Oct. 10, 1967 A. BIBER ETAL 3,346,196

APPARATUS FOR ATOMIZING OIL

Filed Dec. 3, 1964 4 Sheets-Sheet 1

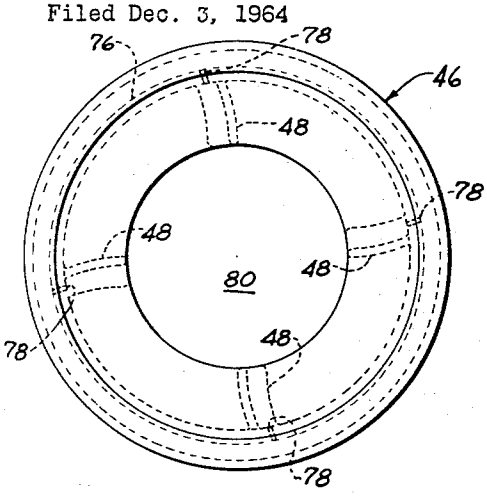


Fig. 4

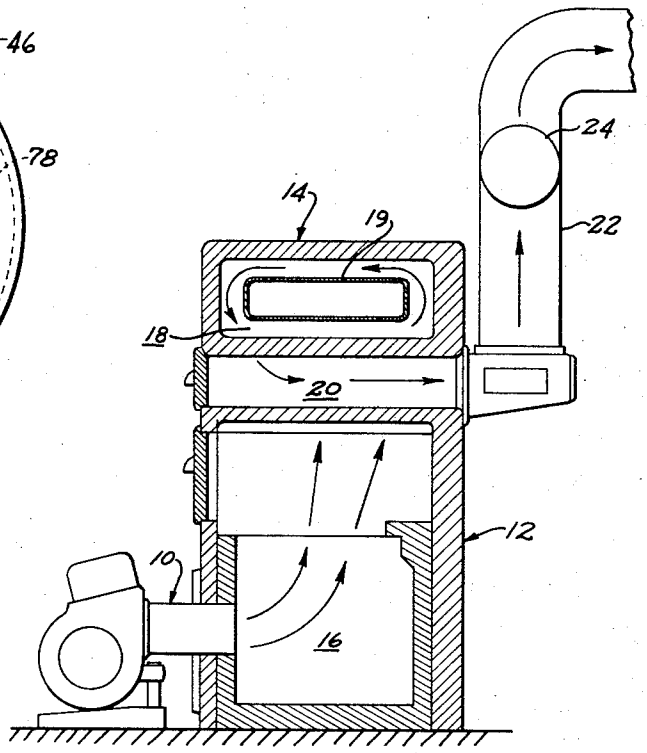


Fig. 1

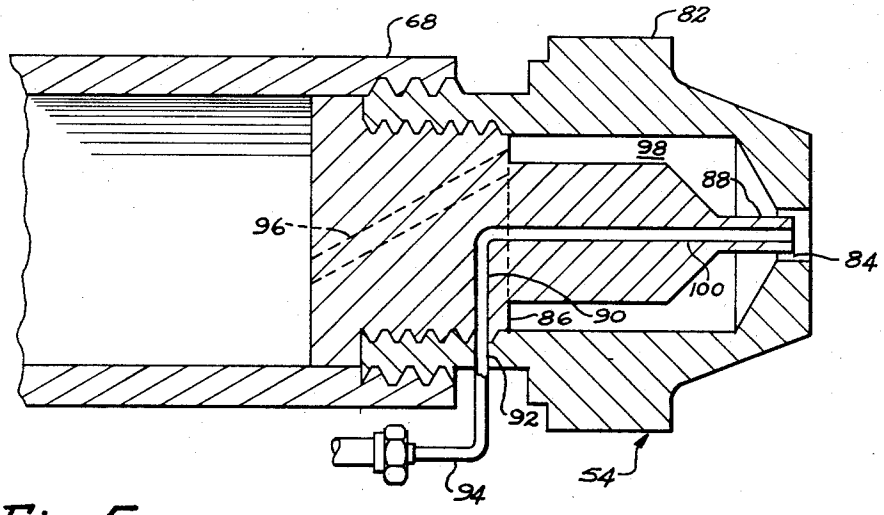


Fig. 5

INVENTORS.
BRUCE R. WALSH &
ALBERT BIBER

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APPARATUS FOR ATOMIZING OIL

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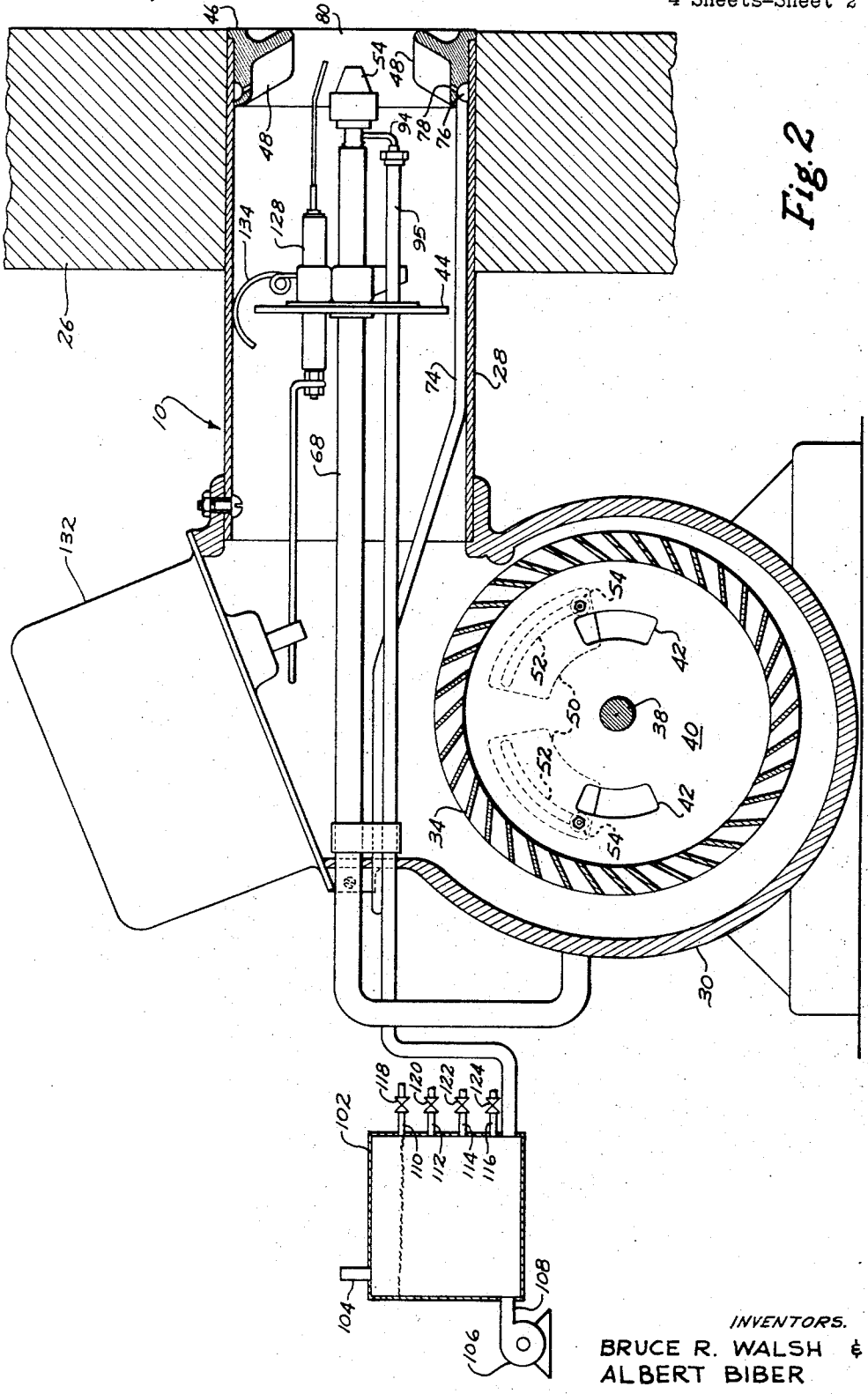


