

THE THEORY AND PRACTICE IN THE USE
OF OVERFIRE JETS

By

WILLIAM S. MAJOR
Project Engineer, Power Department

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In the interest of smoke abatement, overfire jets are now installed on thousands of commercial and industrial coal-fired furnaces. In some respects, jets play a role similar to that of secondary pushers on a stoker. Both are tools for promoting better combustion. Secondary pushers are periodically adjusted to improve combustion conditions of the fuel bed, while overfire jets are periodically employed to improve combustion above the fuel bed.

Causes of Smoke

Smoke is finely divided carbon resulting from the breaking down of hydrocarbons released from the coal during the process of combustion. It occurs when the volatile matter is heated to high temperatures with insufficient oxygen and turbulence to burn them. A number of circumstances can create smoke formation. For instance, all of you are quite familiar with the dense black smoke resulting from blanketing an incandescent bed of partially burned coal or coke with green coal. There is a quick release of hydrocarbons which break down into smoke because the blanket has prevented adequate air and turbulence reaching the volatile as released. If the furnace door, however, is left partially open the density of the smoke is substantially reduced, since overfire air, drawn in by furnace draft, is supplied to the volatiles as released. Although this procedure helps, it will not yield minimum smoke formation because the air is not at sufficient pressure to penetrate and create turbulence in all regions of the furnace.

Excessive agitation of the fuel bed is another well recognized cause of smoke. When this occurs, there is created a sudden release of hydrocarbons beyond the ability of the prevailing air and turbulence to consume them.

Too cold, or too small, a combustion cavity are still other causes of smoke. In the first case, the furnace temperature is lower than the ignition temperature of all or part of the hydrocarbons. With small combustion space, there is insufficient furnace-resident time of the hydrocarbons to insure complete combustion. This condition is frequently the principal cause of smoke from older furnaces and locomotive fireboxes.

Function and Types of Overfire Jets

The overfire jet is a device for providing turbulence and/or overfire air above the fuel bed of hand-fired and stoker-fired furnaces. There are two basic types of jets: (1) plain steam jet (or nonaspirating) and (2) the overfire air jet. The plain steam jet is used where the prime need is added turbulence to break up stratification of the furnace gases and provide better mixing of existing air with the volatiles. The air-inducing jet is used where there is a need for both turbulence and additional overfire air. For meeting these requirements the blower jet and steam-air jet are available. With the first type, air is fed to the furnace through a series of tubes supplied through a header by a moderate or high-pressure blower. When steam is the motive power, steam nozzles located ahead of the entrances to the air tubes are used to aspirate the air to the furnace.

Essential Features of Overfire Jets

As a result of research, sponsored by Bituminous Coal Research, Inc., at Battelle Memorial Institute, there is now a clear understanding of the principles essential for the design of effective and efficient overfire jets. The research covered extensive studies and tests on such factors as: (1) air entrainment with different tube diameters, lengths, and shapes; (2) steam consumption of various

shapes and sizes of nozzles; (3) flow characteristics; (4) spacing of jets; and (5) elevation of jets above the fuel bed. Findings from these studies, coupled with the valuable experience of many smoke departments and combustion engineers, were used in establishment of the requisites for overfire jets.

Fig. 1 shows the essential features that should be considered in the design of a system of blower jets, and Fig. 2 covers similar data for steam-air jets. Design features for a plain steam or nonaspirating jet are shown on Fig. 3.

Technical Report VII, "Application of Overfire Jets to Prevent Smoke From Stationary Plants", is a practical guide for the design, construction, and application of overfire jets. It explains clearly just how to include the essential features shown on Figs. 1, 2, and 3. This book is now being revised to simplify still further the design and construction procedures.

