Chapter 5

Nozzles & Combustion Chambers


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Chapter 5

Nozzles and Combustion Chambers

Part 1: Nozzles

Proper nozzle selection is key to efficient, clean combustion. The proper firing rate, correct spray angle and appropriate spray pattern are essential for clean and reliable combustion.

Construction of the nozzle

The burner 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 heating equipment.

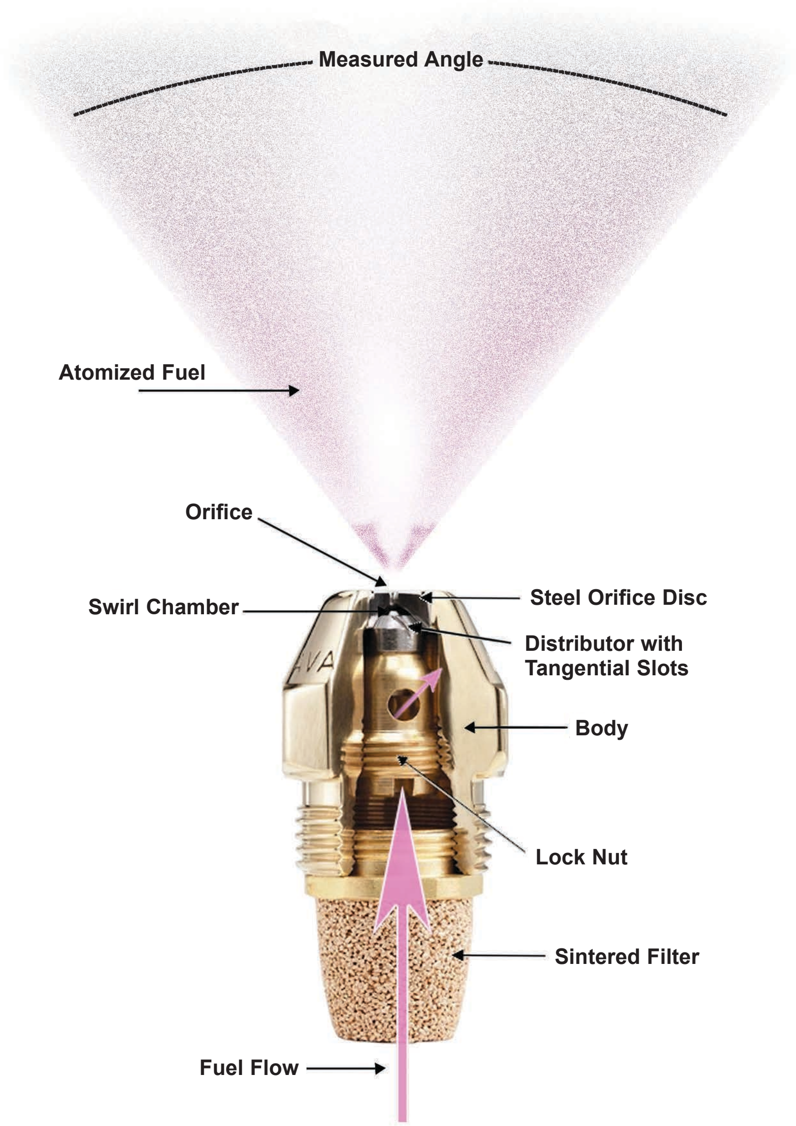
Nozzles are made of either stainless steel or a combination of stainless steel and brass, allowing them to withstand the temperatures, pressures and the variety of fuels found in combustion environments.

Nozzle function

The nozzle performs three vital functions:

1. **Atomizing:** The nozzle breaks fuel down into tiny droplets to create enough surface area for oxygen to better surround the droplets. This is called 'atomization'.
2. **Metering:** A nozzle delivers a fixed amount of atomized fuel to the combustion chamber. Nozzles are rated in gallons-per-hour (GPH) at 100 pounds pressure.
3. **Patterning:** A nozzle is expected to deliver the fuel to the combustion area in a uniform spray pattern and angle best suited to the requirements of each burner and appliance. (boiler, furnace, water heater). Figure 5-1.

