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A. BIBER

3,100,084

CONSTANT FLOW RATE FUEL INJECTION NOZZLE

Filed Aug. 1, 1961

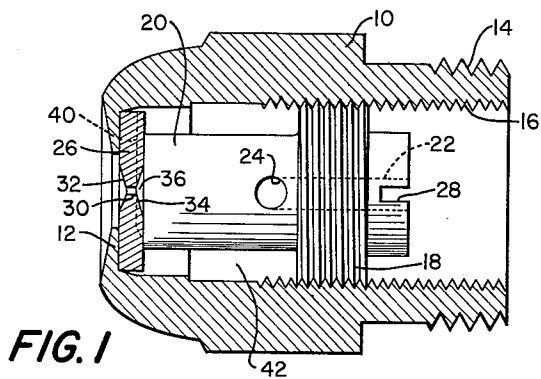


FIG. 1

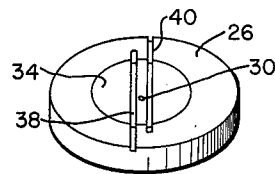


FIG. 2

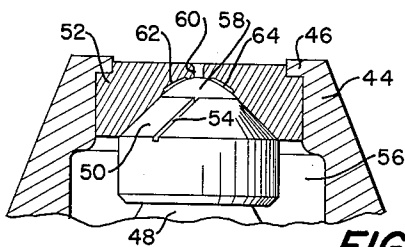


FIG. 3

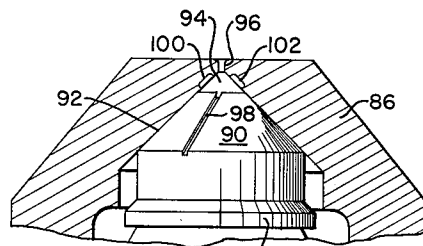


FIG. 4

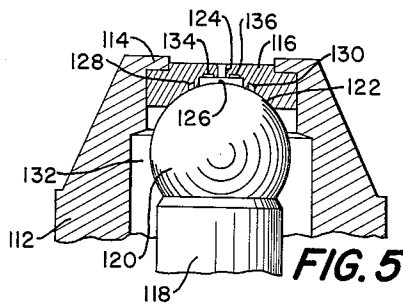


FIG. 5

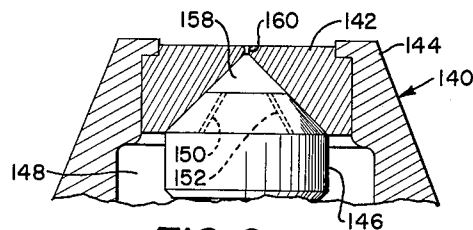


FIG. 6

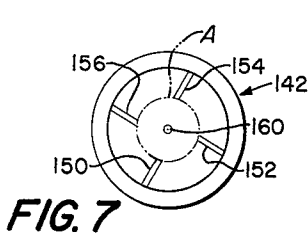


FIG. 7

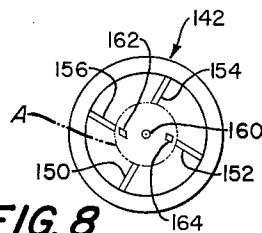


FIG. 8

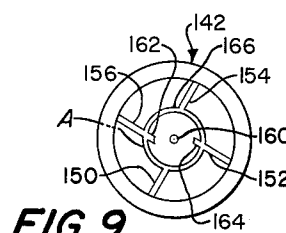


FIG. 9

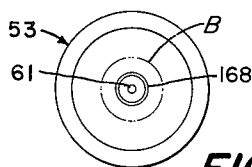


FIG. 10

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3,100,084 CONSTANT FLOW RATE FUEL INJECTION NOZZLE

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4 Claims. (Cl. 239-463)

This application is a continuation-in-part of my co-pending application Serial Number 5,711, filed February 1, 1960, now abandoned.

The present invention relates to spray nozzles having a swirl chamber. More particularly, the invention of this application relates to improvements in spray nozzles of the swirl chamber type which render the rate of flow of a liquid being sprayed therethrough relatively independent of the viscosity of the liquid.

Liquid being sprayed from nozzles having a swirl chamber swirls in the configuration of a hollow cone which progressively diverges with increasing distance from the nozzle discharge orifice. Nozzles which are capable of issuing a liquid spray which swirls in this manner accomplish both superior liquid atomization and concomitant superior liquid-air admixing in contrast to nozzles which spray in the absence of swirling. For these reasons, fuel swirling nozzles are advantageously employed as oil burners. A fuel oil feed to a nozzle of this type has a swirling motion imparted to it by virtue of its being charged along the curved wall of a swirl chamber which is substantially circular in cross section transverse to the nozzle longitudinal axis, the direction of charge having a component which is tangential to the curved wall. Tangential liquid charge along the curved wall of a chamber of circular transverse cross section imparts a swirling helical flow pattern to the liquid. The liquid travels through the swirl chamber in this manner clinging to the peripheral wall thereof due to the centrifugal effect of swirling motion and is finally discharged through an axial orifice in the forward region of the swirl chamber. Thereupon, the liquid issues from the discharge orifice as a hollow conical spray composed of small, well atomized swirling liquid droplets.

