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TESTING AND RATING OF AN ATMOSPHERIC, GAS-FIRED FURNACE EQUIPPED WITH A BURNER AIR INLET DAMPER

ABSTRACT

An atmospheric furnace with an integral draft diverter and an electro-mechanical burner box inlet damper was tested by the tracer gas method for the development of a test procedure. Tracer gas tests were conducted under two conditions: with the diverter open, and with the diverter sealed and the stack restricted. Test results indicated that the flue gas flow patterns inside the heat exchanger were different for the two conditions. There was reverse flow in one of the clam shells when the diverter was open, but no flow reversal when the diverter was sealed. The off-cycle sensible loss which was a measure of the effectiveness of the burner box inlet damper gave similar value for both conditions. Because of the change in flow pattern and the fact that the furnace normally operated in the field with the diverter open, a recommended test procedure was developed which requires that the tracer gas test should be conducted with the diverter open. A calculation procedure was developed to compute the annual fuel utilization efficiency for the type of furnaces that employ a burner box inlet damper or flue damper for off-cycle loss reduction.

Key words: ANSI/ASHRAE 103, atmospheric burner, burner air inlet damper, DoE test procedure, flue draft factor, loss factor, off-cycle loss, optional procedure for power burner, tracer gas test

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TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

In August 1989, the Lennox Industries Inc. submitted a Petition for Waiver to the Department of Energy (DoE) on their G20 and G20R series of atmospheric, gas-fired furnaces with an integral electro-mechanical inlet damper on the burner box. The function of the damper is to reduce the air flow through the burner and the heat exchanger when the burner is off. This will reduce the energy loss from the furnace during the off period. The damper opens when the burner is on and closes by spring force when the burner is off.

The waivers requested by Lennox pertain to the uniform test method for measuring energy consumption of furnaces and boilers as specified in Federal Register, DoE 10 CFR part 430 and ANSI/ASHRAE 103-1982. One part of the Petition for Waiver requested permission to use the optional tracer gas method (which was specified as applicable only for units with power burners or direct vent in the uniform test method) on the G20/G20R atmospheric burner units to determine the off-cycle draft factor D_F. The reason given was that the burner inlet damper restricts air flow through the heat exchanger during the off-cycle just like the stopping of the blower in a power burner unit. Since a D_F value of 1 is assigned to furnaces with atmospheric burners in the test procedure, a value of less than 1 if shown by the tracer gas method can increase the value of the computed annual fuel utilization efficiency (AFUE) by several percentage points depending on how small D_F is.

Following the publication of Lennox's Petition for Waiver in the Federal Register, written comments were submitted to DoE by manufacturers and organizations with regard to the requested waivers. Objections were raised by several organizations on the use of the tracer gas method to determine the off-cycle draft factor D_F for an atmospheric burner with an integral draft diverter for draft relief, and the specific way the method is applied during a test. Lennox proposed to use the test method specified in the current test procedures for power burners with draft diverters. The procedure stated that, following the steady-state test, the integral draft diverter should be sealed and thermally insulated and the stack restricted before the cool-down test, heat-up test and tracer gas test are conducted if the optional tracer gas method is used. One of the comments raised by some organizations was that the draft diverter should not be sealed and the stack should not be restricted during the tracer gas test. The reason given was that during the cool-down period (where the tracer gas test would be performed), air flow through the open diverter and up the stack could increase the amount of air flowing into the combustion chamber by aspiration, nullifying part of the effectiveness of the inlet box damper. A sealed diverter would prevent the aspiration and hence would not give a correct result for the furnace which operates with an open diverter in field installation. Another comment was that the tracer gas method does not always give the theoretical flue draft factor value of 1 when applied to atmospheric furnaces without any damper (values varies in the range of 0.85 to 1 were mentioned). Another comment was that the Lennox petition did not give full details of the methodology of the tracer gas method that was used to support the Lennox petition.