Fig. 2

INVENTORS.
BRUCE R. WALSH &
ALBERT BIBER

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APPARATUS FOR ATOMIZING OIL

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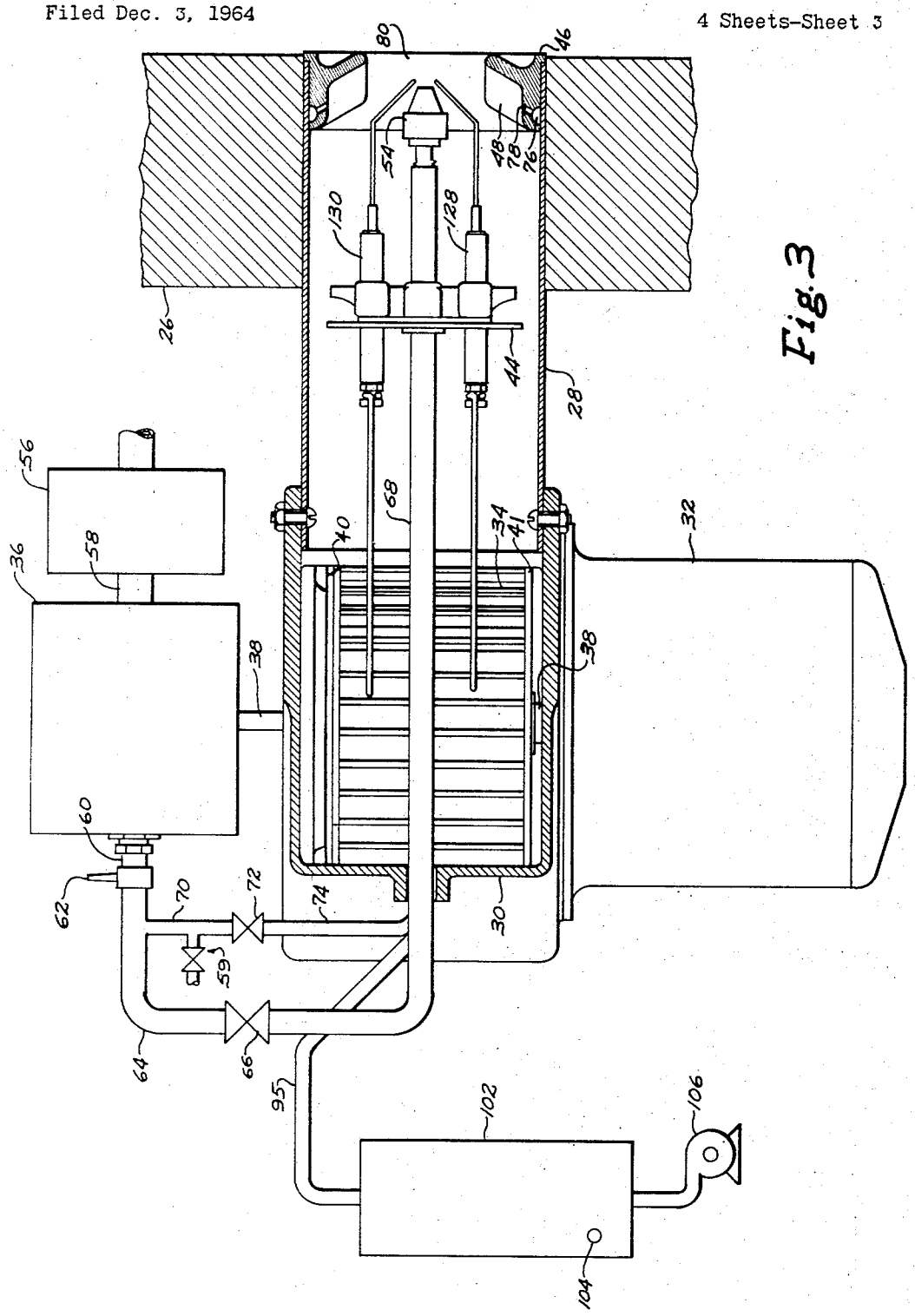


Fig. 3

INVENTORS.
BRUCE R. WALSH &
ALBERT BIBER

Oct. 10, 1967 A. BIBER ETAL 3,346,196

APPARATUS FOR ATOMIZING OIL

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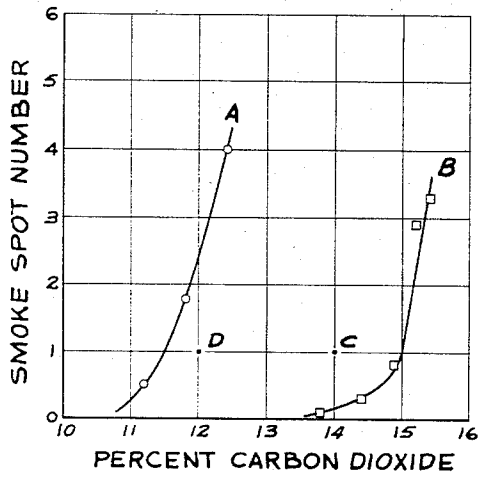


