NILSSON SHIPPING
Fuel Nozzles

Fuel Nozzles
for Oil Burners
Technical Aspects of Applications

An oil burner is a combustion machine. Its purpose is to promote efficient combustion of oil fuel. Mechanically speaking, there are several different types of oil burners, such as vaporizing pot type, low pressure gun type, high pressure gun type, and several types of rotary burners. The fundamental processes upon which all of these different burners are based are the same, however. The process of combustion may be thought of in the following steps:

1. The oil must be vaporized, since all combustible matter must be converted to a vapor or gas before combustion can take place. This is usually accomplished by the application of heat.
2. The oil vapor must be mixed with air in order to have oxygen present for combustion.
3. The temperature of the mixture must be increased above the ignition temperature.
4. A continuous supply of air and fuel must be provided for continuous combustion.
5. The products of combustion must be removed from the combustion chamber.

The simplest type of burner is the vaporizing pot type. In this type of burner, heat is applied to a puddle of oil, causing vapors to be given off from the surface of the fuel. These vapors are then burned after mixing with the proper amount of air. When it is desired to speed up this combustion process, the vaporizing process is accelerated by mechanical means. This is done by breaking the oil up into many extremely small droplets. A very small droplet will, of course, be vaporized in an extremely short period of time when exposed to high temperatures. Also by separating the oil into very small droplets the surface area is increased, exposing more oil surface to contact with air. The simplest method of doing this job with light oils is by the use of nozzles, which separate the fuel into small droplets by their particular design. We shall concern ourselves here primarily with the high pressure atomizing type of nozzles since these are most common in the oil burner industry.

A 1.00 GPH nozzle operating at 100 psi, spraying No. 2 fuel oil breaks the fuel up into droplets, which have an average diameter of approximately .002 inch (50 microns). That means that one gallon of fuel is broken up into something like 55,000,000,000 droplets, ranging in size from .0002" to .010" diameter.

By this process the surface area is increased by approximately 3800 times. The resultant area of one gallon of fuel is approximately 690,000 square inches.

The principal function of a nozzle then is to break the fuel up into these very small droplets. We use the term "atomize" to describe this process even though it is not strictly correct. The size of these droplets is very important in the performance of a burner. Unfortunately there is as yet no commercially feasible method of measuring droplet sizes and all of the work that has been done along that line has been on a laboratory basis. In addition to breaking up the fuel into small droplets, the nozzle is expected to deliver these droplets in a specific pattern. It must be designed to deliver a specified spray angle within specified limits. It must also be designed to distribute these droplets as desired across a cross section of the spray. The common distribution patterns are known as hollow cone and solid cone and these patterns will be discussed later. The second function of a nozzle is metering the fuel. On a normal high-pressure burner, it is customary to supply a fixed pressure to the nozzle. It is also the practice of nozzle manufacturers to calibrate nozzles at a fixed pressure, usually 100 psi. At the predetermined pressure the nozzle must be so designed and dimensioned that it will deliver a definite amount of fuel, within certain limits. Therefore the functional dimensions in a nozzle must be controlled very closely.

Nozzles must be available in a large number of flow rates and spray angles to satisfy the needs of the industry. For example, below 5.00 GPH, 21 different flow rates and 6 spray angles are standard. Standards must also be maintained both as to machining and as to testing, to insure that metering can be depended upon year after year.

How a Nozzle Works

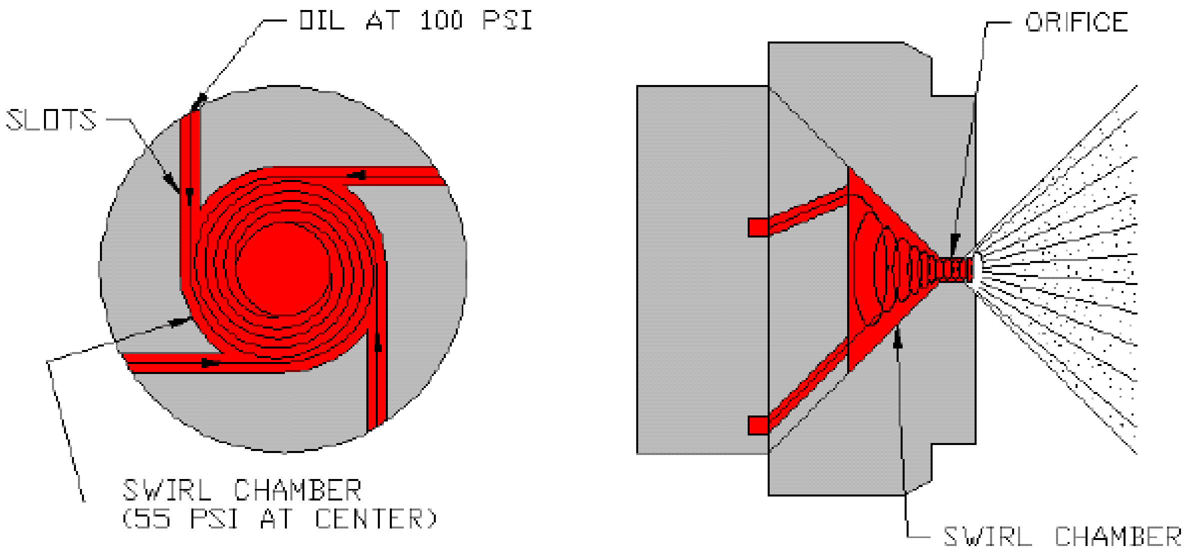

Figure 1

Separation of oil into small droplets requires the application of energy. In the case of nozzles, this energy is supplied in the form of pressure, usually from an appropriately designed motor driven pump. Pressure energy as such will not break up oil it must first be converted into velocity energy. This is done by supplying the fuel under pressure, usually 100 psi on domestic burners, and forcing it through a set of holes or slots. The oil emerges from these slots at very high velocity. Figure 1 shows a schematic cross section of a pressure-atomizing nozzle of the "simplex" type. It will be noted that these slots are cut tangentially into a swirl chamber. The high velocity entering streams of oil set up a very high velocity rotation in the swirl chamber. The velocity of rotation increases as the liquid approaches the center of the swirl chamber so that if we place a discharge orifice at the center of this swirl chamber we will have the maximum rotational velocity in that orifice. The velocity of rotation at the center is so high that an air core is created at the center of the vortex. The oil then will extend into the orifice in the form of a rapidly
rotating tube of oil, leaving an air core in the center. As this tube of oil is rotating it pushes outward against the walls of the orifice because of the centrifugal force developed. All of the 100-psi pressure supplied at the slots is not converted into velocity energy. Some of it remains as pressure energy and the pressure, which tends to push the liquid forward through the orifice, will be
approximately one half of the applied pressure. This pressure forces the oil to emerge from the orifice in the form of a spinning tube which, because of centrifugal force, immediately expands into a cone shaped sheet as it leaves the orifice. This sheet or film of liquid emerging from the orifice stretches to the point where it ruptures and throws off droplets of liquid. At low pressure the velocity of this film is low and it extends a considerable distance in front of the nozzle before it breaks into large and irregular size droplets.
This can be seen in Figure 2. As the pressure is increased, as in Figure 3, 4,
and 5, a definite spray angle is defined and the droplets are smaller and more regular in size.

