AN EXPERIMENTAL STUDY OF SHAPES AND SIZES OF COMBUSTION CHAMBERS FOR THE GUN TYPE OIL BURNER

Thesis for the Degree of M. S.

Richard Bowen Chrouch

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Oil burners

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SHAPES AND SIZES OF COMBUSTION CHAMBERS
FOR THE GUN TYPE OIL BURNER

A Thesis Submitted to
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by
Richard Bowen Chrouch
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THESIS

THE OBJECT OF THE STUDY

The research and study represented by this thesis was carried on for the purpose of determining the most satisfactory sizes and shapes of combustion chambers to be used with the conventional gun type oil burner, using a conical spray and spirally directed air supply.

SUMMARY OF CONCLUSIONS

A. Size

1. Increasing the size of a badly designed combustion chamber will overcome troubles due to the design to a sufficient extent so that the oil will burn without smoke, but more than this cannot be expected.
2. The best size of combustion chamber is that which will contain from 80 to 100 % of the flame. Under low vertical boilers 95 to 100 % of the flame should be contained within the combustion chamber, while in a large hot air furnace best results may be obtained with only 80 % contained in the chamber.
3. From above, the combustion chamber should appear to be full of flame except for a space not less than 1½ inches wide in front of the nozzle. But there appears to be no appreciable advantage in having the bottom of the chamber conform to the shape of the flame.
4. It is desirable to have the combustion chamber built of insulating rather than refractory material for intermittant operation, since the warming up period and the stack losses are reduced.
5. In small sizes, molded chambers are better than those built up out of brick, but molded chambers cannot at present be made of insulating material, which fact negatives most of the advantages of the molded shape.

B. Shape

1. Height

   There are several factors that determine height. They are, in order of importance;

   a. Noise permissable

      Best efficiency with heavy oil is obtained in high (long travel) combustion chambers. Noise is generated within the combustion chamber by violent fluctuations in the rate of combustion, and its intensity and pitch are of course affected by the height of the chamber. Noise is very objectionable in domestic burners. This means either that a low combustion chamber, necessitating the use of lighter oil or a decreased flow, must be used, or else the furnace and flue pipe must be sound proofed.

   b. Efficiency

      Increases in efficiency are desirable up to the point where the gain is overbalanced by the sacrifices necessary to accomplish it. There is a trend toward the use of heavier oils in domestic burners. Unless atomization of these oils is greatly improved, higher chambers or some other provision for increasing length of flame travel within the combustion chamber will become necessary, and sound insulation may be used.

   c. Space limitations

      Some furnaces have very limited space for the combustion chamber. If the use of such a furnace cannot be avoided, fairly good combustion may be obtained by using a chamber which gives the flame a spiraling motion, as the one developed by the author and shown in Fig. 10.

d. Type of furnace
Very few furnaces converted from coal to oil burning restrict the height of the chamber. Some furnaces restrict width or length, which of course necessitates an increase in height. This frequently occurs when a furnace is made to fit some oil burner chamber which has been discontinued.

2. Length and Width
These are of course factors of the shape. The best shape was found to be one which would appear from above to be completely filled with flame except for the space in front of the nozzle where the mixing of oil and air occurs. It is also desirable that the flame be split and the trails be given a spiraling motion to allow more complete combustion to occur before the heat absorbing surfaces above cool the gases. For a 60 to 80 degree nozzle (60 to 80 degree spray angle with No. 3 fuel oil), a shape similar to the one developed in the experimental work for this thesis is recommended. The chamber may be either molded, in which case refractory material must be used, or it may be built up out of insulating brick.

3. Ratio Between Dimensions
The same ratio is used for all sizes (except that width at nozzle is constant). The volume of the chamber should be proportional to the amount of oil burned.

INTRODUCTION

HISTORY OF OIL BURNING

The advance of human progress has been practically parallel to the development of heating. The discovery of fire was the first great advance made by man.

Contrary to popular belief, petroleum was one of the first known combustibles. It is now quite definitely known, for instance, that the fire worshippers used petroleum in their rites as early as 600 B. C.* The word "petroleum" is derived from two Latin words, petra, meaning rock, and oleum, meaning oil. In the Bible, Job, speaking of his lost blessings, mentions "rock that poured me out rivers of oil". Four thousand years ago, according to the Bible, Noah caulked the seams of the ark with pitch taken from native outcroppings of petroleum.

Marco Polo mentions in his account of his travels during the thirteenth century "on the confines toward Georgine (note: in the Baku district on the Caspian Sea)...... a fountain from which oil springs in great abundance, inasmuch as a hundred shiploads might be taken at one time." This oil was not good to use with food, he says, but was good to burn, and was also used to anoint camels that had the mange.

The American Indians early used crude oil in their religious rites and in healing.

Early records indicate that petroleum was first used in lamps. The Vestal Virgins used it in their lamps and also used a mineral substance, probably asbestos, for the wicks.

Russia, where seepage oil was plentiful, was first to refine it in a crude way. The heavier refuse oil then became a problem, and Werner, a mechanic, conceived the idea of burning it. His burner was patented in 1861, and consisted of a series of griddles over which the oil trickled and burned. Other countries were also experimenting with petroleum, and a spray burner invented by Brydges Adams was introduced to America in 1863. Two years later what is generally credited with being the first really practical burner was introduced in London by Aydon. Atomization in Aydon's burner was accomplished by superheated steam.

As a result of work done by Schpakossky and Strange of St. Petersburg, Russia, in June, 1865, an English patent was granted on a small apparatus for blowing a blast of air at right angles across the end of an oil pipe, thus atomizing the oil. Thus were the ancestors of our present burners born.

The first successful locomotive application of oil burning was made by Thomas Urguhart, Locomotive Superintendent of the Great Eastern Railway in England. In 1874 the Russian government adopted oil fuel for all vessels of the Caspian Fleet. In 1881 one of the Boston and Albany Railroad Company's locomotives was converted to oil.

*"Oil Burner's Handbook"

From 1859 to 1892 most of the American production of fuel oil was used to manufacture illuminants, lubricating oil, parrafin, etc., although some oil was used in steam atomizing burners for heat and power. In 1892 the Chicago exposition management decided to heat the World's Fair building with automatic oil burning equipment, and did so very successfully.

The first domestic burners used the natural draft vaporizing principle. This was not very satisfactory. To overcome the disadvantages of this type, burners were designed with a fan or blower that mechanically forced the air for combustion into the combustion chamber. Automatic controls were developed. Since 1919 the domestic burner has had a phenominal growth.

PRESENT STATUS

Over half the energy required by man is in the form of heat. The use of oil for heating is expanding at a very rapid rate. For the calendar year 1928 this use was 31 million barrels, or about 9% of the total oil consumption. Of the 31 million barrels used, 8 million were light distillate or furnace oil, and 23 million, heavier gas and fuel oil. The most rapid expansion is in the installations for small dwellings requiring a lighter grade of oil than the larger heating units in commercial buildings. Over 423,000 homes were equipped with oil burners by 1930, and the number has been increasing at the rate of about 100,000 a year since 1927.*

Oil weighs 30% less and occupies 50% less space than coal containing the same number of B. t. u. It does not deteriorate or ignite spontaneously, and may be stored at a distance from the furnace. It is immediately available, and may be stored or removed with practically no labor. Oil fired furnaces are flexible in operation and capacity and require a minimum of labor. They can be run with no smoke or dust. Less draft is required than with either a stoker or hand fired coal furnace. High efficiencies are obtainable.

As against these advantages there is the high initial cost of the handling equipment and the high prices usually charged for the fuel.

The chief attraction of the domestic oil burner is the automatic operation.

FUTURE ASPECT

Although there is much conflict of opinion, many people believe that the price of oil suitable for domestic use will eventually drop. They base their predictions on the present inefficiency of distribution of this class of oil and the restriction of output, which they believe will in the

*"Oil Conservation and Fuel Supply"

future be reduced. Many persons also feel that as yet only a small part of the world's supply of petroleum has been discovered, and that the discovery of additional sources in the future will further reduce the price.

REASONS FOR THIS STUDY

Although internal combustion engines and apparatus for domestic lighting with oil reached quite a high stage of development with the advent of the twentieth century , the development of combustion apparatus for domestic heating with oil of the heavier grades is still in its infancy. It might be argued that almost as much advance has been made in heating with light oil as in lighting or power development, and that efficient lighting has never been accomplished with heavy oil. It is the author's belief, however, that light oil is too good a fuel to be used for heating, but should be reserved for lighting and power development in internal combustion engines, where the weight of the apparatus used to burn the oil is of primary importance. The apparatus used to burn light oil efficiently will probably always be lighter in weight than that used to burn the lower grades.

Most mechanical oil burners on the market today will atomize oils of low viscosity effectively. Only a few manufacturers recommend that they be operated on oils heavier than No. 3 or No. 4 fuel oil. Heavier oils can be atomized in automatic burners, but preheating or higher atomization pressures are required, and the buying public are not yet willing to pay extra for this advantage. Many very good furnaces and boilers have been designed for use with oil burners.

By far the least development has been made in combustion chambers. When this study was started it was found that many manufacturers of gun type burners were still allowing the dealer or customer to build the combustion chamber, sometimes without even specifying the shape and size. This practice resulted in much dissatisfaction and very nearly brought these burners into disrepute. When the manufacturers came to the conclusion that they must either give definite specifications or else furnish the combustion chamber, they commenced to realize that they did not know the specifications which would give the best results. Research was then instigated, but as yet has not progressed very far. It was for this reason that this study of shapes and sizes of combustion chambers for the gun type oil burner was made. It is hoped that the findings will be of aid to those who must furnish specifications of or build combustion chambers in the future, and to those who wish to make a further study of the subject.

Certain assumptions were made as a basis for this study. They are as follows:

1. The best nozzle to use with a standardized gun type oil burner was one giving a spray angle of 60 to 80 degrees with No. 3 fuel oil.

2. The best oil to use in the tests was No. 3 fuel oil, since it gives the most satisfactory and economical operation when used with the gun type oil burner without changes or accessories.

DESCRIPTION OF APPARATUS AND MATERIALS

I. APPARATUS

A. Tests #1 to #19 and #A1 to #A3, inclusive

The setting and arrangement of accessories used throughout these tests is shown in Figs. 1 and 2.

A sheet metal base ring was used to enclose the combustion chamber and to support the heat chamber. The space between the combustion chamber and the base was filled with rock wool. This base was set on level floor under a chain hoist and adjacent to a 10 inch stack. A 4½ inch hole allowed the burner draft tube to pass through into the combustion chamber. To keep the top of the combustion chamber as low as possible in the heat chamber, the bottom of the combustion chamber was laid directly on the bottom of the base, which, being in contact with the floor, probably allowed some heat to escape. This heat loss could have been reduced by laying the bottom of the combustion chamber on pipe or similar supports and filling the space below with insulating material.

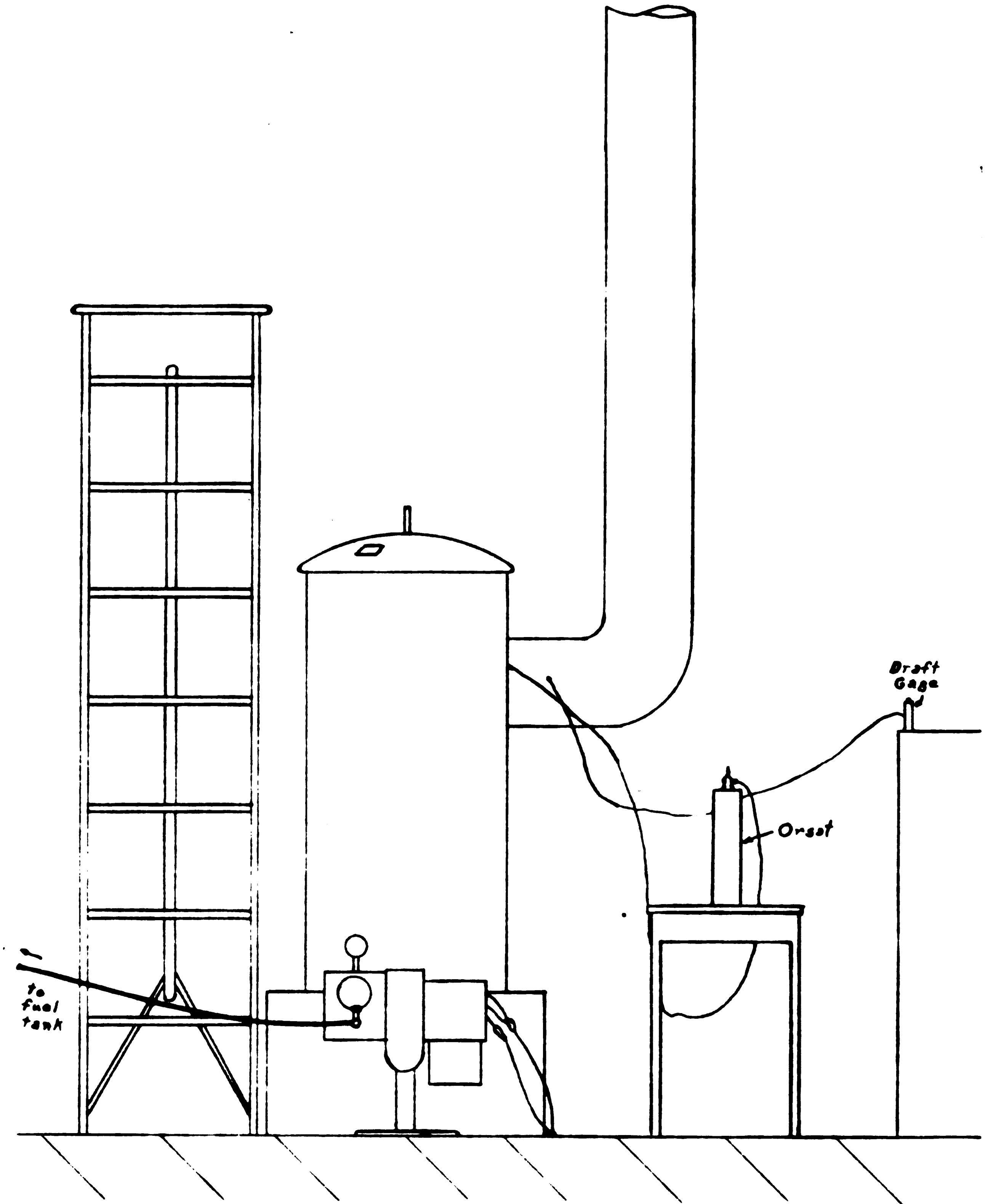
A very simple heat chamber was used. It consisted of a steel cylinder with a cover welded to the top. A hole was cut in the top and fitted with a mica window for observation purposes. A 10 inch flanged hole 37 inches from the bottom of the chamber was used for the flue pipe connection.