Fig. 6

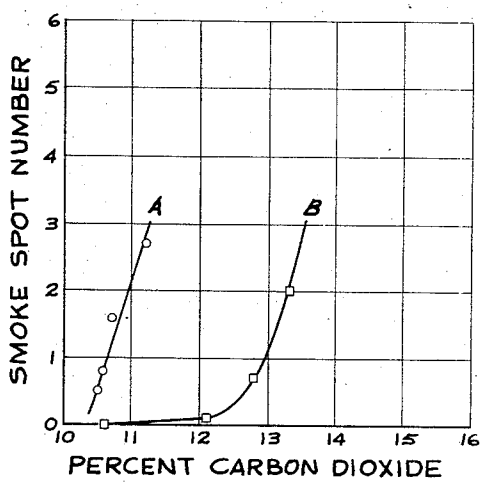


Fig. 7

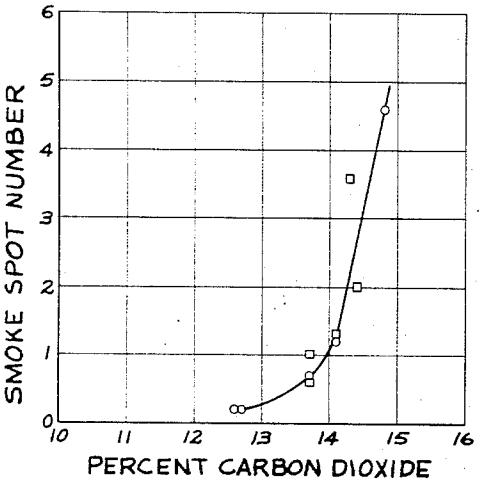


Fig. 8

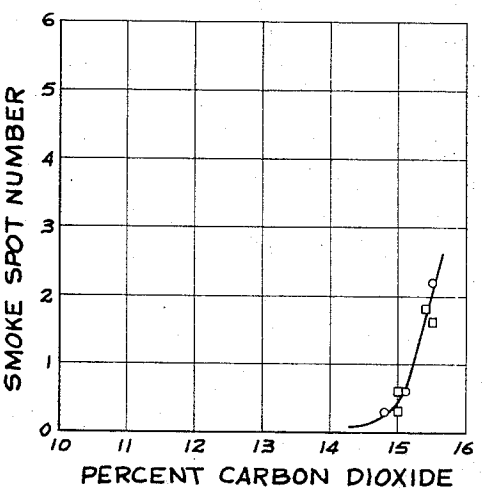


Fig. 9

INVENTORS.
BRUCE R. WALSH &
ALBERT BIBER

United States Patent Office 3,346,196 Patented Oct. 10, 1967

3,346,196

APPARATUS FOR ATOMIZING OIL

Albert Biber, Verona, and Bruce R. Walsh, Pittsburgh, Pa., assignors to Gulf Research & Development Company, Pittsburgh, Pa., a corporation of Delaware

Filed Dec. 3, 1964, Ser. No. 415,720
5 Claims. (Cl. 239—404)

The invention relates to an apparatus and process for the combustion of fuel oil at a substantially optimum level of combustion efficiency.

An optimum in efficiency for any combustion operation is the attainment of substantially complete combustion of the fuel in the presence of only about the theoretically required amount of air, with substantially no excess air being present. This optimum in combustion efficiency is exceedingly difficult to attain. Complete combustion is rarely achieved in a burner unless a substantial quantity of excess air is admitted. However, excess air in a combustion operation is disadvantageous because the excess air constitutes a diluent in the combustion product gases and decreases the temperature of these gases, thereby decreasing the heat exchange potential of the system. Furthermore, passage of excess air through a combustion apparatus decreases the residence time of the hot combustion product gases in a heat exchange system to which the combustion gases are charged. These are the two primary disadvantages of admitting excess air to a combustion apparatus. While it is extremely rare in an oil burner apparatus that complete combustion is achieved unless a substantial amount of excess air is admitted, the oil burner apparatus and process of this invention achieves the unusual efficiency level of substantially complete combustion of fuel in the presence of only about a stoichiometeric quantity of air.

The oil burner apparatus of this invention comprises a plurality of parts operating interdependently. The apparatus includes an aspirating nozzle disposed axially within an air blast tube close to or at the discharge opening of the air blast tube. Fuel oil under atmospheric pressure is exposed to said nozzle from a level which is the same as or somewhat below the level of the nozzle. The aspirating nozzle is adapted so that a swirling stream of compressed air passing therethrough draws the fuel oil into the nozzle where the oil becomes involved in the swirling motion of the compressed air stream and the resulting mixture is sprayed from the nozzle as a swirling diverging mixture of compressed air and highly atomized fuel oil droplets. An air choke having air swirl vanes is disposed at the discharge end of the air blast tube and surrounds the aspirating nozzle. An axial air disk having a diameter smaller than the diameter of the air blast tube is disposed within the air blast tube upstream from the nozzle. An air blower is disposed upstream from the air disk and blows atmospheric air through the annular space between the air disk and the air blast tube to form a hollow cylindrical stream of air directed toward the vaned air choke. The vaned air choke imparts a swirling convergent flow pattern to the air. The air blower blows atmospheric air through the air tube without causing any significant pressure within the tube.

The compressor employed to supply compressed air for the aspirating nozzle is capable of delivering air at a pressure considerably higher than that deliverable by the air blower. For example, the nozzle air compressor can be adapted to deliver air at a pressure above about 1 and up to about 10 pounds per square inch. A nozzle air pressure between about 2 and 5 pounds per square inch is usually sufficient. The compressed air is swirled within the aspirating nozzle and forms an evacuated vortex into which fuel oil under atmospheric pressure is aspirated.

The oil aspirated into the nozzle becomes engulfed in the swirling stream of compressed air and is flung outwardly against the nozzle swirl chamber wall surface under the influence of centrifugal force where it swirls as a thin liquid film. The swirling oil is carried out of the nozzle by the swirling stream of compressed air and, upon release from the confines of the nozzle, the thin oil film being still under the influence of centrifugal force diverges and disintegrates to form a divergent spray comprising highly atomized fuel oil droplets suspended in compressed air. Concomitantly, the vaned air choke directs the air being blown through the air blast tube in a swirling converging path directly intercepting the nozzle spray. An intimate admixture results comprising swirling atmospheric air from the air blower and unpressurized highly atomized droplets of fuel oil suspended in swirling expanding air from the air compressor.