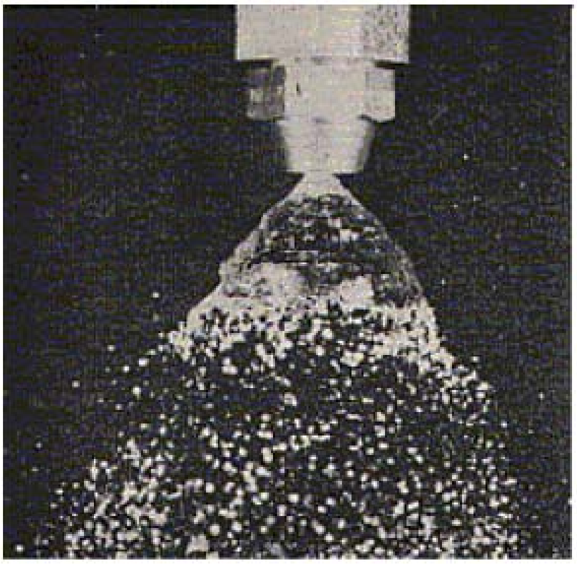

Figure 2-3 psi Pressure

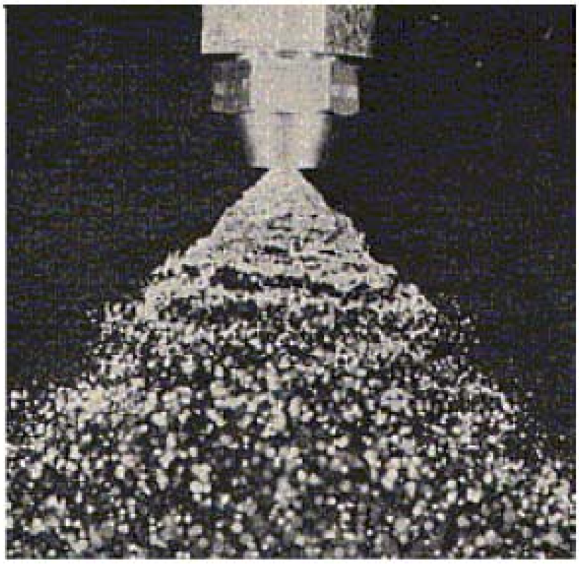

Figure 3-10 psi Pressure

Figure 4-100 psi Pressure

Figure 5-300 psi Pressure

These photographs were made with a light duration of 2 millionths of a second.
As stated previously, the discharge rate of a nozzle is controlled by the dimensions of the slots and orifice. For best operation a definite relationship between the two must be maintained. Parts from one nozzle cannot be used in another nozzle.
The spray angle is governed by the design of the swirl chamber and the orifice.
When the basic performance of a nozzle is understood, the effect of various conditions on nozzle performance can also be understood. Following are the conditions affecting nozzle performance:

Pressure

1. As might be expected, an increase in pressure increases the discharge rate of the nozzle, all other factors remaining equal. The relationship between the pressure and discharge from a nozzle is a fundamental one. The theoretical discharge from any orifice or nozzle is given by the equation Flow Rate = CA (2gh)5In this equation

C is a dimensionless coefficient for the particular nozzle in question.
A is the area of the nozzle orifice.
H is the pressure head applied to the nozzle.
g is acceleration of gravity.

This fundamental equation is modified by various factors encountered in nozzle design, but from it we arrive at a simple formula, which is of value to anyone using nozzles.

$$F_2 = F_1 * \left(\frac{P_2}{P_1} \right)^{.5}$$

In this equation
P1 is pressure at which the nozzle is calibrated.
P2 is any pressure at which it is desired to operate a nozzle other than the calibration pressure.
F1 is the calibrated flow rate at pressure Pl.
F2 is the flow rate at the desired pressure.

For example, a 1.00 GPH nozzle calibrated at 100 psi. is to be used at 125 psi.:

$$F_{125} = 100 * \left(\frac{125}{100} \right)^{.5} = 1.12\mathrm{GPH}$$

This relationship is approximately true for nozzles in the small sizes used for domestic oil burners but not exactly so. The value of the exponent varies somewhat with nozzle design and flow rate and it has been found to be as low as .470. For field calculations, however, the square root relationship is entirely satisfactory and any variation from it is of interest only to nozzle designers or where flow rates are to be calculated at extremely high pressures to fairly close tolerances.

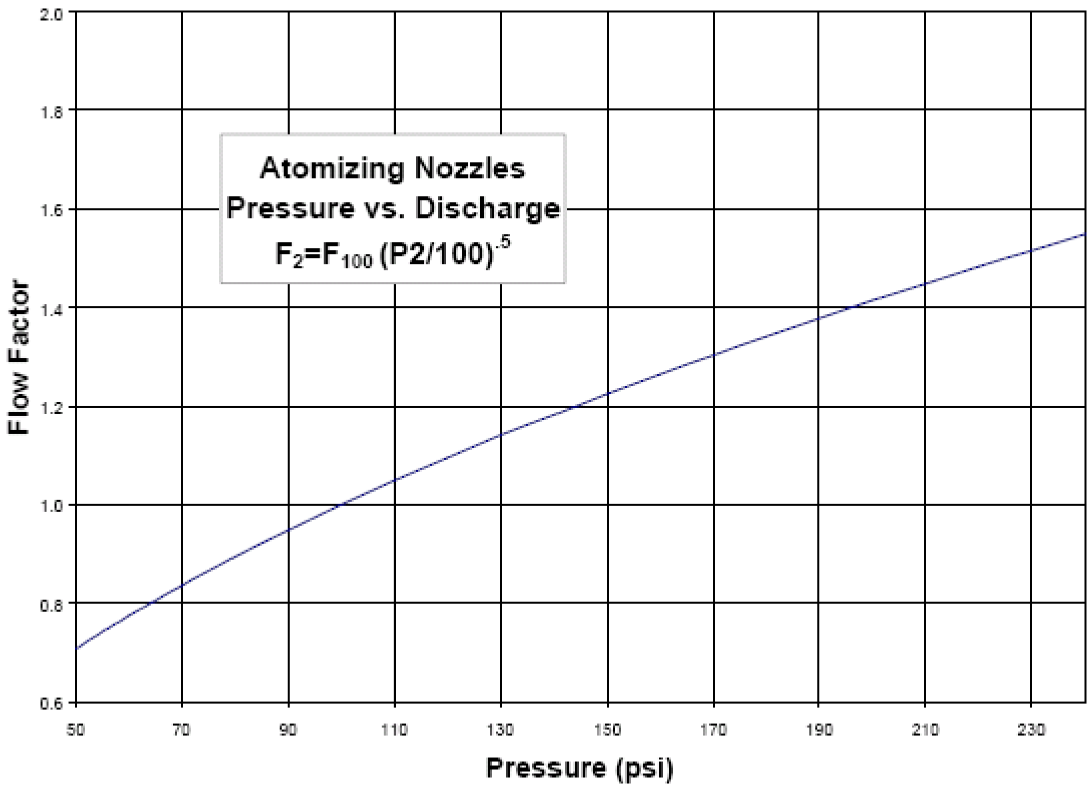

Figure 6

2. After a true divergent spray is established, any increase in the pressure does not change the basic spray angle. In the above photographs it will be noted that the spray angle measured at the orifice is the same at 300 psi as it is at 10 psi. When the spray angle is measured a distance of about four inches in front of the nozzle operating at high pressure, there is a change in the direction the droplets are traveling, but

that is not the basic spray angle of the nozzle. The reason the spray angle appears to change at a distance in front of the nozzle is also quite fundamental. With an increase in pressure, the velocity of the droplets is increased within the body of the spray. An increase in velocity in the spray causes a reduction in pressure in that area. Thus the spray might be said to aspirate air or, more specifically, since the pressure within the spray is lower than that of the air surrounding it, air will tend to push into the spray. As that air moves toward the center of the spray it carries with it the droplets which have lost their velocity to the point where the air can move them. This inward movement of air can easily be demonstrated with a large size nozzle.

3. An increase in the applied pressure will produce smaller droplets in the spray. Some recent research shows that the median droplet size varies inversely as the .3 power of the pressure change. That means that if the pressure is increased from 100 psi to 300 psi, the median droplet diameter is reduced approximately 28%. An increase in pressure from 100 to 150 psi reduces the median droplet diameter by approximately 11%.