Because of the various written comments and objections, DoE requested the National Institute of Standards and Technology (NIST) to conduct an experimental study of the tracer gas method as applied to the Lennox G20 type furnace and make recommendations on its application. A new G20 furnace was provided to NIST by the manufacturer for that purpose. This report describes the results of the study and the procedure recommended by NIST in applying the tracer gas method to the specific type of furnace in question. Tests were conducted to measure the off-cycle flue gas or stack gas flow by using the tracer gas method for both an open diverter and a sealed diverter with restricted stack. The off-cycle sensible heat losses for an open and a sealed diverter, and for a furnace with and without an inlet damper, were computed and compared. Tests were also run to investigate the possibility of reverse flow in the heat exchanger when the diverter was open and when it was sealed. The results of the tests indicated that the operation of the inlet damper did result in a lower off-cycle sensible loss. The results also showed that there was reverse air flow down one of the clam shell heat exchanger during the off-cycle when the diverter was open and no flow reversal when the diverter was sealed. These results are described in the following sections.

Analysis of the test data showed that the tracer gas test can be conducted in the test stack section of the test set-up which is a more convenient location to do the test. A recommended tracer gas test procedure was developed for this type of furnace to account for the decreased off-cycle loss and increased efficiency due to the operation of the burner box inlet damper. Also, at the request of DoE, the Lennox G20 furnace was sent to the ETL Testing Laboratories, Inc., an independent testing organization, for test in according to the NIST recommended test procedure. The test procedure and a comparison of the efficiencies of the furnace obtained from test data at NIST and ETL are presented in the following sections.

2. TEST SET-UP AND INSTRUMENTATION

The Lennox model G20 is a gas-fired, atmospheric burner furnace with an integral burner inlet damper and an integral draft diverter. A continuous burning pilot light is used as the ignition source. The furnace has a name-plate input rating of 29.3 kW (100,000 Btu/hr). The burner/heat exchanger consists of four curved clam shells, each shell ends in an oval shaped exit plenum. A curved baffle plate at the bottom of the plenum splits the flue gas out of the clam shell into two streams which are mixed again in the plenum after passing the plate. A schematic of the furnace from the manufacturer's manual is shown in Fig. 1. The gas supply to the furnace was from the local utility company. The furnace was installed in a high-bay laboratory space with controlled space temperature. A 1.524 m (5 ft) length of insulated stack (R=1.233 $s \cdot m^2 \cdot K/J$ (7 $hr \cdot Ft^2 \cdot {}^oF/Btu$, or R7 in the trade)) was attached to the diverter outlet collar as specified by the ANSI/ASHRAE 103-1982 (and the revised 103-1988). The stack was linked to an exhaust hood/vent pipe arrangement and exhausted to outside through the rooftop. In addition to the insulation on the stack, the top, the front (excluding the louvered opening), and the two sides of the flue gas collection box (draft hood in Fig.1) were also insulated with R7 foil-faced batt insulation. A 50 mm (2 in.) insulation board (R=2.466 $s \cdot m^2 \cdot K/J$ (14 $hr \cdot Ft^2 \cdot {}^oF/Btu$)) was used to cover and seal the diverter relief opening if and when the test required the sealing of the opening. The test unit was extensively instrumented as specified by the ANSI/ASHRAE 103-1982. In addition to that specified by the ANSI/ASHRAE 103-1982, eight type K, 24 gage thermocouples were installed 76 mm (3 in.) in the flue gas exit plenums of the four clam shell heat exchangers. Two thermocouples were placed in the middle of the top and bottom halves of each oval shaped plenum to obtain the approximate average flue gas temperature in each plenum as well as the overall average temperature of the flue gas exit from the four plenums. For the tracer gas test, sampling (and injection) metal tubes were installed. These included (1) four tubes inserted into the bottom and midpoint of the burners, one to each burner, mainly for injection of the tracer gas, (2) four tubes of equal length inserted 76 mm (3 in.) into the center of each of the exit plenums and manifolded together to measure the average concentration of the sample gas, (3) four perforated tubes (six equally spaced holes to each tube) of equal length placed along the length of each exit plenum over one edge of the baffle plate with the holes facing one of the two split flue gas streams coming up the clam shell to measure the average concentration of the tracer gas in each clam shell, (4) one perforated tube with four equally spaced holes along the diameter of the stack 0.38 m (15 in.) from the base of the stack, (5) one perforated tube same as the one in (4) but placed 0.3 m (12 in.) below the top of the stack, and (6) one tube placed near the stack exit downstream of the tube in (5) as a return port for the sampled gas. The gas samples during the tests were analyzed by a carbon dioxide (CO_2) and a carbon monoxide (CO) non-dispersive infrared gas analyzer. The CO_2 analyzer was calibrated with reference gas with known CO_2 concentrations of 2.922, 5.2, and 9.993 percent. The CO analyzer was calibrated with reference gas with known CO concentrations of 10.5, 79.37, and 394.8 ppm. During the test, the sample gas was passed through a condensing beaker immersed in an ice-water mixture and a dryer to obtain the dry sample gas as specified in the Standard.

