possible the co-operation of the universities and the services of the students.

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Discussion

Ollison Craig.[8] This paper, which constitutes a report of data obtained in connection with natural-gas firing in a boiler furnace, gives the data of heat-absorption distribution in the furnace envelope, in a manner similar to that which has been done previously in reports of similar tests on boilers fired with pulverized coal. The data of course are self-explanatory.

The firing of natural gas in this case was done in such a manner that the flame produced was nonluminous. This being the case, it apparently was not possible to determine visually the path of the flow of gases in the furnace. It is interesting to note, however, that this path can be readily visualized merely by the pattern of delta t distribution on the furnace walls and roof. It is generally assumed that uniform distribution of gas flow across a furnace outlet should be more easily obtained with natural-gas-firing than with firing of coal in suspension or firing oil. There has been reason in the past to believe that this is not true and the data contained in this paper supply further evidence.

If natural gas is burned with a nonluminous flame it is a fair assumption that this is because of the intimate mixture of gas and air to such an extent that combustion is not retarded. To the contrary, if a luminous gas flame is desired, it is obtained by delaying gas and air mixture. However, the data in the paper indicate that even though the mixture is sufficiently intimate as to produce a nonluminous flame, it still is not complete by the time the gases pass from the front to the rear of the furnace, as evidenced by the rise in gas temperature after further mixing has taken place at the rear wall because of the turbulence produced by wall impingement. Presumably combustion could be completed in the shortest distance from the burners if the gas and air were thoroughly premixed before passing from the burners. This of course is done in some types of industrial processes.

The paper points out the lesser percentage of heat absorption in the furnace walls by radiation, and a greater percentage of absorption by convection, as compared to pulverized-coal or oil-firing. It also points out the additional mixing that occurred and additional convection heat absorption by the tube screen that was placed in front of the rear wall. This might lead to the idea that still further tubes could be placed in the furnace space to produce additional mixing and to absorb more heat by convection. This of course would be possible with gas firing while it would not be practical with pulverized-coal or oil-firing.

It would be useful if a comparison were made of the data reported in this paper with data reported on previous tests with pulverized-coal-firing. For example, with a given rate of heat release per square foot of tube surface exposed in the furnace, what is the relative rate of heat absorption, or what are the differences in delta t, what differences are there in the temperature of gases leaving the furnace, and reasons for these differences?

It can be assumed that the difference in heat-radiating ability of a nonluminous gas flame as compared to a luminous pulverized-coal or oil flame accounts for the difference in proportion of heat absorbed in the furnace envelope as radiated heat. It also can be assumed that if the natural-gas flame was luminous instead of nonluminous it would have a greater radiating capacity. As a matter of fact, tests at Battelle have indicated that luminous gas flame will radiate more heat than will nonluminous gas flame. It would be of interest if comparative tests could be made in the same furnace and under the same conditions but varying only the difference in the luminosity of the gas flame, determining the comparative heat absorption in the furnace walls, and comparing the average temperature of gases leaving the furnace. Some such method could reduce the difference in superheated-steam temperature in multiple fuel-fired furnaces as between pulverized coal, oil, and natural gas, fired in the same furnace.

[8] Vice-President, Riley Stoker Corporation, Worcester, Mass. Fellow ASME.

F. G. Ely.[9] As the authors point out, this report on the performance of a natural-gas-fired furnace, which is free from ash deposits on the heat-absorbing surfaces, should provide a valuable reference for comparison with coal-fired furnaces in which ash is a prominent factor.

From Fig. 46 of the paper it is noted that in spite of the clean surface, the values of furnace-absorption efficiency are appreciably lower than those of coal-fired furnaces reported in previous committee tests. This may be due in part to the difference in flame luminosity, to the influence of gas-flow patterns, and to the specific arrangement of tubes and refractory in the furnace-wall construction.

It would be of interest to include further information on the construction of the water-cooled floor area, the over-all dimensions of the furnace shown in Fig. 1 of the paper, and a sketch showing the arrangement of rear-wall screen tubes installed prior to test No. 15.

As regards the gas-flow pattern, the authors' interpretation, based on furnace-wall isotherms and the observed color of refractory, appears to be quite reasonable. It is unfortunate that means were not available for introducing some additive which would make the gas stream visible for confirmation of these observations. Further interest would be afforded by comparative tests using only the upper row of burners, to disclose the effect on Δt profiles, gas-flow patterns, and furnace-absorption efficiency.

It is gratifying to note the progress made in calibration checks on testing equipment, such as thermocouple radiation shields, and furnace-tube thermocouples, under circumstances where advantage could be taken of the ash-free condition of the gas.

Ralph Scorah.[10] The authors in collaboration with the owners of this steam generator are to be congratulated on having presented an exceptionally fine paper based on very carefully conducted tests. We note that gas temperatures above about 3000 F were not attempted in order to preserve the instrument. However, the gas temperatures observed below 3000 F can be extrapolated so as to indicate the probable maximum furnace temperature, and this extrapolated temperature can then be compared with the calculated adiabatic temperature of combustion. We would like to ask if the authors could include such data in their closure.

Authors' Closure

Mr. Craig suggests that a luminous gas flame will radiate more heat than will a nonluminous flame. In the same flame volume and shape this is probably true, but for the same heat input, luminosity could be achieved practically only by delaying combustion. Consequently, even though the effective emissivity of the luminous flame would be greater, the mean radiant temperature would be lower and it is conceivable that no net change

[9] Consultant, The Babcock & Wilcox Company, Research & Development Department, Alliance, Ohio. Mem. ASME.

[10] Professor of Mechanical Engineering, University of Missouri, Columbia, Mo.

in total radiation would occur. This is a recurring question, particularly in open-hearth and glass-tank firing, but in these cases a long flame is preferred because of more uniform distribution of heat; the fact that it is luminous is the result of delayed combustion.

Mr. Craig suggests that the results of these tests be compared with those obtained from tests made of pulverized-coal-fired furnaces. The Furnace Performance Factors Committee plans at a later date to make a comprehensive correlation of its work with the objective of finding such general relationships as may exist.

Mr. Ely's comments regarding furnace heat-absorption efficiency are probably correct, and it is interesting to note in this connection that the heat absorption rates up to about 60,000 Btu per hr ft^2 were attained at Sterlington, whereas it was about 40,000 in two pulverized-coal-fired furnaces studied previously.

In answer to Mr. Scorah's discussion, the adiabatic flame temperature was calculated for three different values of excess air, namely, 0, 14. and 27 per cent. The last value is the highest excess air for any of the tests, as measured at the furnace outlet. Owing to furnace leakage the excess air in the vicinity of the burners will be somewhat less than that at the furnace outlet. The corresponding adiabatic flame temperature will, therefore, lie between the temperature of a stoichiometric mixture and the temperature for the gas composition at the furnace outlet.

Following are the values calculated:

Excess air, per cent..........	0	14	27
Flame temperature, F.......	3765	3600	3410

In making these calculations the average values of the preheat temperature, and of the atmospheric humidity for all the full-load tests were assumed. The heating value of the gas was taken as the average of determinations on several samples obtained during the test series. Allowance was made for the dissociation of CO_2 to CO and O_2 and for the dissociation of H_2O to H_2, O_2, and OH. However, at the temperatures prevailing it was not considered necessary to allow for dissociation of H_2, O_2, and N_2 into their corresponding atoms.