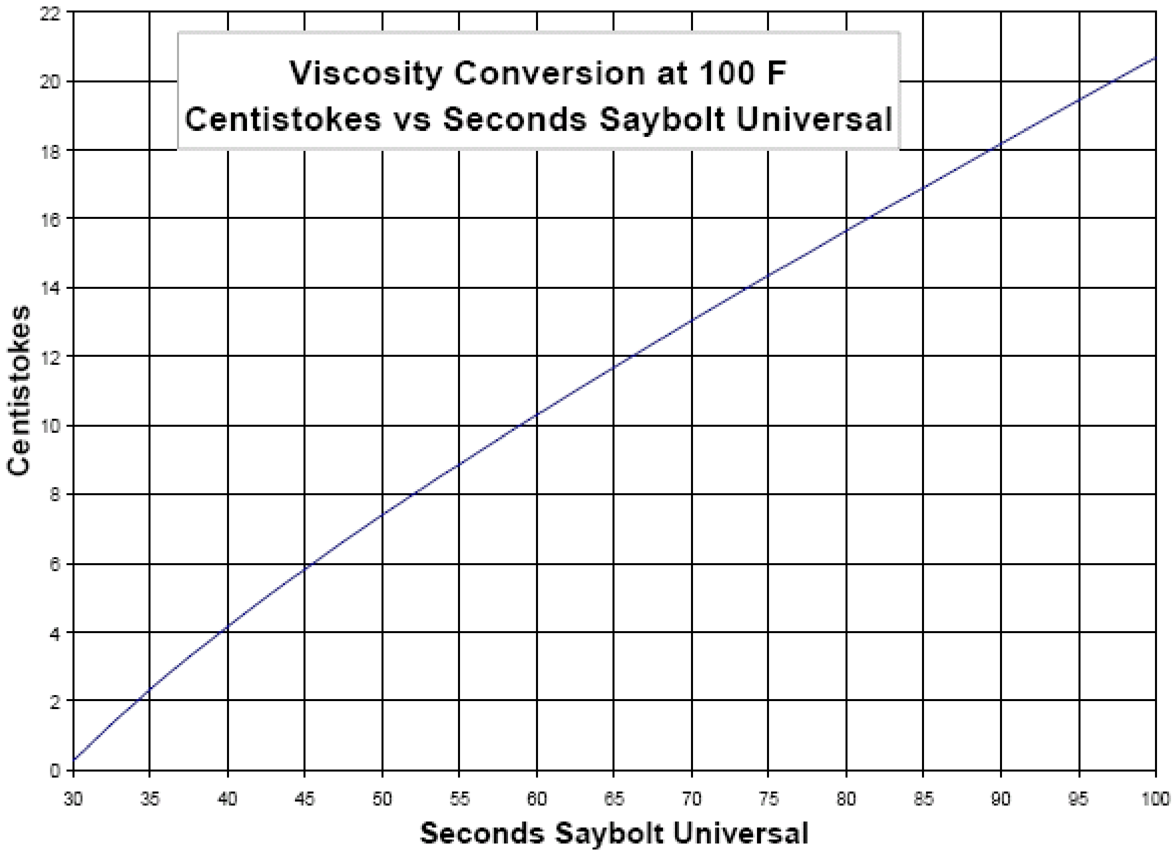

Figure 7

Fuel Properties and the Effects on Sprays

Specific Gravity

Specific gravity is normally used in flow calculations but in the petroleum industry the more common term is API gravity. The relationship between specific gravity and API gravity is given by the equation:

$$\text{Sp.Gr} = \frac{141.5}{API^{0}} + 131.5$$

The effect of specific gravity on discharge rate (volumetric) is as follows:

$$F_2 = F_1 * \left(\frac{d_2}{d_1} \right)^{.5}$$

Where d_1 Specific Gravity for flow F1
Where d_2 Specific Gravity for flow F2

If a nozzle is calibrated on a fuel with a gravity of 36° API (.845 Sp. Gr.) and it is installed on a burner being supplied with fuel with 30° API (.875 Sp. Gr.), the flow rate may be expected to be:

$$\left(\frac{.845}{.875} \right)^{.5} = 98.5\%$$

of the original, in terms of GPH. or a reduction of 1.5%, all other factors remaining constant. Since the specific gravity is reduced with increased temperature, the actual change in firing rate due to the increased specific gravity of the fuel will be somewhat less than that calculated above. Under the conditions given, however, the net result will be an increase in BTU input. In terms of pounds per hour the flow will be:

$$\frac{.875}{.846} * (.985) = 102\% \text{of the orginal}$$

At the same time the BTU per pound is 1.02% less, giving a net increase of approximately 1.0-% in BTU input.
While on the subject of gravity, it might be well to point out that the catalytic cracked fuels generally have a much lower API gravity than the thermally cracked fuels of the same viscosity. If the API gravity of a fuel is very low, it may safely be concluded that it contains a high percentage of catalytic cracked product. As far as droplet size and spray angle are concerned, the atomization of
this type of fuel is not any different from any other type of fuel, all other factors remaining equal. There may be a difference in the appearance of the fire, however, because of the difference in chemical structure. The flame will be longer and there will be a greater tendency to smoke.

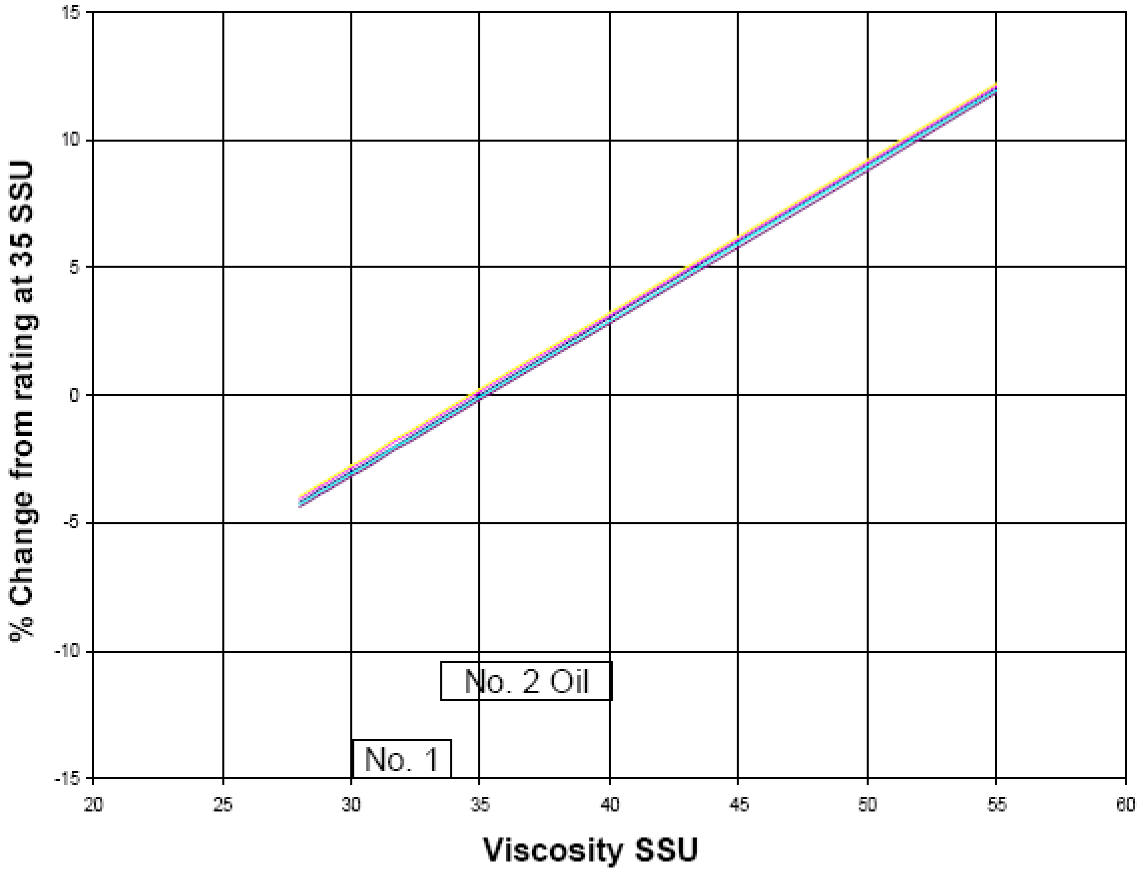

Figure 8

Viscosity

In small nozzles and within the limits of No. 2 fuel oil, the effects of changes in gravity are less important than the effects of changes in viscosity. The viscosity of fuel is a measure of its resistance to flow. In this country the two most common instruments for measuring viscosity are the Saybolt Universal viscosimeter and the kinematic viscosimeter which may appear in one of several different forms.
The Saybolt viscosimeter is so designed that the flow of the oil through an orifice is timed and the number of seconds required for the prescribed sample to flow through the orifice is the viscosity in SSU at that particular temperature. With the Saybolt viscosimeter it is customary in the oil industry to specify viscosity at 100° F. It is possible, however, to specify viscosity at any other temperature which is convenient. A high viscosity in terms of SSU indicates greater resistance to flow.
Fuels with higher viscosities need greater energy to move them whether the flow is through pipes or through nozzles. The most common of the kinematic viscosimeters is the modified Ostwald, which is a capillary tube type of instrument. For viscosities less than 40 SSU this type of instrument is more accurate than the Saybolt and is becoming more common in giving fuel oil specifications. The unit of kinematic viscosity is the centistoke and is determined by timing the flow of a given sample through the capillary pipette and multiplying the number of seconds by a constant for the particular pipette. The curve in Figure 7 shows the relationship between kinematic and Saybolt viscosities. For purposes of calculations it is necessary to determine the absolute viscosity. Absolute viscosity is determined by multiplying kinematic viscosity in terms of centistokes by the specific gravity of the liquid at the same temperature. It is expressed in centipoises, which in turn may be converted into units of length, mass and time (pounds per foot per hour) for calculating Reynolds numbers.