Effect of Overfire Jets on Furnace Performance

It is extremely difficult to formulate definite conclusions as to just what benefits, other than smoke abatement, might accompany the use of overfire jets. Each furnace reacts differently to jets, depending upon the furnace configuration, type of firing equipment, jet location, coal burned, and load conditions. Then, too, expected changes in the furnace-gas composition and efficiency are usually small, and errors in testing can easily alter the interpretation of results. Furthermore, considerable skill and know-how is required in conducting such tests. Most plants do not have the necessary equipment, time, or personnel for this character of testing. These facts account for the limited factual data that have been published on improved furnace performance attributable to jets.

In July, 1938, Koessler¹ reported on investigations of overfire air conducted on a small travelling grate stoker. Air was introduced through the front wall by means of five jets, each with an area of 1.5 sq in., directed downward at an angle of 20 degrees from the horizontal. Samples of gas were taken at 160 points in the furnace, of which 45 were made simultaneously. An approximate

measure of the completeness of combustion at different locations was determined as follows:

$$\frac{\text{CO}_2}{\text{CO}_2 + \text{CO} + \text{MC}_m\text{H}_m + \text{CH}_4}$$

Under conditions when the sample contained only CO_2 , the expression becomes one. Results of this work are shown by the lines on the furnaces shown in Fig. 4. They were plotted from readings taken in a vertical plane passing from front to back through the center of the furnace. Lines marked "1.0" disclose regions in the furnace cavity where there was apparently completeness of combustion. View "A" shows furnace-gas conditions when employing a pressure of about 9 in. wg on the jets; and view "B", using a pressure of 4.5 in. wg; while "C" shows conditions without jets. A study of the patterns in "A" and "B" shows that apparent complete combustion is obtained at a lower level in the furnace when using a 9-in. pressure. Furthermore, from "C" it appears that a substantial portion of the gases left the furnace with unburned gases when overfire air and turbulence above the fuel bed was not used.

Studies of a somewhat similar nature were conducted by Grunert² of the Commonwealth Edison Company of Chicago, nearly 25 years ago. His studies were conducted on forced-draft chain-grate stokers to determine the benefits of overfire air to reduce furnace gas stratification. Fourteen overfire jets located in the ignition curtain wall were supplied air from a booster fan that received its air from the plenum chamber. By means of water-cooled sampling tubes, the gases were simultaneously sampled at a number of points above the fuel bed and at the entrance to the first pass of the boiler. Fig. 5 shows a plot of composite of a large number of readings at the first pass, both with and without overfire jets. It is interesting to note the uniform composition of the gases, low excess air, and lack of unburned gases across the entire width of the first pass when overfire air was used. Other favorable results from overfire air included: (1) shortening of the flame and reduction of the final temperatures when surfaces are of the same degree

of cleanliness, and (2) reduction of slag and soot deposits in the first pass of the boiler. This latter benefit from overfire air turbulence was also reported in Fuel and the Future.³ In this report, it is stated that one means of preventing harmful deposits appears to be: "Creation of maximum turbulence in the furnace so that the deleterious material may be absorbed on particles of fly-ash or carbon in the gas stream."

Furnaces of spreader stokers are particularly responsive to overfire jets. Turbulence imparted by jets breaks up the tendency for gas stratification which is characteristic of this type of firing. Even though there is a wide difference of opinion as to the number, type, and location of the jets, few, if any, spreader stokers are now installed without some form of overfire jet. The value of jet turbulence is well recognized as a necessity for most advantageous furnace combustion and low smoke density.

Table 1 shows smoke densities with and without the turbulent influence of overfire jets on a spreader stoker furnace, as determined from continuous smoke-recording meter charts. These results should not be interpreted as representative for all furnaces, but rather as an indication of just how effective jet turbulence may prove in smoke control under some conditions.

Table 1. Test Results Showing Ringelmann Smoke Densities
With and Without Overfire Jets

Condition	Furnace Output In Per Cent of Rated Output			
	25%	50%	75%	100%
Without jets	2.2	3.3	3.7	3.4
With jets	1.2	0.4	0.2	0.7

Meissner and Funk⁴ have reported that steam or air jets have reduced cinder carry-over and smoke and increased boiler efficiency by as much as 1 to 3 per cent.