The use of a swirling aspirating nozzle as described is highly critical to the attainment of substantially complete combustion of fuel oil in the presence of only approximately a stoichiometric quantity of air. It was found, and illustrated in Example 4, below, that if fuel oil is pumped under pressure through a swirling spray nozzle the highly advantageous combustion performance of this invention is not achieved. While the atomized fuel oil droplets in the spray of an aspirating nozzle are passively suspended in a carrier stream of compressed air and remain there until burned, a radically different condition prevails in the spray from a nozzle to which oil is pumped under pressure. When oil is pumped under pressure through a nozzle, rather than aspirated, the discharge fuel oil droplets are not passively suspended in a carrier air stream, as in the case of an aspirating nozzle, but are impelled from the spray nozzle under their own momentum and can impinge upon the walls of a surrounding combustion chamber and wet those walls with oil before they can be substantially completely vaporized and burned.

It was also found, and illustrated in Example 5, below, that if fuel oil is aspirated under atmospheric pressure by means of compressed air, but the nozzle employed is not equipped with means for swirling the aspirated oil, the extremely high level of combustion efficiency of this invention is not achieved. The reason evidently is that a high degree of fuel atomization is not achievable in the absence of swirling. When a swirling film of oil is released from the confines of a nozzle swirl chamber wall surface centrifugal force causes it to suddenly diverge laterally and disintegrate into a highly atomized mist of oil droplets. A high degree of oil atomization encourages rapid and complete vaporization of individual oil droplets. It is only in the vapor state that oil can admix with sufficient air to support its combustion. It is noted that oil vapor is highly combustible because it freely admixes with air while oil in the liquid state is not combustible because a liquid cannot admix with sufficient air to support combustion. Therefore, a liquid oil droplet only burns at its surface where vaporization can occur, but the liquid nucleus of the droplet will not burn unless it can first vaporize. It is critical to the attainment of the highly superior combustion performance of this invention both that the fuel oil be swirled and sprayed as a mist of highly atomized droplets which will rapidly and completely vaporize and also that the highly atomized oil be suspended in a carrier stream of expanding compressed aspirating air which air will advantageously be present to admix with the oil immediately upon vaporization thereof.

As explained above, the combustion apparatus and process of this invention achieves substantially complete combustion of fuel oil in the presence of only approximately a stoichiometric quantity of air. It has been discovered in accordance with this invention, that in order to achieve this high level of combustion efficiency a portion

of the stoichiometric quantity of air must be compressed air, as contrasted to atmospheric air which is blown through the air blast tube. The pressure of atmospheric air blown through an air blast tube is only high enough to impel atmospheric air through the air blast tube and is well under 1 pound per square inch, rarely reaching 1 to 3 ounces per square inch, and often being close to zero ounces per square inch. On the other hand, the compressed air utilized in accordance with this invention is under a much higher pressure. The compressed air can be under a pressure of from above about 1 up to about 10 pounds per square inch, generally, and is preferably under a pressure of about 2 to 6 pounds per square inch.

A minimum critical ratio of compressed air to fuel oil must be utilized in order to attain substantially complete combustion of the fuel oil without appreciable excess air. This is illustrated in Examples 1 and 7, below. The minimum critical ratio can be as low as about 70 or 75, and is preferably about 90 to 120 cubic feet of compressed air under a pressure of above about 1 up to about 10 pounds per square inch for each gallon fuel oil. This ratio can vary depending upon many different factors such as the pressure of the compressed air, the composition of the fuel oil, the degree of oil atomization achieved by the aspirating nozzle, and the relative dimensions of the various components of the combustion apparatus. However, in each combustion apparatus and process of this invention, a portion and only a portion of the combustion air is compressed air, the remainder of the stoichiometrically required air being blown through the system at or very close to atmospheric pressure. Example 6, below, shows that there is no advantage in increasing the ratio of compressed air to fuel oil above the minimum ratio required for optimum combustion performance. The proportion of the combustion air which must be introduced under compression is a minor proportion of the stoichiometric air requirement, with the major proportion of the stoichiometric air requirement being blown through the system at or close to atmospheric pressure. For example, in certain combustion operations of this invention, between about 5 and 10 percent of the stoichiometrically required air must be introduced under compression, the remainder being introduced under about atmospheric pressure. There is generally no advantage in exceeding the critical minimum proportion of compressed air required to achieve substantially complete combustion with only a stoichiometric quantity of total air.

Since the aspirating nozzle of this invention utilizes pressurized air for its operation, it is advantageous to utilize an aspirating nozzle having an operating ratio of compressed air to aspirated oil such that the total required quantity of compressed air can be introduced into the apparatus of this invention via the aspirating nozzle. Example 7, below, illustrates an advantageous means for increasing the ratio of compressed air to fuel oil discharged from a nozzle. This means comprises increasing the vertical distance between the fuel oil supply reservoir and the aspirating nozzle to increase the height through which the aspirated fuel oil must be lifted. However, many aspirating nozzles are operative only at a ratio of compressed air to aspirated oil which is too low to satisfy the critical minimum compressed air requirements of this invention. In many aspirating nozzles, an attempt to increase the amount of compressed air passed through the nozzle above a critical level results in a velocity at the nozzle discharge orifice which is so high that it exceeds the velocity of flame propagation, whereby either the nozzle spray cannot be ignited or the flame is repeatedly extinguished. In these instances it is necessary to introduce the additionally required compressed air directly into the air blast tube. When the aspirating nozzle is unable to supply the total required quantity of compressed air and additional compressed air must be introduced directly into the air blast tube, the additional compressed air is introduced into the air blast tube at a position on the periphery of said tube immediately upstream from the vaned air choke and is directed toward the swirling vanes of the air choke. Introduction of compressed air at this location permits the vaned air choke to impart a swirling convergent flow pattern to the expanding compressed air, thereby furthering intermixing of the compressed air stream and the separate but closely proximate divergent spray from the aspirating nozzle which is enclosed and intercepted by it.

Compressed air can be advantageously introduced directly into the air blast tube via a hollow ring having air inlet means and having air discharge openings directed toward the air swirl vanes on the air choke. If compressed air is charged to the air tube, it must enter the air tube close to and upstream from the air swirl vanes on the air choke so that the compressed air is swirled by said vanes if the superior combustion performance of this invention is to be achieved. This is illustrated in Example 2, below. Combustion tests showed that highly inferior results are achieved when the compressed air is charged at the downstream end of the air swirl vanes or upstream from the air swirl vanes but close to the axis of the air tube, in both of which instances the air swirl vanes being unable to swirl the compressed air admitted to the air tube. Of course, when the entire required quantity of compressed air is charged through the nozzle, the nozzle imparts a swirling motion to said air.

