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EFFECT OF THE DEPTH OF DRILLED PORTS ON THE LIMITS OF OPERATION OF DOMESTIC GAS BURNERS

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ABSTRACT

This paper describes the effect of variations in the depth of the metal through which the ports are drilled on the limits of operation of domestic gas burners. Quantitative data are presented showing the effect of varying the depth of port from 1½ in. to 1/32 in. on the limits of flash back, blowing, and yellow tips, as well as on the proportion of primary air injected. These data were obtained with two gases of different composition and with four different port sizes. The effect of turbulence on the position of the burner limits is also discussed. The results obtained indicate that a compromise between all the factors involved might result in the selection of a port ¼ in. in depth as the most practicable.

CONTENTS

I. INTRODUCTION

For a number of years the Gas Chemistry Section of the National Bureau of Standards has been engaged in a study of the performance of domestic gas-burning appliances.

Nearly all gas burners employed in domestic appliances are so designed that a portion of the air necessary for complete combustion mixes with the gas before it reaches the burner ports. This is called "primary" air. The additional air required is secured from the atmosphere surrounding the flames and is termed "secondary" air. As the amount of primary air which mixes with a given amount of gas is increased, a limit is reached above which the flames either blow away from the ports or flash back into the burner, depending on the gas rate used. Similarly, if the proportion of primary air is decreased, a limit is reached below which the color of the tip of the inner cone of the flame becomes yellow. It is obvious that unsatisfactory burner operation will result if any one of these three limits is exceeded. A more complete discussion of these limits and their determination is given in two previous papers.[1] [2]

It is apparent that it is desirable to design a burner so that the satisfactory working range between these limits of operation is as great as possible. Some of the factors which affect the position of these limits, and which must be considered because of their consequent effect upon the safe working range, are as follows: (*a*) the composition of the gas (with natural gas the flames are more likely to blow off the ports than to flash back through them, while with manufactured gas the reverse is true); (*b*) the size of the port (increasing the port size decreases the trouble from the blowing of the flames, while decreasing the port size tends to prevent their flashing back); (*c*) the altitude (appreciable decreases in barometric pressure) at which the burner is used; (*d*) the burner temperature; and (*e*) the smoothness and direction of the channels within the burner casting. A discussion of the effects of some of these factors has also appeared in previous papers.[3]

That a deep port tends to prevent the flames from flashing back has long been known, but no definite information has been available regarding the extent of this action, or regarding other effects, either beneficial or adverse, which might result from the use of deep ports, on the other limits of burner operation.

This paper presents the quantitative relationships which have been found to exist between the depth of drilled ports and the positions of the several limits of operation of a domestic gas burner.

II. EQUIPMENT AND METHOD OF TEST

The gas for the majority of these tests was the mixed natural and manufactured supply now being distributed in Washington, D. C., a gas of 600 Btu and 0.67 specific gravity (referred to air).[4] This heating value is maintained by the local gas company by means of a calorimetric proportioning machine. This machine automatically varies the proportions of the natural and manufactured gases as their heating values fluctuate, so that the resulting mixture always has a heating value of 600 Btu per cubic foot. This method insures a constant heating value, but the composition remains variable. Since small variations in the properties of the gas, which would be unimportant from the standpoint of service, might tend to mask the effect of changing from one depth of port to another, it was necessary to use a gas which was as nearly as possible of constant composition as well as of constant heating value. The variation in composition which is the most likely to affect the position of the limits of burner operation is a change in the proportion of hydrogen in the mixture.

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[1] *Method of testing gas appliances to determine their safety from producing carbon monoxide.* BS Tech. Pap. **20**, 125 (1925) T304.

[2] *A method for determining the most favorable design of gas burners.* BS J. Research **8**, 669–709 (1932) RP446.

[3] *The effect of altitude on the limits of safe operation of gas appliances.* BS J. Research **10**, 619–637 (1933) RP553, and also papers cited in footnotes 1 and 2.

[4] The following is a representative analysis of the Washington, D. C., mixed gas for the period covered by these tests: CO_2, 4.1%; "Illuminants", 2.4%; O_2, 0.2%; CO_2, 14.2%; H_2, 19.6%; CH_4, 43.8%; N_2, 15.7%. The proportion of natural gas in the mixture averaged a little over 27.5%.