The sensors were connected to a data acquisition system and a micro-computer. The computer controlled the data scan rate by the use of an off-the-shelf data acquisition and control application software. Due to the large amount of data collected, the data recording rate varied from every 30 seconds per recording during the initial 45 minutes steady-state and 45 minutes cool-down periods of the test, and every five seconds during the cyclic periods of the test where the tracer gas tests were conducted. Each cycle is made up of four minutes of burner on time and 14 minutes of burner off time (which are very close to the 3.87 minutes on-time and 13.3 minutes off-time as specified in the ANSI/ASHRAE 103-1982 for furnaces). Data were analyzed using a commercially available spreadsheet program.

3. TEST PROCEDURE

3.1 Smoke Test

A smoke test was conducted to observe whether there was inflow of air into the clam shell exit plenums at the exits when the main burner was shut off and the burner inlet damper was closed (after the burner has been operated for 20 minutes). Incense was used to generate the smoke.

A. Conduct a smoke test at the outlet of the plenum of the clam shell through the inlet of the diverter opening to observe the flow pattern of air and flue gas at the plenum exit plane.

B. Taking off the louver of the diverter to expose the exit plane of the clam shell plenum, conduct smoke test at the exit plane to observe again the flow pattern of the smoke.

The results of the smoke test showed that there was some draft relief air flow into the exit plenums. However, the smoke became too thin to give any outflow pattern. Also, it was not possible to determine how far the inflow went inside the heat exchangers. Therefore, no additional smoke test was conducted.

3.2 Tracer Gas Test

As is shown in the Appendix A in this report, an effective off-cycle loss factor for an atmospheric furnace with a burner box inlet damper can be defined as:

$$K_L = L_{S,OFF}(\text{measured with damper closed}) \,/\, L_{S,OFF}(\text{measured with damper open}) \quad (1)$$

The following test procedures were used in most of the tests that employ the tracer gas method with carbon monoxide (CO) as the tracer gas to determine the off-cycle sensible heat loss.

- Run steady-state (45 min.), cool-down (45 min.), and cycling tests of heat-up (4 min.) and cool-down (14 min.). Tracer gas test was conducted during the cool-down periods of the test.

- At the beginning of the cool-down period of the first cycle, sample the background CO concentration of the stack gas. This background data is needed to compute the net tracer gas concentration value due to the injection of tracer gas.

- Start the second heat-up and cool-down cycle. Inject tracer gas (mixture of CO and nitrogen with a known CO concentration) at a constant flow rate at one of several locations (at the burners, at the heat exchanger outlet, or at a plane 0.38 m (15 in.) downstream of the base of the stack). The location is described in the individual tests. The injection is to start at one (1) minute before the end of the heat-up period. Continue the injection flow till the end of the cyclic cool-down period.

- Sample of the tracer gas is taken at one of two locations (at the heat exchanger outlets, or at a plane inside the stack 0.3 m (1 ft.) below the top exit of the stack). The location is described in the individual tests. The concentration of the tracer gas is analyzed and recorded every 5 seconds till the end of the cyclic cool-down period.

The tests that were conducted are described below.