Figure 5-1: Nozzle; cutaway view



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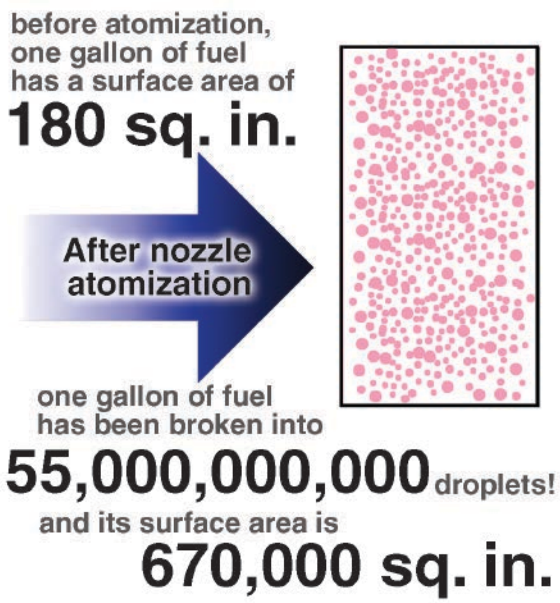
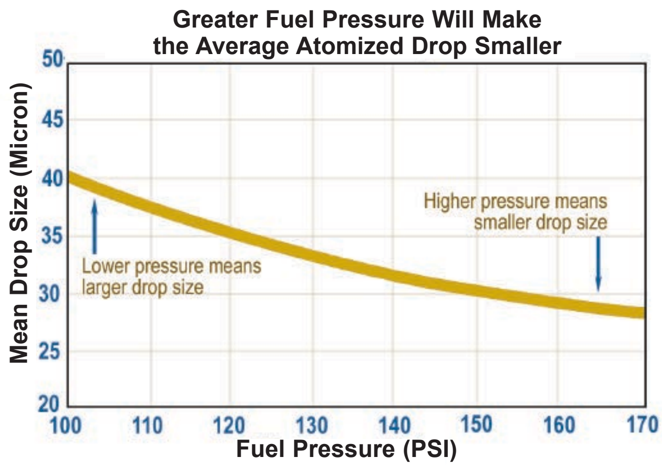


Figure 5-3 shows how the spray from a nozzle changes as the pressure increases. At low pressure, the cone shaped film is long and the droplets are large and irregular. As the pressure increases, the spray angle becomes better defined. Once a stable pattern is formed, any increase in pressure does not 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 are drawn inward by the air flow. This is the same effect a speeding car has on leaves—the fast air of the car moving sucks the leaves into the wake.

Effects of pressure on nozzle performance

Historically, 100 PSI was considered satisfactory for the fixed fuel pressure supplied to the nozzle and all nozzle manufacturers rate their nozzles at that pressure. Most burner and appliance manufacturers often recommend higher pressures for their products. Higher pressures create better atomization to produce a very fine spray, i.e., smaller droplets. See Figure 5-2.

Figure 5-2: Fuel pressure vs. droplet size



How a nozzle works

Heating fuel 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 fuel creates a high velocity swirl, like a tornado. As the fuel swirls against the swirl chamber walls, it creates an area of low pressure in the center. This pressure differential moves the fuel 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.

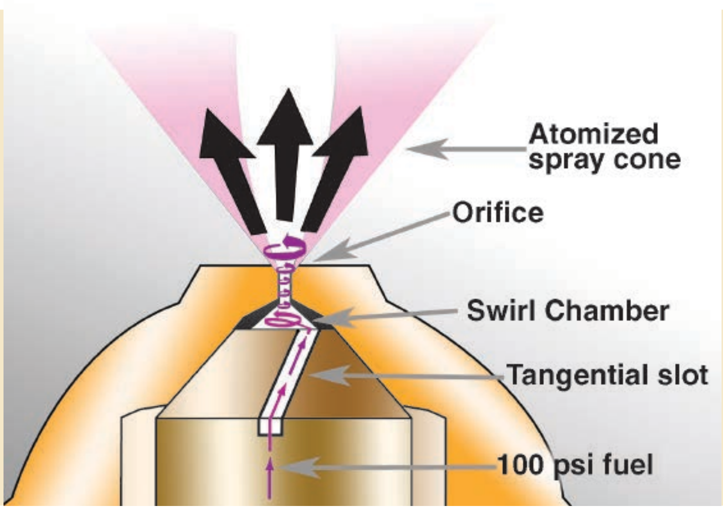
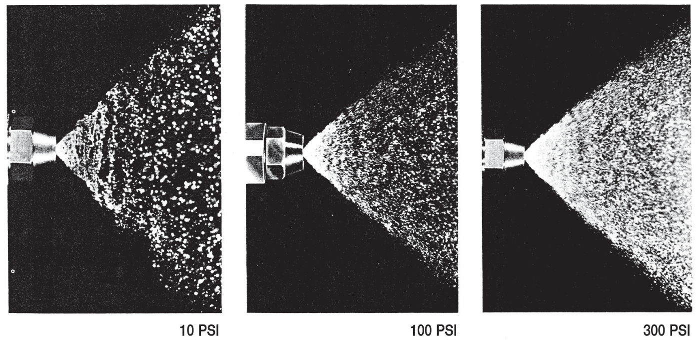