Changes in viscosity have several effects on nozzle performance:

1. With a pressure-atomizing nozzle of the size and type commonly used in domestic oil burners, the flow rate is affected as shown in Figure 8, assuming typical values of gravity. It will be noted that when viscosity is increased from 35 SSU to 45 SSU the discharge rate from the nozzle is increased.

Conversely, if a burner starts with cold oil, its discharge rate will drop off as it warms up. The effect of viscosity on flow rate varies with different designs of nozzles and at different supply pressures. Larger nozzles show less effect of viscosity on flow than small nozzles of similar design. The effect of viscosity is less at higher pressures. For those reasons the effect cannot usually be calculated and the curve in Figure 8 is an approximation based upon laboratory tests on small nozzles at 100 psi using typical fuel samples. This increase in discharge with increase in viscosity may not seem reasonable. However, laboratory data indicate that the phenomenon is real. There is no proven mathematical formula, which explains the change, which takes place, but it is known that the discharge coefficient for this type and size of nozzle increases with viscosity increase as indicated in Figure 8 within the range of viscosities shown. When viscosity is carried to higher values the curve of viscosity vs. discharge coefficient takes a shape similar to a typical Reynolds' number vs. discharge coefficient curve for simple orifices. Reynolds' number is defined as:

$$N_R = \frac{DVd}{u}$$

in which:

D = orifice dimension
V = velocity of liquid
D = density of liquid
U = absolute viscosity of liquid.

N_R probably would explain the phenomenon at least partially if it could be correctly determined. The difficulty in determining N_R lies in selection of the proper D and V. The air core in the orifice complicates both quantities.

The effect of viscosity may be visualized on the basis of purely physical considerations. Since viscosity is resistance to flow, or internal fluid friction, we would expect the tangential velocity in the swirl chamber and orifice to be relatively high with low viscosity liquid, and relatively lower with high viscosity liquid. If the tangential velocity in the orifice is lower the diameter of the air core in the orifice should be smaller and the wall of the spinning tube of liquid passing through the orifice thicker. The result would be increased discharge. It has been found that with extremely high viscosity oil the orifice runs full and the spray becomes a solid stream.

2. Since energy is consumed in overcoming fluid friction, we would expect that with higher viscosity fuels the spray angle would not be as stable as with low viscosity fuels. Figure 9 illustrates the change in the spray. The angle of the film at the orifice is not changed appreciably, but the effective spray angle becomes narrower. The film tends to collapse, projecting the main body of droplets more toward the center of the spray. If the viscosity is high enough, the effective spray angle may collapse to the extent that a long, very narrow flame results.
3. At the same time that the effective spray angle is decreased, the droplet size is increased. The droplet size may be increased to the point that it is impossible to maintain a steady flame front and the oil will burn off the back wall of the combustion chamber. With intermittent ignition, the flame might leave the burner completely and with constant ignition may be long and narrow and noisy. In many cases the flame looks much larger under these conditions because of the fact that larger droplets need more distance to burn completely. It may also be impossible to admit enough air through the burner to clean up the fire. Since an increase in viscosity requires an increase in the amount of energy provided to atomize the oil, it is logical to conclude that the effects of viscosity on spray angle and droplet size can be minimized by increasing the supply pressure. In the case of a 1.00 GPH 80° nozzle whose spray pattern and droplet size are affected by high viscosity, it may be possible to correct the operation by increasing pressure to say 125 psi. This has become standard procedure with many servicemen who encounter high viscosity fuels. If the discharge rate becomes too great, it may be advisable to use the next size smaller nozzle and use the increased pressure. In this connection it might be mentioned that the burners designed to handle heavy fuel, such as No. 4 and No. 5, supply the extra energy not only by increasing the supply pressure but also by preheating the fuel. Preheating the fuel reduces the viscosity to the point where it may be atomized at a reasonable pressure. In the case of the heavier fuels, 300 psi is a common atomizing pressure.

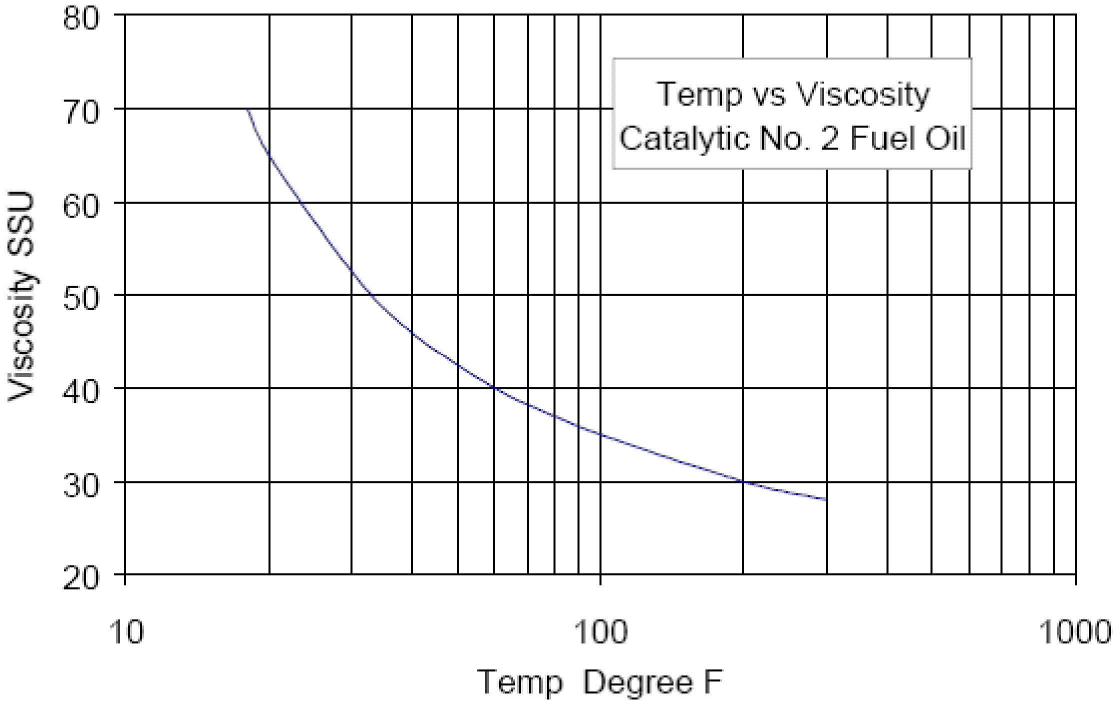

Figure 10

Temperature

Reference has been made above to cold oil and warm oil, and it may be of interest to readers to know what the relationship is between fuel temperature and viscosity. The curve in Figure 10 gives the viscositytemperature characteristics for a typical No. 2 fuel oil. It will be noted that at temperatures, which would normally be encountered with outside tanks in the winter, the viscosity is very high. Fuels whose viscosity at 100° F. is higher than that shown on this curve have an even steeper curve at the lower temperature.