The flue pipe was fitted with a balance damper to keep the draft constant and make adjustment possible. Holes were provided between the damper and the heat chamber for small tubes connected to the Ellison draft gage and Hayes Orsat apparatus, and for a nitrogen thermometer reading to 950 degrees F. At the end of this section of flue pipe an elbow connected the flue with the stack through a section of pipe which could be contracted or expanded by tightening or loosening screws.

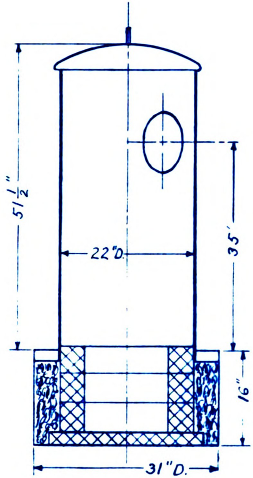
The burner used in tests #1 to #19 was the Motor Wheel Model D gun type burner of 4 gallon capacity, shown in Figs. 4 and 5. This type of burner is quite simple. Atomization is due to the motion imparted to the oil in passing tangentially through small orifices, in the nozzle under high pressure. The atomization is the result of a series of actions:

(a) Friction as the oil comes out of the small orifice.
(b) Flashing into vapor of part of the oil due to the sudden drop in pressure.
(c) Centrifugal motion imparted by tangential slots inside the nozzle.

As no air is used for atomization the necessary air for combustion is blown through a draft tube surrounding the burner assembly. The amount of air is controlled by a register over the inlet. Vanes near the nozzle give the air a circular motion, which helps to mix it with the atomized oil. Oil pressures may be varied between 60 and 150 pounds per square inch. For No. 3 oil the pressure usually used is 100 pounds per square

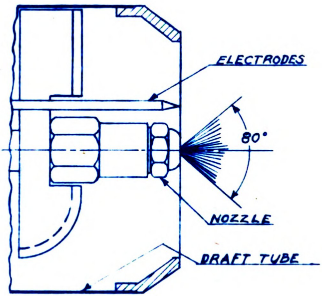


View of Apparatus, Tests #1 - #19
Fig. 1



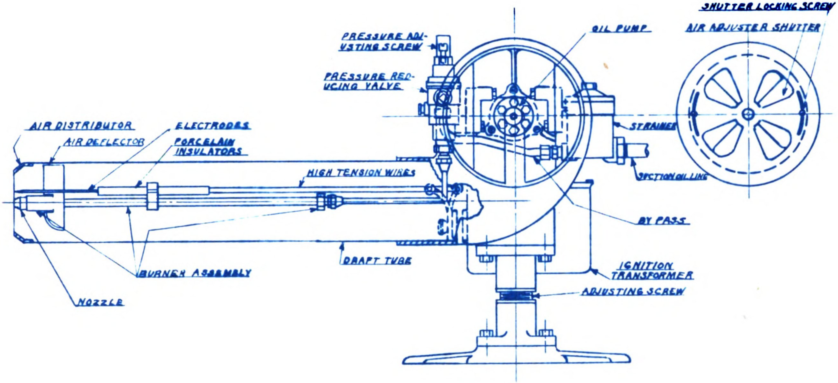
Cross Section of Furnace, Tests #1 - #19

Fig. 2



Nozzle End of Burner

Fig. 3



Model D Burner
Sectional View

Fig. 4

MW Model D Burner

Fig. 5

inch. Lighter oils require less pressure and heavier oils more.

Due to the limited capacity range, it is necessary to operate these burners intermittently. This introduces stakk losses which are the main drawback of this type. However, this loss is not as great as that caused by varying combustion rates in other types. In these tests the burner was operated without automatic controls, and was run continuously during a test, since results with intermittent operation would be almost meaningless.

Fuel was supplied from a 5 gallon tank, resting on the platform of a scale so that the total weight of oil and tank could be obtained at any time. The oil flow was computed from the difference in weights for a definite period of time. The oil was supplied to the burner through copper tubing.

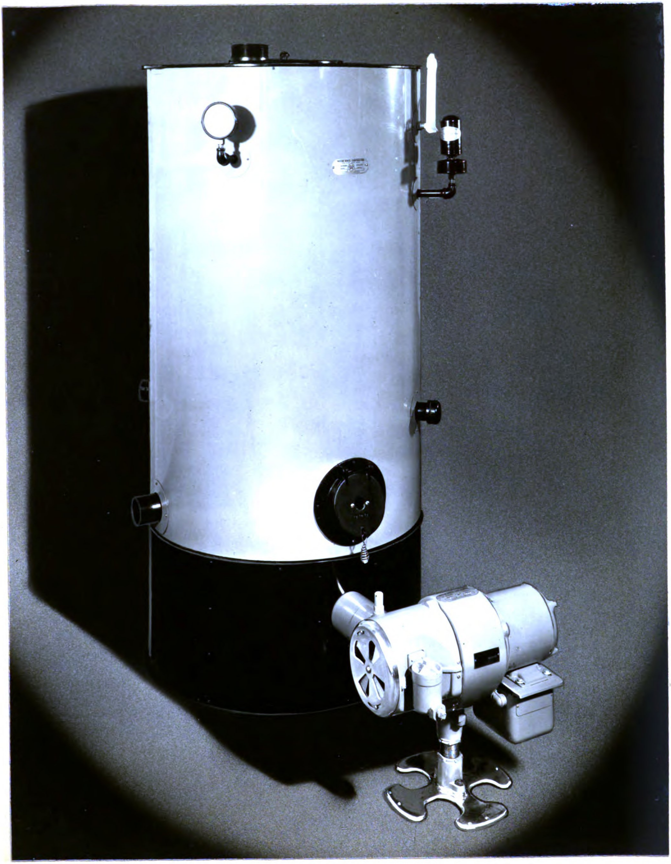
Other accessories were a stepladder, used when looking through the window in the top of the combustion chamber, and a travelling chain hoist. The hoist was of value in experimenting with shapes and sizes of combustion chambers, since by removing the window and hooking the hoist to the heat chamber through this hole, the chamber could be easily lifted off and moved to one side. In doing this it was of course necessary to uncouple the flue pipe connection and remove the thermometer and tubing inserted in it. The combustion chamber could then be easily torn up and replaced. After the replacement, the heat chamber was again lowered in place and connections made. Cracks were covered with furnace cement.

In tests #A1 to #A3 an experimental burner of smaller capacity (2 gallons per hour) was used. Since in operation it was exactly the same as the Model D described above, and differed only in having some smaller or less expensive parts, it will not be described.

B. Tests #B1 to #B3, inclusive

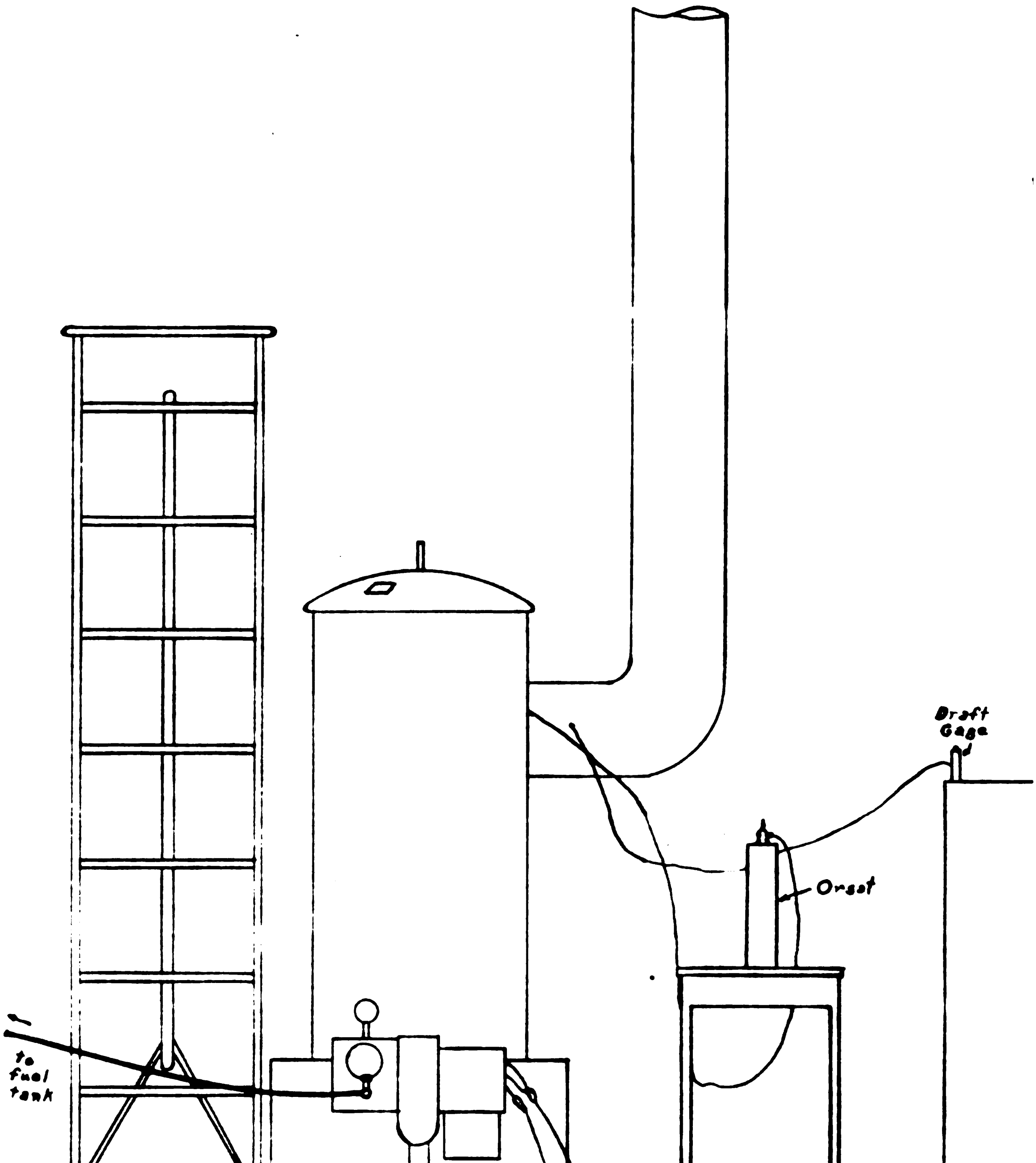
The same equipment was used in these tests, except that a hole about 1 inch in diameter was cut in the back of the heat chamber about 20 inches from the bottom. A piece of ½ inch iron pipe about 5 feet long was bent so that when the end was inserted through the hole in the back of the heat chamber all points in the combustion could be reached with it. The other end extended far enough from the furnace so that it did not get much above room temperature.

A chromel-alumel thermocouple of No. 20 wire, protected with porcelain insulation, was run through the pipe. The hot junction or weld was allowed to protrude about ½ inch beyond the end of the pipe. True temperatures could not be obtained if this was not done, since the iron pipe remained slightly cooler than the surrounding medium. The connection with the lead wires was made near the outer end of the pipe, and was protected from radiated heat by a sheet metal shield placed on the pipe. A direct reading Brown potentiometer was used in these tests.