Figure 5-3: Nozzle spray droplets



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As one might expect, pressure increases cause an increase in the amount of fuel 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%. Reduced diameter also increases the number of droplets and the amount of fuel surface area that will be surrounded with incoming air, thereby improving combustion. Table 5-1 on following page, shows the effect of pressure on nozzle flow. NEVER operate at less than 100 PSI. Lower pressure means larger droplets that are much harder to vaporize and burn.

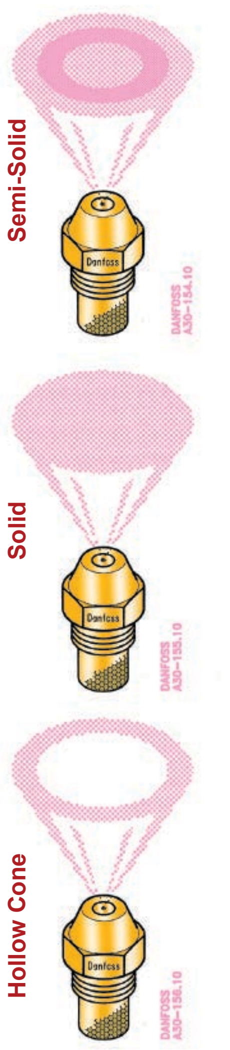


Figure 5-4: Nozzle spray patterns

Spray pattern

Nozzle patterns 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.

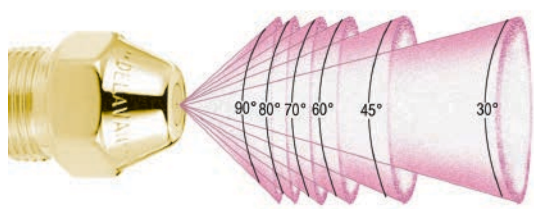
Solid cone: Here the distribution of droplets is more uniform throughout the pattern.

Semi-solid: These are a compromise between solid and hollow.

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. The spray pattern and angle must be such that all the droplets burn completely, in suspension in the combustion area. Unburned fuel must not strike (impinge) on any cool surface such as the chamber walls or floor, the crown sheet of the heat exchanger or the burner end cone. Impingement of unburned fuel will cause high smoke and will lead to future service calls. The correct spray pattern and angle depends on the air-fuel mixing design of the burner and the combustion chamber. See Figures 5-5 and 5-6.

Figure 5-5: Spray angles



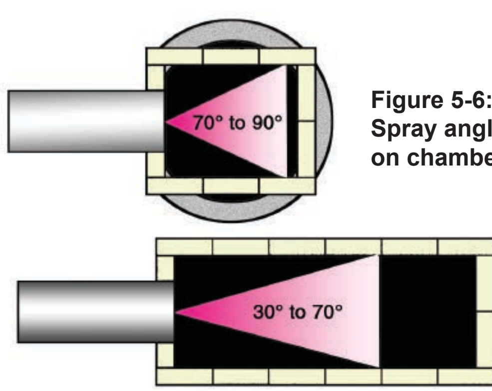


Figure 5-6: Spray angles based on chamber design

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

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Flow rate

Nozzles are available in a wide range of flow rates. The flow rate of the nozzle determines the BTU input into the appliance. 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. Use the manufacturer's recommendations on nozzle selection.