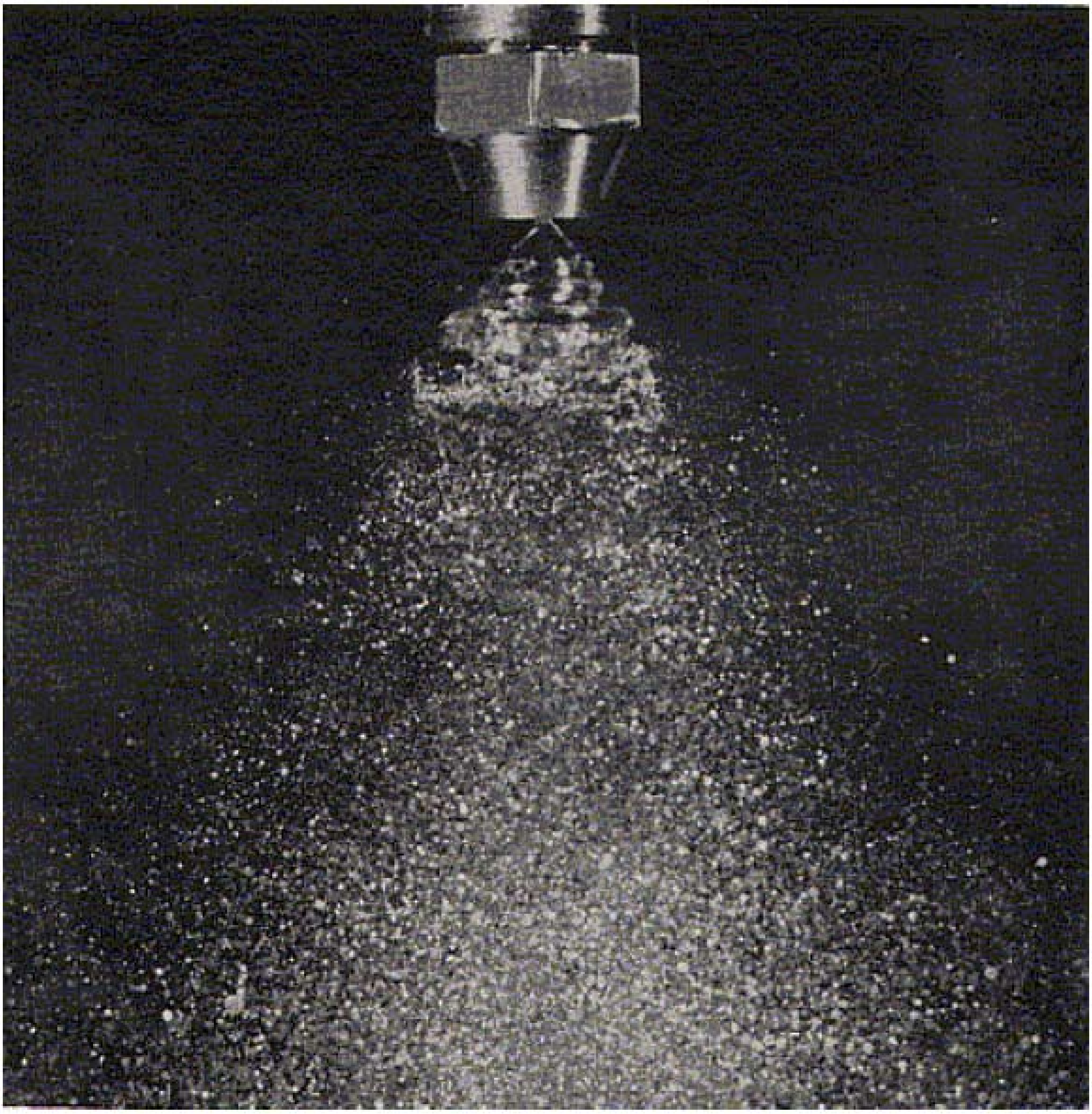

Figure 9

Surface Tension

Several engineers have asked about the effects of surface tension on nozzleperformance. Surface tension is the tendency of the surface of a liquid to contract to the smallest possible area. The effect is similar to an elastic membrane or skin surrounding the body of liquid and pulling it into the shape, which will have the least amount of surface area. That shape is spherical. Surface tension tends to resist any effort to pull the liquid apart or to change its shape. Surface tension also pinches off droplets from the forward edge of the film of liquid as it stretches, forming the spray. Within the range of surface tensions normally found in fuel oils the effect of variations in surface tension may be considered to be very minor. The surface tension found with No. 2 fuel varies from approximately 29 dynes per centimeter to approximately 33 dynes per centimeter. That angle is very small as compared with the difference between fuel oil and water which has a surface tension of approximately 75 dynes per centimeter. Atomization of water produces sprays comparable to fuel oil sprays but it has been found that the spray angle with water is approximately 10° less than with No. 2 fuel oil at the same pressure.

Boiling Range

The boiling range of fuel oil is the range of temperatures over which boiling occurs until all of it has evaporated. A typical No. 2 fuel may have an initial boiling point of say 350° and an end point of 650°. The boiling range will depend upon the composition of the fuel. If the initial boiling point and the
10% point are very high, we may expect the flame front to hold farther away from the burner. If the initial boiling point and 10% point are low, such as might be accomplished by the addition of kerosene or naptha to a given sample, the flame front will hold closer to the burner because of the fact that vaporization occurs more rapidly and consequently combustion can begin sooner. A high boiling range results in a longer fire and if the boiling range is very high, that is above 700° end point, the flame may have the appearance of burning particles traveling through space not being combined into a smooth flame. It may also be difficult to clean up the smoke without considerable excess air. The boiling range does not affect the performance of the nozzle, however, in its function of breaking it up into droplets and delivering it in a specified spray pattern.

Droplet Size

To summarize, the droplet size is dependent upon the following factors:

1. 1.The droplet size is usually larger in the higher discharge rates, assuming the same pressure. That means that a 10.00 GPH nozzle will have larger droplets in its spray than a 5.00 GPH nozzle with the same spray angle at the same pressure. That is one of the reasons for using multiple adapters and two or three nozzles instead of one to improve combustion.
2. The droplet size is smaller in the wider spray angles. A 45° spray will have larger droplets in it than an 80° spray.
3. High viscosity fuel produces larger droplets in a spray than low viscosity fuel at the same pressure.
4. A nozzle with a rough orifice finish produces larger droplet size than a nozzle with a good finish.
5. Increasing the fuel pressure on the nozzle reduces the droplet size.
6. Nozzle design is a very important determinant of droplet size in the spray. The smallest possible droplet size is not necessarily the most desirable. Good droplet size distribution to produce efficient, quiet fires is determined by nozzle design.

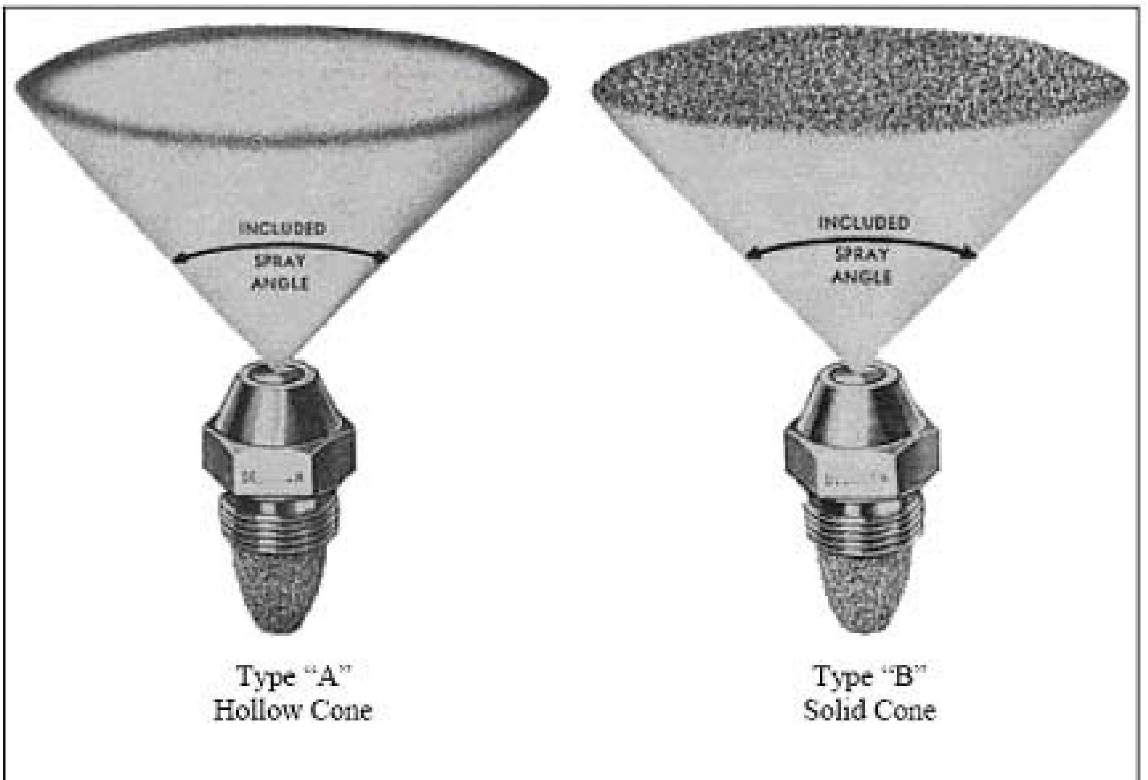

Figure 11

Spray Patterns

Nozzles for oil burner use are provided in two different general types of spray patterns, hollow cone and solid cone. These are illustrated in Figure 11. It will be noted in these illustrations that the hollow cone is a spray in which the concentration of droplets is at the outer edge of the spray with little or no fuel in the center of the spray. The determination of the spray pattern must be made at a proper distance in front of the nozzle to show the true performance. For example, after the droplets have lost their initial velocity the turbulence of the air will cause them to drift and if the pattern is measured say 6" in front of 1.00 GPH nozzle the resultant measurements will indicate solid cone. That is not a true picture, however, of the spray pattern. With a small nozzle it is necessary to evaluate the spray pattern fairly close to the nozzle, possibly 2" from it. As the flow rate increases it is necessary to take our measurements at greater distances from the nozzle. The solid cone spray is defined as one in which the distribution of droplets is fairly uniform across the cross section of the spray.