1. Determine the off-cycle sensible loss with the diverter sealed and the stack restricted and the burner box inlet damper open during cool-down:

   This test was conducted to check the accuracy of the tracer gas method when it is conducted on an atmospheric furnace without an inlet damper. The off-cycle sensible heat loss is computed by both the ANSI/ASHRAE 103-1988 computerized calculation procedure and by the tracer gas method where the product of the measured off-cycle flue gas mass flow rate and the flue gas temperature (as measured at the test plane in the stack) integrated over the entire off-cycle period is used to compute the loss. The results are compared. A loss factor K_L' is computed from the off-cycle sensible heat loss calculated from the tracer gas data and the same loss from the ANSI/ASHRAE 103 calculation procedure where the value of D_F is assumed to be 1. That is,

$$K_L' = (\text{measured } L_{S,OFF}) / (\text{ASHRAE } L_{S,OFF} \text{ with } D_F=1) \tag{1a}$$

Theoretically, the value of K_L' should be the same as D_F and should be equal to 1 for an atmospheric burner without an inlet damper. However, the term K_L' defined here is different from the flue draft factor D_F defined in the ANSI/ASHRAE 103. There the term D_F is defined as the ratio of the off-cycle flue gas mass flow rate evaluated at the steady-state temperature to the steady-state on-period flue gas mass flow rate. Here the term K_L' is defined as the ratio of the measured to calculated off-cycle sensible losses.

2. Determine the off-cycle sensible loss with the diverter blocked and the stack restricted and the burner box inlet damper closed during cool-down - <u>the present optional tracer gas procedure in ANSI/ASHRAE 103-1982 for power burners</u>.

   Conduct test as in Test 1 above but with the inlet damper closed during cool-down as designed. The resulting off-cycle loss using the ANSI/ASHRAE 103 optional tracer gas calculation procedure (for power burners) and the integrated (over 13.3 minutes) loss using the detailed (every 5 seconds) tracer gas and flue gas temperature data are compared to check the agreement between the two calculation procedures.

3. Determine the off-cycle sensible losses with diverter open, and the burner box inlet damper open during the cool-down periods: The integrated loss from the tracer gas and stack gas temperature data is computed and compared with those from Test 1 to see the effect of the opening and sealing of the draft diverter on the off-cycle loss.

4. Determine the off-cycle sensible losses with diverter open, and the burner box inlet damper closed during the cool-down periods: The integrated loss from the tracer gas and stack gas temperature data is computed and compared with those from Test 2 to see the effect of the opening and sealing of the draft diverter on the off-period loss when the inlet damper is operating as designed.

The above four tests are conducted with the tracer gas sample collected in the stack. The following tests are conducted with the tracer gas sample taken from the heat exchanger exits which are much harder to perform. The results will determine whether tracer gas test can be conducted in the stack.

5. Run the following tests with the inlet damper <u>open</u> during cool-down <u>AND</u> <u>closed</u> during cool-down: **Off-cycle losses measured in heat exchanger.**

   A. Inlet damper open case:

      (1) Run the steady-state and cool-down periods as in Test 1 above.

(2) Start the first cyclic heat-up and cool-down cycle. Background sample taken with a perforated long tube inserted above the baffle plate in the exit plenum of the first clam shell (as described in the test set-up section of this report) during the cool-down period.

(3) Start injecting tracer gas at the burner of the first clam shell one minute before the second heat-up period ends.

(4) Tracer gas test sample taken in the first clam shell as in (2) above during the cool-down period that followed (second cycle).

(5) Continue steps (2) to (4) for clam shells 2, 3 and 4 in the next six cycles of heat-up and cool-down.

B. Inlet damper closed case - repeat tests in A above.

The above tests (5A and 5B) were conducted to measure the flue gas mass flow rate through each clam shell which were also conducted by Lennox (Test 5B). The sum of the computed off-cycle sensible losses for the four clam shells was used to check the results of Tests 3 and 4 above where the tracer gas samples were collected in the stack with the diverter open.

6. The results of test 5-B above indicated that flow reversal in clam shell 1 and possibly shell 4 (the two side shells) might have occurred (this will be described in the Test Result section later on in this report). To check whether this was the case, a test was conducted where tracer gas was injected through the perforated tube in the exit plenum of clam shell 1 and sample gas was taken from the tube in the bottom of the burner 1. If there is no flow reversal (downward flow), the sample would indicate only background concentration of the tracer gas. Results indicated that there was downward flow in shell 1. The same test was also conducted in shell 4. The results of these tests will be shown in the Test Results section.