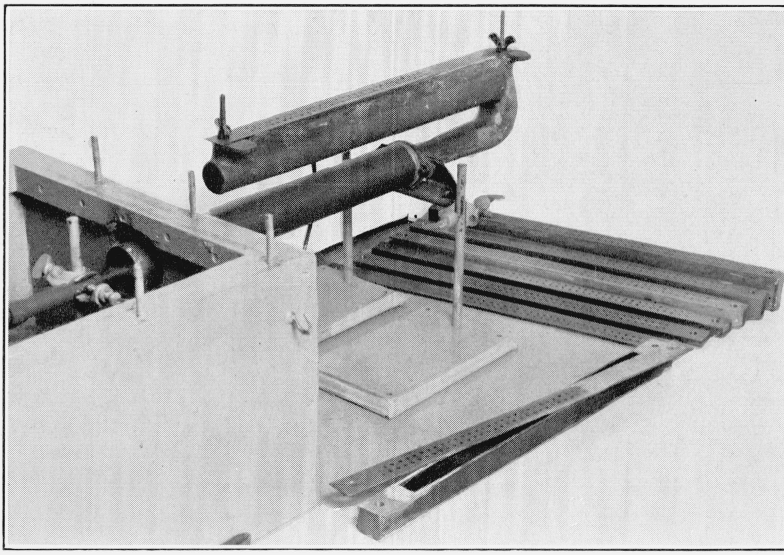

FIGURE 1.—*Burner with 1/32-in. plate attached.*

To the right of the burner are the other plates of the set and in front, with a plate on top of it, is a spacer to increase the volume of the burner head.

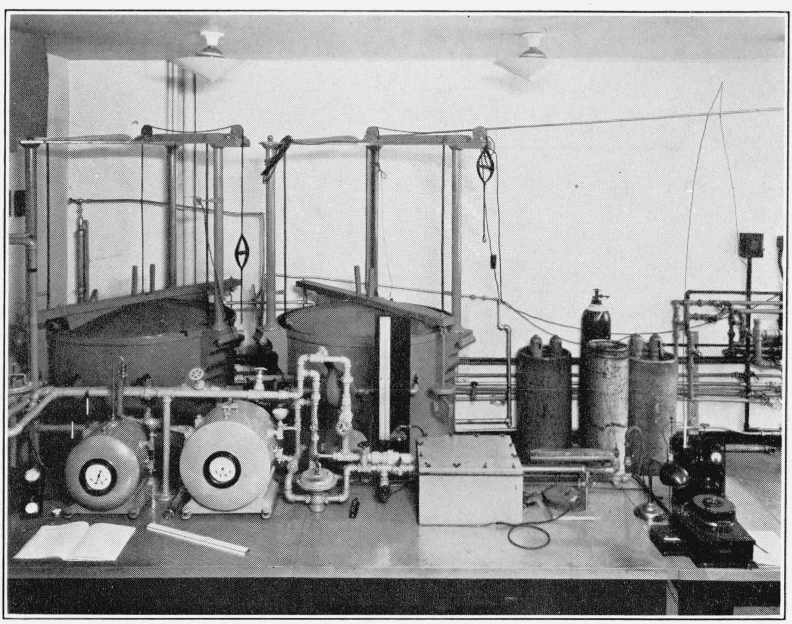

FIGURE 2.—*Equipment used to test gas burners.*

Since the thermal conductivity of hydrogen is about six times that of most of the other constituents of the gas, a preliminary survey of the extent of this variation was made by following the changes in the thermal conductivity over a period of several weeks. From these results a value was selected which recurred the most frequently. By storing the gas supply in two gas holders of 300 and 500 ft^3 capacity, and following the thermal conductivity of the gas in the city main, it was always possible to replenish the supply with gas having approximately this same thermal conductivity and consequently the same composition. The gas for the tests was always taken from the larger of these two holders while the gas to replenish the supply was added to the smaller from the city main. At the end of each day the larger holder was refilled from the smaller.

A few tests were also made with a natural gas having a heating value of 1,170 Btu per cubic foot to determine whether a gas of radically different composition would alter the relative effect of changes in port depth.

In order to determine the effect of changing the depth of the port without at the same time changing any of the other parts of the burner, the following procedure was adopted. A radiant heater burner of the so-called "saxophone" type was selected and the top carefully milled off. Steel plates of the same size as the original burner top, but of various thicknesses (1/32, 1/16, 1/8, 1/4, 1/2, 3/4, 1, and 1½ in., respectively), were then made and each drilled with 62 ports. By means of a bolt at each end of the burner, and a thin film of metal cement, it was possible to attach any of the plates to the burner casting.

Figure 1 shows the burner with the 1/32-in. plate attached. To the right of the burner are the other plates of the set and in front, with a plate on top of it, is the spacer which will be discussed later in the paper.

Four complete sets of these plates were made, each set having the same number of ports but differing in their size, so that any variations introduced (by the changes in port size) into the effect of the depth of the port on the positions of the limits could also be determined. The four drill sizes used were nos. 40, 36, 32, and 28 (drill manufacturers' standard, having diameters of 0.0980, 0.1065, 0.1160, and 0.1405 in., respectively).