The flow rate of liquids being sprayed through nozzles of the swirl chamber variety varies materially with changes in liquid viscosity even at constant liquid delivery pressure to the nozzle. A means has now been discovered for rendering the flow rate of liquids sprayed through a swirl chamber nozzle relatively uniform notwithstanding variation in the viscosity of the liquids being sprayed. This discovery comprises the provision of at least one indentation as described below in the wall of the swirl chamber. When an indentation as described below is provided on the wall of a swirl chamber the liquid flow rate through the nozzle is rendered relatively independent of liquid viscosity. At the same time there is substantially no disruption of the advantageous swirling flow pattern imparted to the liquid in the swirl chamber nor is there any substantial variation in the characteristics of the swirling spray that issues from the nozzle in the absence of such indentation.

In a nozzle having a swirl chamber, said chamber having a longitudinal axis, at least a portion of the wall bounding said swirl chamber being curved, said curved

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wall disposed around said longitudinal axis to define a substantially circular swirl chamber cross section transverse to said longitudinal axis, said swirl chamber cross section being concentric with respect to said longitudinal axis, the rear of said chamber being enclosed, passageway means extending to the rear of said chamber which opens into said chamber in the region of said curved wall and laterally remote from said longitudinal axis, said passageway means being inclined with respect to said longitudinal axis and opening into said chamber in a direction having a component which is tangential with respect to said curved wall surface for swirling a liquid along the surface of said curved wall, an axial orifice opening at the front of said chamber, the improvement of this invention comprises a turbulence increasing means such as at least one exposed indentation in the wall bounding said swirl chamber, said indentation being disposed forwardly in said chamber with respect to the opening of the passageway means, said indentation being spaced apart from both the passageway means opening and said orifice, the region of the wall surface separating said passageway means opening and said indentation being itself free of indentations thereby preventing surface channeling between said passageway means and said indentation, the region of the wall surface separating the indentation and the orifice being itself free of indentations thereby preventing surface channeling between said indentation and said orifice, and the periphery of said orifice opening being free of indentations.

The beneficial effect of an indentation as described on the curved surface of a nozzle swirl chamber wall is evidently due to a partial impartation of turbulence to the flow pattern of the liquid after inception of swirling. To realize the benefits of the indentation, its turbulence increasing effect must be exerted upon the liquid after it has started to swirl. The liquid is charged to the swirl chamber tangentially along the curved swirl chamber wall surface which causes it to swirl in a generally helical pattern in its transit to the nozzle orifice. Swirling motion imparts a centrifugal effect to the liquid urging the major portion of the liquid into close proximity to the chamber wall. Since the major portion of the liquid streams along the swirl chamber wall surface only if the liquid has assumed a swirling motion, a disruption of the wall surface in the form of an indentation will impart turbulence to the liquid only after inception of swirling.

It is essential to this invention that the turbulence increasing indentation on the swirl chamber wall be spaced apart from the liquid inlet passageway opening in order to prevent channeling on the swirl chamber wall surface between the liquid inlet passageway opening and the indentation. The prevention of channeling between the two is accomplished by maintaining the swirl chamber wall in the region between the inlet passageway opening and the indentation itself free of any indentations that could serve as connecting channels between the passageway opening and the indentation of the invention.

There are two important reasons for preventing wall surface channeling between the liquid passageway opening and the indentation. The first reason is that any surface channeling between the two is disruptive to proper nozzle operation and alters the characteristics of the spray issuing from the nozzle. The liquid inlet passageway opens into the swirl chamber tangentially along a curved

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surface thereof and, if the chamber wall is relatively smooth in the region of the opening, the liquid assumes a natural swirling pattern. However, if any surface channel is continuous with the opening, the liquid stream issuing from the opening, initially under centrifugal force, will tend to follow along this channel rather than continue in its original direction. Channeling in this manner therefore inhibits swirling, transforming the nozzle to a non-swirling type. In effect, a disruptive surface channel which adjoins or is continuous with a tangential liquid opening alters the pattern and direction of flow naturally assumed by liquid issuing from such an opening, thereby nullifying the particular advantage of tangential liquid admission, which is the inception of swirling.