Gilg⁵ has reported test data on a large underfeed stoker-fired boiler where the use of overfire air raised the "no-smoke" limit of the furnace equivalent to approximately 25 per cent increased boiler capacity and also raised efficiency 3 per cent through reduction in cinder loss from 7.2 to 4.2 per cent. Other test work on the same type of stoker, conducted by Carroll,⁶ disclosed approximately 3.5 per cent reduction in total heat loss (due to unburned gases) by the use of overfire air, as may be seen in Table 2.

Table 2. Heat Losses, Per Cent of Available Heat

	Without Overfire Air Per Cent	With Overfire Air Per Cent
Heat loss due to:		
Incomplete combustion of carbon	0.43	0.32
Incomplete combustion of hydrogen	0.32	0.03
Incomplete combustion of hydrocarbons	3.67	0.49
Total heat loss due to unburned gases	4.42	0.84

Tests conducted by Engdahl and Stang⁷ on a 100-hp single-retort underfeed stoker-fired boiler showed better heat transfer to the boiler when the furnace had the benefit of overfire jet turbulence. On 24-hour ASME Code tests, the boiler exit-gas temperature was 586°F with 11.7 per cent carbon dioxide using jets, as compared to 624°F with 12.1 per cent carbon dioxide at the same boiler output without jets in operation. Since these results do not follow the normal pattern of higher temperature with lower carbon dioxide, other factors unchanged, it was concluded that cleaner gases entered the boiler when the furnace had jet turbulence. As a result, there was less soot to insulate the tubes and a higher heat transfer to the boiler.

Location of Jets

Few definite rules can be established for locating jets. Maximum turbulence occurs when the jet stream opposes the general direction of gas flow or is directed to slice across the flow. As to distance above the fuel bed, too high an elevation will not be effective because it will strike the gases after smoke has formed. The jet stream, however, should not impinge on the fuel bed or scrub adjacent furnace walls. Fuel-bed matting or clinkering is likely to result from the former, and serious refractory erosion from the latter. Of equal importance is to avoid jet impingement on boiler surfaces since warping, cracking, or distortion of these sections may result.

Since the width of jet penetration is only about one-tenth the depth of penetration, this understanding provides a safe rule to follow for location of jets in order to avoid impingement. For example, if a jet is designed for a depth of penetration of ten feet, it should be located not less than twelve inches from the adjacent wall or boiler surface and not less than twelve inches above the top of the fuel bed. This knowledge of the jet pattern is also employed as a basis for determining the number of jets required in furnace walls to provide turbulence and/or overfire air above the entire fuel bed.

As to travelling grate stokers, two schools of thought exist on jet location. One advocates jets in the rear walls in order to force the lean gases rising from the rear of the fuel bed toward the front walls where the hydrocarbons are released. The other school favors location of jets in the front wall so that the maximum turbulence is available where the hydrocarbons are released.

Underfeed stokers usually perform at low smoke density, except when the fuel bed is manually disrupted. To aid smoke abatement under these conditions upward of 30 to 35 per cent overfire air may be required.

When applying jets above underfeed stokers, the jet streams are directed over the retort. In the case of multiple retort stokers, the jets are set to

coincide with retort spacing. Frequently a length of penetration sufficient to cover the "hump" of the fuel bed is adequate for smoke abatement.

Steam Jets versus Blower Jets

Although steam is not an efficient means of introducing overfire air to a furnace as compared to blower jets, there are frequently cases where the steam-air jet should be used: for instance, on an older furnace with limited life, where the lower initial investment for steam jets outweighs its higher operating cost. For such cases, the jets can be constructed at a nominal cost from standard pipe and fittings available in the average plant maintenance shop. When the furnace need is primarily added turbulence, and additional air would be detrimental to furnace performance, the plain steam jet is the only choice.