The orifice used was selected to give the normal rate of gas flow for this size and style of burner (226 Btu per hour per port) at the "test pressure" for manufactured gas adopted by the American Gas Association, 3.5 in. of water. The same orifice was used for all tests, except those on natural gas,[5] so that any variation in the position of the normal air injection curve for any one gas is the result of differences in the port only. Figure 2 shows the apparatus used for these tests.[6] Having the burner installed as shown and burning gas at a constant rate, the primary air was increased until the flames either lifted from the ports or flashed back into the burner. When this condition was reached, the relative proportion of air and gas was determined. The

[5] For the tests using natural gas, an orifice was used that delivered the normal rate of 226 Btu per hour per port at a pressure of 7.0 in. of water.

[6] A detailed description of this apparatus is given in the Bureau of Standards Research Paper 446 (BS J. Research 8, 669–709, 1932).

primary air was next decreased until yellow appeared in the flame, and the ratio of air to gas again determined. The gas rate was then changed and the same procedure repeated until a series of tests had been made which covered a range of gas rates from one and one-half times that normally used down to the lowest possible "turn-down." A determination of the normal air injection was then made over the same range of gas rates. The results obtained were plotted, using as coordinates "Gas rate—Btu per hour per port" and "Primary air—percent of total air required."

In figure 3, the curves indicate the position of the boundaries of the regions in which flash back, blowing, and yellow tips occur with the mixed gas described above when using the ¼-in. plate of the set having no. 36 ports. Figure 3 also shows the shape and position of the curve

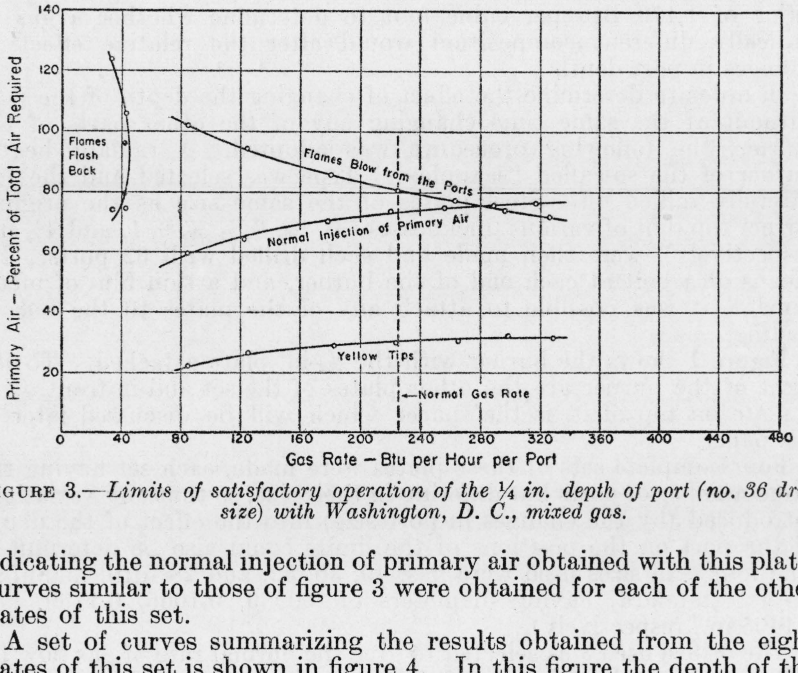

FIGURE 3.—*Limits of satisfactory operation of the ¼ in. depth of port (no. 36 drill size) with Washington, D. C., mixed gas.*

indicating the normal injection of primary air obtained with this plate. Curves similar to those of figure 3 were obtained for each of the other plates of this set.

A set of curves summarizing the results obtained from the eight plates of this set is shown in figure 4. In this figure the depth of the port, in inches, is plotted as abscissa. The ordinate is "Primary air—percent of total air required." The primary air at the normal gas rate [7] (226 Btu per hour per port) was taken from the blowing curve, the normal injection curve, and the yellow-tips curve of figure 3, and the three points were plotted in figure 4 on the vertical coordinate line corresponding to the ¼-in. depth of port. From curves similar to those of figure 3, obtained with the seven other plates of the set, similar points were plotted in positions corresponding to the depths of the respective ports. Smooth curves were then drawn through the points, representing, for each of the three limits mentioned, the primary air (at the normal gas rate) at which the respective limits were encountered with the various depths of port.

[7] Since the curves like those shown in figure 3 for the various depths of port all parallel one another closely, a summary curve derived by selecting the primary air at any other gas rate than the normal would be entirely similar in shape and slope but displaced slightly in its vertical position.