7. With the diverter blocked and the stack restricted as in Test 2 above, run the tests as described in Test 5B above (injection and sampling in individual clam shells with the inlet damper closed). This is compared with Test 5B to examine the effect of the diverter's opening and blocking on the flow phenomena inside the clam shells. The comparison is used to determine whether tracer gas test should be conducted with the diverter blocked and the stack restricted as proposed by Lennox in the waiver petition.

4. CALCULATION PROCEDURE

In all of the test results analyzed, the concentration value of the tracer gas, CO, in the sample was converted into the mass flow rate of the flue or the stack gas by the following equation:

$$M_{X,OFF} = [(C_I - C_T)/(C_T - C_B)] \cdot \rho \cdot V_T \qquad (2)$$

where $M_{X,OFF}$ = mass flow rate of the flue (X=F) or stack (X=S) gas
C_I = CO concentration by volume of the injected tracer gas mixture
C_T = CO concentration by volume of the sample gas from the flow stream

C_B = background or residue CO concentration by volume in the flow stream
ρ = density of gas at temperature T_T at the flow meter
V_T = volume flow rate of the injected tracer gas mixture

The off-cycle sensible loss rate, $Q_{S,OFF}$, as a percent of the burner on-cycle energy input, at time t (counted from the start of the cool-down) was computed from the $M_{X,OFF}$ and the measured flue gas temperature (X=F) or stack gas temperature (X=S) by the following equation:

$$Q_{S,OFF}\ (@\ \text{time } t) = 100 \cdot [C_P \cdot M_{X,OFF} \cdot (T_{X,OFF} - T_{RA})]/(Q_{IN} \cdot t_{ON}) \qquad (3)$$

where $Q_{S,OFF}$ = off-cycle loss rate as a percentage of burner on-cycle input
C_P = specific heat capacity of air
$M_{X,OFF}$ = flue or stack gas mass flow rate from Eqn.(1)
$T_{X,OFF}$ = measured flue (X=F) or stack (X=S) temperature at time t
T_{RA} = room ambient temperature
Q_{IN} = burner energy input rate
t_{ON} = assigned burner on-cycle time = 3.87 minutes for furnaces

The total off-cycle sensible loss, $L_{S,OFF}$, as a percent of the burner on-cycle input, over the whole off-cycle period (13.3 minutes for furnaces as specified in ANSI/ASHRAE 103-1982) was obtained by summing up the values of $(Q_{S,OFF})\cdot(\Delta t)$ in Eqn. 3 at each time interval Δt (5 seconds for the present test series) for the 13.3 minutes period. Trapezoidal rule of integration was used in this study.

5. TEST RESULTS

The results of the various tracer gas tests described in the previous section are shown and discussed below. Based on the test results, a test procedure using tracer gas method is developed and recommended to be used to test the performance of this particular type of furnaces employing a fast closing (within 3 seconds after furnace is off) inlet burner box damper. Energy savings can then be computed which otherwise would not be shown by the existing DoE test procedure.

(1). Test with diverter blocked and stack restricted, inlet damper open, and tracer gas sample collected in the stack (Test 1):

This test is to check the validity of the tracer gas method for measuring the gas flow rate during the off-cycle period. The stack exit area is restricted when the diverter is blocked so that the CO_2 value measured in the stack matches within a set tolerance (±0.2%) to the average CO_2 value measured in the heat exchanger plenums when the diverter was not blocked. This would assure that the total flue gas mass flow rate through the heat exchangers would not change during steady-state operation of the furnace when the diverter is either open or blocked. For this test, the inlet damper was held open during cool-down and the furnace operated just as an ordinary atmospheric furnace. The ANSI/ASHRAE 103-1982 procedure for an atmospheric furnace can be used to compute a value of the off-cycle sensible loss where the flue draft factor D_F is assumed to be 1. The results of a number of tests computed by the ANSI/ASHRAE procedure (using the flue gas temperature measured in the test plane in the stack) gave a $L_{S,OFF}$ value of from 5.90% to 6.40% (average 6.15%). The tracer gas method conducted in the stack portion of the set-up gave a $L_{S,OFF}$ value of from 5.31% to 5.60% (average