There are varying degrees of this fullness and as flow rate increases it becomes more and more difficult to maintain a true solid cone spray. For example, in normal designs, such as found on the market today, it is possible to build a true solid cone spray up to about 5.00 GPH. Above that flow rate the spray tends to become more and more hollow as the flow rate increases. Using the construction, which gives a true solid cone at 5.0 GPH, the wall of the spray will be thicker at 15.00 GPH discharge rate than with a nozzle designed to be strictly hollow cone. For that reason it will have advantages in some burners. The application of the two principal spray types can be quite simple from a theoretical point of view, but from a practical standpoint compromises must be made. Generally speaking, it is well to use a spray type which matches the air pattern for the particular burner in question.

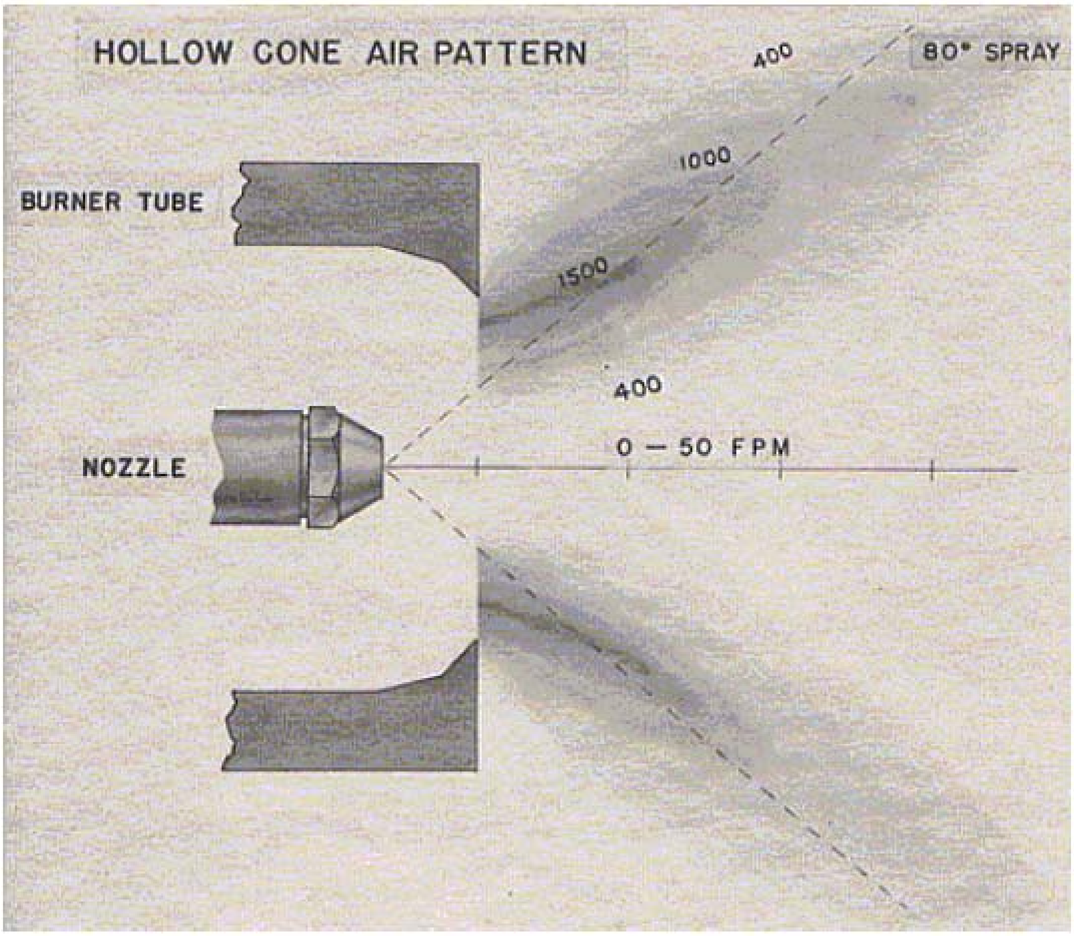

Figure 12

Figure 12 shows the air pattern from a burner, which has a very definite hollow cone "air spray". It will be noted that no air velocity is measurable at the center of the pattern and by superimposing an 80°-spray angle from the nozzle on the air pattern it can be seen that good matching is obtained. On this particular burner best results are obtained in actual tests with nozzles ranging from 80° to 85°. In this burner a solid cone nozzle or a narrow angle nozzle produces very rough operation and produces smoke in the center of the flame, which cannot be cleaned up by any adjustment of the air. This burner then is a clear-cut case of hollow cone requirement. Figure 13 showsan air pattern from a burner with a mild form of solid "air spray". This burner in actual test will give slightly better CO~ with solid cone nozzles than with hollow cone. Some burners have a much higher air velocity in the center of the pattern than this one shows and in those cases the solid cone will naturally give best efficiency.

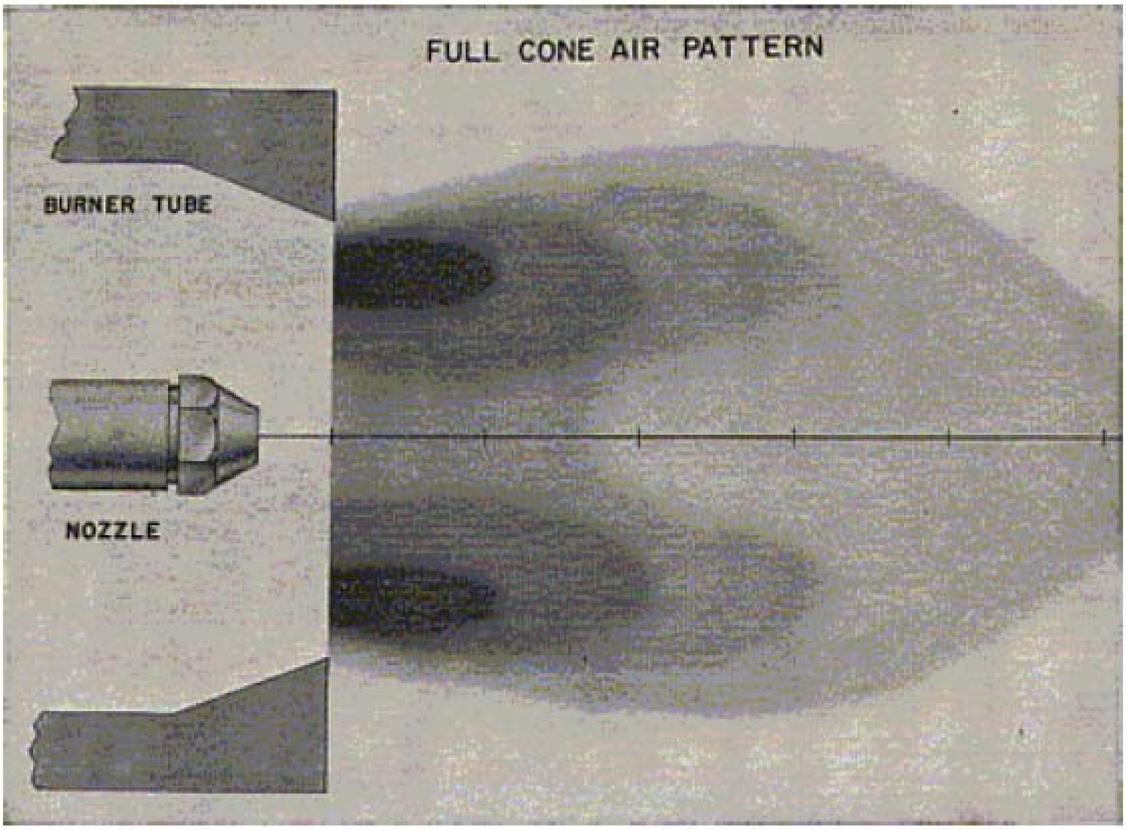

Figure 13

The flame, however, will be long and narrow and will require a long, narrow combustion chamber.
In actual applications the use of hollow cone and solid cone nozzles seems to resolve itself into a few simple rules, to which, of course, there are some exceptions:

1. In flow rates up to approximately 2.00 GPH it seems wise to standardize on hollow cone nozzles for all applications. Even the manufacturers who build burners with highest air velocity at the center of the pattern have standardized on hollow cone nozzles because of the fact that a solid cone nozzle naturally gives a very long flame and could not be contained in a round or square combustion chamber. If a spray is required with more fuel spray near the center, it appears advisable to select a nozzle with a narrower spray angle rather than go to the solid cone type. The use of hollow cone nozzles in these small sizes also insures quietest possible operation. In many instances the use of a solid cone nozzle will result in pulsations which can be cleared up by changing to a hollow cone nozzle. In some cases it is necessary to use hollow cone nozzles for reasons of noise even if it means sacrificing 1% CO_2. Hollow cone nozzles are more stable in their spray angle and droplet size distribution under adverse conditions than solid cone nozzles of the same flow rate. This is an important consideration in fractional gallonage nozzles where a supply of fuel of high viscosity may cause a reduction in the effective spray angle and an increase in droplet size.
2. From 2.00 GPH to 3.00 GPH hollow or solid cone sprays may be selected to fit the air pattern in which they are to operate. This range apparently is not critical and is usually not subject to the troubles, which are found below that range and above that range.

3. Above 3.00 GPH it has been found to be advisable to standardize on solid cone sprays. The main reason for this is that smoother ignition is obtained with solid cone sprays in the majority of burners. A burner, which must have a hollow cone spray in order to give a clean fire, will probably be able to ignite a hollow cone spray satisfactorily. Most conventional burners, however, ignite more smoothly with a solid cone spray. In this flow range pulsation is not as prevalent as in the smaller sizes and the effect of viscosity on the spray angle is not noticeable.
4. There will, of course, be exceptions to all the rules given above. A burner manufacturer whose research indicates that he will get best results with a solid cone nozzle in the small sizes may be entirely justified in adopting solid cone nozzles even as low as 1.00 GPH. However, the serviceman who does not have the solid cone nozzle in his stock is perfectly safe in installing a hollow cone nozzle in the proper spray angle. All burners in the small sizes can use a hollow cone nozzle in the correct spray angle and it is not necessary for a serviceman to carry a complete stock of solid cone nozzles in those small sizes.
5. The designations of hollow cone and solid cone sprays as used by different nozzle manufacturers may be confusing to someone using nozzles because they do not agree in all cases. This lack of unanimity probably arises from the fact that the different manufacturers use different methods of evaluating spray patterns. It is therefore safest to follow the general rules given above or consult the manufacturer whose nozzle is to be used for his recommendation

Variable Flow Nozzles

Variable flow nozzles, are available in various types. We shall describe these briefly but without the use of illustrations.

1. Air Atomizing. In this type of nozzle, atomization is not accomplished by the pressure of the fuel but by supplying the energy in the form of compressed air. The air and the fuel are generally piped separately into the nozzle where the air picks up the oil and as it expands breaks up the oil into very tiny droplets. This type of nozzle is usually not a metering nozzle, and a metering device must be provided in the pump. The flow rate on this type of nozzle can be varied over a range of approximately 3 to 1 with reasonably good atomization.
2. A bypass or return flow nozzle is identical in construction to a simplex nozzle with the exception that a return orifice is provided to "bleed" oil from the swirl chamber. The nozzle is so designed that with this bypass orifice completely closed the operation of the nozzle is essentially simplex. When the bypass line is opened, however, with constant supply pressure, the energy of the fuel coming through the slots is available for atomization but part of the fuel is bled back through the bypass line to the tank. With this type of nozzle it is possible to vary the discharge rate over a range as high as 10 to 1 with good atomization over the entire range and with constant supply pressure. For fuel burning purposes a more common "turndown ratio" is approximately 3 to 1. That is the limit of the air handling parts of most burners.
3. Another type of variable flow nozzle, which is currently popular in the jet engine field, is the dual orifice type. This type of nozzle is essentially two simplex nozzles combined into one nozzle. A small nozzle is used for the lower flow rates and the spray from the secondary nozzle with larger dimensions is combined with it for the higher flow rates.
4. A variable flow nozzle which has been popular in the past is known as a duplex nozzle. In this design one orifice is used and the size of that orifice is such that it is capable of handling the maximum discharge rate. One set of small slots and one set of large slots are provided and flow variation is obtained by feeding to the two different sets of slots as desired. This type of nozzle is generally considered satisfactory only for low viscosity fuels and over a narrow flow range.

In general, the variable flow nozzles are used as such only on commercial and industrial equipment because of their higher cost and the cost of controls. Each type of nozzle requires a specific type of control. Air atomizing is quite common in domestic sizes and in a few cases bypass nozzles have been adapted to domestic burners but both are operated at a fixed flow rate. Otherwise these types are considered commercial.

Storage and Handling Of Nozzles

Nozzle manufacturers put a great deal of effort into providing clean, tested nozzles. If these nozzles are to remain in that condition until installed on a burner, it is necessary to handle them with care. For example, a .75 GPH nozzle is necessarily made with some very small fuel passages. The slots will be .006 wide and about .005 deep. It does not take a large particle of any kind of dirt to plug that size slot. In that same nozzle the orifice finish is like a mirror and must remain that way to prevent streaks in the spray. Any damage to the finish of the orifice at the outlet side will ruin the nozzle. It is quite obvious then that a nozzle must be kept clean and undamaged both in storage and in the process of installing it. Nozzles should be stored in the original containers and kept in a place where they will not become excessively hot. They should also be keptwhere dust will not accumulate and where no one will tamper with them.

Nozzles should not be carried in a serviceman's pockets. The nozzle manufacturers provide handy boxes for carrying nozzles. These are inexpensive and should be used. When installing a nozzle, care must also be exercised in its handling. If you have dirt or grease on your hands and take hold of the nozzle by the strainer, it is possible to squeeze dirt through the strainer mesh and that will eventually work into the nozzle and clog it. When picking up a nozzle, pick it up by the solid end of the strainer so as not to squeeze the screen and dent it or force dirt through it. Before installing a nozzle in a burner, it is wise to flush the nozzle line with at least a pint of fuel or to blow it out with compressed air if that is available. Care must be taken not to bump the face of the nozzle with a wrench or other tool or to lay it down in such a way that the orifice might become damaged by the surface on which it stands. When installing a nozzle, do not remove the strainer and look inside the nozzle. The nozzle manufacturer attached the strainer before the nozzle was ever tested or handled in the plant. That strainer remains on the nozzle to protect it at all times and the chances are that the nozzle is cleaner as received than it will be if a serviceman removes the strainer.