In the case of the flash-back limit the maximum gas rate, in figure 3, at which flash back occurred (47 Btu per hour per port) is plotted in figure 4 at 47 on the ordinate for the ¼-in. depth. The same numerical scale serves for maximum gas rate in the case of flash back and for primary air in the case of the other three limits. The maximum gas rates at which flash back occurred with the other depths of port were taken from the curves similar to those of figure 3 and plotted in figure 4 in the manner just described. A smooth curve was then drawn through the points as before.

These curves indicate the manner in which these various limits shift as the depth of the port is varied, all other conditions remaining constant.

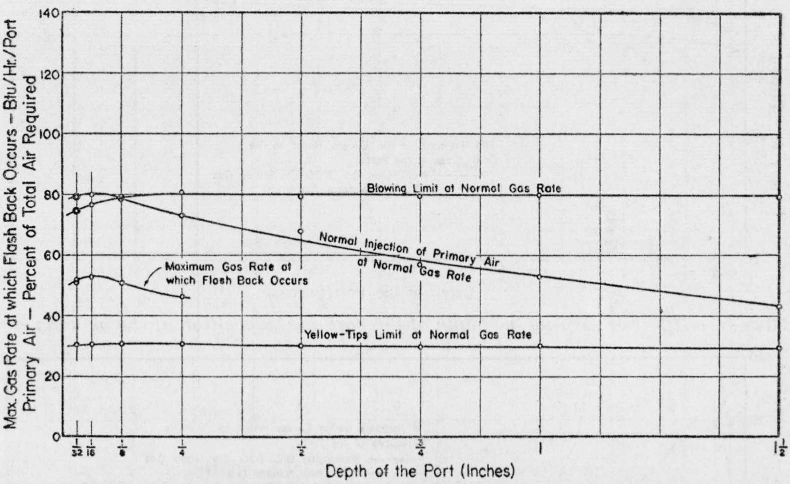

FIGURE 4.—*Summary of the results from curves similar to those of figure 3, showing the effect of varying the depth of the port on the positions of the several limits.*

Normal gas rate of 226 Btu per hour per port. Drill size, no. 36.

III. DISCUSSION OF THE RESULTS

In order to avoid the possibility of drawing false conclusions and to insure the applicability of the conclusions drawn over a range of port sizes and fuel supplies, an attempt has been made to eliminate from consideration any variations which might result from unknown or uncontrolled variables. For this purpose the curves similar to those of figure 4 for each of the limits studied have been separated from those of the other limits and plotted together in figures 5 to 8. In this way peculiarities and variations common to all, or most, of the curves of a set become evident, and these alone may reasonably be considered as resulting from variations in the depth of the port.

A number of other interesting facts and relationships may be deduced from a study of the curves presented in this paper. For example, the effect (on the limits) of varying the size of the port, which was treated in Research Paper RP446 referred to above, is evident from the relative positions of the curves, but relationships which are not pertinent to the effects of the depth of the port will not be discussed here.

1. EFFECT OF PORT DEPTH ON THE BLOWING LIMIT

An inspection of figure 5 at once discloses that the effect of changing the depth of the port from 1½ in. to ¼ in. is small and constant—all the curves are nearly horizontal straight lines. In the case of the two larger ports (nos. 28 and 32) the flames are blown from the ports a

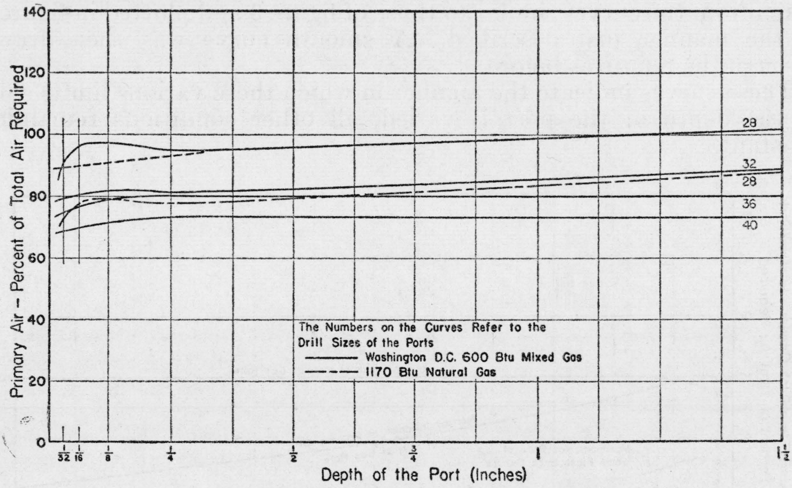

FIGURE 5.—*Effect of varying the depth of the port on the position of the blowing limit.*