Regardless of whether the total required quantity of compressed air is introduced through the aspirating nozzle or is introduced partially through the aspirating nozzle and partially directly into the air blast tube, the vaned air choke is a critical component of the apparatus of this invention. This is illustrated in Example 2, below. The major portion of the stoichiometrically required air flows through the air blast tube and not through the nozzle. If complete combustion is to be achieved in the absence of excess air, substantially all the air flowing in the air blast tube must admix intimately with the spray from the aspirating nozzle. This intimate admixture is largely accomplished by means of the vaned air choke which, in cooperation with the air disk, imparts to the air flowing in the air blast tube a convergent swirling flow pattern and causes this air stream to enclose and intercept the diverging swirling spray from the aspirating nozzle. Intimate admixture occurs as a result of the intersection of the convergent swirling air stream from the vaned air choke and the divergent swirling spray from the aspirating nozzle.

This invention will be more clearly understood by reference to the accompanying drawings in which—

FIGURE 1 schematically shows the oil burner apparatus of this invention together with a furnace-heat exchanger combination,

FIGURE 2 is a sectional side view of the burner apparatus,

FIGURE 3 is a sectional top view of the burner apparatus,

FIGURE 4 is a front view of the air choke of the burner apparatus,

FIGURE 5 is a sectional side view of an aspirating nozzle of the burner apparatus, and

FIGURES 6, 7, 8 and 9 are curves representing data taken to illustrate the exceptional combustion performance of the apparatus of this invention and the criticality of various structural componets of the burner apparatus of this invention.

A schematic representation of the oil burner apparatus of this invention together with a furnace-heat exchanger combination is shown in FIGURE 1. The oil burner assembly is indicated generally at **10**, the furnace is indicated generally at **12**, and the heat exchanger is indicated generally at **14**. The flame from oil burner assembly **10** is charged to combustion chamber **16** which has an overhead opening leading to heat exchange cham-

ber 18 whereby hot combustion product gases rise from combustion chamber 16 to heat exchange chamber 18. A fluid to be heated is circulated in an enclosed conduit 19 which passes through exchange chamber 18. Conduit 19 is advantageously an air duct of a forced air heating system which extends to heat exchange chamber 18 from an air blower. The hot combustion product gases lose heat to conduit 19 in heat exchange chamber 18 and leave the furnace through chamber 20 in a relatively cool condition. The gases are then vented through a flue pipe 22 which is provided with adjustable damper 24.

Reference is now made to the side sectional view of oil burner assembly 10 shown in FIGURE 2 and the top sectional view of oil burner assembly 10 shown in FIGURE 3. As shown in FIGURES 2 and 3, air blast tube 28 of oil burner assembly 10 extends through a furnace wall 26. Air blast tube 28 is secured into the discharge opening of air blower housing 30. Motor 32 is disposed on one side of air blower housing 30 while air compressor 36 is disposed on the other side of air blower housing 30. Motor 32 drives both blower 34 and air compressor 36 by means of rotating shaft 38. Rotating shaft 38 is connected to blower 34 by means of rotatable circular plate 41, shown in FIGURE 3. Blower 34 draws air from the atmosphere through air openings 42 in stationary circular plate 40 and blows it through air blast tube 28. Disk 44 in air blast tube 28 has a diameter slightly smaller than the diameter of air tube 28, thereby forcing the air blowing in air blast tube 28 to be confined close to the wall of the air blast tube so that when the air reaches air choke 46 disposed at the discharge end of the air blast tube a swirling motion is imparted to it by means of vanes 48 attached to the interior of air choke 46. The amount of air blown through air tube 28 is adjusted by varying the size of air openings 42 to provide substantially a stoichiometric total quantity of air to the burner. The adjustment in blower air flow rate is accomplished by means of air opening cover plates 50 which are provided with narrow longitudinal slots 52 to permit movement of said cover plate relative to bolt and nut assembly 54 and air openings 42. Cover plates 50 can be secured at any desired position with respect to air openings 42 by loosening bolt and nut assembly 54, moving cover plate 50, and then retightening bolt and nut assembly 54.

Aspirating nozzle 54 is disposed coaxially with respect to air blast tube 28 very close to or substantially at the discharge end thereof and substantially in the center of air choke 46. Air compressor 36 supplies compressed air to aspirating nozzle 54. Air compressor 36 draws air from the atmosphere through filter-muffler 56 and pipe 58 and discharges compressed air to aspirating nozzle 54 through pipe 60, pressure regulator 62, pipe 64, throttle valve 66, and pipe 68. Pressure regulator 62 is adapted to discharge air at any pressure within a range of above about 1 to about 10 pounds per square inch. Excess compressed air can be vented through pipe and valve assembly 59.

If, during burner operation, an increased compressed air-fuel oil ratio is required to produce optimum combustion performance and aspirating nozzle 54 is not capable of accepting additional compressed air without the flame being blown out, the apparatus is adapted so that compressed air is supplied directly to air choke 46. Compressed air is supplied to air choke 46 through pipe 70, throttle valve 72, and pipe 74 which leads directly into continuous hollow ring 76 within the body of air choke 46. Compressed air within hollow ring 76 is discharged through a plurality of openings 78. Referring to FIGURE 4, which shows a front view of air choke 46, it is seen that each air opening 78 is associated with an air swirl vane 48 so that compressed air discharged from hollow ring 76 has a swirling motion imparted to it. Air choke 46 with the cooperation of air disk 44 thereby causes both the atmospheric air blown through air blast tube 28 by air blower 34 and the compressed air from hollow ring 76 to be discharged through discharge opening 80 of the air choke as a substantially hollow swirling converging stream of air disposed to intercept and admix intimately with the swirling diverging substantially hollow stream of compressed air and atomized oil droplets discharged from aspirating nozzle 54.