Whenever it is possible, determine the manufacturer's recommendations on nozzle selection and never overfire the rating of a heating appliance.

Specialty nozzles

Special nozzles are available for mobile home installations and other units with very low firing rates. These nozzles resist plugging by flushing contaminants through immediately before the metering slots. This extra filter gives the nozzle 35% greater filtration capacity. The internal filter does not change the nozzle's performance, it just increases its longevity.

Nozzle brand interchange

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

Figure 5-7 describes the manufacturers' different designations for their spray patterns.

Burner manufacturers test their burners in different appliances and determine what brand and type of nozzle works best in that application. Burner manufacturers publish nozzle recommendations called OEM Specification Guides. Be sure to have this information at hand.

When working on a unit not listed in the Specification Guide, understand that untested nozzles may yield unpredictable results.

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, nozzles should be left in the original container until they are ready to be installed. Nozzles should be stored in a proper nozzle box available from the manufacturer.

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. Never disassemble a nozzle that is to be used.

Only install nozzles with clean tools to reduce the possibility of contamination. Before installing a new nozzle, flush out the nozzle assembly and adapter with clean fuel, kerosene or a solvent.

Before installing the nozzle in the adapter, be sure the inside of the adapter is clean and

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 5-7: Manufacturers use different designations for their spray patterns

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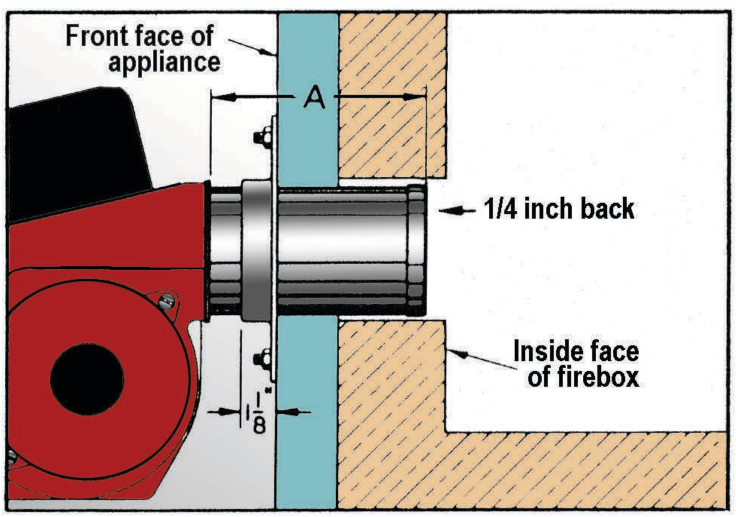
free of contamination. Carefully examine the sealing surface of the adapter to be sure there are no scratches or nicks. These can be caused by careless handling, or just wear and tear. If it is scratched or nicked, then replace the adapter. Do not take a chance—a leak between the nozzle and the adapter can cause serious problems. Do not put thread sealant on the nozzle threads. Tighten the nozzle into the adapter one-eighth to one-quarter turn past hand tight (about 11 to 15 foot pounds).

The nozzle orifice face is polished to a mirror finish. Do not damage 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.

Nozzles should not be very hot while operating as they are cooled by the air and fuel travelling past them. Nozzles may overheat from poor, or no over-fire draft. Most appliances should have at least -.01 draft to prevent the heat from backing up into the nozzle area. *Note: Negative draft rules do not apply to positive pressure boilers, always refer to manufacturer's instructions for details.*

With negative pressure boilers, be sure the end of the burner air tube does not extend into the combustion chamber. The face of the tube should be flush or recessed up to ¼" from the face of the chamber. As always, follow manufacturer's instructions. Figure 5-8.

Figure 5-8: Burner installation, chamber guide



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.

Flame patterns – Air/Fuel mixture

What constitutes a perfect burner flame? Theoretically, each droplet of fuel that leaves the nozzle would mix completely with the oxygen in the air which would result in perfect combustion. This air volume, generated by the burner fan, would be delivered to the exact amount required by the amount of fuel being fed through the nozzle, see Figure 5-9. While perfect combustion is not possible, technicians should always attempt to set burners to the manufacturers guidelines

There are several elements needed for the proper air-fuel mixture: fuel volume, fuel spray pattern, fuel spray angle, air volume and the pattern of air as it exits the burner. The air pattern of the burner is a critical factor. The air pattern cannot be seen or controlled, it is fixed by the burner design and by the appliance it fires into. The volume of air can be controlled by adjusting the burner, but air patterns are not always affected by air volume. Equipment manufacturers do thorough testing to prescribe the best matched nozzle type for each application.