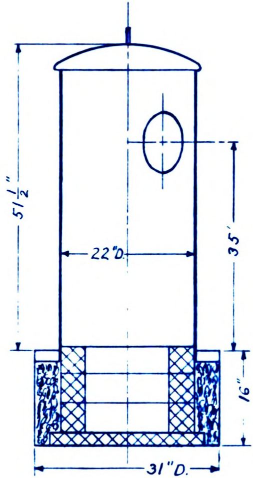


MW Burner and Boiler

Fig. 6

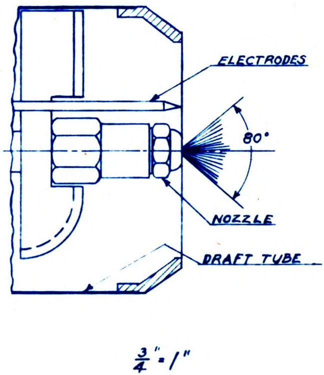


View of Apparatus, Tests #1 - #19
Fig. 1



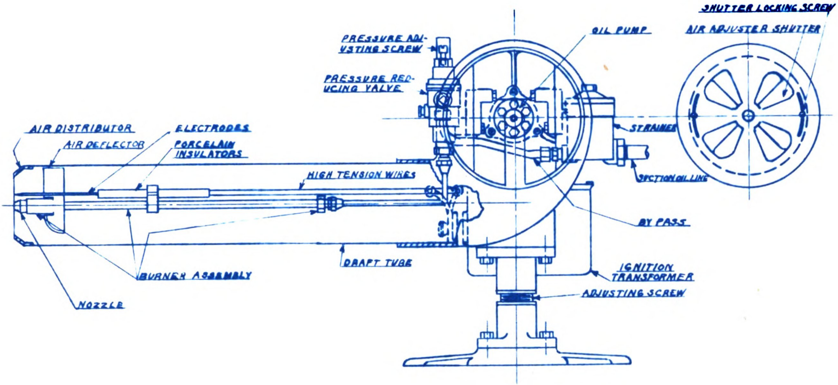
Cross Section of Furnace, Tests #1 - #19

Fig. 2



Nozzle End of Burner

Fig. 3



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Fuel was supplied from a 5 gallon tank, resting on the platform of a scale so that the total weight of oil and tank could be obtained at any time. The oil flow was computed from the difference in weights for a definite period of time. The oil was supplied to the burner through copper tubing.

Other accessories were a stepladder, used when looking through the window in the top of the combustion chamber, and a travelling chain hoist. The hoist was of value in experimenting with shapes and sizes of combustion chambers, since by removing the window and hooking the hoist to the heat chamber through this hole, the chamber could be easily lifted off and moved to one side. In doing this it was of course necessary to uncouple the flue pipe connection and remove the thermometer and tubing inserted in it. The combustion chamber could then be easily torn up and replaced. After the replacement, the heat chamber was again lowered in place and connections made. Cracks were covered with furnace cement.

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B. Tests #B1 to #B3, inclusive

The same equipment was used in these tests, except that a hole about 1 inch in diameter was cut in the back of the heat chamber about 20 inches from the bottom. A piece of ¼ inch iron pipe about 5 feet long was bent so that when the end was inserted through the hole in the back of the heat chamber all points in the combustion could be reached with it. The other end extended far enough from the furnace so that it did not get much above room temperature.

A chromel-alumel thermocouple of No. 20 wire, protected with porcelain insulation, was run through the pipe. The hot junction or weld was allowed to protrude about ¼ inch beyond the end of the pipe. True temperatures could not be obtained if this was not done, since the iron pipe remained slightly cooler than the surrounding medium. The connection with the lead wires was made near the outer end of the pipe, and was protected from radiated heat by a sheet metal shield placed on the pipe. A direct reading Brown potentiometer was used in these tests.

C. Tests #C1 to #C6, inclusive
In these tests the Motor Wheel Model D burner was used with their Model 800 boiler. The 10 x 14½ inch insulating brick combustion chamber was used, in the standard 3 inch brick depth (13¾ inches). The setting is shown in Figs. 5 and 6.

Two different flue pipe arrangements were used, one as simple as possible and one very complicated. They are shown on the data sheets for Tests #C1 and C 5. A balanced damper was used in both arrangements. One elbow was used in the first, and three in the second.

Auxiliary apparatus included scales for measuring the oil flow rate, an Orsat flue gas analyzer, an Ellison draft gauge, and a high temperature thermometer for measuring the temperature of the flue gases.

D. Tests #D1 and #D1a, inclusive
The apparatus and accessories used in Tests #1 to #A3 were also used for this series. The hole in the back of the heat chamber was sealed with a mica window, through which the height of the flame and the action of the nozzle could be observed.

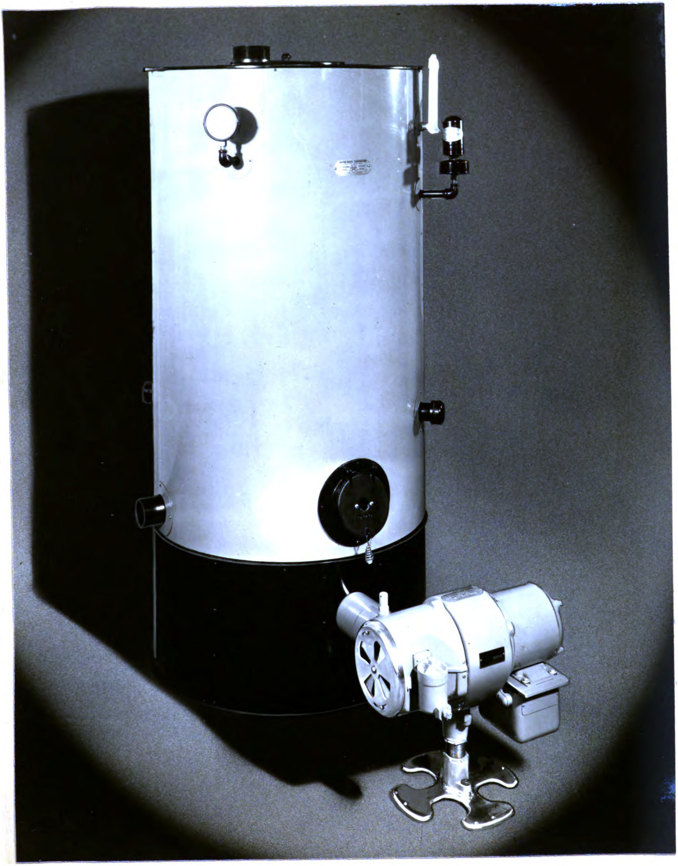
These tests were made to compare the nozzle then in use (Wilson 80 degree) with the Benjamin Air Rifle nozzles in various angles. It was decided to change to the Benjamin Air Rifle 60 degree nozzle, since it gave nearly as high efficiency and was much less expensive, it being thought that low first cost was more important to buyers of oil burners than very slight savings in fuel consumption.

E. Tests #E1 to #E3, inclusive
The apparatus used in the previous temperature measurements (Tests #B1 to #B3) was used for these tests, except that a platinum-platinum-rhodium thermocouple was used in place of the Chromel-Alumel, in conjunction with a Leeds and Northrop potentiometer reading in millivolts. The protecting pipe, instead of being held in place by hand, was held by wires so that it would not move while the potentiometer was being balanced. In the B series of tests the thermocouple was held against the wall of the combustion chamber, but in this series readings were taken at certain points in the flame itself, necessitating the more rigid means of support.

II. MATERIALS

A. Fuel Oil
The oil used in all tests was No. 3 fuel oil.* Two different lots were used. The first, used in Tests #1 to #C2 inclusive, had a specific gravity of .8593 and a Baume

*See Table, "Commercial Fuel Oil Specifications".



MW Burner and Boiler

Fig. 6

gravity (A.P.I.) of 33.2. One gallon weighed 7.164 pounds at 60 degrees F. The second lot, used in Tests #C3 through #E3, had a specific gravity of .8550 and a Baume gravity (A.P.I.) of 34.0. A gallon weighed 7.128 pounds at 60 degrees F. The specific gravity was obtained by accurately weighting a sample, the volume of which at 60 degrees F. was exactly known. This gravity was checked by a hydrometer reading.

The oil used was considered to be representative of No. 3 fuel oil and in general of the type of oil most commonly used in gun type burners. Except for the slight difference in gravity, the two lots of oil were practically identical.

The 1929 report of the A. S. M. E. Special Research Committee on Diesel Fuel Oil Specifications gives the following approximate formula for the higher heating value of fuel oils, in B.t.u.'s per pound;
H= 17680 plus 60 x degree Baume
This formula gives the heating value of the first lot of oil as 19672 B.T.u. per pound and that of the second lot as 19720.

B. Refractory Materials
The combustion chamber used in Test #1 was built of ordinary refractory brick, about 2½ inches thick. It was not considered necessary to rebuild this shape out of insulating brick, first, because, except for the warming period (½ to ¾ of an hour), refractory brick backed by insulation was found to remain nearly as hot as insulating brick, and secondly, because the shape used in this test was so poor that it was not worth further testing.

In Tests #2 through #16 either Johns-Manville, Sil-o-cel or Babcock and Wilcox white insulating brick were used. The former were not recommended for more than 2500 degree F., by the manufacturer, and did not stand up well when the oil flow was in the vicinity of 4 gallons per hour, especially if much excess air was used.

In Tests #17 through #19 the shape used was molded in a metal basket or container. The material used was a mixture of Firecrete and a granular mineral insulating material such as is sometimes used in insulating furnaces. It proved to have insulating qualities at least as high as the insulating brick used in other tests. The shape of this chamber is shown in Fig. 13. It will be noted that it is very shallow. This was done with the view in mind of making a combustion chamber that could be sold with the burner and slid into the ashpit of almost any furnace. It was found to be impractical for an oil consumption of more than 2 1/3 gallons per hour, unless bricks were laid on top so as to increase the height.

All the remaining chambers were built of insulating brick, it having been decided to make this construction standard until molded sectional chambers of semi-insulating material were put in production.

TEST PROCEDURE

A. Tests #1 to #16, inclusive

When the apparatus used in these tests* had been set up and all arrangements made, it was next necessary to decide on the shapes to be tested. To form a basis for comparison it was decided to first try the shape then recommended by the Motor Wheel Corp., shown in Fig. 8. One of these was obtained already built. It was set into the base and the draft tube of the burner inserted in the opening left for it. The spaces around the tube were cemented with refractory cement and the space between the chamber and the shell of the base filled with rock wool. The heat chamber was then set in place on the base and connected with the stack. The thermometer, draft tube and Orsat tube were inserted into the flue pipe between the balance damper and the heat chamber. All cracks and crevices were then cemented so that no air could leak in and cause inaccurate results.

The burner was then started and adjusted so that the flame was centered in the combustion chamber and symmetrical. The oil flow was measured and kept constant by weighing, the oil and tank about every 15 minutes, making slight pressure adjustments to keep the flow constant. This was done because changes in atomization pressure had less effect on the accuracy of the results than changes in the flow, which were sure to occur if the burner was run longer than one hour without cleaning the nozzle screen. This was because a very small screen was used. The latest models of nozzles have much larger screens, and are relatively free from this trouble.

When the combustion chamber had reached its normal operating temperature, the air adjustment was made. In Tests #1 to # 9, inclusive, no particular rule for making the adjustment was followed, as it was desired to observe the effects of various amounts of excess air on the combustion of the oil. In most of these tests, however, and in all tests from #10 through #16, at least one setting was just below the smoke line** so as to furnish a basis for comparison and also approximate the best field conditions. In case the smoke line could not be reached by closing the shutters, the adjustment obtained with the shutters closed was used instead, as the cracks through which the air was leaking are infrequently cemented in practice, and it was of course desirable to simulate actual conditions.

Readings were then taken and recorded as shown on the data sheets (*post*   ). The sketches of the flame were

*see p.7

**The smoke line is the division between invisibility of the stack gases and visability due to the presence of smoke.

made from observation through the window in the top of the heat chamber.

This procedure was the same for each test in this series, except that after Test #9 the air adjustment was in all cases just below the smoke line.

The combustion chambers tested were designed as improvements on preceeding ones. They were built of high temperature insulating brick, using a templet to insure the accuracy of the shape.

B. Tests #17 to # 19, inclusive
These tests were conducted in the same manner, except that the combustion chamber was built very differently. As mentioned in the description of Apparatus and Materials, this chamber was cast or molded in a sheet metal basket. Due to the low cost of the basket and to the ruggedness and strength added to the chamber by it, it was decided to leave it on the chamber, and this was accordingly done. A wood pattern was used for the inside shape. It was found that the pattern must be perfectly waterproof or it will swell due to the absorbing of moisture so that it cannot be removed for at least a week without destroying it. A material which is unaffected by moisture would be best for this use. The pattern was held in place with supports nailed to the top and resting on the basket. A round tube was also supported in the basket in such a way as to make a hole through which the draft tube of the burner could be inserted. The material was then mixed and poured. When dry, the form was removed and the chamber was ready for use. Very little cracking occured when the chamber was subjected to heat for the first time.

C. Tests #A1 to #A3, inclusive
These tests were conducted in the same manner as previous tests but with a different burner. This burner was exactly the same in operation as the Model D, but had a capacity of 2 gallons instead of 4. Since it cost very nearly as much to make, it was not adopted.

