inted in U.S.A.

67-GT-53

an ASME publication

$1.50 PER COPY
75C TO ASME MEMBERS

Supplementary Firing of Gas Turbine Exhaust Systems

ED GJERDE

Vice President, Engineering,
Hydro Combusion Corporation,
Santa Fe Springs, Calif.

Several factors require consideration in designing the most effective supplementary fired waste-heat recovery system. Among the problems for which solutions must be found are temperature profile going into the waste-heat recovery unit, flame length and stability, effect of laminar flow characteristics of exhaust streams, effects of radiation on exhaust temperature profiles, exhaust-duct velocity limitations, and the adverse effects of flame impingement on the waste-heat recovery equipment. The results obtained from a series of tests to determine the optimum system design are described briefly.

Contributed by the Gas Turbine Division for presentation at the Gas Turbine Conference and Products Show, Houston, Tex., March 5-9, 1967, of The American Society of Mechanical Engineers. Manuscript received at ASME Headquarters, January 23, 1967.

Copies will be available until January 1, 1968.

Supplementary Firing of Gas Turbine Exhaust Systems

ED GJERDE

PURPOSE

Due to the increasing attention being given to the question of whether or not to install a supplementary fired waste-heat recovery unit in order to obtain maximum efficiency from a gas turbine system, the purpose of this paper is to identify and suggest solutions for such problems as might ordinarily be expected to appear in the course of selecting, installing, and operating equipment for supplementary firing of waste-heat recovery units coupled with gas turbine exhaust systems.

WHY INSTALL A SUPPLEMENTARY FIRED WASTE-HEAT RECOVERY UNIT?

The. use of the gas turbine as a prime source of power in industrial applications has been proven very successful, based on the reliability and versatility of the system. The efficiency of the gas turbine system has been improved by the addition of heat-ecovery equipment that utilizes the hot exhaust gases from the gas turbine to generate additional useful thermal energy. The heat-recovery units that are usually employed are waste-heat boilers. The term "total energy system" is that ordinarily used to describe the method of using a gas turbine driving a generator, with the exhaust gases from the turbine being directed through a waste-heat boiler, where the heat from the exhaust is used to provide additional useful energy.

In some cases, the demands on thermal-energy recovery systems are exceeding the thermal-energy potential of the gas turbine exhaust stream. Because of these demands, a new concept in the total energy system is coming into prominence: that of adding heat energy to the *gas* turbine exhaust stream. This is accomplished by the burning of additional fuel in the duct, which increases the energy potential of the exhaust gases--thus making it possible to meet the demands of the thermal-energy recovery system.

FACTORS AFFECTING PERFORMANCE

The successful supplementary firing burner must provide the additional thermal energy required of the system, and provide an acceptable temperature profile into the heat-recovery unit. The controlling factors that determine the *temperature* profile are

(a) flame length and stability of the supplementary firing burner

(b) velocity of the gas turbine exhaust gases at the point in the exhaust duct where the burner is mounted

(c) addition of heat energy required, in terms of Btu/lb of exhaust gas flow per hr

(d) distance between the face of the supplementary firing burner and the face of the heat-recovery unit

(e) distribution of exhaust gas flow in the exhaust duct, upstream of the supplementary firing burner

The most important of the factors listed is the flame length and stability, under all operating conditions. It is desirable to maintain a minimum flame length, to insure that complete combustion is occurring in the vicinity of the burner heads. When flame length exceeds 18 to 40 in., there is a good indication that the fuel-to-air ratio is too high, and combustion is extending into the duct area, where mixing and cooling will occur, with the result that incomplete combustion is probable.

Extended flame length will .create undesirable temperature profiles, and, in some cases, particle burning has been found to occur as far down the duct as 40 ft from the face of the burner. When this condition exists, spot overheating of the heat-recovery unit will occur because of flame impingement, and the effective heat transfer in the heat-recovery unit will be limited to that hot spot created by the excessive flame length.