A sectional view of aspirating nozzle 54 is shown in FIGURE 5. The nozzle comprises a body 82 which is secured to compressed air line 68 in fluid tight engagement therewith. Nozzle body 82 is provided with a forward cylindrical axial discharge opening 84. Plug 86 is secured into the interior of nozzle body 82 in fluid tight engagement with respect to said nozzle body. Plug 86 is provided with a forward axial duct 88 having an outer diameter smaller than nozzle discharge opening 84 and extending coaxially a portion of the distance into nozzle discharge opening 84. Axial bore 100 extends through duct 88 until it meets lateral bore 90. When plug 86 is secured tightly into nozzle body 82, lateral bore 90 is in alignment with lateral bore 92 in nozzle body 82. An oil conduit 94 extends from bore 92 in fluid tight engagement therewith. Plug 86 is also provided with one or more peripheral slots 96 which enter swirl chamber 98 in a tangential manner. Compressed air from conduit 68 enters swirl chamber 98 in a forward and tangential direction through tangential slots 96 and swirls within swirl chamber 98 toward discharge opening 84. The swirling motion of the air stream in nozzle discharge opening 84 creates an evacuated vortex into which fuel oil is drawn through pipe 94, bores 92, 90, and 100. The aspirated oil is caught up in the swirling air stream and a swirling diverging spray of compressed air and atomized oil droplets is discharged from nozzle discharge opening 84. As shown in FIGURES 2 and 3, nozzle 54 is disposed substantially at the center of air choke 46 so that the swirling converging stream of air from air choke 46 and the swirling diverging stream of air and atomized oil droplets from nozzle 54 intercept each other and intimately admix in the region of choke discharge opening 80.

FIGURE 2 shows that oil line 94 extending from aspirating nozzle 54 is coupled to fuel supply line 95 which in turn provides access to oil reservoir 102. Reservoir 102 is at or slightly below the level of nozzle 54 and is maintained at atmospheric pressure by means of vent 104. Pump 106 supplies fuel oil to reservoir 102 through line 108. The level of oil within reservoir 102 is adjusted by means of a plurality of overflow conduits 110, 112, 114 and 116, provided with overflow valves 118, 120, 122 and 124, respectively. Overflow conduits 110, 112, 114 and 116 discharge into a common header, not shown, which can return the oil to an oil storage tank, not shown. The level of oil in the tank can only be as high as the level of the lowest overflow valve which is open. The oil suction lift to aspirating nozzle 54 is adjusted by selectively opening any of valves 118, 120, 122 or 124 and closing any valve disposed below the open valve. Varying the oil lift to aspirating nozzle 54 is a means for effecting a desired change in the ratio of compressed air to fuel oil discharged by aspirating nozzle 54.

The mixture of atomized oil droplets, compressed air and atmospheric air at air choke discharge opening 80 is ignited by means of a pair of arcing electrodes 128 and 130 which have connection with a power transformer 132. The electrodes, as well as compressed air conduit 68 and oil conduit 95 extend through air disk 44 and are suspended within the interior of air blast tube 28 by means of a plurality of spring supports 134.

Example 1

A pair of tests were conducted to illustrate the criticality of the ratio of compressed air to fuel oil in the apparatus of the drawings. The apparatus utilized in each test comprised an air blast tube four inches in diameter having an air blower at its inlet end and an air choke

having swirl vanes at its discharge end which reduced its discharge opening to two inches. A swirling aspirating nozzle was disposed coaxially within the air blast tube with its discharge opening ¾ of an inch upstream from the discharge opening of the choke. The nozzle was connected to an oil reservoir under atmospheric pressure whose oil level was one inch below the nozzle. An air disk 3½ or 3¾ inches in diameter was disposed in the air blast tube upstream from the nozzle. The air blast tube was directed into a furnace having an overhead flue.

The nozzle air compressor in each test produced 180 cubic feet of air per hour at a pressure of 5.3 pounds per square inch, of which only 48 cubic feet per hour was swirled through the aspirating nozzle. In each test, the 48 cubic feet per hour of air swirled through the nozzle aspirated 0.80 gallon per hour of oil through the nozzle. In the first test no air ring was utilized in the air blast tube and the excess 132 cubic feet per hour of compressed air produced by the compressor was vented to the atmosphere. However, in the second test an air ring was utilized in the air blast tube immediately upstream from the vaned air choke, and the excess 132 cubic feet per hour of compressed air produced by the compressor not swirled through nozzle was charged to the air ring from which it was discharged in the direction of the vanes of the air choke. The air ring used comprised a ¼ inch tube bent to form a continuous ring having a four inch outer diameter and a 3½ inch inner diameter.

The only difference between the first and second tests is that the second test utilized the compressed air ring while the first test did not. The results of the first and second tests are illustrated in FIGURE 6 as a graph of smoke spot number versus percent carbon dioxide in the flue gas discharging through the stack of the furnace. In each test, a number of smoke spot number versus percent carbon dioxide readings were obtained by varying the amount of atmospheric air blown through the air blast tube. The results of the first test, which omitted the compressed air ring, are illustrated in curve A of FIGURE 6, while the results of the second test, which utilized the compressed air ring, are illustrated in curve B of FIGURE 6.

The test data of smoke spot number versus percent carbon dioxide in a sample of flue gas produced during combustion was taken in accordance with the method described in ASTM Standards on Petroleum Products, 1960, page 1041. For purposes of analyzing the test results, it is noted that best combustion results are indicated by the combination of a high carbon dioxide content, indicating a high degree of combustion, and a low smoke content, which also indicates a high degree of combustion. While the percent of carbon dioxide can be increased by reduction of air input, this will have the adverse effect of increasing smoke content. On the other hand, smoke content can be decreased by merely admitting a large excess of air but this will have the adverse effect of greatly diminishing the relative content of carbon dioxide. Optimum results are achieved with the combination of relatively high carbon dioxide content and relatively low smoke content.

As explained above, an optimum in performance for any combustion apparatus is the attainment of substantially complete combustion of the fuel while admitting only about the exact amount of air theoretically required for complete combustion, with essentially no excess air being present. While this optimum in combustion performance is exceedingly difficult to attain and it is extremely rare that complete combustion is achieved unless excess air is admitted, it is shown below that the apparatus of this invention achieves the unusual result of substantially complete combustion of fuel in the presence of approximately only a stoichiometric quantity of air.

Calculations based upon the particular fuel oil used in all the tests of this application showed that a carbon dioxide content in the flue gases of 15.6 percent when there is little or no smoke theoretically indicates complete combustion of the fuel in the presence of exactly a stoichiometric quantity of air. The calculations also showed that 1389 cubic feet of air is stoichiometrically required for complete combustion of each gallon of the particular fuel oil used in all the tests. In both tests of this example, the air compressor supplied only a small proportion the theoretical air required for complete combustion of the fuel, the remainder being atmospheric air supplied by the air blower. In the first test of this example, the air compressor supplied 48 cubic feet of pressurized air per hour to the nozzle to aspirate 0.80 gallon per hour of fuel oil and this was the total supply of compressed air to the system so that the air blower would have been required to supply about 1063 cubic feet per hour of atmospheric air to complete stoichiometric air requirements. In the second test of this example, the air compressor supplied 48 cubic feet per hour through the nozzle to aspirate 0.80 gallon per hour of fuel oil, and also supplied 132 cubic feet per hour of compressed air through the compressed air ring, so that the air blower would have been required to supply about 931 cubic feet per hour of atmospheric air to complete stoichiometric air requirements.