D. Tests #B1 to #B3, inclusive
The same furnace was used for these tests. The 10 x 14½ inch insulating brick combustion chamber, which had tentatively been adopted as standard, was used. A 1 inch hole was cut in the back of the heat chamber about 20 inches from the bottom. The thermocouple was threaded through the 5 foot curved pipe and connected through the lead wires with the potentiometer.

The burner was started and the oil flow measured and kept constant as before. A Wilson 3.A.8 nozzle was used in the first test of the series, and gave an oil flow of 1.06 gallons per hour at approximately 100 pounds per square inch pressure. The air inlet shutters were closed, since the smoke line could not be reached. The draft at the flue was maintained at .05 inches of water. When the combustion chamber had reached its normal operating temperature, CO_2 readings were taken. The thermocouple was then inserted and temperature readings taken at the surface of each wall of the chamber, at three levels, one through the centers of the lower tier of bricks, one through the centers of the middle tier, and one through the centers of the top. This included one reading made right at the nozzle tip. The thermocouple junction was also moved around in the flame until the hottest point was discovered and this temperature recorded.

This procedure was repeated in the succeeding tests of the series. In Test #B3 the smoke line could be reached and therefore the adjustment was made so that the burner operated just below the smoke line.

E. Tests #C1 to #C6, inclusive

For these tests a 10 x 14½ inch brick combustion chamber was built under a Motor Wheel Model 800 boiler. A Model D burner was installed, the chamber surrounded with rock wool insulation, and the opening in the boiler jacket closed and sealed. The boiler was connected with a stack 10 inches in diameter through a horizontal flue pipe. (see Fig. 14). Only one elbow was used. The flue pipe was equipped with a balance damper and had holes near the furnace end for the thermometer, draft tube and Orsat tube, which were inserted. All cracks and holes through which air could enter were sealed with cement. The valve which allowed water to circulate through the boiler was opened and the burner started. The oil flow was measured and kept constant as in previous tests. It was decided that, since this series of tests was run in part to determine whether a complicated flue pipe and stack connection could cause poor operation even with a good draft, it would be advisable to try various drafts in each test. This was not done in the first test, however, as trouble had never been experienced with this combination. Consequently, the balance damper was set to give .035 draft and left there. The amount of excess air was cut down till the smoke line was reached, then increased till smoke was no longer visable. The burner was then shut off and the furnace allowed to cool till the stack temperature had fallen below 150 degrees F. It was then restarted and the top of the stack watched for smoke. If smoke was observed for more than 30 seconds after starting, the air adjustment shutters were opened slightly and the procedure repeated, till within this limit. When this adjustment was obtained, readings were taken as shown on the data sheets.

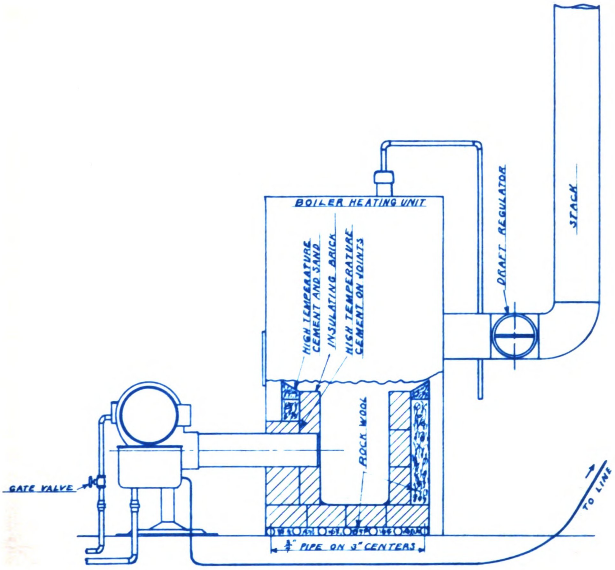
The procedure was the same in Tests #2, #3 and #4, except that various drafts were tried.

For Tests #5 and #6, the simple flue connection used previously was replaced by a very complicated one having three elbows (see Fig. 15). The tests were conducted in the same manner. In Tests #1 to #4, inclusive, Wilson 80 degree nozzles in sizes AA, E, F, and G were used. In Tests #5 and #6 AA and G nozzles were used.

F. Tests #D1 and #D1a
These tests were conducted for the purpose of determining whether Benjamin nozzles could be substituted for the Wilson 80 degree nozzles previously used with the new combustion chamber shape. It was known from past experience that Benjamin 80 degree nozzles did not give the same shape of flame as Wilson 80 degree nozzles, so it was decided to test a number of Benjamin nozzles covering a wide range of spray angles. The special furnace used previously in Tests #1 through #B3 was used in these tests also. A mica window was cemented over the hole which had been cut in the back to allow the taking of temperature measurements. The 10 by 14½ inch insulating brick combustion chamber was again used, as it was thought to be the best developed regardless of the nozzle used.

To obtain the accuracy necessary for comparison, the air inlet shutters were adjusted till the burner was operating exactly on the smoke line. To allow of making this adjustment with the shutters it was necessary to make all other cracks and openings ahead of the fan air tight with cement. In Test #D1 eight Benjamin nozzles were tested, all of 2 gallon capacity and covering a range of spray angles from 45 degrees to 90 degrees. Data was taken as shown on the data sheet, .

As a result of Test #D1 it was decided that the best nozzle was between 60 degrees and 70 degrees. Test #D1a was run to get a more accurate comparison of the 60, 65 and 70 degree nozzles and to compare their performance, with Wilson 80 degree nozzles of the same capacity. It was thought that the discrepancies in the first test were due at least in part to varying oil flow, which of course changes the air-fuel ratio and makes a considerable change in the CO_2 readings. In Test #D1a, therefore, the oil flow was measured at the time the air adjustment was made, using 100 pounds per square inch oil pressure. This flow was maintained throughout the run for each nozzle. Data was taken as shown on p.*D1a*. The draft was maintained then at .05 inches of water as before. Great care was used to insure accuracy, as it was realized that the results would probably be very close, and if inaccurate, could be misleading.



Burner Installation in Boiler

Fig. 7

G. Tests #E1 to #E3, inclusive

For these tests the window was removed from the hole in the back of the special furnace used in the previous test. The 10 by 14½ inch combustion chamber was used with the Model D burner and Wilson 80 degree nozzles in three different sizes. A platinum-platinum rhodium thermocouple with the necessary leads was obtained, and also a Leeds and Northrup balancing type potentiometer reading in millivolts. The thermocouple was threaded through the protective pipe and allowed to project about ¼ of an inch as before. The burner was then started and, when the furnace had come up to heat, the thermocouple was inserted and supported by a vertical wire attached to the outer end of the pipe. This wire was adjusted till the hot junction of the couple was in the same horizontal plane as the nozzle. The pipe was then moved in or out and the horizontal wires attached to the pipe adjusted so that the junction was on a line from the nozzle to the middle of the back and at the correct distance from the nozzle for the reading. The correct distance from the nozzle was obtained by lowering a small piece of metal, cut to the desired length, on a stiff wire through the removable window in the top of the chamber. This was used as a guide in makin g the adjustment, and was removed and the window replaced before taking the readings.

The air adjustment used was that which was considered representative of field practice, and consequently the CO_2 readings are a trifle low as compared with previous tests.

A different nozzle was used for each test, and for each nozzle readings were taken at every inch from the nozzle to the back of the chamber (10 inches, as the nozzle was set flush with the front wall). Other data was taken as shown on the data sheets. In Test #E3 great difficulty was encountered due to the intense heat. The first protective pipe was so badly burned that another one had to be made to take its place. Also, observation was difficult due to the density of the flame. For this reason some of the positions at which readings were taken in the preceding two tests were omitted in Test #E3.

DISCUSSION OF RESULTS

A. Tests #1 to #16, inclusive

It may seem odd to the reader that in all these tests only one height was used, that of 3 bricks or 13¾ inches. This was done for the sake of expediency. If the height had been varied comparisons of any sort would have been made very difficult. The height chosen was the highest that it is generally practical to use, due to limitations in furnace dimensions.

In Tests #1 and #2 one of the shapes recommended by the Motor Wheel Corporation previous to 1935 was tried. It was not the object to test this chamber ever a wide range of capacities, but merely to learn specifically how it performed under a very small oil flow, this being considered the main weakness of this design. As is shown by the results, the performance was very poor. In Test #1 a 60 degree Wilson nozzle was used in place of the regular 80 degree nozzle to determine whether the narrower spray would better fit this chamber. It was found to be about as good (or rather as bad) as the 80 degree spray. An 80 degree spray with a large amount of excess air (Test #2) gave even poorer efficiencies, although of course the combustion was much cleaner. In both cases the air-vapor mixture did not receive a sufficient amount of heat before leaving the combustion chamber to give anything approaching satisfactory combustion.

It was apparent that one of the main faults of the first chamber was too large an horizontal area. The chamber could not be narrowed very much without crowding the flame, a condition that causes poor combustion. It was therefore decided to try a shorter shape. Accordingly, the shape shown in Fig. 9 was designed, built and tested.

This chamber of course had a smaller volume, and it was feared that it might not be able to handle a very large quantity of oil. It was therefore tested for oil flows from 2.86 gallons per hour to 4.12. Although for the larger flows most of the combustion took place above the combustion chamber, combustion was efficient nevertheless. This was possible only because very little heat was being removed through the heat chamber. In a regular heating furnace the flame cannot burn more than a foot above the combustion chamber without giving materially reduced efficiencies. The maximum capacity of this chamber may therefore be set at about 3½ gallons per hour. Test #5 shows that the chamber remained hot enough to support combustion even with a large amount of excess air being blown through. The volume of the chamber was still much too great to give high efficiencies with an oil consumption of only 1 gallon.

For the next test it was decided to try shortening the chamber even more. The chamber shown in Fig.10 was then evolved and tried out in Tests #6 through #9. This chamber was tested through the entire range of capacities and handled the entire range from 1 to 3¼ gallons very efficiently. For the range from 3¼ to 4¼ gallons it is recommended that, if the height cannot be increased, the length and width both be increased by 2 inches, making the chamber 12 by 16½ inches.

The increased efficiencies obtained with this shape are attributable to several facts:
1. The gases are allowed to expand without restriction. This allows the mixture of the oil and air to take place properly and gives a softer flame, that is, one which does not appear to be concentrated in certain areas.
2. The nearness of the back wall causes the oil-air mixture to be brought up to the ignition temperature more quickly. This, according to W. A. Bone, whose theory of hydroxylation* is now widely accepted, is the most favorable for the combustion of the heavier hydrocarbons, which crack easily.
3. The flame is divided by the back wall and is made to double back on itself in order to escape from the chamber. Friction with the outcoming gases tends to reverse their direction again, thus causing the flame to spiral. This materially reduces the speed of travel through the combustion space, permitting combustion to be more nearly completed before reaching the cold heat absorbing surfaces above.

Test #9 represents the first comparison of the 80 degree nozzle manufactured by the Benjamin Air Rifle Company with the 80 degree Wilson nozzle then standard on the M W Model D burner. It was found to give poorer results under the conditions of the test.

It having been suggested that the best flame shape would be one which doubled in on itself instead of outward, it was decided to investigate this idea. It was thought that the shape shown in Fig. 11 might give this action, and it was accordingly built and tried (Tests #10 to #12, inclusive). Instead of performing as expected, the flame held to nearly the same shape as in the 10 x 14½ inch chamber used in the preceding tests, except that it was of course about 2 inches narrower. The flame could not be made to travel very far into the vertex opposite the nozzle except when a large amount of oil was being burned, showing that it is natural for a flame to diverge rather than to converge. Notwithstanding, the results obtained were quite good for moderate rates of oil consumption. This was due to the reduced horizontal area of the chamber.

However, as the desired action was not obtained, another chamber was designed. It is shown in Fig. 12. This chamber did cause the flame to perform in the suggested manner, in that it made the flame turn in and double back on itself. A number of desirable features had to be sacrificed to obtain this action, however. The main fault was that the included angle of the nozzle end of the chamber was much too small, as shown by the fact that carbon deposits formed on the side walls about 3½ inches out from the burner. This carbon deposit was made while operating on an oil flow of 2.72 gallons per hour. None was formed when operating on a flow of 1.76 gallons per hour. This means the upper limit for the chamber would have to be set at about 2 gallons. Another very bad result of this narrowness is that the cold oil which strikes the walls breaks down, and the part which is not deposited as hard carbon or soot burns very smokily and inefficiently, requiring more excess air to be admitted than would be used with proper combustion.

The turning of the flame inward and then back toward the middle no doubt helps the efficiency, since it retards the travel of the gases and burning vapor, and helps somewhat to bring the fuel-air vapor up to good combustion temperature. From the appearance of the flame and the results obtained, however, the outward spiraling motion given by the 10 x 14½ inch chamber previously tested evidently performs these functions more effectively.

Tests #15 and # 16 were made chiefly to see whether the carbon deposit would burn off if the oil flow were reduced. It was found that it would not.

B. Tests #17 to #19, inclusive

A good design should include among its features ease of manufacture and ease of installation. In Tests #17 through #19 a chamber was tested which, it was hoped, would make it possible to equip the oil burner with a combustion chamber at the factory that could be easily shipped and fitted into the ashpit of practically any furnace. It was realized that if this were to be done the chamber would have to be very shallow and also somewhat narrower, making it doubtful that satisfactory performance could be obtained. The shape used is shown in Fig. 13.