The second reason for avoiding any surface channel between the swirl chamber wall indentation of this invention and the liquid inlet opening follows from the first. It has been found that an indentation of this invention exerts its beneficial flow rate stabilizing effect by partially disrupting the smoothness of flow of liquid which is already in a swirling state of motion and no beneficial effect is exerted by acting upon the liquid prior to inception of swirling. The presence of a surface channel in the swirl chamber wall linking the liquid inlet means and the indentation of this invention converts the latter into a mere extension of the liquid inlet means. Due to the centrifugal effect in the swirl chamber, the linking channel will fill the indentation with liquid being introduced into the swirl chamber which has not yet begun to swirl. Therefore, an indentation which is connected by a surface channel with the liquid opening means will be filled with charge liquid and being so filled cannot function in the manner of an empty indentation, which function is the impartation of turbulence to a liquid swirling outside of itself. A groove which is merely an extension of the passageway means operates as a channel for the incoming liquid and as a channel tends to avoid turbulence rather than create it.

Another essential characteristic of the swirl chamber wall indentation of this invention is that it must be spaced apart from the discharge orifice of the nozzle. When the indentation on the swirl chamber wall terminates in advance of the discharge orifice, it exerts the advantageous effect of decreasing the lateral spread of the resulting spray. This is accomplished by impartation of turbulence to the swirling liquid. When employing the nozzle as an oil burner this feature of the invention is especially advantageous since a fuel spray having a decreased lateral spread yields a more compact flame upon ignition. A compact flame is relatively more manageable and can be directed to any region in a furnace with a minimum of undesirable lateral impingement upon the furnace wall. In contrast, lateral impingement would increase wall corrosion and wear.

If the swirl chamber wall indentation should extend to the orifice opening in contravention of this invention, loss of compactness and distortion of the spray issuing from the nozzle would result in that the spray issuing from the orifice periphery in the region of the indentation would diverge laterally to a greater extent than the spray issuing from the remaining periphery of the orifice. Unbalance of the spray would be highly undesirable in the case of a burner nozzle since a distorted flame would result. If a single indentation should extend to the discharge orifice opening, the only way to modify the resulting unbalance or distortion of the spray without removal of the indentation would be to surround the entire periphery of the orifice with grooves parallel to the first. However, this expedient would not recover loss of spray compactness but rather would only tend to render the unbalance of the spray more uniform. It is therefore apparent that either a single indentation or a bank of parallel indentations which extend to the discharge orifice would serve to increase the lateral spread of the spray, a feature which, as already noted, is highly undesirable

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in the case of burner nozzles. Moreover, a bank of parallel grooves would tend to serve as straightening vanes rather than turbulence increasing means, thereby obviating the advantage of the invention. For these reasons it is essential that the indentation of this invention be spaced apart from the discharge orifice and that the periphery of the discharge opening be maintained free of indentations.

Liquid swirling through a swirl chamber travels in a helical path along the curved wall of the swirl chamber. In order to impart turbulence to the swirling liquid, the turbulence increasing indentation of this invention, which can be an elongated slot or groove, should extend, in relation to the tangential liquid inlet opening, so that the swirling liquid will travel across it transversely. If the slot or groove extends parallel to the direction of the swirl it will be incapable of imparting turbulence. An example of a suitable slot or groove is one that extends radially with respect to the discharge orifice but which, of course, does not extend to the orifice.

It has been discovered that the most advantageous indentation configuration of this invention is an endless circular groove machined in the wall of a frusto-conical swirl chamber on a plane substantially normal to the longitudinal axis of the nozzle in a region of the swirl chamber substantially midway between the liquid inlet opening and the discharge orifice. Such a ring-like indentation was found to be superior to other indentations of this invention in that it imparted exceptional uniformity in liquid flow rate through a nozzle notwithstanding changes in liquid viscosity without appreciable alteration of the flow rating possessed by the nozzle in its absence. In this characteristic a ring-like indentation is unique from other indentation configurations of this invention since other configurations tend to impart to a nozzle uniformity of flow rate at a flow level somewhat different from rated flow capacity of the same nozzle prior to modification with the indentation. Therefore, this preferred embodiment of the invention permits the modification of nozzles in accordance with this invention in existing installations where flow capacity is critical.

Whatever the depth, the configuration, or the number, the indentations of this invention are adapted to maintain unchanged the essential character of the spray issuing from the nozzle in their absence. Therefore, the indentations of this invention must not destroy the liquid swirling pattern in the swirl chamber. The indentations should only disturb the liquid smoothness of flow to a degree required to stabilize the liquid flow rate notwithstanding varying liquid viscosity without appreciably altering the character of the swirling spray issuing from the discharge orifice in their absence.