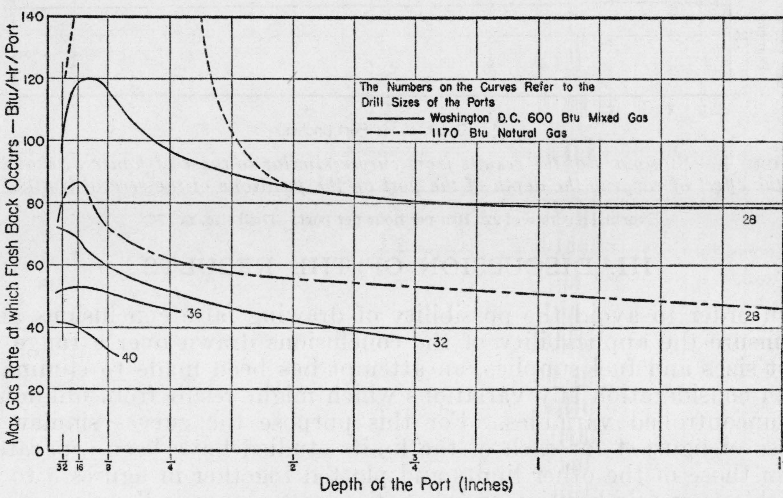

FIGURE 6.—*Effect of varying the depth of the port on the position of the flash-back limit.*

little more readily (the primary air which may be introduced into the mixture is a little less) as the depth of the port decreases.

A slight rise, most marked with the no. 28 port and on both gases, occurs from a depth of ¼ to ⅛ in. All the curves have a distinct downward curvature (i. e., blowing occurs more readily) as the depth approaches 1/32 in. A possible explanation for this downward curvature will be considered after the effects on the other limits have been discussed.

2. EFFECT OF PORT DEPTH ON THE FLASH-BACK LIMIT

It is evident from figure 6 that the effect on the position of the flash-back limit is very slight with ports deeper than ¾ in. and that the effect begins to be considerable only with ports less than ¾ in. deep,

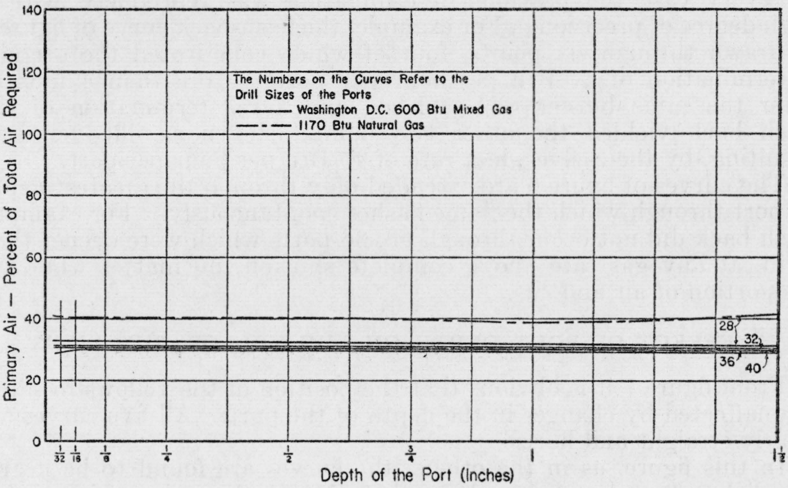

FIGURE 7.—*Effect of varying the depth of the port on the position of the yellow-tips limit.*

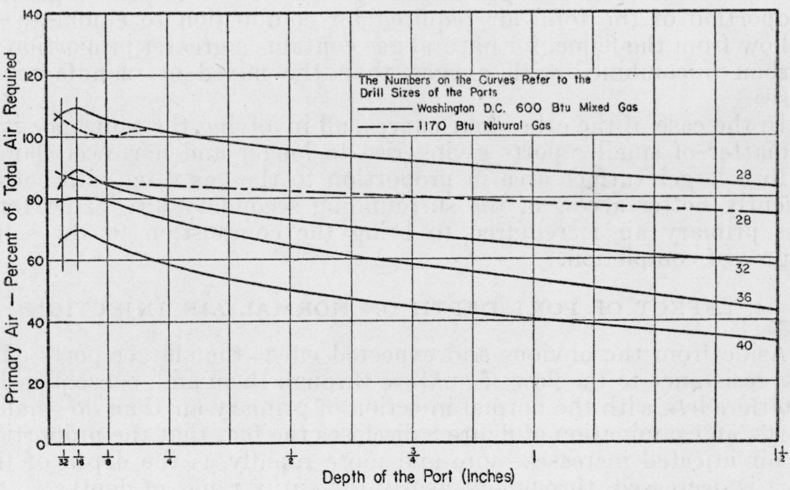

FIGURE 8.—*Effect of varying the depth of the port on the normal injection of primary air.*

when it increases more and more rapidly—the flames flashing back through the ports spontaneously at higher and higher gas rates as the depth is decreased. In the case of three of the curves a downward bend is again noted at the 1/16 in. depth, which is more susceptible to flash back than either the ⅛ or 1/32 in. depths.