The maximum capacity was found to be about 2 1/3 gallons per hour, at which capacity the flame trails would extend about 1¼ feet above the top of the combustion chamber, This maximum capacity will vary somewhat according to how far the flame may be allowed to extend above the chamber. 1¼ feet was taken as being about average height allowable for hot air furnaces and boilers. This is equivalent to 26 inches from the base or supports on which the combustion chamber is laid to the highest point reached by the undeflected flame. CO_2 readings were about 1½ points lower than with the 10 x 14½ inch chamber for the same range.

It was found that if a row of brick was added around the top of the chamber, performance was materially improved. The effect was the same as making the chamber full depth, but a good deal less labor was used than in building one of brick full depth.

Since this chamber was molded, a sloping bottom was also tried, the theory being that since it had been found best to have the side walls at the nozzle end follow the shape of the spray, better performance could be obtained by making the bottom that way also. This theory was disproved. The flame has a natural tendency to rise, and anything that crowds it from below causes it to change from the horizontal to the vertical direction more quickly, thereby reducing the time spent in the chamber and consequently the efficiency of combustion. A flat bottom, which is less expensive to make, gives better performance. It would probably be best if the space below the spray were partially but not completely filled.

C. Tests #A1 to #A3, inclusive
These tests show the great similarity between all "gun" or "pressure" type domestic oil burners.

D. Tests #B1 to #B3, inclusive
After some of the preceding tests a certain brand of temporary refractory cement used to build the chambers was observed to have fused in some places and run down the walls. Corners on some of the Sil-o-cel bricks had been removed by the molten cement. Although it was not known at what temperature this cement would melt, it was feared that the temperature was too high for the insulating brick used in the walls. Refractory brick could of course have been substituted, but for the reasons given in the section on "Apparatus and Materials" it was desired to use the insulating brick for all capacities if possible.

It was found by experimentation with the apparatus used in these tests that the oil flow rate, made practically no difference in the temperatures from 2 gallons per hour up to the maximum capacity. Tests were therefore made over the range from 1 to 2½ gallons only, as above this results were all much the same and were very difficult to obtain, due to the density of the flame and the quantity of heat produced. It was also discovered that the chamber was liable to be damaged if too much excess air were used with large oil flows, as the temperatures in the chamber might then be increased to as high as 2800 Degrees F. or more.

The temperature readings showed several things:
1. With proper adjustment the maximum temperature on the walls is about 2300 degrees F.
2. Although the flame is pushed rather close to the nozzle with this shape, the nozzle is not overheated. A piece of paper on the adaptor (next to the nozzle) was found to have gone through about 30 hours of operation without being burned or charred.
3. The coolest point is that where the oil enters and

the hottest that where the flame leaves the chamber.

E. Tests #C1 to #C6, inclusive
This series was run to determine whether irregularities in the stack and flue were connected with puffing and pulsating, which sometimes occurs on starting and stopping when the nozzle size is large relative to the capacity of the furnace or boiler. Another object was to determine whether the new standard shape (10 x 14½) reduced or obviated this objection.

As regards the first question it was found that a stack complicated by elbows, long horizontal sections, declining sections, etc., while it may furnish a good draft after the furnace has been running awhile, or when not in operation, usually builds up a rather high back pressure when suddenly called upon to carry away the full flow of stack gas, such as happens when an intermittant oil burner starts after a long period of idleness. A simple direct stack of the same height and diameter will develop much less back pressure and is able to handle the load more quickly, thus eliminating to a large degree the puffing and pulsating. Insertion of an elbow or horizontal section is equivalent to reducing the diameter of the flue or stack.

It is desirable that the stack have suffieient capacity when cold to carry off the volume of gas produced by normal combustion.

The size and shape of the chamber appear to have little effect on puffing and pulsating when starting. They do affect the tendency to "flutter", however. "Flutter"is due to bad combustion. Since the new shape gives much better combustion, the tendency to flutter is greatly reduced. In fact, it was found that as soon as the stack temperature had climbed to within 100 degrees or so of its normal operating level, the air could be closed down until the fire was nearly smothered without causing any flutter. Likewise, large amounts of excess air could be admitted without flutter.

F. Tests #D1 and #D1a
These tests bring out the fact that two nozzles having exactly the same rating and spray angle may perform very differently. This is due largely to the fact that there is no exact standard on which to base the ratings. The essential parts of a nozzle are the swirling chamber and the orifice. The oil passes through tangential slots into the swirling chamber where it travels spirally to the orifice, from which it enters the combustion space. The viscosity of the oil and the pressure on it affect greatly the speed at which it swirls. The centrifugal force which atomizes the oil and determines the spray angle is imparted by the swirling, and it is readily apparent that

the spray angle and degree of atomization are dependant on the viscosity of the oil and the pressure on it.

G. Tests #E1 to #E3, inclusive

These tests make the data on operating temperatures in the standard 10 x 14½ inch insulating brick chamber more complete. One of the most interesting facts revealed is that the fuel-air mixture reaches very nearly full temperature in the first inch of travel. No flame can be seen closer than about 2 inches from the burner, apparently indicating that a short time elapses before combustion becomes visable after the combustion temperature is reached.

Another point brought out is that under normal operation the insulating brick walls average only 100 to 250 degrees F. lower in temperature than the flame itself. High temperature walls ignite the incoming fuel-air mixture more quickly and show that little heat is being lost through them.

CONCLUSIONS

The factors that influence the design of combustion chambers for the gun type oil burner are countless. There are a few, however, which are much more important than the others, and these will be discussed here.

I. SIZE

In the past practically all combustion chambers for the burning of atomized oil were designed on the theory that size would make up for poor design, and this is also true of the majority of modern designs. The reason for the continuation of this practice is that the theory is partly true. It is true in that if a furnace manufacturer builds a combustion chamber for a gun type oil burner and finds that it gives unsatisfactory combustion, he may get what is at present considered satisfactory combustion simply by increasing the dimensions of the chamber. The principle drawbacks of this system of designing are the increased cost of the chamber due to the greater amount of material, labor and space required, greater combustion noise, and lower combustion efficiency, which means increased fuel costs.

The best size of combustion chamber is that which will contain from 80 to 100 % of the flame, depending on whether the space above the chamber is free or filled with cold surfaces, and the temperature of surrounding surfaces which absorb heat by radiation. In a modern hot water or steam boiler setting there is frequently very little combustion space between the top of the combustion chamber and the crown sheet or header, and since it is a well known principle that a vaporous fuel does not burn well if not surrounded by surfaces at the proper combustion temperature of the fuel, it follows that the flame in this type of boiler must be kept below the crown sheet. This means that in most cases the flame must be almost wholly within the combustion chamber, and imposes a very definite limit on the capacity of the boiler. This applies particularly to boilers designed for oil burners, which are usually made with low crown sheets, to obtain a longer passage for the hot gases without increasing outside dimensions of the boiler. Converted coal boilers, especially those designed for hard coal, have on the other hand a rather large combustion space above the combustion chamber, which is placed in the ashpit, and in these greatest efficiency will usually be obtained by burning 10 to 20 % more oil than will burn in the combustion chamber, unless the boiler is equipped with water walls.

Horizontal hot water and steam boilers usually have ample combustion space, as do also warm air furnaces, and best results will usually be obtained by using 5 to 20% more oil than will burn in the combustion chamber.

If the combustion chamber is the right shape as well as the right size, the chamber should appear from above to be full of flame except for a space not less than 1½ inches wide in front of the nozzle.

Improper design means that the combustion chamber will have to be made larger to handle a given oil flow than would be necessary with correct design. This means more brick or similar material to buy, more labor to set it up, lower capacity due to the fact that the space provided for the combustion chamber is in most furnaces very restricted, and reduced furnace efficiency, which makes higher fuel bills for the owner.

It is desirable at this point to mention the difference between combustion chambers built of refractory material and those built of insulating material. Where a continuous fire is held, and the lining of the combustion chamber or firebox is backed with insulating material to prevent loss of heat, a refractory brick lining is quite satisfactory, especially as it is much cheaper, refractory brick and shapes usually being molded of a special clay in the usual way, whereas insulating bricks and shapes are either mined or quarried from limited sources, or are manufactured by a rather intricate process. But where operation is intermittant, as with the gun type oil burner, it is very desirable to have the combustion chamber cool as slowly as possible, and come up to heat as quickly as possible after starting. Insulating brick should therefore be used. The main difficulty at presant in the use of insulating material is that it must be cut to shape, and cannot be molded, making any except rectangular shapes expensive and difficult to obtain. Another disadvantage, a minor one in most cases, is the relative weakness of insulating as compared with refractory brick, which is offset by the ease and accuracy with which they may be cut to special shapes.

Where large combustion chambers are used, the most satisfactory ones are built of brick. Combustion chambers used with domestic oil burners are usally small, however, and difficulty is often experienced in building them out of brick in the desired shape. A compromise must usually be made. At present, to the author's knowledge, there is no molded combustion chamber on the market made of insulating material, but there are several made of refractory material. This means that the users of these chambers believe the advantages of the molded shapes are greater than the advantages derived from the use of insulating material. This point is at present controversial, and must be decided by research and experience.

II. SHAPE

There is no one combustion chamber shape that is best for all gun burners, for all types of nozzles, or for all furnaces. Since the number of shapes must necessarily be limited, each manufacturer, dealer or contractor who furnishes complete heating units must decide on a few shapes and sizes which will be most satisfactory.

HEIGHT

The factors to be considered in determining the inside height of the chamber are, in order of their importance, as follows:

1. The amount of noise permissible. Where noise is not objectionable, as in boiler plants, it is found that the highest efficiency is obtained by having the flame enclosed for a considerable distance by incandescant brick. By having the burning oil thus enclosed until combustion is completed, the heat is retained in the flame and causes combustion to take place at the maximum rate. This high rate of combustion is highly desirable, especially when burning the heavier fuel oils. The most widely accepted reason for this fact is the theory of hydroxylation. According to this theory, the quicker the hydrocarbons are transformed into the products of combustion, the less chance there will be for the oil to "crack" into carbon and hydrogen with accompanying absorption of heat and incomplete combustion.

But in domestic installations noisy combustion is usually very objectionable, as it has an irritating effect on the nerves. For this reason it has been found best to make the height for this class of installation, which is the normal field of the gun type burner, equal to the greatest horizontal dimension. The reason that the reduction in height or length decreases the noise is that the combustion of the oil takes place in a series of violent fluctuations which might almost be considered separate explosions. Each of these fluctuations generates a low pitched booming, ordinarily called "rumble", or combustion noise. A high or long combustion chamber accentuates the noise much the same as a long organ pipe would. Conversely, a low or short one keeps the noise to a minimum. It must be remembered, however, that while height is an important factor in the control of combustion noise, it is not the only one.

2. Efficiency. As high an efficiency as is possible without sacrificing too many other valuable features is of course to be desired, since it means lower fuel bills. As mentioned previously, greatest efficiency is obtained by having the flame entirely enclosed with incandescent insulating material for nearly the full length of its travel. This length depends mainly on the kind of oil being burned. Light oils such as kerosene or distillate burn very close to the nozzle, while heavy, viscous oils travel much farther before being completely burned. The trend is toward the use of heavier oils in domestic burners, due to its lower cost, and for this reason it may become necessary to install longer or higher combustion chambers and to insulate the furnaces against sound as well as heat transfer. A high degree of sound proofing might be attained simply by enclosing the flue pipe with sound absorbing material and avoiding the use of open draft regulators and dampers. This could be done at small expense.

3. Space limitations. The space allowed for the combustion chambers is sometimes so small that a sufficient length of enclosed flame travel can only be obtained by keeping the oil flow very low or by special means. One of these special ways is to incline the burner so that the flame starts downward, reverses direction and comes back up before leaving the chamber. Another is to set the burner tangential to the inside perimeter of a cylindrical combustion chamber of fairly large diameter, thus causing the flame to spiral several times before leaving the chamber. The chamber shown in Fig. 10, developed in conjunction with this thesis, gives a spiraling motion. Various other means have been tried but have generally proven unsuccessful. It is best to avoid, if possible, the use of furnaces having very restricted combustion space.

4. Type of furnace. Nearly all furnaces converted from the use of hand fired coal have sufficient room for the combustion chamber of an oil burner when the grates and other unnecessary parts are removed. Furnaces designed especially for oil burners are usually more restricted, having in many cases been designed to fit closely on a combustion chamber which has been discontinued. This is especially true of vertical boilers built for oil burners. The restriction, if it exists, is usually in both horizontal and vertical dimensions, and can best be overcome by raising the boiler or lowering the floor inside it and equipping it with a fairly high combustion chamber of small section (say vertical dimension $1\frac{1}{2}$ times average horizontal dimension for No. 3 fuel oil). As mentioned before, such furnaces should be avoided if possible.