5.45%) when the product of the 5-second flue gas mass flow rate and flue gas temperature was integrated over the 13.3 minutes off-cycle interval. When the ANSI/ASHRAE 103-1982 optional tracer gas procedure for power burner was used (where the value of the tracer gas concentration and flue gas temperature at the point 5.5 minute into the cool-down period were used in the calculation), the loss was 5.95%. Both values of the off-cycle loss by the tracer gas methods (integrated over 13.3 minutes or the ASHRAE-103 optional procedure) agree well with the ASHRAE computer program computed value, with an average ratio of $L_{S,OFF}$(measured) to $L_{S,OFF}$(ASHRAE procedure with $D_F = 1$) of 5.45/6.15 = 0.89 for the integrated tracer gas result and 5.95/6.15 = 0.97 for the optional tracer gas procedure. These values gave an effective loss factor (K_L') value of 0.89 and 0.97 (Eqn.1a), respectively. As mentioned in the Introduction, these values fall in the range of values obtained by some of the commentators. An example of the tracer gas result where the off-cycle flue gas mass flow rate and the computed $Q_{S,OFF}$ as a function of time is shown in figure 2 ($M_{F,OFF}$) and figure 3 ($Q_{S,OFF}$). Note that the flue gas flow rate (measured using the tracer gas concentration data) and the flue gas temperature measured in the stack (sealed diverter) were used in Eqn.3 to compute $Q_{S,OFF}$.

It is noted that the optional tracer gas procedure gave a result closer to the result by the regular ASHRAE procedure ($D_F = 1$) than the integrated tracer gas result. This is because that during the first minute into the cool-down period, the flue gas flow rate and the temperature both decrease rapidly. The uncertainty in measurement, especially at the low side of the gas analyzer scale (due to the initially higher gas flow rate), and the difference in response time of the temperature sensor and the gas analyzer during the period probably gave the less accurate result by the integrated procedure. Note that this effect would appear in all results computed by the integration procedure.

(2). Test with the diverter sealed and the stack restricted, inlet damper closed during cool-down (Test 2 in Test Plan):

This is the procedure requested by Lennox in its Petition for Waiver for the use of the optional tracer gas method. The test is similar to (1) (Test 1) above except that the inlet damper is closed as designed during cool-down. The test result gave an integrated (over 13.3 minutes) off-cycle sensible loss of 1.56%. Using the ANSI/ASHRAE 103 optional tracer gas procedure (using tracer gas and temperature data at the point 5.5 minutes into the cool-down period) gave a loss value of 1.75% which agree well with the integrated value. The flue gas mass flow rate and the off-cycle sensible loss rate are shown in figures 4 ($M_{F,OFF}$) and 5 ($Q_{S,OFF}$).

(3). Test with diverter open, inlet damper open, and tracer gas test conducted in stack (Test 3):

This test is to check the effect of the draft diverter on the off-cycle sensible loss of the furnace when the diverter is not sealed during the tracer gas test. The integrated results over the 13.3 minutes period gave a $L_{S,OFF}$ value of from 3.94% to 4.69%, with an average value of 4.32%. This compares with the value of 5.45% from Test 1 where the diverter was blocked with the stack restricted. The value from Test 1 is about 21% higher because, even though the restriction of the stack when the diverter was blocked resulted in a flue gas mass flow rate through the heat exchanger that was the same as the open diverter case under steady-state conditions, the flow rate through the heat exchanger was different during the off-period for the blocked diverter case due to a higher draft caused by the added stack height at the heat exchanger exit. The total flow rate through the stack was actually higher with the diverter open, but most of the additional flow entered the stack through the diverter opening and did not go through the hot heat exchanger. The stack gas mass flow rate and the off-cycle sensible loss rate are shown in figures 6 and 7, respectively. Comparing Fig.2 with Fig.6 and Fig.3 with Fig.7, it is seen that even though the flow rates through the stack were quite different, the sensible losses were much closer.