Curve A of FIGURE 6 shows that tests made without a pressurized air ring and with a ratio of compressed air to fuel oil of 60 cubic feet of compressed air per gallon of fuel oil resulted in a flue gas having only 11.5 percent carbon dioxide at a smoke spot number of 1. Curve B of FIGURE 6 shows that tests made with a pressurized air ring and with a total ratio of compressed air to fuel oil of 225 cubic feet of compressed air per gallon of fuel oil advantageously increased the percentage of carbon dioxide in the flue gas to 15.0 at a smoke spot number of 1. The comparison between curves A and B of FIGURE 6 shows that a remarkable improvement in combustion is achieved at the higher ratio of compressed air to fuel oil made possible by the use of the pressurized air ring. The percentage of carbon dioxide in the flue gas at a smoke spot number of 1 at the higher ratio of compressed air to fuel oil is in the vicinity of the 15.6 carbon dioxide flue gas percentage theoretically indicating complete combustion of the fuel oil with no excess air.

Example 2

Two tests were performed to illustrate the cooperative effect between the vaned air choke at the discharge end of the air blast tube and the pressurized air ring. The first test of this example was performed under the same conditions as the tests of curve B of FIGURE 6 except that the air swirling vanes were removed by machining from the interior surface of the air choke. The result of this test is shown at point C in FIGURE 6. The second test of this example was performed under the same conditions as the tests of curve B of FIGURE 6 except that the air choke was removed entirely from the apparatus. The result of this test is shown at point D in FIGURE 6.

Point C in FIGURE 6 shows that when utilizing a pressurized air ring the removal of the air swirling vanes from the air choke disadvantageously reduced from 15 to 14 the percentage of carbon dioxide in the flue gas at a smoke spot number of 1. Point D of FIGURE 6 shows that the removal of the air choke entirely when utilizing a pressurized air ring disadvantageously reduced from 15 to 12 the percentage of carbon dioxide in the flue gas at a smoke spot number of 1. The tests of this example show that the compressed air ring and the vaned air choke cooperate to produce a carbon dioxide content in the flue gas at a smoke spot number of 1 which is comparable to the percentage of carbon dioxide in flue gas indicating theoretically complete combustion with no excess air.

Example 3

Further tests were conducted to illustrate the interdependence between the compressed air ring and the vaned air choke. In these tests a compressed air ring was

disposed snugly around the discharge end of the aspirating nozzle remote from both the wall of the air blast tube and the air choke so that air blown by the blower through the air blast tube flowed between the compressed air ring and the vaned choke. This is contrasted to the tests of Examples 1 and 2 wherein the compressed air ring was disposed directly at the wall of the air blast tube upstream from and adjacent to the air choke and remote from the nozzle. The tests of this example indicated that when the compressed air ring is disposed directly around the nozzle and remote from the air choke not only is there no improvement in combustion but, on the contrary, there is a deleterious effect upon combustion. These tests, therefore, illustrate the criticality of disposing the compressed air ring directly at the wall of the air blast tube immediately upstream from the vaned air choke.

Example 4

Two tests were performed to determine the effect of the compressed air ring in a combustion apparatus similar to that shown in the drawings except that the aspirating nozzle is replaced by a swirling oil spray nozzle wherein the oil is pumped under pressure through the nozzle with a swirling motion, rather than aspirated. In each of these tests 0.87 gallon per hour of fuel oil was pumped through a swirling spray nozzle under a pressure of 100 pounds per square inch. In each test an air choke having air swirling vanes was utilized which reduced the discharge opening of the air blast tube from 4 inches to 2 inches and the pressure nozzle was disposed coaxially within the air blast tube with its discharge opening recessed ¾ of an inch from the discharge opening of the air choke. In the first test of this example no compressed air ring was utilized and no compressed air was charged to the burner apparatus. In the second test of this example, a compressed air ring was utilized upstream from and adjacent to the vaned air choke and 95 cubic feet per hour of air compressed to a pressure of 1.25 pounds per square inch was passed through the air ring and discharged directly to the swirl vanes of the air choke. The results of the first test are shown in curve A of FIGURE 7 and the results of the second test are shown in curve B of FIGURE 7.

As shown in FIGURE 7, when utilizing a non-aspirating pressurizing oil spray nozzle, the use of a pressurized air ring advantageously increased the percentage of carbon dioxide in the flue gas from about 10.65 to almost 13 at a smoke spot number of 1. While this improvement is substantial, the improved results do not approach the 15.6 percent of carbon dioxide in the flue gas which would theoretically be achieved at complete combustion with stoichiometric air. Comparing the results of this example with the results of Example 1, it is seen that the best results by far are achievable when utilizing a swirling compressed air aspirating nozzle rather than a non-aspirating swirling pressurized oil nozzle.

Example 5

Two tests were conducted to illustrate the effect of the compressed air ring in a burner apparatus utilizing an aspirating nozzle of the non-swirl type. The aspirating nozzle of this example is similar to the aspirating nozzles used in the previous tests except that the means for swirling the pressurized air admitted to the nozzle was removed prior to the tests. Therefore, pressurized air admitted to the nozzle traveled through the nozzle with a non-swirling motion to aspirate fuel oil existing under atmospheric pressure. In the first test, 55 cubic feet per hour of air under a pressure of 5.7 pounds per square inch was passed through the nozzle in a non-swirling manner to aspirate 0.95 gallon per hour of fuel oil. An air choke having air swirl vanes reduced the discharge opening of the air blast tube from 4 inches to 2 inches and the discharge opening of the nozzle was recessed ¾ of an inch from the center of the discharge opening of the choke. No compressed air ring was utilized in the first test. In the second test, 58 cubic feet per hour of air under a pressure of 6.1 pounds per square inch was passed through the nozzle in a non-swirling manner. In the second test, a compressed air ring was disposed adjacent to and upstream with respect to the vaned air choke and 122 cubic feet per hour of compressed air under a pressure of 6.1 pounds per square inch was passed through the compressed air ring. A number of data points were obtained in both the first and second tests by varying the flow rate of air blown through the air blast tube. Referring to FIGURE 8, the data obtained in the first test, which was conducted without the compressed air ring, is indicated by the circular symbols, while the data obtained in the second test, which was conducted with the compressed air ring, is indicated by the square symbols.