The invention will be more clearly understood by reference to the accompanying drawings illustrating preferred embodiments of the invention, wherein:

FIGURE 1 is a central, longitudinal sectional view of a nozzle according to the invention, with the swirl stem being shown in elevation;

FIGURE 2 is a perspective view of an orifice plate adapted for use in the nozzle shown in FIGURE 1;

FIGURE 3 is a detail view of a modified nozzle embodying the principles of the invention, the swirl stem is shown in elevation and the orifice plate and nozzle housing are shown in section;

FIGURE 4 is a view similar to that shown in FIGURE 3 of another modified nozzle;

FIGURE 5 is a view similar to FIGURES 3 and 4 of another modified nozzle embodying the principles of the invention;

FIGURE 6 is a view of still another modified nozzle with the orifice plate and housing shown in section and the swirl stem shown in elevation; and

FIGURES 7, 8, 9 and 10 are elevational views of various orifice plates adapted for use in the nozzle shown in FIGURE 6.

Referring to FIGURE 1, the reference numeral 10 des-

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ignates a generally tubular nozzle housing having an inturned lip 12 at one end and external threads 14 at the other end by means of which the nozzle is coupled to a high-pressure fuel oil line (not shown) by conventional means. The interior of the nozzle housing 10 is partially threaded as shown at 16 for threadingly receiving the radially enlarged and externally threaded portion 18 of a swirl stem 20. Although not shown, it will be understood that the nozzle can, as is conventional, include screening or filtering means for preventing the entry of foreign matter into a central passageway 22 in the swirl stem 20. The passageway 22 extends, as shown, axially from one end of the swirl stem 20 past the enlarged and threaded portion 18 of the swirl stem 20, and thence opens laterally as shown at 24 to the exterior of the swirl stem 20.

An orifice plate 26 is disposed within the housing 10 and is seated against the inturned lip 12 in sealing engagement therewith, the orifice plate 26 being retained in this position by pressing engagement of the swirl stem 20 therewith, it being noted that such relationship of the parts is easily accomplished by the threaded connection between the housing 10 and the swirl stem 20, the swirl stem 20 being provided with a kerf 28 or the like for ready manipulation by a tool such as a screw driver (not shown).

The orifice plate 26 is provided with a central circular aperture or orifice 30 therethrough, such orifice 30 at its end remote from the swirl stem 20 being outwardly flared as at 32. The surface of the orifice plate 26 defining the end of the orifice 30 closest to the swirl stem 20 is outwardly flared as at 34 so that the surface 34 of the orifice plate 26 defines jointly with the adjacent surface of the swirl stem 20 a swirl chamber 36. Such swirl chamber 36 and the orifice 30 are circular in transverse section, except as hereinafter pointed out, and have a common central axis. The swirl chamber 36 in this nozzle construction is generally of frusto-conical configuration and may be considered as having its minor end coterminous with a discharge orifice of restricted diameter.

As best shown in FIGURE 2, the orifice plate 26 is provided with a pair of slots or grooves 38 and 40 that are eccentrically located in the orifice plate 26, but which are symmetrical with respect to each other in relation to the central axis of the nozzle. Each of the slots 38 and 40 extend from a peripheral position on the circular orifice plate 26 across the surface 34 and terminate at a position spaced from the center of the orifice plate 26 a lesser distance than is the radius of the swirl stem 20 that abuts the orifice plate 26. Referring again to FIGURE 1, it will be seen that the organization is such that fuel oil entering the nozzle will pass through the passageway 22, the lateral extension 24 of the passageway 22, and thence into the annular space 42 intermediate the housing 10 and the swirl stem 20. The fuel oil then enters the swirl chamber 36 through the slots or grooves 38 and 40. Fuel oil in the swirl chamber 36 thence exits from the nozzle through the orifice 30.

The slots or grooves 38 and 40 can be conveniently made in the orifice plate 26 by making cuts in the orifice plate 26 by means of a circular saw, not shown, and it is preferred that such slots have a uniform depth, the depth being such that the slots 38 and 40 have a very shallow depth where they pass most closely to the orifice 30. Of course, as will be appreciated, the slots 38 and 40 can be of varying depth and/or width along their lengths; however, it is essential in order to realize the advantage of the invention that the slots or grooves 38 and 40 extend into the orifice plate 26 for at least a major portion of their projections across the area of the surface 34.

Though two slots have been shown in the form of the invention illustrated in FIGURES 1 and 2, only one slot can be employed, if desired.

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Attention is now directed to the form of the invention shown in FIGURE 3.

This form of the invention includes a housing 44 including an inturned lip 46. A swirl stem 48 is provided that includes a frusto-conical or tapered end portion 50. An orifice plate 52 is retained between the lip 46 and the tapered surface 50 of the swirl stem 48, the abutting surfaces of the swirl stem portion 50 and the orifice plate 52 being complementary so as to be liquid tight.

The frusto-conical or tapered portion 50 of the swirl stem 48 is provided with a plurality of oil slots which are inclined with respect to the longitudinal axis of the nozzle, one of which is shown at 54, so that fuel oil in the annular space 56 intermediate the housing 44 and the swirl stem 48 can enter a swirl chamber 58 and have a swirling motion imparted thereto. As clearly shown in the drawing, the swirl chamber 58 defined between the orifice plate 52 and the planar end of the swirl stem 48 is generally conical in configuration, with the apex end thereof being coterminous with a central discharge orifice 60 in the orifice plate 52. In this form of the invention, the surface of the orifice plate 52 defining the swirl chamber 58 is provided with a pair of shallow, diametrically opposed slots or grooves 62 and 64.