(4). Test with diverter open, inlet damper closed, and tracer gas test conducted in the stack (Test 4):

This test is similar to test in (2) (Test 2) above except that the diverter was not blocked during the cool-down and heat-up periods. The tracer gas test (10.9% CO tracer gas) conducted in the stack gave a $L_{S,OFF}$ value of from 1.84% to 1.97%, with an average value of 1.91%. This is a much lower value than the value of 4.32% (Test 3) when the damper was held open. From Eqn.1a, an effective loss factor can be computed as K_L' = (measured loss)/(loss when D_F=1) = 1.91/6.15 = 0.311, or, as will be explained later, from Eqn.1, K_L = 1.91/4.32 = 0.442 if the tracer gas test value of $L_{S,OFF}$ (damper open) is used. An example of the test results is shown in figures 8 and 9 for the measured stack flow rate $M_{S,OFF}$ and the loss $Q_{S,OFF}$ over the 13.3 minutes cool-down period. Comparing to the results in (3) (Test 3), the flow rates and the off-cycle sensible loss rates both showed a lower value for the damper closed case, with a larger percent difference in $Q_{S,OFF}$ than $M_{S,OFF}$. Figures 10, 11, 12 and 13 give a comparison for the two cases from another set of test data. The larger percent change in $Q_{S,OFF}$ is explained by examining figure 12 where the stack temperature variations are shown for the two cases. It is seen that the stack temperature decreased more rapidly when the damper was allowed to close, since a closed damper reduced the air flow through the heat exchanger and the amount of heat energy removed from the heat exchanger. Since the value of $Q_{S,OFF}$ is a product of the mass flow rate and temperature (Eqn. 3), $Q_{S,OFF}$ shows a larger percent decrease than either $M_{S,OFF}$ or stack temperature.

In figure 13 a comparison of the average flue gas temperature as measured at the heat exchanger exit plenums is shown for the damper open and closed cases. It is seen that although there is a major difference in the stack gas temperature between the two cases, the difference in flue gas temperature is fairly small. The reason for the small difference in the flue gas temperatures is that, inside the heat exchanger, heat transfer to the air on the circulating air side of the clam shells predominates. For the test furnace, the circulating air flow rate when the indoor fan is on was more than 0.76 kg/s (100 lb_m/min) or 0.63 m^3/s (1330 cfm) at Standard condition. In contrast, the maximum flue gas flow rate (flue side of the clam shells) was about 0.0114 kg/s (1.5 lb_m/min) when the burner was on. For the test furnace, the fan off time was factory-set at 90 seconds after the burner was off, and this time delay was used during the test. Due to the large fan air flow rate, the decrease in the heat exchanger temperature would be primarily due to the air side heat transfer regardless of the statue of the inlet damper in the first 90 seconds after the burner was off. In Fig. 13 it is seen that the flue gas exit temperature decreased from 235 C (455 F) to 105 C (221 F) during the first 90 seconds. After the fan is off, the much larger flow passage area in the air side gives less resistance to air flow than the flue side in the heat exchanger. This, together with the lower air temperature at the air side, made the air side the predominate side of heat transfer even when the fan is off. Since the heat transfer in the heat exchanger is mainly controlled by the air side and the effect of the flue side is secondary, the flue gas temperature in the exit plenums would be close for the damper open and closed cases as shown in Fig.13.

(5). Test with diverter open, inlet damper open, and injection/sampling in each burner/exit plenum (Test 5A):