The design of the supplementary firing burner should be such that the maximum exposure of the exhaust gas from the turbine to the flame of the burner is accomplished--with a minimum of pressure drop across the burner. In evaluating the design and construction of supplementary firing burners, it was found that ceramic burner heads are very undesirable for this application because of heat

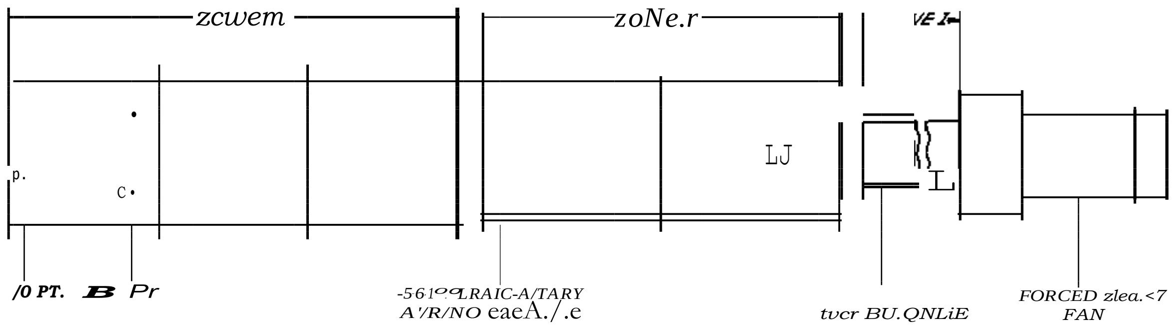

Fig. 1 Drawing of test cell

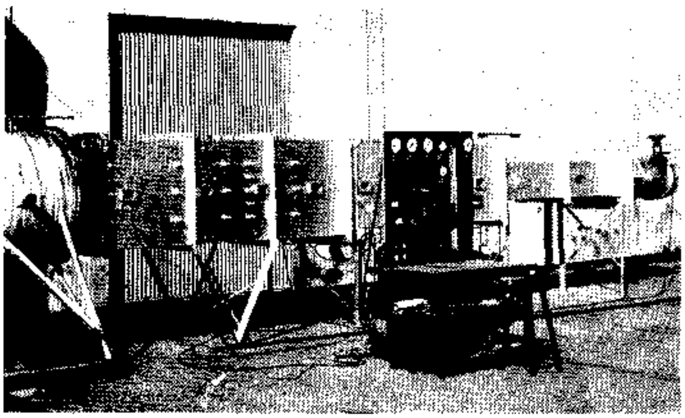

Fig. 2 Photograph of test cell

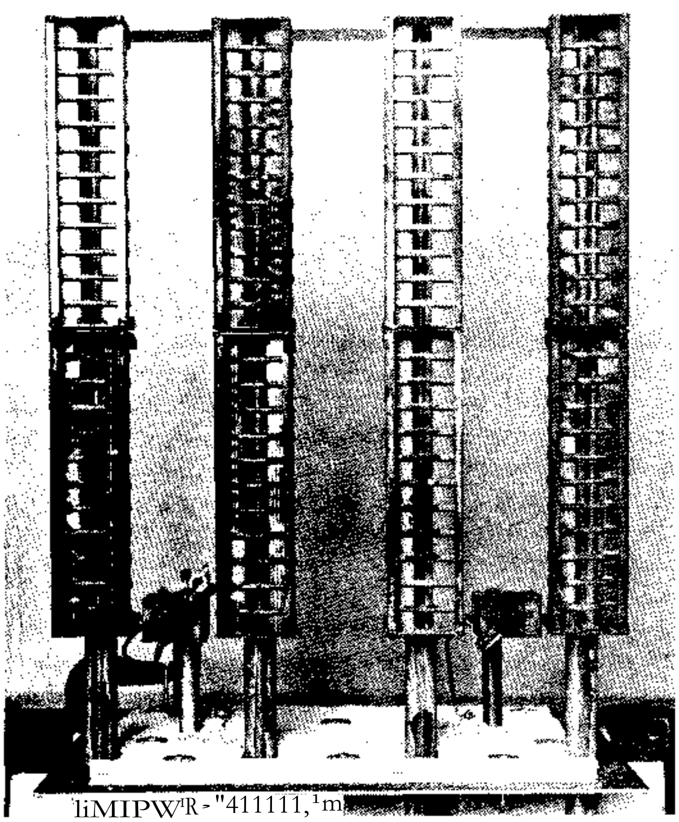

Fig. 3 Photograph of supplementary firing burner in test cell

retention, weight, breakage due to thermal shock, unstable flame condition in the burner, and the Dhysical size (which causes excessive pressure crop in the exhaust duct). Stainless steel was found to be the best material for this application, as it eliminates these problems.

DESCRIPTION OF TEST PROGRAM TO DETERMINE PERFORMANCE

To evaluate the supplementary firing system, a test cell was constructed as shown in Figs.1 and 2. To simulate the exhaust flow from a gas turbine exhaust system, a forced-draft fan was used to provide the air for the system, which is a part of the cold-air Zone I in Fig.1. At the transition between Zone I and Zone II a duct-mounted burner was installed, which is capable of heating the air going into Zone II up to a typical gas turbine exhaust temperature, at any rate of airflow weight within the limits of the forced-draft fan.

In the transition section between Zone II and Zone III, a supplementary firing gas burner was installed, having the configuration shown in Fig.3. This array of stainless steel burner heads with stainless steel headers is capable of providing the necessary heat release to simulate a typical supplementary firing burner in a gas turbine exhaust system. The physical size of each of the heads is 3 in. wide by 12 in. long, Fig.3. The pressure drop created by this type of burner might range from a maximum of 0.25-in. H_2O to a minimum below 0.05 in. H_2O, in a typical gas turbine exhaust-duct installation.

Temperature profiles were taken in a horizontal plane across the duct, Fig.1, by the use of an aspirating thermocouple probe which was long enough to transverse the full width of the test cell. By careful location of the entry holes for the temperature probe, it was possible to obtain the temperature reading at any point in the duct (although entry holes were provided also to permit insertion of the probe in a vertical