For newer furnaces, however, where both overfire air and turbulence are needed, the blower jet will generally show sufficient savings in operating costs to justify the added investment cost.

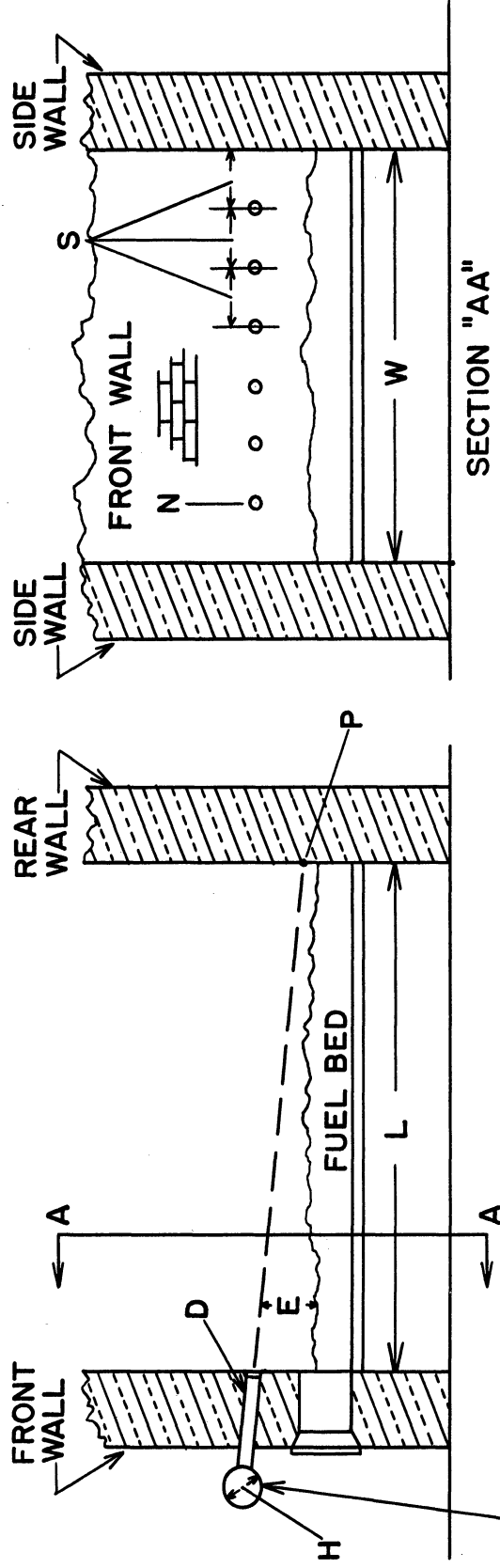
Summary

The overfire jet is a tool to accompany good firing practices in the interest of smoke abatement. Its basic function is to provide turbulence and/or overfire air where the hydrocarbons are released close to the fuel bed and thus to prevent smoke formation. Benefits, other than smoke abatement, that have accompanied the use of overfire jets include: (1) reduction of slag and soot formations on boiler tubes, (2) shortening of the flame and reduction of the final temperatures when surfaces are of the same degree of cleanliness, (3) ability to operate with slightly lower excess air without unburned combustible gases, (4) increased boiler and furnace efficiency, (5) reduction of both quantity and carbon content of the cinder carryover, and (6) substantial increase in the "no-smoke" limit of the furnace.

