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AIR FORCE FLIGHT DYNAMICS LABORATORY
DIRECTOR OF LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT PATTERSON AIR FORCE BASE OHIO

INVESTIGATION OF SINGLE STAGE INCINERATION OF THE 50 MW ELECTROGASDYNAMICS FACILITY NO_X CONTAMINATED EFFLUENT

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TECHNICAL MEMORANDUM AFFDL-TM-75-45-FXN

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INVESTIGATION OF SINGLE STAGE INCINERATION OF THE 50 MW ELECTROGASDYNAMICS FACILITY NO_x CONTAMINATED EFFLUENT

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April 1975

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FOREWORD

This is a report of an experimental investigation of the possibility of reducing the NO_x in the effluent of an electrogasdynamics test facility to an innocuous level by incineration in a natural gas fired boiler.

This Technical Memorandum has been reviewed and is approved.

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TABLE OF CONTENTS

SUMMARY

This experiment was conducted to determine the feasibility of eliminating the noxious NO_x in the 50 MW Electrogasdynamics Facility effluent by incineration. During the experiment, almost all of the NO_2 was converted to NO, but none of the NO was reduced to N_2 and O_2. Since the results of this experiment demonstrated that direct single stage incineration of the NO_x laden 50 MW Facility effluent does not reduce the total NO_x exhausted, it is concluded that the direct single stage incineration process will not provide effective air pollution control for the 50 MW Electrogasdynamics Facility.

INTRODUCTION

One of the characteristics of any electric arc heated gasdynamics test facility such as the 50 MW Facility, is that oxides of nitrogen (NO_x) are formed. The extremely high air temperatures attained when the air is passed through an electric arc causes dissociation of the diatomic oxygen and nitrogen into oxygen and nitrogen ions. When the air is cooled, nitrogen oxides are formed. It has been estimated that as much as five percent of the 50 MW Facility test gas is converted to NO_x during recombination.

Some of the NO_x is removed by a barometric condenser which is part of the pumping system, but concentrations as high as 20,000 parts per million of NO_2 and 15,000 parts per million of NO have been measured at the outlet of the pumping system. A scrubber has been used to remove the NO_x from the 50 MW Facility pumping system effluent, but scrubbing has proved inadequate. A crude combustion experiment indicated that it might be feasible to reduce the NO_x by connecting the 50 MW Facility exhaust stack to a boiler system forced draft fan inlet and incinerating the NO_x in the boiler combustion chamber.

This experiment was conducted in order to ascertain whether or not the direct incineration process will effectively reduce the noxious NO_x contaminents in the 50 MW Facility effluent to an innocuous level.

TEST OBJECTIVES

The overall objective of this test program was to investigate the direct incineration process as an acceptable method for reducing the NO_x concentration in the 50 MW Gasdynamics Test Facility effluent to an innocuous level.

The specific objectives of this test were (1) to verify that there would be no degradation of the boiler operating characteristics caused by mixing NO_x with the combustion air; (2) to determine how much of the NO_2 from the 50 MW Facility could be reduced to NO during normal boiler operation; and (3) to determine whether or not any part of the NO could be reduced to N_2 and O_2.

EQUIPMENT

The 50 Megawatt Facility vacuum pumping system incorporates a two stage steam ejector system. The steam ejectors are driven by two natural gas fired boilers each with a capacity of 110,000 lb per hour of steam. One of these boilers was used for this experiment. The boiler when operated at maximum load, uses approximately 50,000 scfm (Reference 4) of air and 2750 scfm (Reference 5) of gas. The adiabatic flame temperature of the boiler is 3150°F (Reference 1).

The test gas was a commercially furnished 100 pound bottle of nitrogen tetraoxide (N_2O_4) pressurized by nitrogen. The liquid N_2O_4 flow rate was measured by a Fisher Porter Rotometer rated at 1.84 gpm of water, full scale. The N_2O_4 was injected into the inlet plenum of the 50,000 scfm forced draft fan. The N_2O_4-air mixing time prior to entering the boiler was 0.56 seconds. This is sufficient time for nearly all the N_2O_4 to dissociate the NO_2 based on the first order rate constant of $10^{16} \exp(-13000/RT)$ when R = 1.98726 cal/(g-mole)(°K) and T = 300°K (Reference 3). The residence time of the gases in the boiler is between 1.4 and 1.7 seconds. The N_2O_4 injection system is shown in schematically on Figure 1.

The steam ejector system was used to load the boiler. One stage is designed for 47,700 lb per hour of steam of 200 psig, the other is rated at 149,500 lb per hour of steam at 200 psig.

INSTRUMENTATION

The normal boiler instruments were used to obtain steam pressures and furnace draft data.