Improbable as it seemed when first observed, the effect is a definite one, exhibited by three of the five curves, with a tendency indicated in the case of the other two. These reversals were verified both by immediate repetition and by checks after intervals of several weeks when the gas used had been replaced repeatedly by a fresh supply. In every case the previous determination was reproduced with a high degree of precision. For example, the flash-back curve of figure 3 is drawn through six points, four of which constituted the original determination of 47 Btu per hour per port. More than 4 months later the same burner was replaced and a redetermination of the flash back yielded the other two points (shown as filled circles), resulting, by themselves, in a rate of 45 Btu per hour per port.

The curves of figure 6 are extended only through the greatest depth of port through which the flame flashes spontaneously. For example, flash back did not occur through no. 36 ports which were deeper than ¼ in. at any gas rate above complete shut-off, no matter what the proportion of air and gas.

3. EFFECT OF PORT DEPTH ON THE YELLOW-TIPS LIMIT

From figure 7 it is obvious that the position of the yellow-tips limit is unaffected by changes in the depth of the port. All five curves are nearly straight and horizontal.

In this figure, as in the others, the curves are found to be nearly parallel and arranged one above the other in the order of increasing port size. The reason for this is more or less obvious in the other cases, and here natural gas might be expected to require a greater proportion of the total air required for combustion to eliminate all yellow from the flame, for natural gas contains a greater proportion of carbon uncombined with oxygen than the mixed or manufactured gases.

In the case of the other four curves, all involving the same gas, it is a matter of smaller ports giving rise to longer and narrower flames with a larger surface area in proportion to the gas rate, with consequently better access of the surrounding secondary air. Therefore, less primary air is required to bring the combustion to the same degree of completion.

4. EFFECT OF PORT DEPTH ON NORMAL AIR INJECTION

Aside from the obvious and expected effect that larger ports offer less resistance to the flow of mixture through them and, consequently, interfere less with the normal injection of primary air than do smaller ports, an examination of figure 8 discloses the fact that the proportion of air injected increases more and more rapidly as the depth of the port is decreased, throughout nearly the entire range of depths.

It is again noted that a reversal begins at a depth of $\frac{1}{16}$ in., the $\frac{1}{32}$ in. depth permitting the injection of less primary air, at the normal gas rate, than the $\frac{1}{16}$ in. depth, which appears to permit the maximum injection with the particular set of conditions under which these tests were made. This reversal, however, seems to be absent in the case of the natural gas.

IV. PECULIARITIES OF THE CURVES OF FIGURES 5, 6, AND 8

In searching for an explanation for the reversals of curvature exhibited by many of the curves of figures 5, 6, and 8, with maxima at or near the 1/16 in. depth, it was instructive to consider the mechanism of the flow of the mixture through the ports. The individual port may be considered as a small channel in which length of channel and depth of port are synonymous terms. As such a channel becomes shorter and shorter it loses the characteristics of a channel and assumes those of an orifice. The flow of a gas through a small channel (at a given pressure drop) is limited primarily by the viscosity of the gas. As the channel becomes shorter, the "end effects" become more and more important. Eventually the end effects predominate and the channel becomes an orifice, the flow through which (at a given pressure drop) is limited primarily by the density of the gas.

Just before the transition from channel to orifice, the gas flow fills the channel completely. The effective cross section of the gas stream is that of the port. The velocity in the stream varies from a maximum in the axis to zero in contact with the walls. On shortening the channel, that is, decreasing the depth of the port, a ratio of depth to diameter is reached at which the channel no longer is completely filled by the gas stream. The entrance end of the channel acts like a sharp-edged orifice, and the effective cross section of the stream is that of the vena contracta. The stream of gas is no longer in contact with the walls of the channel and the velocity at the surface of the stream is only slightly less than the average for the whole.

Such a situation was reported for the case of a channel-type orifice of no. 2 drill size in a previous paper.[8] On account of the large difference in size, length of channel, and pressure drop in the two cases, it was uncertain whether the transition (which occurred at a ratio of diameter to length of channel of 2.21 in the case of the no. 2 orifice) would occur at the same ratio of diameter to length of channel in the case of the ports used in this investigation. Accordingly, the effect was investigated with the burner plates of the no. 36 drill size used as multiple orifices having different lengths of channel.