FIGURE 8 shows that when utilizing a non-swirl aspirating nozzle, no improvement is obtained by utilizing a compressed air ring. In the tests of this example in which no compressed air ring was utilized the flue gases contained about 14 percent carbon dioxide at a smoke spot number of 1, and this result was substantially unchanged when utilizing a compressed air ring. Therefore, while a compressed air ring functions cooperatively with an aspirating nozzle having means for swirling the aspirating air, it does not produce improved results when utilized with an aspirating nozzle which is devoid of aspirating air swirling means.

These results are explicable because nozzle swirling induces a high degree of oil atomization whereby the pressurized air passing through the compressed air ring is enabled to intimately admix with the oil. A high degree of oil atomization encourages rapid and complete vaporization of individual oil droplets. It is only in the vapor state that oil can admix with sufficient air to support its combustion. Oil vapor is highly combustible because it can freely admix with air while liquid oil is not combustible because a liquid cannot admix with sufficient air to support combustion. Therefore, a liquid oil droplet only burns at its surface where vaporization can occur, but the liquid nucleus of the droplet will not burn unless it can first vaporize. Lack of swirling means in a nozzle results in a very poorly atomized oil spray whereby the oil is unable to vaporize sufficiently rapidly to utilize the pressurized air passing through the compressed air ring, thereby rendering the compressed air ring innocuous.

Example 6

Further tests were conducted utilizing a swirling air aspirating nozzle which was designed to require about twice the amount of compressed air to aspirate a given volume of fuel oil as was required by the swirling air aspirating nozzle of the tests of Example 1. In the tests of this example, the swirling air aspirating nozzle utilized 99 cubic feet per hour of air at a pressure of 4.5 pounds per square inch to aspirate 0.81 gallon per hour of fuel oil under atmospheric pressure. This constitutes a ratio of compressed air to fuel oil of about 122 cubic feet of compressed air per gallon of fuel oil. The first test of this example did not utilize a compressed air ring while the second test of this example utilized a compressed air ring adjacent to and upstream with respect to the vaned air choke and 81 cubic feet of air under a pressure of 4.5 pounds per square inch was passed through the air ring. Except that a different nozzle was employed, the first test of this example utilized the apparatus of the test illustrated by curve A of FIGURE 6 and the second test of this example utilized the apparatus of the test illustrated by curve B of FIGURE 6. A number of data points were obtained in both the first and second tests of this example by varying the flow rate of air blown through the air blast tube. The results of the test of this example utilizing the compressed air ring are indicated by the square symbols in FIGURE 9 and the results of the test of this example in which no air ring was em-

ployed are indicated by the circular symbols in FIGURE 9.

As indicated in FIGURE 9, no improvement was achieved by utilizing a compressed air ring, the percentage carbon dioxide in the flue gas at a smoke spot number of 1 being about 15.2 both with and without an air ring. The results shown in FIGURE 9 indicate that when a swirling air aspirating nozzle produces a spray having a high ratio of compressed air to fuel in the combustion apparatus, nearly optimum combustion is achieved. Therefore, the additional pressurized air discharged through the compressed air ring become innocuous.

Example 7

To further illustrate the criticality of the ratio of compressed air to fuel oil, the nozzle and apparatus of Example 6 was employed in two tests, each not utilizing a compressed air ring. In the first test, 92 cubic feet per hour of swirling air under a pressure of 4 pounds per square inch was passed through the nozzle and aspirated 1 gallon per hour of fuel oil under atmospheric pressure from a level 1 inch below the nozzle to produce a flue gas have 14.8 percent carbon dioxide at a smoke spot number of 1. In the second test, the oil level was changed to require an oil lift of 5 inches rather than 1 inch whereby 106 cubic feet per hour of swirling air under a pressure of 5 pounds per square inch gauge was required to aspirate 1 gallon per hour of fuel oil. In the second test the flue gas contained 15.4 percent carbon dioxide at a smoke spot number of 1, which very closely approximates the optimum carbon dioxide percentage of 15.6, theoretically indicating complete combustion of the fuel oil with exactly stoichiometric air.

The showing of Example 7 is highly significant since it indicates that an increase in the ratio of compressed air to fuel oil can be achieved without the utilization of a compressed air ring. Example 7 shows that a desired increase in the ratio of compressed air to fuel oil can be achieved by increasing the amount of compressed air required to aspirate a given quantity of fuel through the nozzle through the expedient of increasing the oil suction lift to the aspirating nozzle.

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.

We claim:

1. An apparatus for the combustion of fuel oil comprising an air blast tube having an air inlet end and an air discharge end, air blower means for blowing atmospheric air through said air blast tube from the inlet end to the discharge end thereof, air choke means having air swirl vanes disposed at the discharge end of said air blast tube, compressed air delivery means near the periphery of said air blast tube upstream from said air choke means, said compressed air delivery means adapted to discharge compressed air toward said air swirl vanes, an aspirating nozzle axially disposed in said air blast tube in the vicinity of said air choke means, fuel oil supply means for supplying fuel oil under substantially atmospheric pressure to said aspirating nozzle, air compressor means for supplying pressurized air to said aspirating nozzle and to said compressed air delivery means, air swirl means in said aspirating nozzle for swirling the pressurized air supplied to said aspirating nozzle, said aspirating nozzle adapted so that the swirling motion of pressurized air passing therethrough aspirates said fuel oil and discharges a swirling mixture of pressurized air and atomized oil, said air compressor means supplying a sufficient volume of compressed air to said compressed air delivery means so that substantially complete combustion of the aspirated oil is achieved with only substantially a stoichiometric quantity of air being supplied to said apparatus by said air blower means and said air compressor means.

2. The combustion apparatus of claim **1** wherein said compressed air delivery means is disposed within said air choke means.

3. The combustion apparatus of claim **1** wherein said compressed air delivery means comprises a hollow ring extending along the periphery of said blast tube having means for receiving compressed air and means for discharging said compressed air in the direction of said air swirl vanes.

4. The combustion apparatus of claim **1** including means for adjusting the output of said air blower means and said compressed air delivery means so that substantially a stoichiometric quantity of air is supplied to said apparatus by both said air blower means and said compressed air delivery means.

5. The combustion apparatus of claim **1** including a disk having a diameter smaller than said air blast tube disposed in said air blast tube upstream from said nozzle.

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EVERETT W. KIRBY, *Primary Examiner.*