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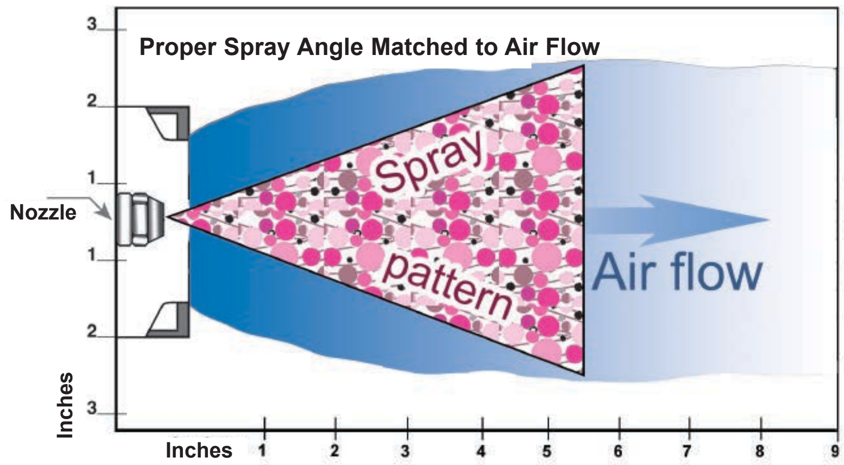
Figure 5-9



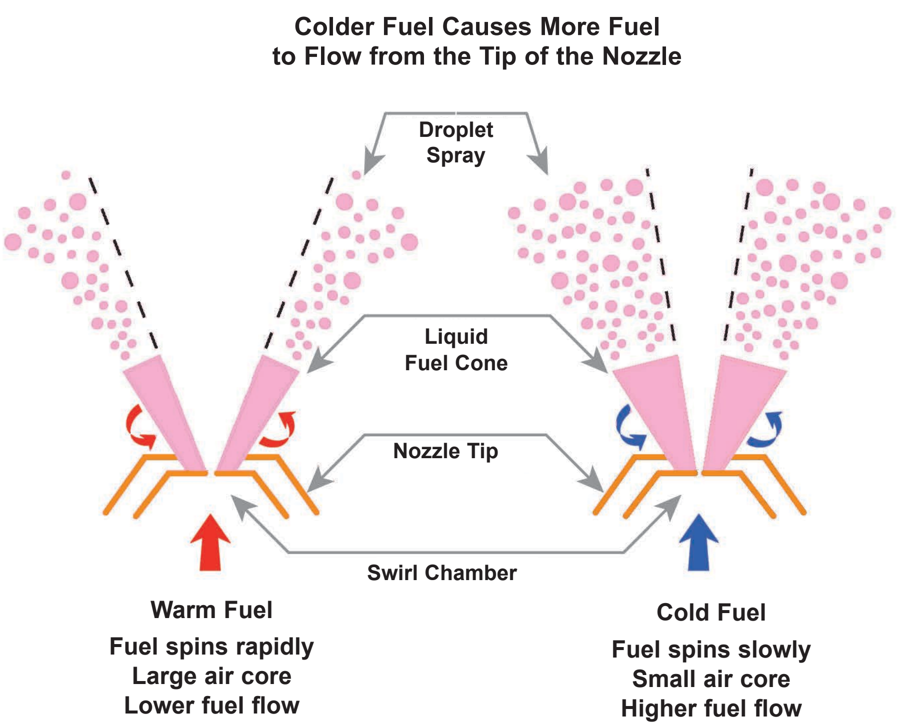
To assess whether efficient combustion is occurring requires a combustion analyzer along with the manufacturer's specifications. Any changes made when working on the burner or appliance will potentially affect the combustion process and must be performed using instruments designed to measure those effects.

The best burner adjustment is one that allows for a smokeless operation with a safe amount of excess air typically 25 – 35%. This is covered in-depth in the combustion chapter.