Protecting Nozzles

The National Bureau of Standards has set up limiting specifications on fuel oils for various types of burners. These specifications form a guide for the oil burner and fuel oil industries in designing and operating of equipment. The specification with which we are primarily concerned in connection with nozzles for domestic oil burners is the specification for No. 2 fuel and in some cases
No. I fuel. The top limit for viscosity of No. 2 fuel is given as 40 SSU measured at 100° F. Most refiners of No. 2 fuel oil hold the viscosity considerably lower than that, usually around 34 to 37 SSU at 100° F., because of the fact that fractional gallonage nozzles give better performance with the lower viscosity fuel. Because of the very small dimensions in these nozzles, it is necessary to supply them with fuel with a viscosity low enough that atomization will be satisfactory. Putting a fuel oil with the viscosity above 40 SSU through a .75 GPH nozzle is like trying to pump No. 5 fuel oil through a 1/8" pipe. Recommended viscosity for fractional gallonage nozzles is 34 to 36 SSU. For best results, burners firing .50 GPH and .65 GPH should be supplied with No. 1 fuel, if the local supply of No. 2 fuel is in the high side of the specification. This is common practice in some areas. There is an added advantage in this procedure in that the sludging tendency of No. 1 fuel is not as great as with No. 2 fuel. Line filters for domestic oil burners have been recommended for many years. They are particularly helpful in insuring satisfactory operation of burners using small nozzles. An effective line filter will remove much of the sludge and solid contamination which may be present in the fuel oil or which might be formed in the tank. The 100-mesh screen usually installed in a fuel unit is not fine enough to protect a nozzle and the nozzle
strainer or filter is not large enough to stop all the foreign matter, which might be present in the fuel. Some of the filters designed to protect 1.35 GPH nozzles do not do an adequate job on .50 and .65 GPH nozzles. Filters for these burners should be carefully selected. In order to be effective, the filtering element in a line filter should be replaced at each summer cleanup. After replacing this
filter cartridge, it is usually advisable to flush out the lines as well so that any loose particles, which might have been dislodged during the filter changing operation, will be eliminated before they can cause trouble. As stated previously, nozzle manufacturers attach strainers to the nozzles during assembly. The hole size in these strainers is selected to fit the particular size of nozzle in question. For example, it is common practice to use 200 mesh strainers (hole size .0029"square) on nozzles under 1.00 GPH. Nozzles from 1.00 GPH through 1.35 GPH are equipped with 120 mesh screen (hole size .0043" square). Nozzles above 1.35 GPH are equipped with 100 mesh strainers (hole size .0055" square). On small nozzles it is advisable to use a filtering medium which is finer than any of the screens available and for that purpose nozzle filters are available with openings .0013, .0020, and .0025. These will provide a degree of protection which will insure greater burner efficiency over a longer period of time because when plugging occurs it is the filter and not the nozzle which is affected.

Nozzle strainers and screens should not be reused or cleaned after they become
contaminated.

Nozzle Temperature

During operation a nozzle has a heating system and a cooling system. It is heated by the radiant heat from the flame and from the combustion chamber. The shorter the combustion chamber from the nozzle to the back wall, the higher will be the rate of heat transfer. The cooling system for the nozzle consists of the fuel passing through it and the air passing over the nozzle and the adapter.
After a certain period of operation these two systems will cause the nozzle temperature to reach equilibrium. Usually a burner does not operate that long and its temperature during operation will probably not reach the maximum possible. The maximum nozzle temperature is reached a few minutes after the burner is shut off. When the burner is shut down, the flow of oil through the nozzle stops and the flow of air over the nozzle and the adapter also stops.
The chamber, however, continues to radiate heat to the nozzle and the temperature of the nozzle goes up until the combustion chamber begins to cool off. Then the nozzle temperature begins to drop off. This cycle is shown on the temperature curves in Figure 14. In this particular instance an attempt was made to find the maximum temperatures at which a nozzle might operate in a domestic burner. The nozzle used was a 1.10 80° and the combustion chamber was built of lightweight refractory 8” square. The effect of these temperatures on the nozzle is quite important. The rate of gum formation and sludge formation is increased with an increase in temperature. The fact that
the highest temperature occurs at a time that the oil is stationary in the nozzle also promotes the formation of gum and sludge. Gum eventually builds up after a number of starts and stops and reduces the flow through the nozzle and might even distort the spray pattern. Sludge buildup in the slots will, of course, tend to clog them, particularly in small nozzles where the slot openings are very small.
The tendency of oils to form gum and sludge varies, depending upon the crude from which the oil is made and partly upon the method of refining. It has been found that some blends of fuels have a much greater tendency to form sludge and gum than oils from a single refinery. In the particular tests run in conjunction with the above temperature tests, it was found that blends of catalytic fuels and thermally cracked fuels were the worst offenders.

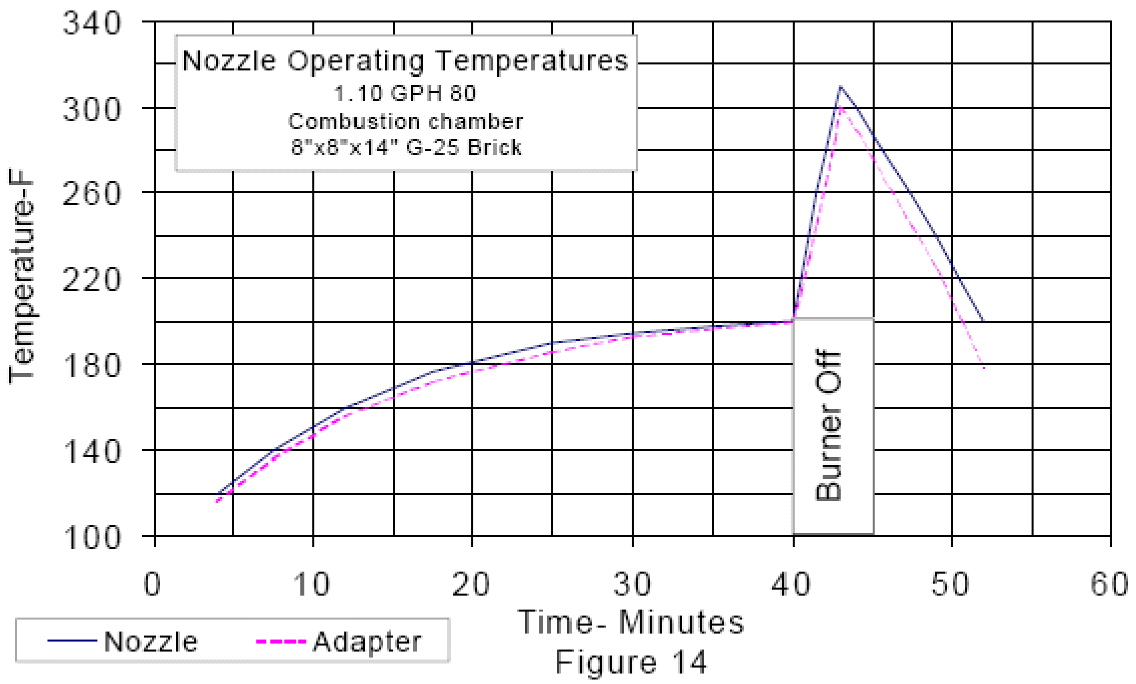

Figure 14

Cleaning Nozzles

The sludge formations in nozzles are soft at first, but with repeated applications of heat they are baked on the walls of the nozzle and look like carbon. They are not washed off by repeated applications of fuel in the process of operating the burner, and it is extremely difficult to clean them off by any process and be sure that the small slots and the threads are all clean. For that reason many service organizations have established the practice of not attempting to clean old nozzles at all. Instead they plan to install a new nozzle at each cleanup of the oil burner. They have found that the cost of labor in cleaning is greater than the cost of a new nozzle and both the service organization and the customer save money by this procedure. In the case of nozzles which are found to give an off center spray when first installed, it is recommended that the nozzle be very carefully removed, put in its original container and be returned to the nozzle manufacturer under his guarantee. Nozzles returned in this manner must be kept clean and undamaged so that the manufacturer can determine the possible cause of failure.

Adapters

Careless handling of adapters can cause the sealing face to be damaged so that when a nozzle is installed a leak occurs. Adapters should be kept clean and should never be thrown into a bin or a bag. In large quantities they should be kept in the box as they are received from the nozzle manufacturer and in smaller quantities should be protected in the same manner. In any case adapters should not be free to rattle around and damage each other. An adapter which has had several different makes of nozzles installed in it might have its face damaged by repeated screwing of the nozzle into it. That type of adapter should also be replaced with a new one.A damaged adapter will show up as a leak. In most cases this will be evidenced by the appearance of a drop of oil hanging from the tip of the nozzle. Even though the leak occurs at the adapter seat, the burner air will blow the oil forward and it will drop off the end of the nozzle into the flame. When screwing a nozzle into the adapter, a torque, not to exceed 100 inch pounds should be used. That is the equivalent of 25 pounds pressure on the 4-inch handles of a Nozzle Changer. Normally 50-inch pounds torque will do the job if the adapter is in good condition. A torque greater than 100 inch pounds can distort the nozzle and result in malfunction.

Conclusion

A nozzle is a piece of precision equipment. It will give good service if properly handled, applied, and protected and supplied with the proper grade of fuel