Stack and furnace temperature thermocouples were specially installed for this test. The stack temperature thermocouple is located at the junction of the boiler case and the stack. The furnace temperature thermocouple is platinum vs. platinum-10% rhodium bare couple at the end of a two foot long ceramic probe installed through one of the flame viewing ports.

Stack sampling instrumentation included a stainless steel pitot type probe located in the center of the stack about 12 feet above the boiler and a stainless steel bellows pump, located about eight feet from the probe, which pumped the stack sample to the gas analyzer in the boiler control room. The sample pump was a Metal Bellows Corporation model MB-150. Sample flow rate was eight liters per minute and residence time in the tubing was about 18 seconds. The stack sampling arrangement is shown schematically on Figure 1.

The stack gas NO_x concentration was measured with a portable NO_x analyzer. The analyzer incorporates a pair of Beckman instruments, one a nondispersing IR instrument with an NO filled detector and the other a UV instrument filtered for NO_2 detection (Reference 2). A cold trap (dry ice temperature) is in the line to the NO analyzer to remove the NO_2 and water vapor. Response time for the NO_2 section of the analyzer is about five seconds and for the NO section about ten seconds. The instruments were calibrated with gases containing 425 ppm NO_2 and 45 ppm

NO in N_2; 894 ppm NO_2 and 81 ppm NO in N_2; and another containing 1160 ppm NO in N_2.

The furnace temperature, the NO concentration and the NO_2 concentration were recorded on Hewlett-Packard strip charts operating at two inches per minute. All other data were recorded manually once every minute during high fire operation of the boiler.

TEST PROCEDURES

The test was conducted in two phases consisting of one run each. The first was used to establish a base line of operation. The second to test the NO_x incineration in the boiler. The NO_x analyzer was calibrated on-line before and after each run. Boiler operation was the same for both runs. The boilers were brought to approximately 100 psig steam pressure at low fire. Then the gas flow was increased to maximum flow rate. When boiler pressure reached 200 psig, valves to the steam ejectors were opened. Steam flow to the ejectors was controlled manually so as to maintain 220 psig in the boiler with near maximum gas flow. This condition was maintained for eight minutes during the first run and 13 minutes during the second run. The N_2O_4 flow was started two minutes after the steam flow started during the second run. The flow rate was adjusted to eight pounds per minute. After the N_2O_4 flow was stopped, boiler operation was continued for several minutes to purge it of all NO_2. Time, boiler steam pressure, wind box pressure, furnace pressure, main steam header pressure, steam pressure to ejectors, outside air temperature, N_2O_4 flow rate, and stack temperature were manually recorded. The stack analysis data and furnace temperature were recorded on strip charts which were started before the boiler was fired.

RESULTS

The first run was made to establish a base line for the critical data. Furnace temperature was determined to be 2750°F. There was no measurable NO_2 in the flue gas. The NO concentration in the flue gas averaged 120 ppm, see Table II.

The second run was made to satisfy the test objectives. Neither the flame temperature nor the stack temperature varied when the flow of NO_2 to the boiler was started. The test N_2O_4 flow rate of eight pounds per minute is approximately equivalent to the flow rate of NO_x from the 50 MW HTL when operating at 3 1/2 pounds per second airflow. Flue gas analysis showed NO_2 concentration to be 70 ppm and NO concentration to be 1370 ppm making the total NO_x concentration 1440 ppm, see Table III. A simplified overall mass balance of the flow through the boiler furnace (Table I) indicates that the NO_x concentration would be 1285 ppm if no NO was formed and if none of the NO_2 was reduced beyond NO.

Stack analysis (Table II and Table III) shows that if the NO_x concentration from the boiler, determined by the data from the first run, is subtracted from the total NO_x concentration of the second run (1440-120 = 1320 ppm) the results are in close agreement with the theoretical mass balance which was based on inlet conditions. This indicates that none of the NO_x was totally reduced to N_2 and O_2 but that about 95% of the NO_2 was reduced to NO. In a computer model analysis of this experiment made prior to the actual test, L.K. Burnell and J.D. Hyde (Reference 1) predicted that NO would not dissociate into N_2 and O_2; that substantial

(250 to 700 ppm) amounts of NO_2 would be left undissociated; and finally, that there would be no real abatement of NO_x. The amount of NO_2 in the stack effluent was considerably below the prediction but none of the NO was reduced; therefore, the prediction of no real abatement was substantiated.