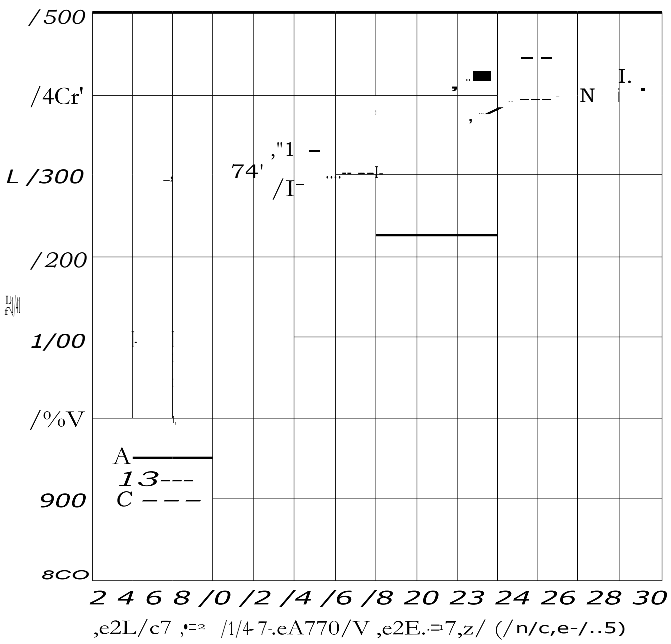

Fig. 4 Graph of temperature profile at 3500 fpm at 8 ft

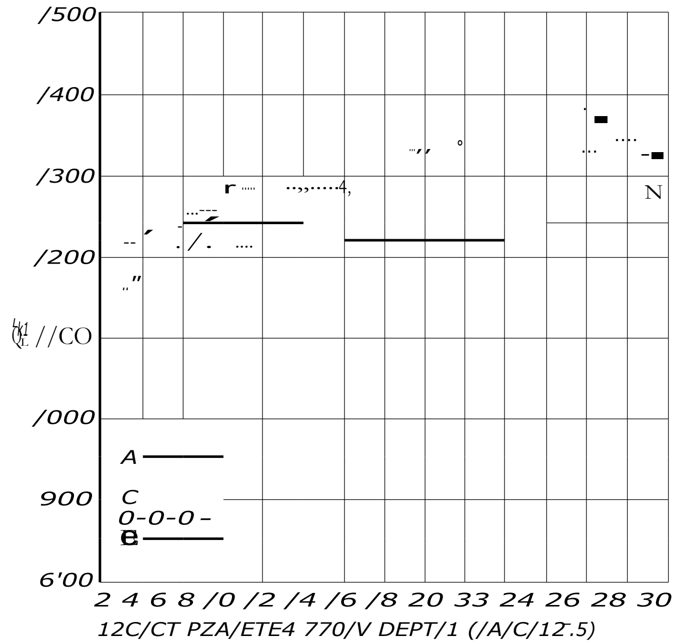

Fig.5 Graph of temperature profile at 3500 fpm at 10 ft

plane as well as in the horizontal plane, no significant data were obtained by utilizing the additional locations that would alter the results reported).

The mass flow through the supplementary firing test burner, Fig.3, was set at 116.5 lb/min/sq ft at 800 F--which represents a typical gas turbine exhaust condition for an application of this kind. Temperature profiles were taken at a point 8 ft downstream from the face of the supplementary firing burner, at locations A, B, and C. Fig.1 shows the location of the probe points and Fig.4, the graph of the temperature profiles taken at this point. Temperature profiles were taken also at a point 10 ft downstream from the face of the supplementary firing burner, at locations A, B, C, D, and E. Fig.1 shows the location of the probe points and Fig.5, the graph of temperature profiles taken at this point.

The fuel flow rate into the supplementary firing burner was calculated to provide a mean average temperature of 1300 F in Zone III of the test cell. Taking the 10-ft test readings, Fig.5, it is quite evident that a temperature profile of 1300 F   100 deg F is reasonable. These conditions are representative of what can be done in temperature profiles on waste-heat recovery systems. The velocity of the 800 F exhaust airflow through the supplementary firing burner was 3550 fpm.

OBSERVATIONS RESULTING FROM TEST PROGRAM

It is imperative that the temperature of the hot gases going into the heat-recovery unit have as even a temperature and mass flow weight profile as possible, as this allows even heat-transfer rates into the convection areas of the heat-recovery unit which will result in a higher thermal efficiency for the entire system.

The effects of radiation on the convection section of the heat-recovery unit is relatively low. In general, radiation will represent 3 to 7 percent of the total heat transfer of the system, calculated on the basis of radiation from non-luminous gases,[1,2] which, in this case, will be water vapor and carbon dioxide at 1300 to 1500 F. The percentage of radiation will increase as the temperature of the exhaust gases increases, regardless of the flame length; but it will remain relatively low in terms of total heat transfer of the system. These conditions will not hold true when extended flame lengths are encountered, and where flame impingement occurs.

[1] Chemical Engineering Handbook, Chief Editor, J. H. Perry, McGraw-Hill Book Company, Inc., New York, N. Y., 4th edition, 1963, pp. 10-40, et seq.

[2] R. M. Fristrom and A. A. Westenberg, Flame Structure, McGraw-Hill Book Company, Inc., New York, N. Y., 1965, p. 50, et seq.