Attention is now directed to FIGURE 4 wherein another nozzle construction is shown. The reference numeral 86 designates a nozzle housing, and the reference numeral 88 designates the swirl stem having a frusto-conical end portion 90 that seats against a complementary inner surface 92 of the housing 86. A conical swirl chamber 94 is defined at the end of the swirl stem 88 adjacent an orifice 96 formed in the nozzle housing 86. A plurality of inclined oil slots are formed in the frusto-conical portion 90 of the swirl stem 88, one of such slots being shown at 98. As in the case of the nozzle shown in FIGURE 3, a portion of the surfaces defining the swirl chamber 94 is provided with a pair of slots or grooves 100 and 102 that are diametrically positioned and extend radially from, but which are spaced from, the orifice 96.

Attention is now directed to the form of nozzle illustrated in FIGURE 5. The reference numeral 112 designates a nozzle housing provided with an inturned lip 114 against which is seated an orifice plate 116, the latter being held in position by means of a swirl stem 118 having a sphere-like terminal portion 120 that engages the orifice plate 116. The terminal portion 120 engages the orifice plate 116 in an area 122. The orifice plate 116 is provided with a discharge orifice 124 that communicates with a more or less cylindrically shaped swirl chamber 126. The surface 122 of the orifice plate 116 is provided with a pair of inclined oil slots 128 and 130 whereby fuel oil can pass from the annular space 132 to the swirl chamber 126 and have a swirling motion imparted thereto. The flat surface of the orifice plate 116 defining the end of the swirl chamber 126 remote from the swirl stem 118 is provided with a pair of diametrically opposed, radially extending slots or grooves 134 and 136 that are spaced from the orifice 124.

A series of tests were conducted with respect to nozzles embodying the features disclosed in the nozzles shown in FIGURES 1, 3, 4 and 5. Each of such tests was conducted with a liquid fuel charged under 100 pounds per square inch gauge pressure at room temperature. Each test was conducted for six minutes during which time the total amount of fuel flowing through the nozzle under test was collected and measured in terms of volume, measurements also being made of the viscosity of the fuel undergoing the test in centipoises and of the temperature of the fuel. The tests with respect to each of the nozzles were made with three grades of fuel, namely, kerosene, a low and a high viscosity grade of No. 2 fuel oil, such fuels generally having viscosities in centipoise respectively of about 1.5, 2.6 and 4.7 (room temperature).

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After testing a particular nozzle with each of the three fuels, the average flow rate obtained with the three fuels was calculated and the deviation from that average in gallons per hour when employing each individual fuel was determined and tabulated.

Tests made with respect to a nozzle incorporating the features disclosed in FIGURE 1 are shown in Table 1.

Table 1

	Kerosene	No. 2 (low viscosity) fuel oil	No. 2 (high viscosity) fuel oil
Total, cc.....	430	432	430
Time, minutes.....	6	6	6
Flow rate, gallons per hour.....	1.14	1.14	1.14
Deviation from average flow rate, gallons per hour.....	0.00	0.00	0.00
Line temperature, ° F.....	79	78	79
Centipoises.....	1.45	2.72	4.96

Table 2 gives the test results made prior to the modification of a commercial nozzle similar to that shown in FIGURE 1 so as to include the slots or grooves 38 and 40. The commercial nozzle involved was a 0.8 gallon per hour, 70° spray angle nozzle.

Table 2

	Kerosene	No. 2 (low viscosity) fuel oil	No. 2 (high viscosity) fuel oil
Total, cc.....	305	312	329
Time, minutes.....	6	6	6
Flow rate, gallons per hour.....	0.81	0.82	0.87
Deviation from average flow rate, gallons per hour.....	.02	.01	.04
Line temperature, ° F.....	85	85	85
Centipoises.....	1.38	2.49	4.58

Tests were made with a commercial nozzle modified to correspond to the nozzle shown in FIGURE 1, such tests being made with differing depths of the slots 38 and 40. Tables 3 and 4 show the results of these tests, with the nozzles constituting the basis for Tables 3 and 4 having respectively deeper and shallower slots or grooves.