TABLE I

MASS BALANCE

Basis: 1 Minute

IN			OUT*		
Air	129.1	Moles	Air	116.75	Moles
Methane	6.17	Moles	CO_2	6.17	Moles
NO_2	0.174	Moles	H_2O	12.34	Moles
			NO_x	0.174	Moles
Total	134.43	Moles	Total	135.43	Moles

$$NO_x \text{ conc.} = \frac{0.174}{135.43} \times 10^6 \text{ppm}$$

$$= 1285 \text{ ppm}$$

*Assumes complete combustion, i.e.:

$$6.17\ CH_4 + 12.34\ O_2 \rightarrow 6.17\ CO_2 + 12.34\ H_2O$$

TABLE II

STACK ANALYSIS - RUN 1

NO	120 ppm
NO_2	0

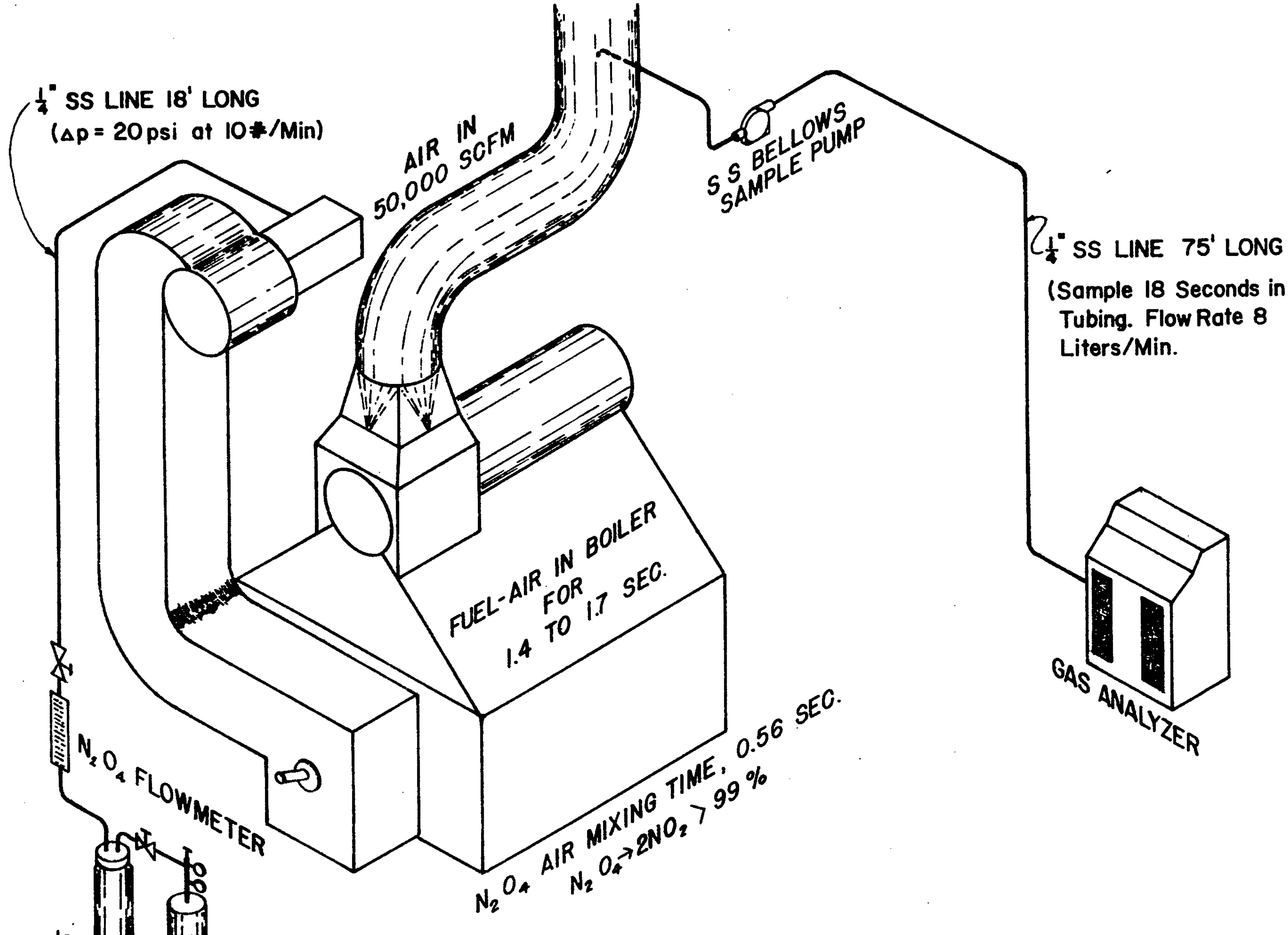
TABLE III

STACK ANALYSIS - RUN 2

NO	1370 ppm
NO_2	70 ppm

CONCLUSIONS

One boiler can ingest a large (eight pounds per minute) quantity of NO_x without any perceptible degradation of boiler performance. While 95% of the NO_2 was reduced to NO, none of NO was reduced to N_2 and O_2; therefore, the total NO_x emission remained constant and unimproved. Direct incineration of the 50 MW effluent in the boilers is not an effective technique for reducing its air pollution contribution.



NO_x INCINERATION
in
50 MW FACILITY BOILER

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