LENGTH AND WIDTH

In all combustion chambers used with the domestic gun type oil burner the oiland air enter through the front side about 4 to 10 inches above the bottom and the flame and products of combustion come out of the top. Practically all chambers are built up out of insulating or refractory brick or are molded out of refractory material. The front side is the side through which the nozzle and draft tube enter. Length is measured from front to back. The flame, if allowed to take its natural shape, is in the form of a cone, the width varying according to the nozzle spray angle, the amount of pressure on the air supply and the direction given it by the deflector vanes in the end of the draft tube. All three of these factors vary, depending on conditions of operation and upon the particular make and model of burner being used. In developing the proper shape for combustion chambers, therefore, allowance must be made for some variation.

With this in mind the author developed in the laboratories of the Heater Division of the Motor Wheel Corporation a combustion chamber which he believes to be in advance of others in use today. This design was adopted by the Motor Wheel Corporation and is at present used with their gun type oil burner. The data for tests made in its development is included in the back of this thesis.

The first step in such a development was to examine existing designs and attempt to determine what was wrong with them. The principal fault was seen by observation to be too great length and insufficient width. They were intended for narrow long flames, which are now known to be inefficient as compared to a short wide flame, as the air mixes with the oil much better and more quickly in the latter. Of the more modern designs in use the circular shape has least faults as it has no corners to allow air to escape without mixing with the oil or to spoil the shape of the flame by eddies and minor turbulences. Its shape is not the best for maximum efficiency, however.

It was later decided to mold the adopted shape (10 x 14½) in two pieces out of semi-insulating refractory material, and the shape was modified for this purpose slightly, by rounding the corners, leaving the principal dimensions unchanged, however. This chamber was not put into production in sufficient time to permit tests on samples to be shown here.

The main advantages of this shape are as follows:
1. It is designed to be specifically for 60 to 80 degree nozzles, which give best atomization with No. 3 fuel oil and other commonly used heating oils.
2. It is so shaped that the flame produced by a 60 to 80 degree nozzle, with an oil flow of from 13.6 to 29.5 gallons per hour and up, appears, when viewed from above, completely to fill the chamber except for 1½ to 3 inches in front of the nozzle. Since these chambers were made with flat bottoms, the space under the nozzle is of course not filled under any circumstances, but by comparison it was found worth while. Indeed, the main effect, so far as could be observed, was to deflect the flame upward slightly, which is undesirable as it means a higher combustion chamber must be used.
3. The flame remains in the chamber longer for a given height than with any other shape except perhaps the circular chamber previously mentioned with burner set tangentially. This can be used only with a narrow spray angle and consequently is not as efficient, due to poorer atomization. On the other hand the chamber developed in the tests described herein gives spiraling action with a wide spray angle. The principle is that the atomized oil, after thorough mixing with the air, is very quickly raised to a high temperature, then split by the close back wall and each half turned outward and then back toward the nozzle. Friction with the outcoming blast aids the spiraling thus started. Under normal conditions about one spiral is completed before the flame trails leave a combustion chamber 13¾ inch deep, but if nothing disturbs it, the spiraling will continue for 1 to 3 feet.

RATIO BETWEEN DIMENSIONS

Except for very small oil flow (less than 1 gallon per hour) and for the width at the nozzle, which must remain constant, other dimensions should be left in the same ratio for any capacity, being varied so that the volume is proportional to the amount of oil being burned.

CAPACITY OF CHAMBERS

The capacity of the chambers tested is shown by the graph on p. 38. If the lowest acceptable efficiency is made 11% CO_2, then the chamber used in Tests #3 to #5, inclusive, would have a range from 2¼ gallons per hour to the maximum capacity of the burner, 4¼ gallons. The chamber used in Tests #6-#9, which was adopted by the MW corporation, would have a range from 1 5/8 to the maximum gallons per hour. The chamber used in Tests #10 to #12 would have a range from 1 5/8 to 3¾ gallons per hour. However, as 11% CO_2 is a very high limit for low oil flows, the range can properly be extended ½ gallon lower on the chambers used in Tests #6 to #9 and #10 to #12, and ¾ gallon on the chamber used in Tests #3 to #5. Thus it is seen that each chamber can be made to cover a wide range.

To obtain better efficiency on the high end of the range (up to 4¼ gallons) a 12 x 16½ inch chamber is recommended, and for the low end (down to one gallon) an 8 x 12½ chamber would be better. For the middle range the 10 x 14½ chamber (Fig. 10) should be used. All should have as nearly the same shape as the 10 x 14½ chamber as is possible.

TABLE #1

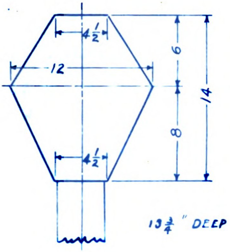
CAPACITY OF WILSON NOZZLES

Heat Output Ratings for Determining Correct Nozzle Size
(For #3 Fuel Oil, Heat Content of 141,000
B. T. U. per gal.).

NOZ-ZLE SIZE	GALLONS PER HOUR 100 LBS. PRESSURE	DRAFT AT STACK	SQ. FT. STEAM E.D.R (gross) 65% EFF.	SQ. FT. WATER (gross) 65% Eff.	B.T.U. OUTPUT 65% EFF.
AA	1.25	.04-.05	480	768	115,000
A	1.5	.04-.05	575	920	139,000
B	1.75	.04-.06	670	1070	162,000
C	2.0	.04-.06	770	1232	185,000
D	2.25	.05-.07	865	1384	208,000
E	2.5	.05-.07	960	1536	230,000
F	3.0	.05-.08	1150	1840	277,000
G	3.5	.06-.08	1350	2160	324,000
H	4.0	.06-.08	1540	2464	370,000

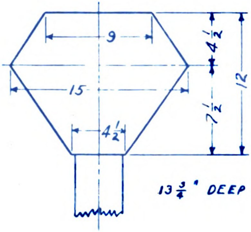
Ratings will be 2% less for No. 2 Fuel Oil and 4% less for No. 1 Oil.

NOTE: A nozzle disc marked 3C8 indicates that it was tested with No. 3 Oil, has a capacity of (C) 2 gal. per hour, and has an 80 (8) spray angle. On a 60 deg. spray angle the last figure would be "4".



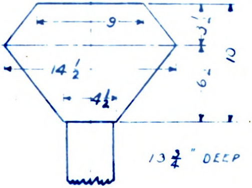
Combustion Chamber
Tests #1 & #2

Fig. 8



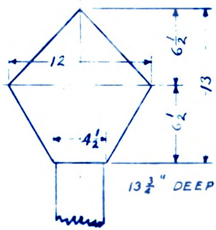
Combustion Chamber
Tests #3 - #5

Fig. 9



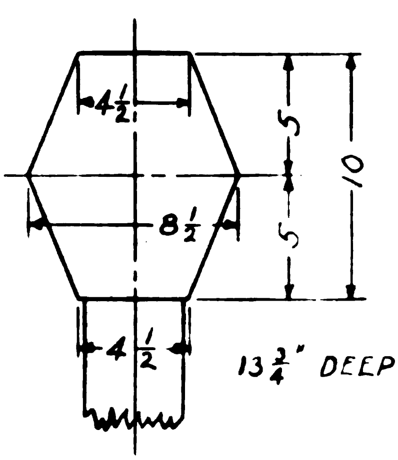
Combustion Chamber
Tests #6 - #9
(Adopted)