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 i.e.,

Figure 5-10: Comparison of warm vs. cold fuel on nozzle flow rates



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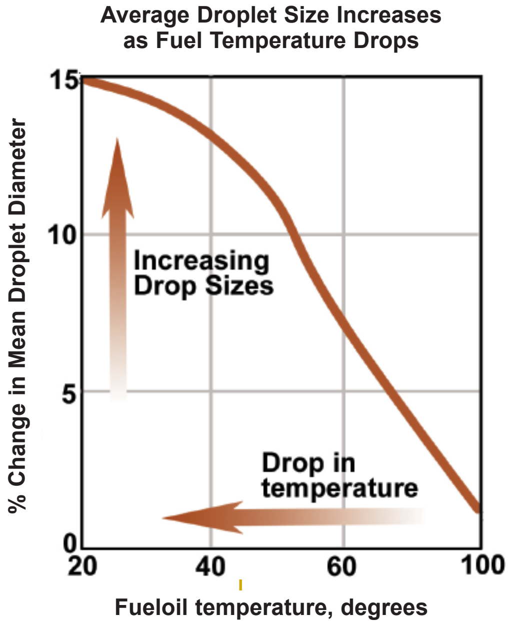


Figure 5-11:
Nozzle droplet size in relation to temperature

the thickness of the fuel. For example, gasoline is "thin"—having a lower viscosity while grease is "thick"—having a higher viscosity.

The viscosity of the fuel will increase with a drop in temperature.

As the viscosity of the fuel entering a nozzle increases, so does the flow rate. Here is how it happens: as higher viscosity fuel enters the nozzle through the tangential slots then moves into the swirl chamber, the rotational velocity slows down. As a result, the walls of the cone of fuel leaving the nozzle orifice are thicker meaning more fuel enters the chamber and the fuel 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, and less stable. This creates incomplete combustion resulting in smoke and soot. It is also more difficult to light cold fuel, potentially delaying ignition. See Figure 5-10 on previous page.

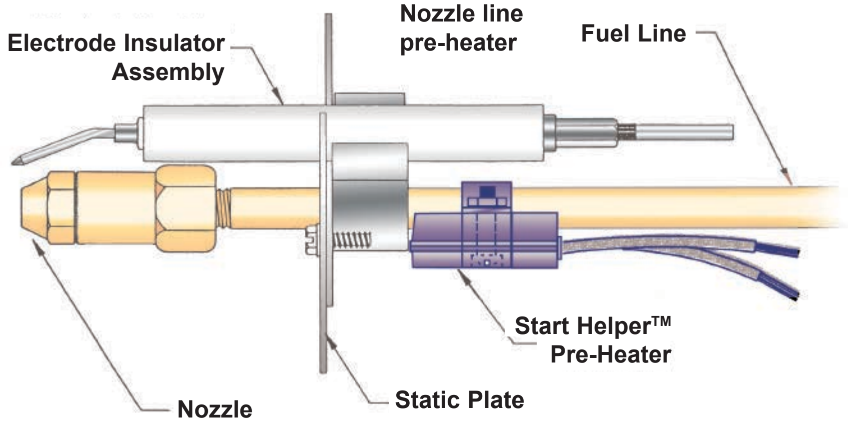
Exposed outdoor, above-ground storage tanks suffer most dramatically from the problems of cold fuel. A tune up performed on a hot day when the temperature of the fuel in the tank is 80°F will have the burner adjusted to run properly at that viscosity. As the temperature drops, viscosity increases and the fuel becomes thicker, the amount of fuel flowing through the nozzle increases causing the burner to over-fire.

This can happen to a lesser degree to underground tanks that are normally at about 50 to 55° F. Since fuel trucks are not heated, it can take several days for a fresh load of cold fuel to warm up in an underground storage tank. Until the fuel warms, viscosity problems can occur. See Figure 5-11.

The easiest way to reduce the effects of cold fuel is to increase pump pressure. This decreases droplet size which makes burners less susceptible to problems caused by high viscosity fuel. Increased pump pressure also increases the flow rate, so the nozzle size should be decreased to maintain the proper flow rate (see Table 5-1, p.66). Another solution to cold fuel is to install a nozzle line heater. This simple, strap-on device increases the temperature of the fuel arriving at the nozzle to about 130° F. See Figure 5-12.

