efficient combustion.

To burn the oil in suspension means that the fire must never touch *any* surface—especially a cold one. The cold surface will reduce the temperature of the gases turning the vaporized carbon in the fuel into smoke and soot before it has a chance to burn. For combustion to be self-sustaining, the heat produced by the flame must be sufficient to ignite the fresh mixture of oil vapor and air coming into the combustion zone from the burner. The hotter the area around the burning zone, the easier and more completely the oil will burn.

The combustion chamber provides the necessary room for all the oil to burn before contacting or impinging on cold surfaces. It also reflects heat back into the burning zone, ensuring clean, quick combustion. If the chamber is too small or the wrong shape for the burner air pattern, or the nozzle is too close to the floor, there will be flame impingement, causing smoke and soot. With non-flame retention burners, an oversized chamber refractory will not reflect enough heat back into the burning zone to burn the carbon—smoke will be created. If the chamber sides are too low, combustibles will spill over the top and burn incompletely. It is your job to be able to diagnose an incorrectly built chamber as well as to build and design a correct one.

Chamber materials

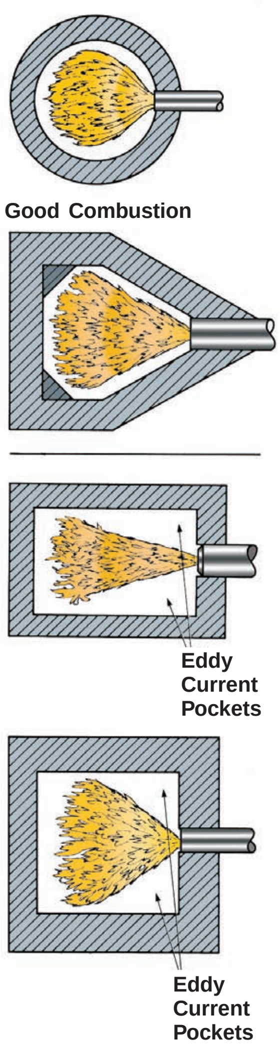
Chambers should heat up quickly, reflect as much heat back into the burning zone as possible, and cool off quickly when the burner shuts down. There are five common types of materials used in combustion chamber construction.

Insulating fire brick: The porous nature and lightness of this brick makes it highly resistant to the penetration of heat. The side of the brick facing the fire glows red hot in about 15 seconds while the rear surface remains relatively cool. (The bricks come in a variety of sizes and are available in precast chambers). For fires up to 3 GPH, you can use 2000°F firebrick. It will take up to 3000-degree temperatures, but structurally it cannot take the starting violence of a large fire. Proper refractory cement should be used with the insulating brick so the expansion of the brick and cement will be equal.

Common fire brick or hard brick: This weighs more than insulating brick and it absorbs much more heat before it begins reflecting any back into the burning zone. It is unsatisfactory for residential purposes, but is used in commercial units because it stands up better to the shock loads of high firing rates. The brick comes in the standard size of 9" long by 4.5" high, and 2.5" deep. It is also made in runners and pre-cast chambers.

Metal fire chambers: Metal chambers are used primarily in factory-built "packaged units" because they can be shipped in place without damage or breakage and do not require bracing. Metal chambers are much better than common fire brick. However, they are sensitive to improper nozzle selection and overfiring. A nozzle-firing rate that is too high, or a lopsided fire can distort or even burn a hole through the wall of the chamber. Direct flame impingement on the chamber must be avoided. Metal chambers must have free flowing air behind them to keep them from burning through. Do not put any kind of insulating material, including soot, around the chamber. The higher flame temperatures of flame retention burners is tough on metal chambers; it is usually a good idea to replace a burned out metal chamber with a pre-cast ceramic one.

Figure 5-19: Combustion chamber design



Ceramic chambers: Ceramic material is excellent for chambers. It reflects heat quickly while absorbing very little and it is easy to install. If the old chamber is still in good condition, you may use ceramic blanket material to line the old chamber. Be sure to seal any air leaks in the old chamber first. If the old chamber is deteriorated, wrap the material with a stainless steel binder. If the old chamber was too small or the wrong shape, lining it will not help. Ceramic chambers become brittle after firing. Do not touch it with a vacuum cleaner hose or flame mirror after it has been used. The material is intended for firing rates below 3 GPH, and will withstand about 2,300°F. It can be purchased by the foot or is available in pre-shaped sizes. The material gives quieter operation, less smoke and fuel savings.

Molded chamber: Many manufacturers install their own molded chambers in their packaged units. They are usually made of semi-insulating refractory material.

Chamber shapes

The best shape for a chamber is round or oval so the hot gases can sweep back smoothly. In a square or rectangular chamber, eddy currents develop in the corners requiring more excess air to burn completely. The correct height is most important. All combustion should take place in the chamber. There should be little if any flame above the chamber. The top of the chamber should be about as far above the nozzle as the floor is below it. See Figure 5-19.

Sizing the chamber

The gallons-per-hour firing rate determines the size of the chamber. A firing rate of .75 to 3 GPH requires 80 square inches of chamber floor space per gallon of fuel. A firing rate from 3.5 to 5 GPH requires 90 square inches, and over 5.5 GPH requires 100 square inches per gallon. See Table 5-2 and Figure 5-20.