Fig. 10



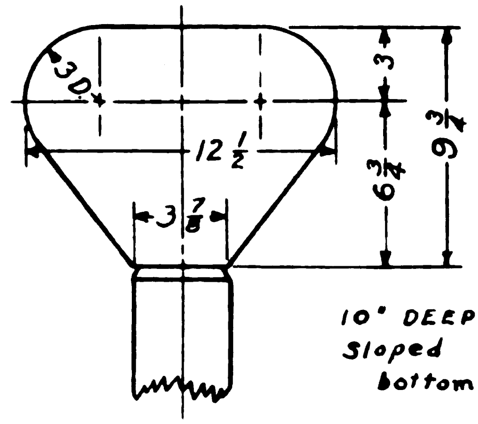
Combustion Chamber
Tests #10 - #12

Fig. 11



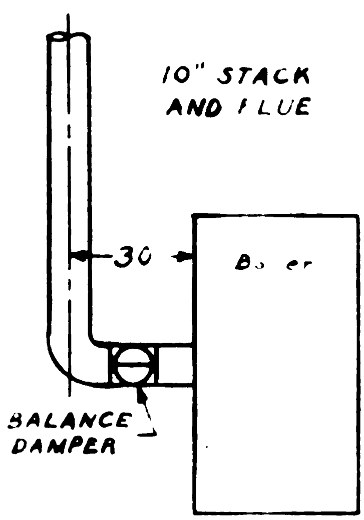
Combustion Chamber
Tests #13-#16

Fig. 12



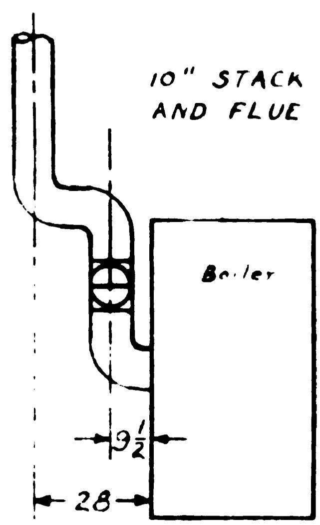
Molded Combustion
Chamber
Tests #17-#19

Fig. 13



Flue Set Up
Tests #C1-#C4

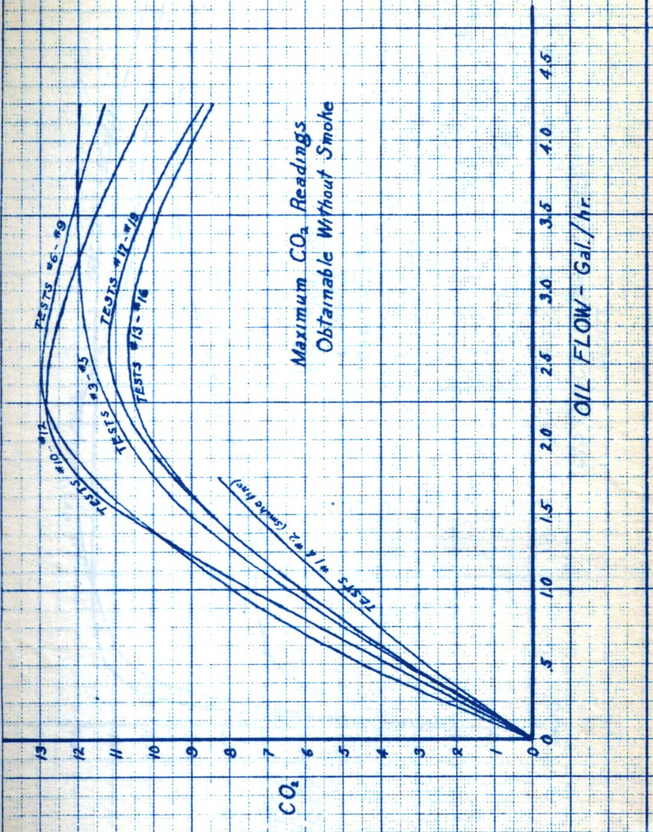
Fig. 14

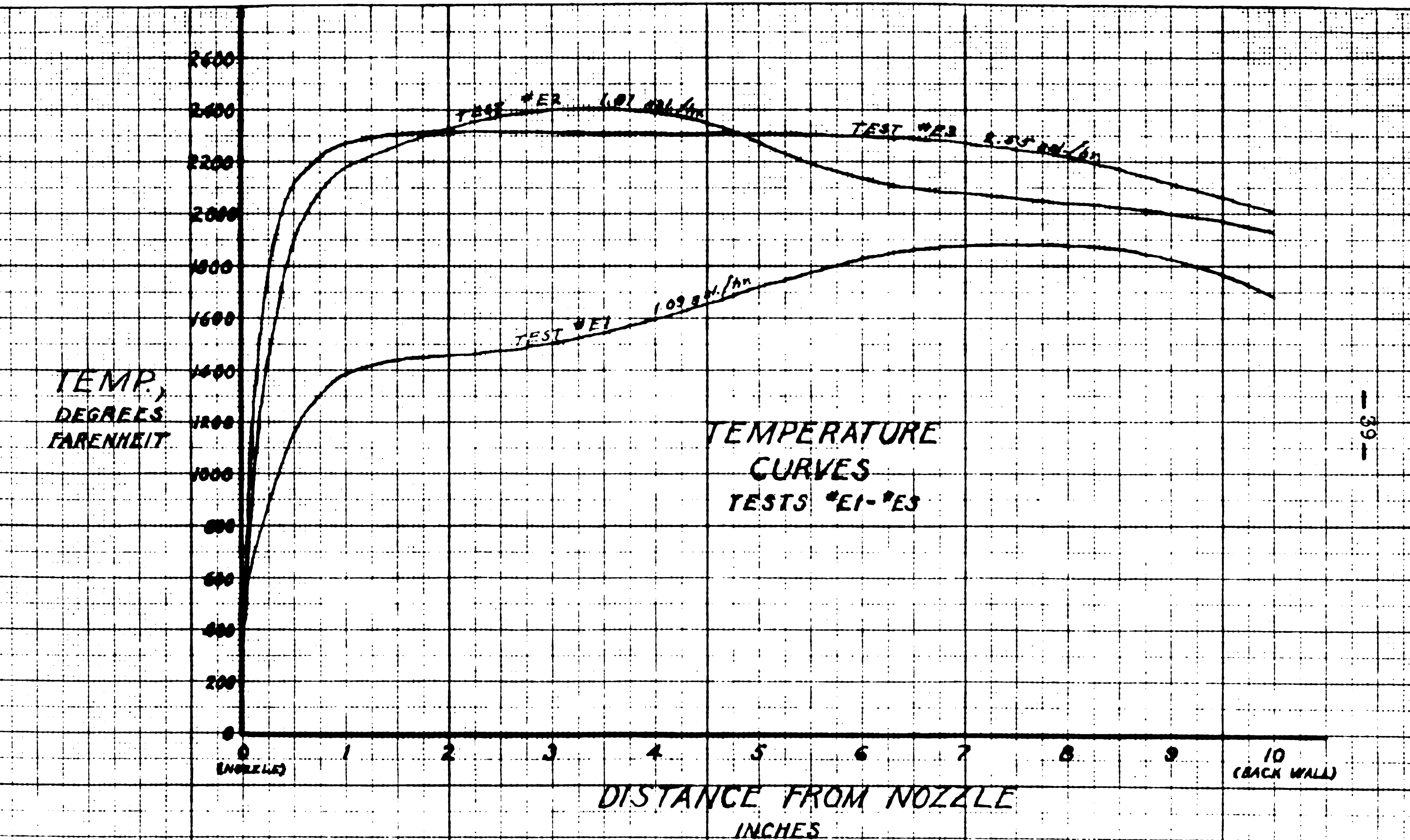


Flue Set Up
Tests #C5 & C6

Fig. 15

CURVES


Maximum CO₂ Readings
Obtainable Without Smoke
CO₂
OIL FLOW - Gal./hr.
TESTS #6 - #9
TESTS #10 - #12
TESTS #3 - #5
TESTS #17 - #18
TESTS #13 - #16
TESTS #1 & #2 (Smoke line)
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
1
2
3
4
5
6
7
8
9
10
11
12
13


TEMP., DEGREES FARENHEIT
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0 (NOZZLE)
1
2
3
4
5
6
7
8
9
10 (BACK WALL)
TEST #E2
TEST #E3
TEST #E1
TEMPERATURE CURVES
TESTS #E1-#E3
DISTANCE FROM NOZZLE
INCHES

DATA

TEST #1

Development of a Combustion Chamber

Nozzle: Wilson 3-C-4 (60 deg.)
Actual Oil Flow: 9 lb. 0 oz. 1.26 gal. per hr.
(1 gallon weighs 7.164 lb.)
Combustion Chamber Used: See Fig. 8.

Results:

Draft:	.06 in. of water
CO_2:	6.3
Stock Temp.:	835 deg. F.
Air Adjust:	Minimum
Smoke:	Smoke line
Noise:	Faint

Remarks: Flame hits back of chamber, forming soot. Dead spots on sides. Flame 6" from nozzle.

TEST #2

Nozzle: Wilson 3-C-8 (80 deg.)
Actual Oil Flow: 8 lb 7½ oz. or 1.18 gal. per hr.

Results:

Draft:	1/.05	2/.05
CO_2 :	2.9	3.9
Stack temp:	850	730
Air Adjust:	1 7/8" open	1" open
Smoke:	None	None
Noise:	Rumble	Faint

Remarks:

1. Flame too small for chamber. 8" from nozzle.

2. Flame 6" from nozzle.

TEST # 3

Nozzle: Wilson 3-G-8
Actual Oil Flow: 20 lb. 8 oz. or 2.86 gal. per hr.
Combustion Chamber Used: See Fig. 9.

Results:

Draft:	.07
CO_2	11.9
Stock temp.	Over 1000
Air Adjust:	1 3/8 " open
Smoke:	None
Noise:	25 yd. *

Remarks: Bottom of chamber red hot.
No soot. Flame 2" from nozzle.

*Combustion noise becomes inaudible at 25 yd. distance.

TEST #4

Nozzle: Wilson 3-H-8
Actual Oil Flow:
1. 25 lb. 8½ oz. or 3.56 gal. per hr.
2. 29 lb. 8 oz or 4.12 gal. per hr. (140#/in.^{2})

Results:

Draft:	1/.08	2/.08
CO_2	10.0	12.6
Stack temp:	Over 1000	Over 1000
Air Adjust:	Max.	Max.
Smoke:	None	Smoke line
Noise:	35 yd.	35 yd.

Remarks:

1. Bottom of heat chamber red hot. 1½ ft. of flame above combustion chamber. Flame 4" from nozzle.

2. Lower 2/3 of heat chamber red hot. Flame in stack. 4 in. from nozzle.

TEST #5

Nozzle: Wilson 3-F-8
Actual Oil Flow: About 2 gal per hr.

Results:

Air Adjust: 1 7/8 " open

Remarks: This was to determine whether a 2 gal. nozzle would work with this chamber without puffing out. No puffing was noticable and the fire did not go out.

TEST #6

Nozzle: Wilson 3-F-8
Actual Oil Flow: 13 lb. 6 oz. or 1.87 gal. per hr. ($120\#/in.^2$)

Combustion Chamber Used: **See Fig. 10.**

Results:

Draft:	1/.07	2/.07	3/.07
CO_2	10.5	11.0	7.7
Stack Temp.:	About 1000	About 1000	950
Air Adjust:	3/16 open	5/16 open	½ open
Smoke:	5%	S.l.*	None
Noise:	Faint	Faint	Faint

Remarks:

1. Flame completely fills chamber. No soot. Flame 2" from nozzle.

2. Heat Chamber red hot at bottom. Flame 1½" from nozzle.

3. Furnace much cooler, showing excess air. Flame 5" from nozzle. Does not fill chamber.

* Smoke line

Test #7

Nozzle: Wilson 3-G-8
Actual Oil Flow:

1. 23 lb. 12 oz. or 3.315 gal. per hr. (120#/in.^{2})
2. 24 lb. 9 oz. or 3.43 gal. per hr. (140#/in.^{2})

Results:

Draft:	1/.08	2/.08
CO_2	11.2	12.0
Stack Temp.:	Over 1000	Over 1000
Air Adjust:	1 1/8 open	1 1/8 open
Smoke:	None	Near s.l.
Noise:	Normal	Loud

Remarks:

1. Flame in stack. Bottom of heat chamber red hot. Flame 2 ½" from nozzle. Combustion chamber full of flame and some above it. Heat chamber too small for this oil flow.

2. Heat chamber hotter than before. Flame in and above combustion chamber. 2" from nozzle. Part of flame swirls back into the original path and goes around again, completely filling all corners of the chamber.

TEST #8

Nozzle: Wilson 3-H-8
Actual Oil Flow: 29 lb. 5 oz. or 4.09 gal. per. hr. (120#/in.^{2})

Results:

Draft:	.075
CO_2	11.6
Stack Temp.:	Over 1000
Air Adjust:	Maximum
Smoke:	None
Noise:	Loud

Remarks: Heat chamber red hot about 2/3 of the way up. Flame trails 2½ ft. above combustion chamber. Flame 2" from nozzle.

TEST #9

Nozzle: Benjamin 2 gal., 80 deg.
Actual Oil Flow: 14 lb. 4 oz. or 1.99 gal.per. hr. $(140\#/in.^2)$

Results:

Draft:	1/.07	2/.07
CO_2	7.9	9.5
Stack temp.:	About 1000	About 1000
Air Adjust:	5/16 open	¼ open
Smoke:	None	S.l.
Noise	Faint	Faint

Remarks:

1. Flame 2" from nozzle. Outgoing flame is narrower.

2. Same as above except redder flame.

TEST #10

Nozzle: Wilson 3-E-8
Actual Oil Flow: 14 lb. 1 oz. or 1.96 gal. per. hr.
Combustion Chamber Used: See Fig. 11

Results:

Draft:	.08
CO_2	12.7
Stack Temp.:	900 deg. F.
Air Adjust:	¼ open
Smoke:	Near s. l.
Noise:	23 yd.

Remarks: Flame still whips back. Hits front wall at top. 1½" from nozzle. Chamber appears too long.

TEST #11

Nozzle: Wilson 3-G-8
Actual Oil **Flow:** 22 lb. 5 oz. or 3.11 gal. per. hr.

Results:

Draft:	.09
CO_2	12.0
Stack temp.:	Over 1000
Air Adjust:	1 5/8 open
Smoke:	None
Noise:	9 yd.

Remarks: Heat chamber red hot in front about 8 in.
Flame 2" from nozzle.

TEST #12

Nozzle: Wilson 3-A-8
Actual Oil Flow: 7 lb. 6 oz. or 1.03 gal. per. hr.

Results:

Draft:	.06
CO_2	6.1
Stack Temp.:	800
Air Adjust	Minimum
Smoke:	None
Noise:	2 yd.

Remarks: Flame 2" from nozzle. Combustion chamber 2/3 Full.

TEST # 13

Nozzle: Wilson 3-E-8
Actual Oil Flow: 12 lb. 10 oz. or 1.76 gal. per.hr.
Combustion Chamber Used: See Fig. 12

Results:

Draft:	.065
CO_2	9.4
Stack Temp.:	900
Air Adjust.:	7/32 open
Smoke:	Near s.l.
Noise:	5 yd.

Remarks: Flame 1½" from nozzle. Combustion chamber full of flame. Soot forms on the side walls about 3" from the nozzle, but disappears when the chamber is hot. This is the first chamber tried that would make the flame double in at the end of its travel instead of allowing it to swirl outward.

TEST #14

Nozzle: Wilson 3-G-8
Actual Oil Flow: 19 lb. 8 oz. or 2.72 gal. per. hr.

Results:

Draft:	.075
CO_2	10.6
Stack Temp.:	Over 1000
Air Adjust:	1 3/16 open
Smoke:	Near s.l.
Noise:	14 yd.

Remarks: Combustion chamber is too small for this oil flow. Flame trails 2½ ft. above it. When starting cold combustion is very poor as some oil strikes cold bricks on sides. To prevent smoking when starting the amount of excess air used must be greater than in this test. Carbon was deposited on the side walls about 3" from the nozzle, and did not burn off.

TEST #15

Nozzle: Wilson 3-A-A-8
Actual Oil Flow: 7 lb. 2 oz. or .99 gal. per. hr.

Results:

Draft:	.05
CO_2	6.1
Stack temp.:	500
Air Adjust.:	Minimum
Smoke:	None
Noise:	4 yd.

Remarks: Carbon deposits from previous test alter shape of flame and cause undesirable turbulences. Flame 3" from nozzle.

TEST #16

Nozzle: Benjamin 2 gal., 80 deg.
Actual Oil Flow:

1. 12 lb. 4 oz. or 1.71 gal. per. hr.
2. 14 lb. 1 oz. or 1.96 gal. per hr. (140#/in.^{2})

Results:

Draft:	1/.06	2/.06
CO_2	8.7	8.7
Stack temp.:	900	over 1000
Air Adjust	¼ open	7/16 open
Smoke:	Near s.l.	Near s.l.
Noise:	6 yd.	10 yd.

Remarks:

1. Flame only ½" from nozzle. Carbon deposits still present, lowering efficiency.

2. Carbon deposit still present. Soft flame, ½" from nozzle. The narrowness of this chamber alone makes it undesirable.

TEST #17

Nozzle: Wilson 3-E-8
Actual Oil Flow: 12 lb. 0 oz. or 1.68 gal. per hr.
Combustion Chamber : See Fig. 13

Results:

Draft:	.10
CO_2	9.1
Stack Temp.:	High
Air Adjust:	Minimum
Smoke:	None
Noise:	10 yd.

Remarks: Flame 2½" from nozzle. Chamber about ¾ full. A little flame above chamber at back.

TEST #18

Nozzle: Wilson 3-G-8
Actual Oil Flow: 21 lb 10 oz. or 3.02 gal. per.hr.

Results:

Draft:	.10
CO_2	10.5
Stack Temp.:	High
Air Adjust:	15/16 open
Smoke:	None
Noise:	15 yd.

Remarks: Flame 1" from nozzle. Combustion chamber completely filled. Flame trails 2 ft. above chamber. Back of heat chamber red hot about 2 ft. up. Too much oil for this chamber.

TEST #19

Nozzle: Wilson 3-F-8
Actual Oil Flow:

1. 19 lb. 2 oz or 2.67 gal. per hr.
2. 22 lb. 6 oz or 3.12 gal. per hr. (140#/in.^{2})

Results:

Draft:	1/.07	2/.10
CO_2	11.5	10.6
Stack Temp:	High	High
Air Adjust:	11/16 open	1 open
Smoke:	Near s. l.	Near s. l.
Noise:	17 yd.	19 yd.

Remarks:

1. Flame fills combustion chamber. Nearly 2 ft. of flame above combustion chamber at back. Back of heat chamber red hot about 1½ ft. up. Flame 1½" from nozzle.

2. Two feet of flame above back of combustion chamber. Back of heat chamber red hot about 2 ft. up. Flame 1½ " from nozzle.