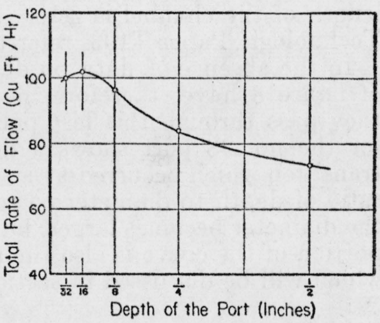

FIGURE 9.—*Effect of varying the depth of the port on the total flow through the ports under a constant pressure drop.*

The gas rate was maintained at the "normal rate" throughout the entire series of tests. The air was adjusted to an average "good adjustment" with the burner of 1/32 in. port depth in place. The drop in pressure through the ports was then determined by means of a sloping manometer, and the sum of the rates of flow of gas and air was determined by metering both.

For subsequent burners of different depth of port the air was set to give the same pressure drop through the ports, and then the total flow through the ports was determined. The total rate of flow is plotted against the depth of the port in figure 9. It is clear that the

[8] BS Tech. Pap. 193 (1921).

flow increases as the depth of the port (i. e., the length of the channel) decreases from ports ½ in. to $\frac{1}{16}$ in. in depth. The rate of flow is distinctly less, however, in the case of the port $\frac{1}{32}$ in. deep, which indicates not only that the behavior of the curves of figures 5, 6, and 8 can be explained on the basis of a sudden decrease in the flow of mixture through the port $\frac{1}{32}$ in. deep as compared with the port $\frac{1}{16}$ in. deep, but that the change takes place at approximately the same ratio of diameter to length of channel as in the case of the orifices previously studied.

1. NORMAL INJECTION

In the case of the normal injection of primary air, the reversals in the curves of figure 8 may be accounted for quite readily on the basis of the considerations just outlined.

When the depth of the port was changed from $\frac{1}{16}$ in. to $\frac{1}{32}$ in., if the transition from capillary flow to orifice flow also took place, a decrease in the effective cross section of the stream of mixture would also take place. Such a decrease in the cross section of the stream issuing from the port must result in a decrease in the volume of mixture discharged. Since the gas delivered is constant, the decrease must take place entirely in the quantity of air injected. This results in turn in a smaller proportion of air in the mixture in the case of the $\frac{1}{32}$ in. depth of port.

A further decrease in depth apparently changes the character of flow through the port (which has now become an imperfect orifice) in such a way as to decrease the flow further as the port approaches more completely the form of a true sharp edged orifice in which the length of the channel is zero. Such an effect is shown in figure 7 of Technologic Paper T193, referred to above.

In the absence of data on depths less than $\frac{1}{32}$ in., the four curves of figure 8 have, therefore, been allowed to continue downward as they pass through this last point. The dotted portion of the curve for the no. 28 port shows a definite rise after passing through the transition which occurred at a somewhat greater depth. The critical ratio of depth to diameter corresponds to a somewhat deeper port as the diameter becomes larger, but, in addition to that effect, the dotted portion of the curve is also the result of a turbulent condition of flow, which will be discussed in section V.

2. BLOWING

In the case of the blowing curves in figure 5, the sharp drop from a depth of $\frac{1}{16}$ in. to $\frac{1}{32}$ in. shown by the no. 28 port may be explained on the basis of a transition from capillary to orifice type of flow. With the capillary type of flow the velocity at the rim of the port is very low, which permits the flame to maintain itself very near to the port. This flame in the slow-moving mixture at the port rim in effect seals the rest of the flame to the port. After the change to the orifice type of flow the boundary of the stream is no longer in contact with the walls at the exit end of the channel and its velocity is only a little less than the average velocity. There is no longer a slow-moving boundary, the burning of which keeps the flame in place, and consequently the flame is blown off the port at much lower average velocities than before. A lower average velocity at a given gas rate necessarily means less air, both of which are found experimentally.

3. FLASH BACK

In the case of the flash-back curves of figure 6 the rising curves indicate flash back at higher and higher gas rates as the depth of the port becomes less. That is, as the port channel becomes shorter the susceptibility to flash back increases, as might be expected. The flame in the slow-moving boundary, assisted by pulsations and slight turbulence, finds it easier to creep down through the port at one side. On changing to the orifice type of flow such an opportunity may be largely removed because the boundary layer may not be moving as slowly as it does when it is in contact with the channel wall. The proportion of air in the mixture most likely to flash back remains about the same. Flash back can occur only if the velocity of flow is reduced, which requires that the gas rate be less.