Table 3

	Kerosene	No. 2 (low viscosity) fuel oil	No. 2 (high viscosity) fuel oil
Total, cc.....	325	330	349
Time, minutes.....	6	6	6
Flow rate, gallons per hour.....	0.86	0.87	0.92
Deviation from average flow rate, gallons per hour.....	.02	.01	.04
Line temperature, ° F.....	81	80	81
Centipoises.....	1.43	2.66	4.82

Table 4

	Kerosene	No. 2 (low viscosity) fuel oil	No. 2 (high viscosity) fuel oil
Total, cc.....	458	449	453
Time, minutes.....	6	6	6
Flow rate, gallons per hour.....	1.21	1.19	1.20
Deviation from average flow rate, gallons per hour.....	.01	.01	.00
Line temperature, ° F.....	82	82	84
Centipoises.....	1.42	2.58	4.64

Tables 5 and 6 show test results obtained with respect to a well-known commercial 1.0 gallon per hour, 80° spray angle nozzle. This type of nozzle is generally similar to that shown in FIGURE 3. Tables 5 and 6 respectively present the test results obtained with such a nozzle prior to and after the formation of the slots or grooves 62 and 64.

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Table 5

	Kerosene	No. 2 (low viscosity) fuel oil	No. 2 (high viscosity) fuel oil
Total, cc.....	353	362	388
Time, minutes.....	6	6	6
Flow rate, gallons per hour.....	0.93	0.96	1.03
Deviation from average flow rate, gallons per hour.....	.04	.01	.06
Line temperature, ° F.....	77	77	78
Centipoises.....	1.49	2.50	5.03

Table 6

	Kerosene	No. 2 (low viscosity) fuel oil	No. 2 (high viscosity) fuel oil
Total, cc.....	415	408	422
Time, minutes.....	6	6	6
Flow rate, gallons per hour.....	1.10	1.08	1.11
Deviation from average flow rate, gallons per hour.....	.00	.02	.01
Line temperature, ° F.....	72	73	77
Centipoises.....	1.56	2.64	5.11

Tests were made with respect to still another well-known commercial 1.0 gallon per hour, 70° spray angle nozzle, such type of nozzle corresponding generally to that shown in FIGURE 4. The test results obtained are presented in Tables 7 and 8 showing nozzle performance prior to and after fabrication of the slots or grooves 100 and 102.

Table 7

	Kerosene	No. 2 (low viscosity) fuel oil	No. 2 (high viscosity) fuel oil
Total, cc.....	335	345	365
Time, minutes.....	6	6	6
Flow rate, gallons per hour.....	0.89	0.91	0.96
Deviation from average flow rate, gallons per hour.....	.03	.01	.04
Line temperature, ° F.....	78	77	78
Centipoises.....	1.46	2.75	4.24

Table 8

	Kerosene	No. 2 (low viscosity) fuel oil	No. 2 (high viscosity) fuel oil
Total, cc.....	403	398	393
Time, minutes.....	6	6	6
Flow rate, gallons per hour.....	1.06	1.05	1.04
Deviation from average flow rate, gallons per hour.....	.01	.00	.01
Line temperature, ° F.....	72	74	75
Centipoises.....	1.56	2.60	5.26

Tests were made with respect to a nozzle incorporating the features shown in FIGURE 5, and the results of these tests are shown in Table 9.

Table 9

	Kerosene	No. 2 (low viscosity) fuel oil	No. 2 (high viscosity) fuel oil
Total, cc.....	428	428	446
Time, minutes.....	6	6	6
Flow rate, gallons per hour.....	1.13	1.13	1.18
Deviation from average flow rate, gallons per hour.....	.02	.02	.03
Line temperature, ° F.....	82	81	83
Centipoises.....	1.42	2.61	4.70

In each of the tests described above wherein slots or grooves were provided, the slots or grooves were generally of depths within about .005 inch to about .01 inch, and had a length of about 75 percent of the slope length of the swirl chamber wall.

FIGURE 6 shows a nozzle 140 having an orifice plate 142 secured in fluid tight engagement between nozzle

body 144 and swirl stem 146. An elevation view of orifice plate 142 is shown in FIGURE 7. Oil enters through chamber 148 and passes through inlet passageways 150, 152, 154 and 156 into conical swirl chamber 158 having orifice opening 160 at its forward end. The oil inlet passageways terminate at the rear of swirl chamber 158 and do not extend into swirl chamber 158. The plane in which the rear of swirl chamber 158 lies is designated by the letter A in FIGURES 7, 8 and 9. FIGURES 7, 8 and 9 are all elevational views of orifice plate 142.

A series of tests were made employing the nozzle of FIGURE 6 having the same orifice plate 142 shown in FIGURE 7 but modified by the addition of slots 162 and 164, as shown in FIGURE 8. Slots 162 and 164 are in the wall of swirl chamber 158 but are discontinuous with respect to the oil inlet passageways, as shown. The results of these tests are shown in Table 10.