TEST # A1

TEST OF A FLANGE TYPE BURNER OF TWO GALLON CAPACITY

Nozzle: Wilson 3-E-8

Actual Oil Flow:

1. 13 lb. 1 oz. or 1.82 gal. per hr.
2. 16 lb. 5 oz. or 2.28 gal. per hr. (140#/in.²)

Combustion Chamber Used:

10 x 14½ insulating brick. See Fig. 10.

Results:

Draft	1/.075	2/.07
CO_2	10.7	9.8
Stack temp.:	980	1000
Air Adjust:	11/16 crack	¼ crack
Smoke	None	None
Noise:	17 yd.	10 yd.

Remarks:

1. Flame fits chamber. 3" from nozzle.
2. Flame 3" from nozzle. Combustion chamber about 2/3 full. The nozzle probably plugged during this run.

TEST #A2

Nozzle: Wilson 3-F-8
Actual Oil Flow: 16 lb. 6 oz. or 2.29 gal. per hr.
(85#/in.^{2})

Results:

Draft:	.08
CO_2	13.0
Stack Temp.:	Over 1000
Air Adjust:	Maximum
Smoke:	Near s.l.
Noise:	28 yd.

Remarks: Bottom of heat chamber red hot. Chamber about 4/5 full of flame. Flame 3" from nozzle. Maximum capacity of the burner.

TEST #A3

Nozzle: Wilson 3-A-A-8
Actual Oil Flow: 7 lb. 2 oz or .99 gal. per hr.

Results:

Draft:	.06
CO2	8.7
Stack temp.:	800
Air Adjust:	3/16 crack
Smoke:	Near s.l.
Noise:	1 yd.

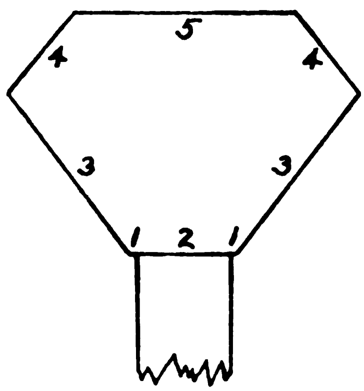
Remarks: Chamber about 2/3 full of flame. Flame $2\frac{1}{2}$" from nozzle. The combustion chamber is too large for this oil flow rate.

TEST #B1

TO DETERMINE TEMPERATURES AT VARIOUS POINTS
IN THE 10 x 14½ INSULATING BRICK COMBUSTION CHAMBER

Nozzle: Wilson 3-A-8
Actual Oil Flow: 7 lb 10 oz. or 1.06 gal. per hr.

Temperatures Read At:



t - temp. at centers, top teir of bricks,

m - temp. at centers, middle teir.

b - temp. at centers bottom teir.

Readings:

CO_2 :

Air Adjust:
Stack temp.:
Smoke:
Draft:

Temp. Readings:

t	1/1365	2/1370	3/1420	4/1710	5/1390
m	1525	335	1585	1705	1560
b	1575	1545	1620	1665	1510

Max. Flame Temp.: 1980

TEST #B2

Nozzle: Wilson 3-E-8
Actual Oil Flow: 13 lb. 4 oz. or 1.85 gal. per hr.

Readings:

CO_2:	10.5
Air Adjust:	Minimum
Stack temp.:	918
Smoke:	Near s.l.
Draft:	.065

Temp. **Readings.**

t	1/1955	2/2135	3/2135	4/2155	5/2280
m	2125	360	2180	2205	2270
b	2120	2260	2185	2195	2230

Max. Flame temp.: 2380

TEST #33

Nozzle: 3-F-8
Actual Oil Flow: 18 lb. 7 oz. or 2.57 gal. per hr.

Readings:

Draft: .075
CO_2: 11.2
Air Adjust: 9/16 open
Stack Temp.: 1100
Smoke: Near s.l.
Draft:

Temp. Readings:

t	1/1965	2/2200	3/2070	4/2080	5/2140
m	2080	250	2115	2075	2120
b	2060	2085	2045	2060	1950

Max. Flame Temp.: 2300

TEST #C1

TO DETERMINE THE CAUSES OF "PUFFING" AND "FLUTTERING"

Nozzle: Wilson 3-F-8
Actual Oil Flow: 18 lb. 14 oz. or 2.63 gal. per hr.
Combustion Chamber: 10 x 14½ insulating brick.
See Fig. 10
Flue Set Up: See Fig. 14

Results:

Draft:	.035
CO_2	10.6
Stack temp.:	595
Air Adjust:	31/32 open
Smoke:	Near s.l.
Noise:	17 yd.

TEST #C2

Nozzle: Wilson 3-G-8
Actual Oil Flow: 21 lb. 2 Oz. or 2.95 gal. per hr.

Results:

Draft:	1/.015	2/.03	3/.05	4/.075
CO_2:	11.6	12.2	12.0	12.0
Stack temp.:	670	650	640	640
Air Adjust:	1¾ open	1 9/16 open	1 5/16 open	1 3/8 open
Smoke:	Near s.l.	Near s.l.	Near s.l.	Near s.l.
Noise:	17 yd.	18 yd.	13 yd.	17 yd.

Remarks:

1. Furnace puffs very badly when starting. If ignition is delayed an explosion occurs. A negative draft was observed when starting.

2. Pressure developed on starting in combustion space - evidenced by gas blowing through hole in door. Puffs badly.

3. Appears to be best combination.

4. Pressure in combustion chamber considerably reduced. Puffs on starting and smokes for a few seconds.

TEST #C3

Nozzle: Wilson 3-E-8
Actual Oil Flow: 12 lb. 12 oz. or 1.79 gal. per hr. (2nd lot of oil -7.128 lb. per gal.)

Results:

Draft:	1/.015	2/.03	3/.05
CO_2	9.5	10.4	8.9
Stack Temp:	545	550	510
Air Adjust:	5/8 open	½ open	3/8 open
Smoke:	Near s.l.	Near s.l.	Near s.l.
Noise:	10 yd.	9 yd.	8 yd.

Remarks:

1. The puff on starting is not so noticable, but there is nevertheless a small pressure (about .02 to .03 in. of water) for several seconds after starting.
2. Fairly good operation. No puffing.
3. No puffing, but reduced efficiency dueto too high a draft. A .03 draft is best.

TEST #C4

Nozzle: Wilson 3-A-A-8
Actual Oil Flow: 8 lb. 1 oz. or 1.13 gal. per hr.
($95\#/in.^2$)

Results:

Draft:	1/.015	2/.05
CO_2	7.6	5.8
Stack temp.:	425	425
Air Adjust:	Minimum	Minimum
Smoke:	None	None
Noise:	2 yd.	4 yd.

Remarks:

1. No puffing or fluttering when starting, running, or stopping.
2. No puffing or fluttering, but efficiency is reduced. Best draft for this oil flow is probably about .02.

TEST #C5

Nozzle: Wilson 3-A-A-8
Actual Oil Flow: 7 lb. 8 oz. or 1.05 gal. per hr. ($80\#/in.^2$)
Combustion Chamber Used: Same as tests #C1 - #C4
Flue Set Up: See Fig. 15.

Results:

Draft:	1/.015	2/.03	3/.05
CO_2 :	7.8	7.6	6.7
Stack temp.:	405	415	415
Air Adjust:	Minimum	Minimum	Minimum
Smoke	None	None	None
Noise	4 yd.	5 yd.	5 yd.

Remarks:

1. Puffs on starting.

TEST #C6

Nozzle: Wilson 3-G-8
Actual Oil Flow: 21 lb. 0 oz.or 2.95 gal. per hr.

Results:

Draft:	1/.015	2/.045	3/.075
CO_2:	11.8	11.8	10.5
Stack temp.:	650	635	625
Air Adjust:	2 3/32 open		
	+ 9/64 cr-ack	2 3/32 open	1 22/32 open
Smoke:	Near s.l.	Near s.l	Near s.l.
Noise:	18 yd.	16 yd.	18 yd.

Remarks:

1. Puffs badly and tends to flutter when adjusted for efficient operation. An explosion occurs if ignition is delayed.
2. Puffs badly.
3. Reduced draft on starting, but no back pressure. The greater draft required and the wider opening of the air inlet shutters indicate that the elbows have the effect of reducing the stack diameter, due to the greater friction or resistance..

TEST #D1

COMPARISON OF BENJAMIN AND WILSON NOZZLES

I. Benjamin Nozzles

Nozzle Angle	CO_2	Air Adjust	Description of Flame
45°	10.0	5/8 open	The flame cone is very narrow. Flame trails hit front wall above nozzle, then continue about 13" above chamber. Flame 1 ½" from nozzle.
55°	11.6	½ open	Flame trails about 14" above chamber. Flame 2" from nozzle. Combustion chamber ¾ full.
60°	11.1	¼ open	Flame trails about 14" above combustion chamber, which is ¾ full. Flame 2" from nozzle.
65°	11.1	11/16 open	Flame trails about 12" above chamber which is nearly full. Flame 1 ½" from nozzle.
70°	11.6	½ open	Combustion chamber full of fire. Flame trails about 12" above it. Flame 1 ½" from nozzle.
75°	11.3	9/16	Combustion chamber full. Flame trails about 11" above Back. Flame 1 ½" from nozzle.
80°	11.5	3/8	Combustion chamber full. Most of flame is over back of chamber. Fire trails 11" above it. Flame 1 ½ " from nozzle.
90°	11.4	½ open	Combustion chamber full. Fire trails about 12" above back of chamber. Flows 1 ½" from nozzle. Very little turbulence or swirling motion.

II. Wilson Nozzles

Nozzle Angle	CO_2	Air Adjust	
3-C-8 (80°)	11.6	7/32	Oilflow 1.37 gal. per hr. All Benjamins tested burned about 1.8 gal. Fire trails about 12" above combustion chamber, which is 4/5 full. Flame 1 ¾" from nozzle.
3-E-8 (80°)	12.0	9/16	1.88 gal. per hr. Fire trails about 14" above combustion chamber, which is 4/5 full. Flame 1 ¾ from nozzle.

Note: All runs made on smoke line with No. 3 oil and 10 x 14 ½ brick combustion chamber.

TEST #Dla

CHECK ON BENJAMIN NOZZLES

Nozzle Angle:	60°	65°	70°
CO_2	11.6	11.4	11.3
Air Adjust:	21/32 open	21/32 open	21/32 open
Smoke:	S.1.	S.1.	S.1.

Actual Oil Flow:

60° : 12 lb. 13 oz. or 1.80 gal. per hr.
65° : 13 lb. 0 oz. or 1.82 gal. per hr.
70° : 12 lb. 15 oz. or 1.81 gal. per hr.

Description of Flames:

60° : Five trails about 12" above combustion chamber, which is ¾ full of fire. Flame 2½" from nozzle.

65° : Fire trails about 14" above combustion chamber, which is ¾ full of fire. Flame 2½ from nozzle.

70° Five trails about 13" above combustion chamber, which is 4/5 full when viewed from above. Flame 2" from nozzle. This flame is sweeping through the chamber instead of doubling back.

TEST #E1

Flame Temperatures in the 10 x 14½ Insulating Brick Combustion Chamber

Nozzle: Wilson 3-A-8
Actual Oil Flow: 7 lb. 12 oz. or 1.09 gal. per hr.
Actual Oil Flow: 7 lb. 12 oz. or 1.09 gal. per hr.
Draft: .05
CO_2 8.8
Air Adjust ¼ open
Smoke: None

Readings:

Position	Temp., °F
Nozzle	470
1"	1445
2"	1430
3"	1450
4"	1584
5"	1705
6"	1907
7"	1802
8"	1884
9"	1832
Backwall	1679

Discussion: Readings were taken along a horizontal line from the nozzle to the back wall, equidistant from both sides. A platinum--platinum rhodium couple was used. The flame was visable 1½" from the nozzle. The air adjustment was made so that CO_2 was about 2% below maximum.

TEST #E2

Nozzle: Wilson 3-E-8
Actual Oil Flow: 12 lb. 14 oz. or 1.81 gal. per hr.

Draft:	.05
CO_2	10.5
Air Adjust:	5/8 open
Smoke:	None

Readings:

Position	Temp., °F
Nozzle	350
1"	2237
2"	2205
3"	2441
4"	2350
5"	2328
6"	2090
7"	2058
8"	2085
9"	1995
Backwall	1950

Discussion: Combustion chamber is full of flame. The flame trails about 20" above the chamber, and is visible 2" from the nozzle. It is rather soft and hazy, making observation difficult.

TEST #E3

Nozzle: Wilson 3-F-8
Actual Oil Flow: 18 lb. 3 oz. or 2.55 gal. per hr.

Draft:	.06
CO_2	10.8
Air Adjust	1 3/8 open
Smoke:	None

Readings:

Position	Temp., °F
Nozzle	250
1"	2295
3"	2297
5"	2290
7"	2320
Backwall	2000

Discussion: Combustion chamber is full of flame. The flame trails 36" above the chamber and is visable in the stack near the flue connection on the furnace. Flame is visable 2" from nozzle. Due to the high temperature inside and the large amount of radiated heat outside, and to the density and relative opacity of the flame, great difficulty was experienced in obtaining accurate readings. For this reason less positions were used than in the two previous tests.

ROOM USE ONLY