The nozzle line heater is wired in parallel with the limit control energizing it whenever there is power to the heating system. Inside the nozzle line heater is a solid-state, self-regulating heating element that maintains the temperature in the nozzle line. As the fuel temperature drops, the heat output from the element increases to compensate.

Figure 5-12:
Nozzle line
pre-heater



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Nozzle after-drip

Nozzle after-drip is when fuel drips from the nozzle orifice after the burner shuts down. If the combustion area is still hot, this fuel burns with a smoky fire. If the combustion area is not hot enough, the fuel drips out and collects in the bottom of the chamber or in the burner air tube. When the burner comes back on, all this extra fuel lights and results in smoke, soot and noise.

There are three basic causes of after-drip:

1. A defective fuel unit shut off valve.
2. Air entrapped in the nozzle line (typically caused by high vacuum).
3. Fuel 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, the pressure-regulating valve in the fuel unit is not good and the fuel unit should be replaced. If an oil valve is installed, the pressure should not drop at all.

If air is trapped in the nozzle line or adapter, it will cause an after-drip, see Figure 5-13. A bubble of trapped air will be compressed to 1/7th its original volume by the 100 PSI pressure of the fuel. 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 fuel out of the nozzle causing an after-drip for several seconds. This can lead to a carbonized heat exchanger, delayed ignition and the smell of fumes.

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

Older appliances often had brick chambers which radiate much more heat after shutdown than today's ceramic fiber chambers. If the appliance has a brick chamber, installing a ceramic liner will reduce the amount of radiated heat.

Burner nozzle anti-drip valves

Another solution to nozzle after-drip is the use of nozzles with anti-drip valves commonly referred to as check valves. These valves are designed to cut-off fuel flow from

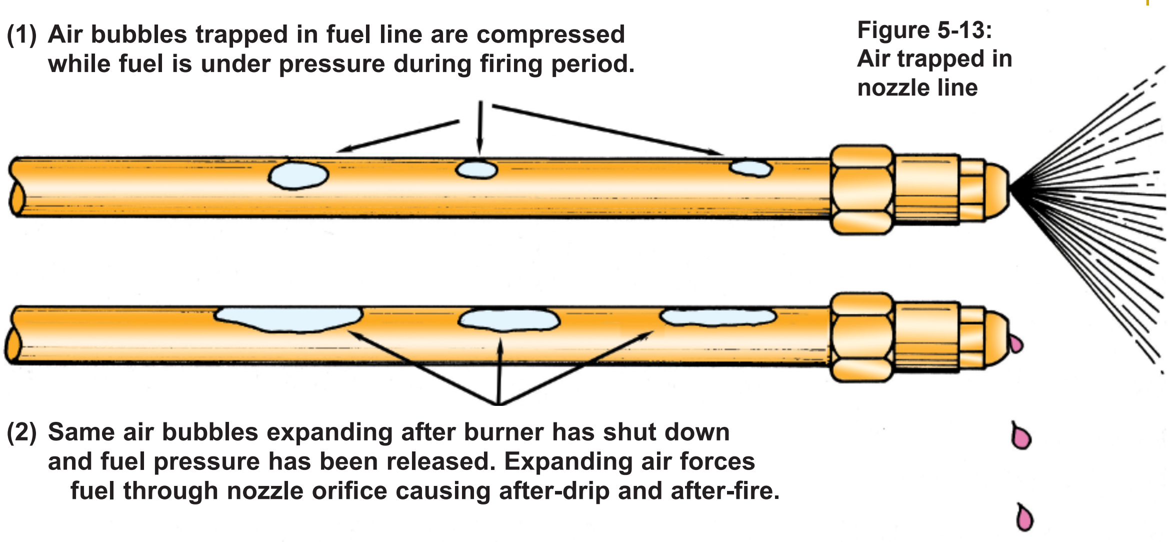

Figure 5-13: Air trapped in nozzle line

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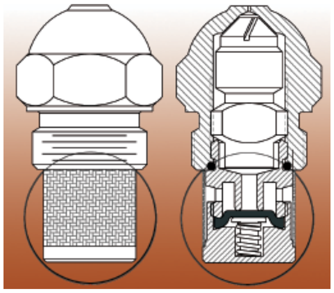


Figure 5-14:
Hago Ecovalve

Figure 5-15: Delavan
ProTek valve

the nozzle quickly upon pressure drop. See Figures 5-14 and 5-15.