Table 10

	Kerosene	No. 2 (low viscosity) fuel oil	No. 2 (high viscosity) fuel oil
Pressure, p.s.i.g.-----	100	100	100
Total, cc.-----	418	440	435
Time, minutes-----	6	6	6
Flow rate, gallons per hour-----	1.10	1.16	1.15
Deviation from average flow rate, gallons per hour-----	.04	.02	.01
Line temperature, ° F-----	78	77	79
Centipoises-----	1.52	2.55	5.22

Following the completion of the tests illustrated in Table 10, the same orifice plate was modified from the form shown in FIGURE 8 to the form shown in FIGURE 9 by the machining of ring groove 166 on the swirl chamber wall. Ring groove 166 permitted surface channeling between passageways 150, 152, 154 and 156 and slots 162 and 164. Thereupon another series of flow rate tests were conducted under conditions similar to those employed in obtaining the data of Table 10 and the results of these tests are shown in Table 11.

Table 11

	Kerosene	No. 2 (low viscosity) fuel oil	No. 2 (high viscosity) fuel oil
Pressure, p.s.i.g.-----	100	100	100
Total, cc.-----	525	520	480
Time, minutes-----	6	6	6
Flow rate, gallons per hour-----	1.39	1.37	1.27
Deviation from average flow rate, gallons per hour-----	.05	.03	.07
Line temperature, ° F-----	78	78	78
Centipoises-----	1.52	2.54	5.32

A comparison of the test results shown in Tables 10 and 11 shows that the prevention of surface channeling between the passageways 150, 152, 154 and 156 and the slots 162 and 164 as exists with the orifice plate of FIGURE 8 results in a higher uniformity of flow rate with varying viscosities as contrasted to the allowance of surface channeling between passageways 150, 152, 154 and 156 and slots 162 and 164 by the addition of circular ring groove 166, as indicated in FIGURE 9.

The most important operating distinction between a nozzle employing an orifice plate as shown in FIGURE 8 and a nozzle employing an orifice plate as shown in FIGURE 9 is that the spray issuing from a nozzle employing the former is in the form of a hollow cone of swirling droplets while the spray issuing from a nozzle employing the latter is not hollow but rather is in the form of a compact, non-swirling jet. It was found that while the indentations 162 and 164, which are separated from the passageways 150, 152, 154 and 156 did not impair the swirling nature of the spray, the circular ring indentation 166, which is continuous with respect to passageways 150,

152, 154 and 156, completely transformed the nature of the spray from a swirling to a non-swirling type.

A series of tests was made with still another nozzle, this one having a general nozzle construction as shown in FIGURE 3 and employing a basic orifice plate 53 as shown in FIGURE 10 in which a circular ring groove 168 was machined in the swirl chamber wall approximately midway between the plane in which the rear of the swirl chamber lies, which plane is indicated by the letter B, and the discharge orifice 61. The results of tests made before and after machining of the ring groove 168 are shown in Tables 12 and 13, respectively.

Table 12

	Kerosene	No. 2 (low viscosity) fuel oil	No. 2 (high viscosity) fuel oil
Total, cc.-----	390	400	420
Time, minutes-----	6	6	6
Flow rate, gallons per hour-----	1.03	1.05	1.11
Deviation from average flow rate, gallons per hour-----	.03	.01	.05
Line temperature, ° F-----	84	86	85
Centipoises-----	1.44	2.56	4.74

Table 13

	Kerosene	No. 2 (low viscosity) fuel oil	No. 2 (high viscosity) fuel oil
Total, cc.-----	408	408	408
Time, minutes-----	6	6	6
Flow rate, gallons per hour-----	1.08	1.08	1.08
Deviation from average flow rate, gallons per hour-----	.00	.00	.00
Line temperature, ° F-----	90	90	90
Centipoises-----	1.36	2.43	4.35

It is seen from Table 13 that when employing an orifice plate as shown in FIGURE 10 exceptional uniformity of flow rate is achieved. Comparing the flow rates in Table 13 with the flow rates of Table 12, it is seen that the circular ring groove of FIGURE 10 imparts uniformity of flow rate at varying liquid viscosities without essentially changing the basic flow level of the nozzle, the average flow rate in the three tests of Table 12, conducted with the same basic nozzle, being 1.06 gallons per hour and the average flow rate in the three tests of Table 13 being 1.08 gallons per hour. The circular ring groove of FIGURE 10 stabilized the flow rate of the nozzle with a smaller alteration of basic nozzle flow rating than any other indentation configuration tested. Additionally, the circular ring of FIGURE 10 in no way interfered with the swirling, hollow, conical spray pattern produced by the nozzle in its absence.

It is seen from the drawings of the nozzles that the slots for charging a stream of swirling oil to the swirl chamber are the only means for admitting pressurized liquid to the swirl chamber. It is also seen from the drawings that the swirl chamber is free of means tending to substantially disrupt the swirling motion of liquid therein.

Various changes and modifications can be made without departing from the spirit of this invention or the scope thereof as defined in the following claims.