Installing a low firing rate chamber

There are many very good pre-cast

Table 5-2: Combustion chamber sizing data (preferred)

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

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

Figure 5-20: Recommended minimum inside dimensions of refractory-type combustion chambers

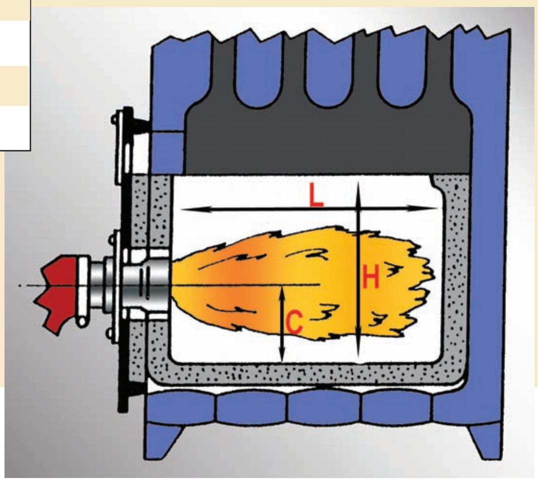
NOTES:

1. Flame lengths are approximately as shown in column 2. Tested boilers or furnaces will often operate well with chambers shorter than the lengths shown in column 2.

2. As a general practice, any of these dimensions can be exceeded without much effect on combustion.

3. Chambers in the form of horizontal cylinders should be at least as large in diameter as the dimension in column 3. Horizontal stainless steel cylindrical chambers should be 1 to 4 inches larger in diameter than the figures in column 3 and should be used only on wet base boilers with non-retention burners.

4. Wing walls are not recommended. Corbels are not necessary, though they might be of benefit to good heat distribution in certain boiler or furnace designs, especially with non-retention burners.



chambers available. If the existing chamber is in reasonable condition, ceramic liners are an option. If you find yourself in a situation where the chamber must be replaced and there is no pre-cast one available for that furnace or boiler, you may have to build a chamber. If so, the following step-by-step procedure may be helpful—especially for dry base boilers.

1. Remove the old chamber.

2. Seal up any leaks in the unit base.

3. Lay down a 1" layer of powdered insulating material on the unit floor. This will reduce sound transmission and level uneven surfaces.

4. If you are building the chamber on non-combustible material, lay down a 1" floor of insulating fire brick.

5. Using insulating firebrick, build the bottom half of the chamber in a shape suitable to the burner's fuel and air patterns.

6. Pack rockwool or vermiculite around the outside of the chamber.

7. Take a piece of smoke pipe slightly larger than the burner air tube, and use it to form the burner air tube opening. Then build up the chamber around it, making sure to observe the proper floor to nozzle center line, and making the end of the smoke pipe recess one quarter inch for the inside face of the chamber.

8. Install the top half of the chamber and pack, making sure that on a dry base boiler the bricks extend at least one course above the dry base.

9. Build up the front of the chamber and finish off the outside with a 50-50 mix of Portland cement and insulating material.

10. Use the same material to cap off the top of the chamber over the packed vermiculite. Form the cap so it is pitched from the chamber up to the boiler.

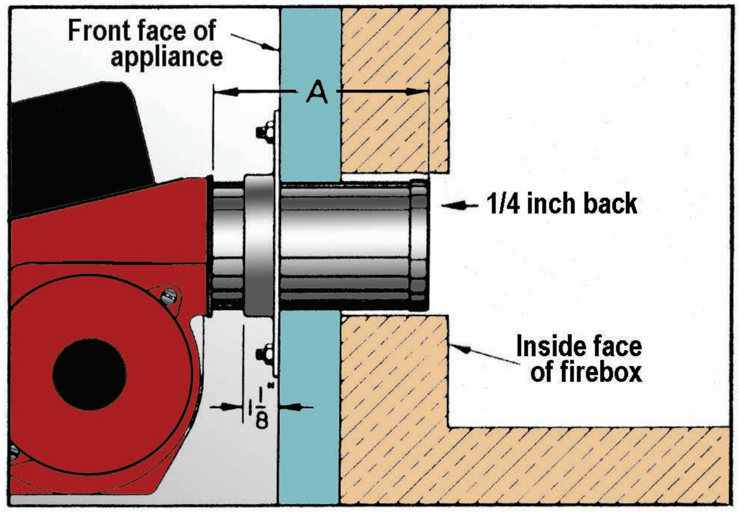
11. Install the burner with the face of the end cone one-quarter inch back from the chamber face. See Figure 5-21.

12. Snugly stuff the space around the air tube with fireproof rope.

13. Cap off the inside and outside around the air tube with the 50-50 mix.

14. Fire the chamber in short bursts for 10 to 20 minutes to dry the chamber materials.

Unlike dry base boilers and furnaces, wet base boilers may be fired without a chamber. The water jacket surrounds the fire zone. The flame from modern burners are self-propagating, they do not need hot refractory reflecting heat back into the flame to burn cleanly. Although a chamber wall is not needed, a target wall with little wing walls is still a good idea. As with chambers, the nozzle must be properly sized so the flame does not impinge on any cold surfaces.



"A" = Usable air tube length.

Air Tube Insertion

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

Figure 5-21: Burner installation, chamber guide

There are advantages to chamberless firing:

• Target walls are less expensive than chambers.

• Heat transfer to the water improves because there is no insulating chamber material between the cast iron and the fire.

• Nitrogen oxide emissions are reduced.

• Flame temperatures are lowered since there is no chamber to reflect heat back into the fire and the iron absorbs all that heat. Lower flame temperatures produce lower NOx emissions.

Finally, when in doubt about nozzles, chamber, chamber design or chamber materials refer to the manufacturer's instructions, ask your supplier, or call the manufacturer's technical service hot line.