Nozzle check valves can also eliminate the incomplete atomization that can occur on startup and shut down of the burner. They also eliminate after-drip associated with air bubbles in the nozzle line or expansion of the fuel caused by reflected heat from the combustion chamber. Figure 5-16 shows how these valves reduce smoke emissions.

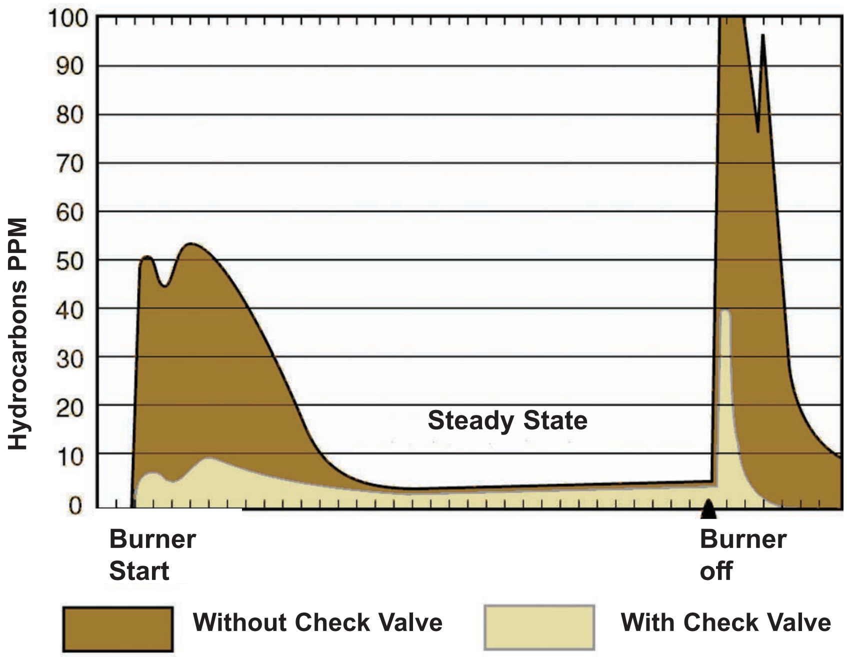
These check valves are built into the nozzle strainer assembly and must be installed or changed at the time the nozzle is changed. The check valve is calibrated to open and close within a very tight tolerance of the burner operating pressure. For this reason, different nozzle check valves are manufactured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

Part II Combustion Chambers

Introduction

The flame from the burner 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

Figure 5-16: Standard vs. anti-drip valve; emissions chart.
Dark tint area is a standard nozzle,
light shaded area is with a nozzle check valve.



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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 fuel combustion:

- The fuel must be completely atomized and vaporized.
- The fuel must burn, in complete suspension.
- The mixture of air and fuel vapors will burn best in a hot chamber or hot refractory.
- The right amount of air must be supplied for complete efficient combustion, not too much, not too little.

The chamber also reflects heat back into the burning zone ensuring clean, efficient 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. If the chamber sides are too low, combustibles will spill over the top and burn incompletely.

Chamber materials

Chambers should heat up quickly, reflect as much heat back into the combustion 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.

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 were used years ago and most appliances that have one are probably due for a new high efficiency replacement unit. However, there are triple pass units on the market that operate with stainless steel inserts that heat up very quickly and enable more efficient combustion.

Ceramic chambers: Ceramic material is excellent for chambers. It heats up quickly while absorbing very little and it is easy to install.

Molded chamber: Most manufacturers install molded chambers in their appliances. They are usually made of semi-insulating refractory material.

Modern wet-base appliances typically operate without chambers due to the following:

- Target walls are less expensive than chambers.
- Heat transfer to the water improves when there is no insulating chamber material between the heat exchanger and the fire.
- Flame temperatures are lowered since there is no chamber to reflect heat back into the fire and the iron absorbs all that heat.

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

Chapter 5: Additional Resources

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You will find:

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- Technical Bulletins
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