I claim:

1. In a nozzle having a swirl chamber, said chamber having a longitudinal axis, said chamber being bounded by a wall curved around said longitudinal axis to define a substantially conical swirl chamber surface concentric with respect to said longitudinal axis the wider base of which is rearward in the swirl chamber, liquid passageway opening means in the rear of said chamber in the region of said conical surface and laterally remote from said longitudinal axis adapted to impart a swirling motion to a liquid along said conical surface, said passageway opening means being the only means for supplying pressurized liquid to said swirl chamber, said chamber being free of means tending to substantially disrupt the swirl-

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ing motion imparted to said liquid, an orifice opening at the front of said chamber concentric with said axis, the improvement comprising at least one exposed indentation in said conical surface bounding said swirl chamber, said indentation being disposed forwardly in said chamber with respect to said passageway opening means, said indentation being spaced apart from said passageway opening means and the region of the wall surface separating said passageway opening means and said indentation being itself free of indentations thereby preventing surface channeling between said passageway opening means and said indentation, said indentation also being spaced apart from said orifice to maintain the periphery of said orifice opening free of indentations, said indentation adapted to render liquid flow rate more independent of viscosity without substantial disruption of the swirling flow pattern of said liquid.

2. In a nozzle having a swirl chamber, said chamber having a longitudinal axis, said chamber being bounded by a wall curved around said longitudinal axis to define a substantially conical swirl chamber surface concentric with respect to said longitudinal axis the wider base of which is rearward in the swirl chamber, liquid passageway opening means in the rear of said chamber in the region of said conical surface and laterally remote from said longitudinal axis adapted to impart a swirling motion to a liquid along said conical surface, a discharge orifice opening at the front of said chamber concentric with said axis, said passageway opening means being the only means for supplying pressurized liquid to said swirl chamber, said chamber being free of means tending to substantially disrupt the swirling motion imparted to said liquid, the improvement comprising at least one groove in the conical surface bounding said swirl chamber, said groove extending substantially radially with respect to said discharge orifice and disposed forwardly in said swirl chamber with respect to said passageway opening means, said groove being spaced apart from said passageway opening means and the region of the wall surface separating said passageway opening means and said groove being free of indentations capable of permitting surface channeling between said passageway opening means and said groove, said groove also being spaced apart from said orifice to maintain the periphery of said discharge orifice opening free of indentations, said groove adapted to render liquid flow rate more independent of viscosity without substantial disruption of the swirling flow pattern of said liquid.

3. In a nozzle having a swirl chamber, said chamber having a longitudinal axis, said chamber being bounded by a wall curved around said longitudinal axis to define a substantially conical swirl chamber surface concentric with respect to said longitudinal axis the wider base of which is rearward in the swirl chamber, liquid passageway opening means in the rear of said chamber in the region of said curved wall and laterally remote from said longitudinal axis adapted to impart a swirling motion to a liquid along said conical surface, said passageway opening means being the only means for supplying pressurized liquid to said swirl chamber, said chamber being free of means tending to substantially disrupt the swirling motion imparted to said liquid, an orifice opening at the front of said chamber concentric with said axis, the improve-

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ment comprising at least one endless exposed groove extending around said longitudinal axis in the conical surface bounding said swirl chamber, said groove disposed forwardly in said chamber with respect to said opening means, said groove being spaced apart from said passageway opening means and the region of the wall surface separating said passageway opening means and said groove being free of indentations capable of permitting surface channeling between said passageway opening means and said groove, said groove also being spaced apart from said orifice to maintain the periphery of said orifice opening free of indentations, said groove adapted to render liquid flow rate more independent of viscosity without substantial disruption of the swirling flow pattern of said liquid.

4. In a nozzle having a swirl chamber, said chamber having a longitudinal axis, said chamber being bounded by a wall curved around said longitudinal axis to define a substantially conical swirl chamber surface concentric with respect to said longitudinal axis the wider base of which is rearward in the swirl chamber, liquid passageway opening means in the rear of said chamber in the region of said conical surface and laterally remote from said longitudinal axis adapted to impart a swirling motion to a liquid along said conical surface, said passageway opening means being the only means for supplying pressurized liquid to said swirl chamber, said chamber being free of means tending to substantially disrupt the swirling motion imparted to said liquid, a discharge opening at the front of said chamber concentric with said axis, the improvement comprising at least one exposed, endless groove in the conical surface bounding said swirl chamber on a plane substantially normal to said longitudinal axis, said plane at a position along said axis intermediate said passageway opening means and said discharge orifice whereby said groove is separated from said passageway opening means and the region of the wall surface separating said passageway opening means and said groove being free of indentations capable of permitting surface channeling between said passageway opening means and said groove, and said groove also being separated from said orifice to maintain the periphery of said discharge opening free of indentations, said groove adapted to render liquid flow rate more independent of viscosity without substantial disruption of the swirling flow pattern of said liquid.

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