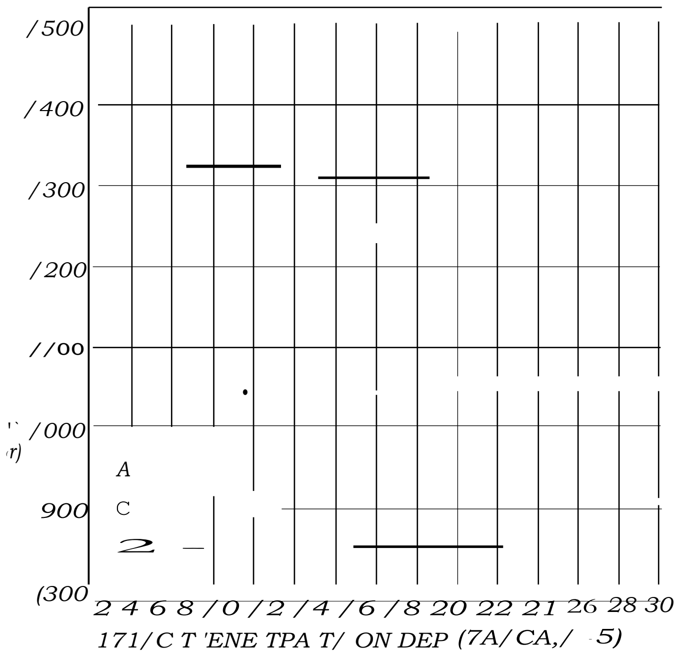

Fig. 6 Graph of temperature profile at 1020 fpm at 10 ft

The velocity of the gas turbine exhaust in the area of the supplementary firing burner is important, and the test data indicate that a velocity of 3500 fpm ± 500 fpm appears to be the most desirable range. At velocities of 6000 fpm, combustion was found to be stable and turndown ratios were excellent, but the temperature profile was undesirable because of the laminar-flow effect of the hot gases off the burner heads and the colder air from the gas turbine exhaust. To obtain the same temperature profile (or mixing of the hot and cold gases) as was obtained at a velocity of 3500 fpm, the duct length between the face of the supplementary firing burner and the point at which the temperature profiles were taken had to be increased by approximately one third. On the other hand, by decreasing the velocity across the supplementary firing burner to 1020 fpm, stratification will occur in the duct downstream of the supplementary firing burner, Fig.6.

In supplementary firing systems, where the burner is mounted in the exhaust duct and is firing in a horizontal plane, velocities of the exhaust gases in the duct will affect the temperature profile and, therefore, the heat-transfer rate of the heat-recovery equipment. It is important that the exhaust gas velocities in the duct be maintained as close to 3500 fpm as possible during the major part of the operating cycle of the system, Figs.5 and 6. If the burner is mounted in the exhaust duct in such a manner that it is firing vertically, the lower velocity ranges will not represent a problem in temperature profiles.

CONCLUSIONS

The design of the supplementary firing duct burner must be such that the flame length is short--18 to 40 in. maximum—to produce a stable flame in duct velocities ranging from 500 fpm to 6000 fpm; it should provide for automatic ignition of the burner system; and it should provide automatic controls sufficient to effect full modulating control over the operating range of the gas turbine/waste-heat boiler combination.

The pressure drop created by the burner mounted in the turbine exhaust duct should not exceed 0.25 in. H_2O.

The burner heads should be fabricated of stainless steel, and the burner gas headers that are located inside the gas turbine exhaust duct must be of stainless steel.

The optimum exhaust gas velocities in the supplementary firing burner section should be in the range of 3500 fpm 500 fpm for the horizontal-firing burners, and from 500 fpm to 4000 fpm for the vertical-firing burners.

The length of the exhaust duct between the supplementary firing burner and the heat-recovery unit will be governed by duct velocities and the temperature profile required at the heat-recovery unit. Temperature profiles of ± 100 deg F can be obtained in the exhaust duct system of a typical gas turbine installation.