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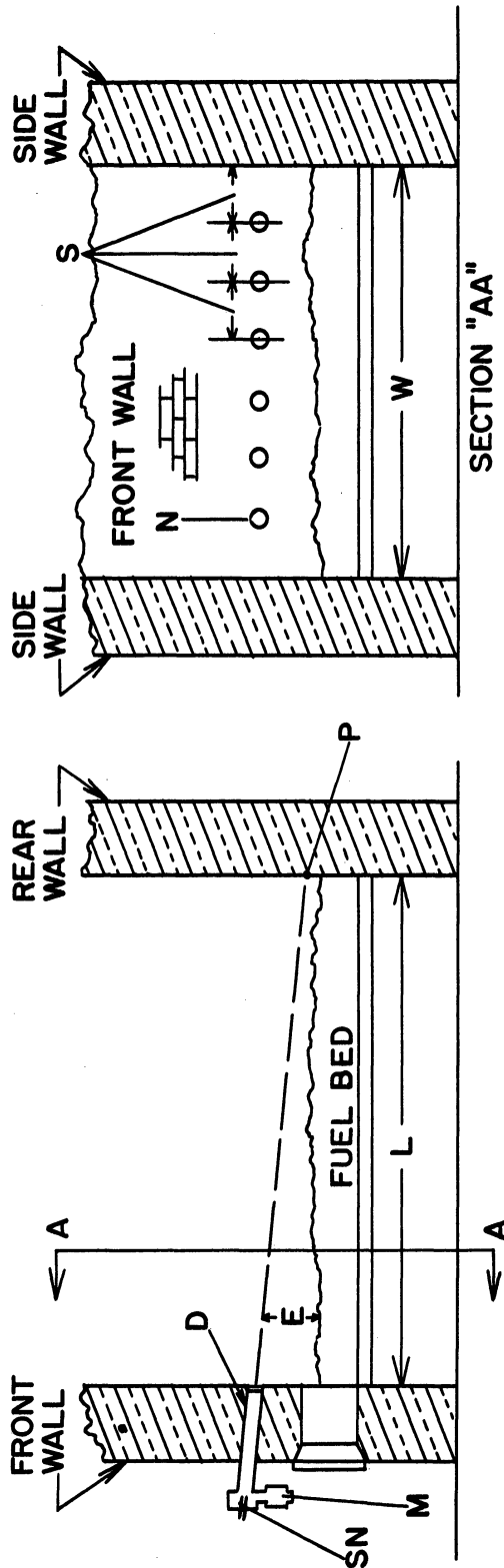
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FIGURE 1- ESSENTIAL FEATURES FOR EFFICIENT BLOWER JETS



- (D) DIAMETER OF AIR TUBE**
(S) SPACING OF AIR TUBE
(N) NUMBER OF AIR TUBES
(E) ELEVATION OF AIR TUBES ABOVE FUEL BED
(H) SIZE OF HEADER DUCT
(B) BLOWER (OR FAN) CAPACITY
**(P) AIM AIR TUBES AT A POINT APPROX. 6" ABOVE
TOP OF FUEL BED**
- BLOWER (B) MAY
BE CONNECTED
TO EITHER END
OF HEADER**

FIGURE 2- ESSENTIAL FEATURES FOR EFFICIENT AND QUIET STEAM-AIR JETS



- (D) DIAMETER & LENGTH OF AIR TUBE
- (S) SPACING OF AIR TUBES
- (E) ELEVATION OF AIR TUBES ABOVE FUEL BED
- (N) NUMBER OF AIR TUBES
- (SN) SIZE AND LOCATION OF STEAM NOZZLE
- (M) MUFFLER OR SILENCER
- (P) AIM AIR TUBES AT A POINT APPROX. 6" ABOVE TOP OF FUEL BED