V. EFFECT OF TURBULENCE ON THE FLASH-BACK AND BLOWING LIMITS AND ON THE NORMAL INJECTION OF PRIMARY AIR

Turbulence in the burner casting affects the position of some of the limits of operation of a burner. The blowing limit and the normal injection of primary air may be affected only slightly but the flash-back limit is affected markedly. This effect is naturally more pronounced as the depth of the port becomes small and its diameter large.

In this particular case the effects of turbulence made their appearance only on the no. 28 port and at depths less than ½ in. The effects are shown by the dotted curve branching from the one for the no. 28 port in figures 5, 6, and 8. In addition to the abnormal trend of the curves, the turbulence was evidenced by a vibratory motion of the flame surfaces and by an accompanying (or perhaps resulting) singing noise, which at times increased to a scream.

The term "turbulence" used in the present sense simply serves to express one of the factors which appear to cause this rather complicated phenomenon and may have little or no connection with the term as used in ordinary pipe flow. Computations disclosed the fact that at the higher rates of flow through the burner casting, indeed, at the points where "singing" began, the velocity through the casting was near to or greater than the critical velocity at which the flow becomes turbulent in a long, smooth, straight tube. In view of the relative shortness of the burner casting, however, and the various disturbing factors incident to its irregular shape, this coincidence may have little significance. The high frequency of the singing noise suggests either a vibration of the air column within the burner, or the rapid alternations of position of the flame surface itself as a source. The latter can actually be seen, and no sound is heard unless the flame is present (the flow remaining unchanged). Vibrations which may cause the pulsations in the flame may, however, originate somewhere in the burner casting.

An attempt was made to lessen the intensity of the pressure fluctuations or to damp out the turbulence, if turbulence was the direct cause, by interposing the spacer (shown in fig. 1) between the casting and the plate through which the ports were drilled.

The spacer was used in additional tests of ports which had previously shown no indication of being affected by turbulence, and the results indicated that the interposition of the spacer had no significant effect.

When used with ports with which turbulence had caused trouble, however, the spacer eliminated the difficulty almost entirely by providing more space and time for the turbulence to die out after the velocity had dropped below the critical value in the larger part of the burner head. The solid portion of the curves in figures 5, 6, and 8 below a depth of ½ in. for the no. 28 port were determined with the spacer in place.

VI. CONCLUSIONS

The effect on the position of the yellow-tips limit of burner operation when the depth of the port is varied from 1½ in. to $\frac{1}{32}$ in. is negligible.

The effect of such changes in depth on the position of the flash-back and blowing limits is small until the depth has decreased to ¼ in., the burner being more susceptible to flash back and a very little more susceptible to lifting as the depth decreases.

Below ¼ in. the effect of decreasing the depth of the port becomes more marked, the change from ¼ in. to $\frac{1}{16}$ in. being roughly equal to that from 1½ in. to ¼ in. The injection of primary air is limited by the resistance to flow through the ports and increases more and more rapidly as the depth decreases to $\frac{1}{16}$ in.

Ten of the fifteen curves shown in figures 5, 6, and 8 pass through a maximum at a depth of $\frac{1}{16}$ in., while most of the others show a change in curvature in this direction at that depth.

A port depth of $\frac{1}{16}$ in. with the diameters of the ports studied was found by experiment to permit the largest flow at a given pressure difference, and corresponds closely to that ratio of length of channel to diameter of orifice at which the change from the channel type of flow to the orifice type occurs. This transition, in which the stream of fluid no longer fills the channel and a contraction appears is concluded to be the cause of the decreased susceptibility to flash back, the increased susceptibility to lifting, and the decrease in the injection of primary air which occurs as the depth of the port is decreased from $\frac{1}{16}$ in. to $\frac{1}{32}$ in.

These effects are found with natural gas as well as with the mixed gas with which most of the tests were made.

In general, these effects are the same, regardless of the size of the port, between no. 40 and no. 28.

With the no. 28 port the inability of the ports less than ½ in. deep to suppress turbulence which arises in the burner casting leads to a marked increase in susceptibility to flash back and also to blowing, as well as to a decreased injection of primary air. This turbulence was shown by computation to be the result of the flow through the casting exceeding the critical velocity, at the normal gas rate of 226 Btu per hour per port.

A study of the curves presented in this paper leads to the conclusion that some improvement in operation of burners of domestic appliances might be expected as a result of using ports ¼ in. deep, instead of less; but that little is to be gained by making them deeper than ¼ in. The uniformly adverse effects of turbulence might be avoided for the most part by increasing the cross section of the burner casting to a point where the velocity of flow will be less than the critical velocity. Otherwise, ports smaller than no. 28 or deeper than ½ in. are required to suppress the turbulence so produced in a burner such as that on which these tests were made.

WASHINGTON, January 18, 1937.