FIGURE 3
STEAM JET FOR TURBULENCE ALONE,
NO AIR ENTRAINMENT

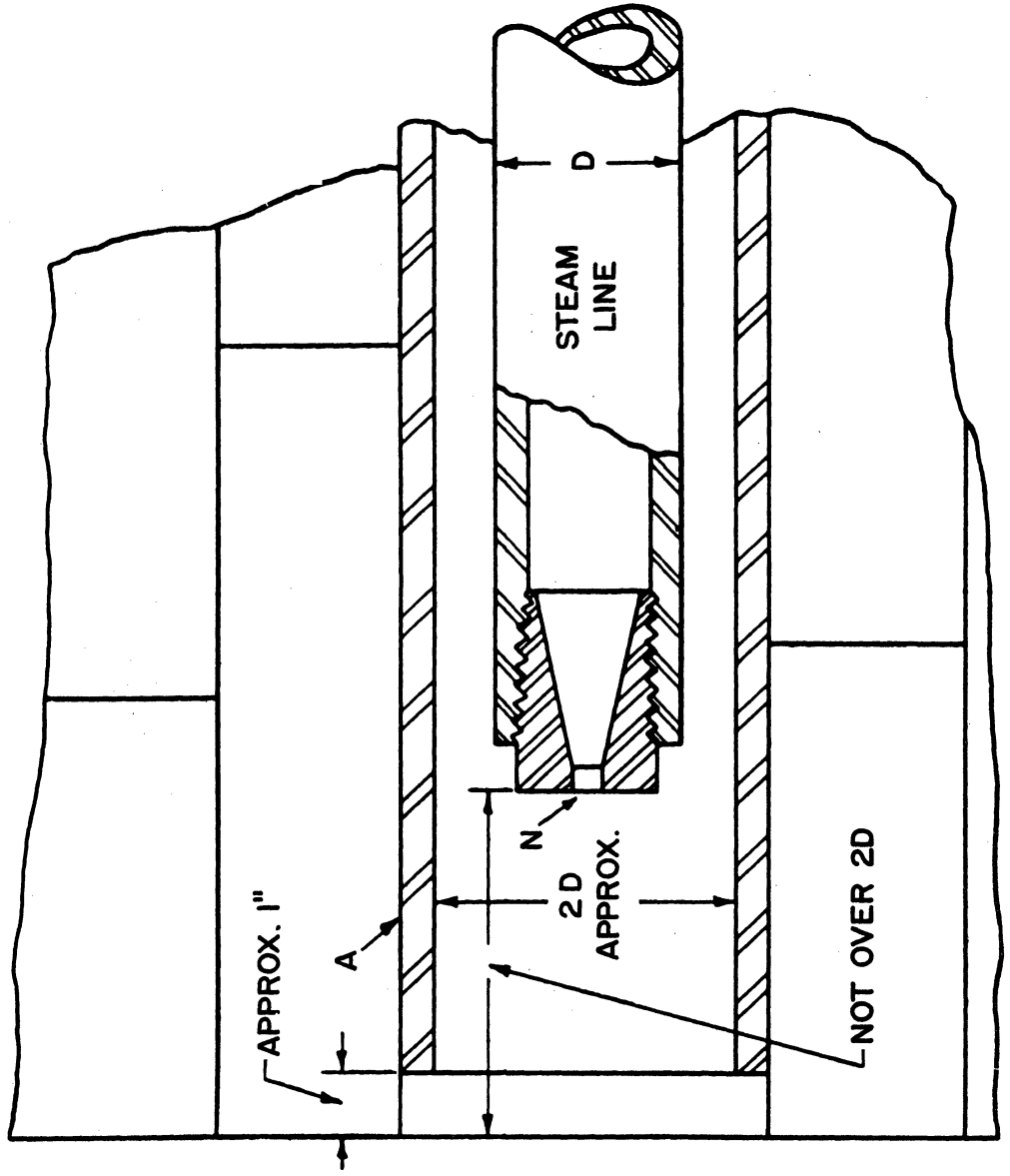
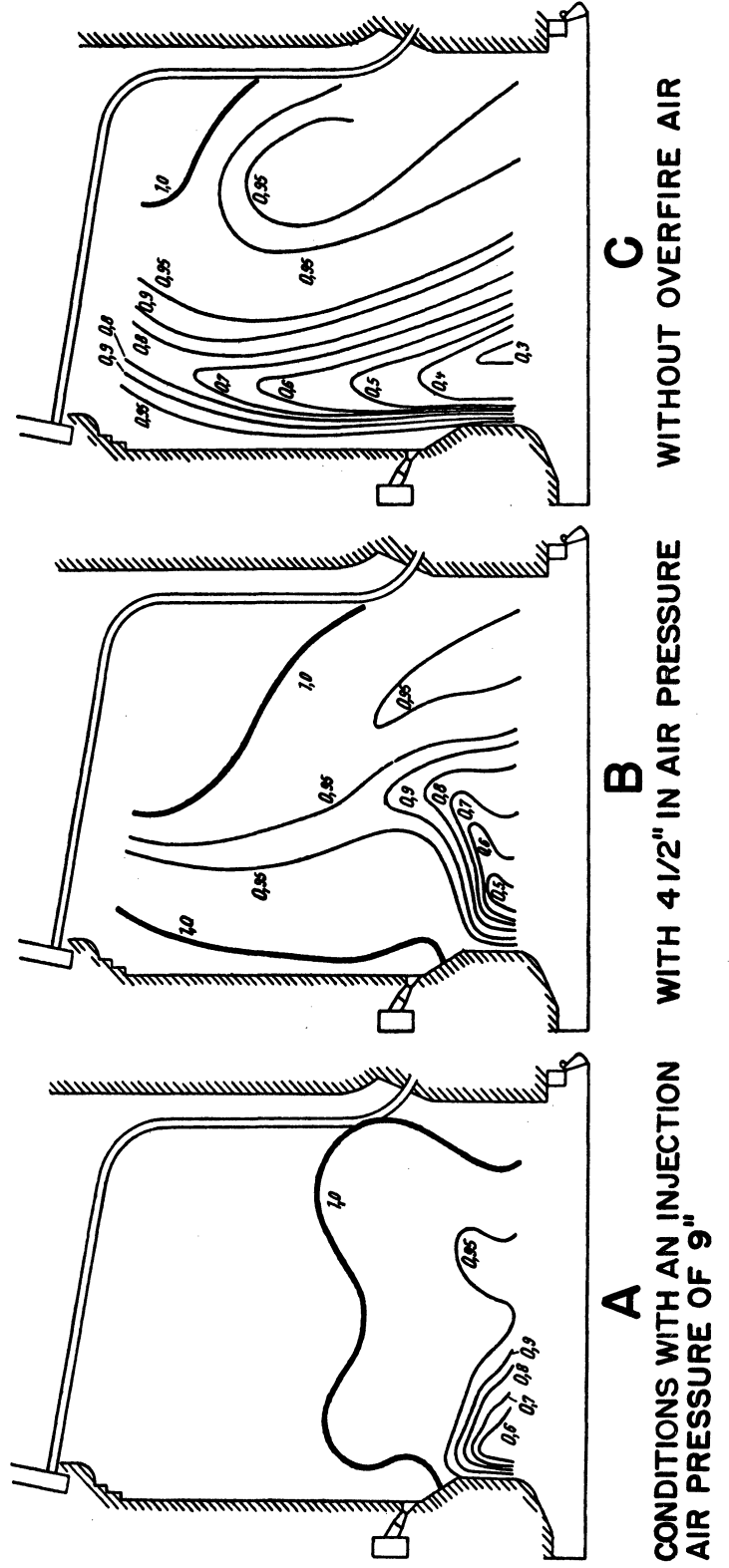


FIGURE 4-DIAGRAMS SHOWING
 COMPLETENESS OF COMBUSTION IN
 A CHAIN GRATE STOKER FIRED FURNACE
 (READINGS TAKEN ALONG VERTICAL PLANE
 THROUGH CENTER OF FURNACE)



**FIGURE 5-GAS COMPOSITION ENTERING
FIRST PASS OF BOILER
TEST DATA ON FORCED DRAFT CHAIN
GRATE STOKER FIRED FURNACE**