This test is to check the difference in results when tracer gas test is conducted in the stack (stack gas data for computation) and in the heat exchangers (flue gas data for computation). Because of the lower flue gas flow rate and the tracer gas test in each individual clam shell, 1.09% CO tracer gas was used for injection in each burner (midpoint of the burner), and flue gas sample was collected by a multi-hole, perforated stainless steel tube in the exit plenum (see Test Set-up). The flue gas mass flow rate and the off-cycle sensible loss in each clam shell were computed and the results of the four clam shells were summed up. The results of the tracer gas concentration in each clam shell and the sum of the flow rates and the off-cycle losses are shown in figures 14, 15 and 16. From Fig. 14 it is seen that the flow through all four clam shells followed the same pattern. Note that the higher the concentration, the lower the flow rate. The shell with the pilot light had the highest flow and the third shell which is located next to the pilot light shell and also has another clam shell on the other side had the second highest flow. The two end shells, each has one side exposed to the cooler side walls of the furnace, had the lower flow rate. Figure 15 shows the sum total mass flow rate through all four shells, and figure 16 shows the total off-cycle sensible loss rate. Because the flow was measured in the heat exchanger, the flue gas temperature in the exit plenums was used to compute the loss. Comparing figures 6 vs. 15 and 7 vs. 16, it is seen that even though the flow rates are very different (Figs. 6 and 15) because one was in the stack and the other was in the heat exchanger and the diverter was open, the losses ($Q_{S,OFF}$) agree well with each other throughout the cool-down period. The total loss integrated over the period was 4.99% versus the <u>average value</u> 4.32% computed in Test 3 above. This indicates that the tracer gas method can be applied in the stack where both the tracer gas sampling and the temperature are simpler to measure. This point will be shown to be true also for the damper-closed case described next.

(6). Test with diverter open, inlet damper closed, and injection/sampling in each burner/exit plenum (Test 5B) AND reverse injection/sampling (Test 6):

The first test is similar to test described in (5) (Test 5A) above except that the inlet damper is allowed to close as in (3) above. The result of the tracer gas concentration in each clam shell is shown in Fig. 17. Here the tracer gas pattern is much different from Test 5A (inlet damper open). The concentration in shell No.1 decreased rapidly after 4 minutes into the cool-down period to almost the ambient level. Similar but much less prominent pattern also happened in Shell No.4. Since it is not possible to have a large upward flow (burner to exit plenum) to cause the dilution in the concentration value in shell No.1, flow from the ambient into the exit plenum of shell No.1 must have occurred. A second test was therefore conducted to determine the possibility of reverse flow in shell No.1 (Test 6 in Test Procedure). In the test, tracer gas was injected into the exit plenum of shell No.1 and sample was taken from the bottom of shell No.1 below the burner. The result showed that the tracer gas concentration increased rapidly at the burner level, indicating that the flow was from the top to the bottom. Figure 18 shows the result of the test. Tests were ran with two different sample-draw flow rates. No difference in results was observed. The same test was also ran in clam shell No.4 as shown in the same figure. No reverse flow was shown in the first 13.3 minutes of cool-down period. However, CO concentration did start to go up at the end of the 14 minutes cool-down period. The reason for the flow reversal is that, for the end clam shells, only one of its surface sees the hot clam shell next to it. The other surface sees the much cooler side surface of the furnace which is cooled by the air circulating the air-side of the heat exchanger when the burner is on and the circulating fan is running. Radiant and convective heat transfer from the clam shell surface to the cooler side surface decrease the temperature of the shell and the gas inside it to below those in the interior shells, setting up the reverse flow due to difference in gas density.

Because of the flow reversal, it is not possible to accurately compute the flue gas flow rate and the off-cycle loss in shell No.1 and shell No.4 from the concentration data obtained in the first test (Test 5B). However, if it is assumed that the flow reversal started at four minutes into cool-down in shell No.1 and that the flow became very small in shell No.4 after about 12 minutes, estimated values of the total sensible loss can be calculated. This was done and the results are shown in figures 19 ($M_{F,OFF}$) and 20 ($Q_{S,OFF}$). The two step changes in the curves were where the adjustments were made. The estimated value of the total $L_{S,OFF}$ over the 13.3 minutes cool-down period was 2.2%. This compares fairly close to the average value of 1.91% in (4) above (Test 4). However, this 2.2% value is only an estimate. Also, it is not possible to determine the source of the air that passed through the heat exchanger. Part of the air came through the pilot light relief opening in the damper plate, and part of the air came through the draft diverter opening due to the reversed flow in shell 1.

(7). Test the same as (6) above (with injection/sampling in each burner/exit plenum) except that the diverter was blocked - (Test 7):

This test was conducted to check whether there was flow reversal as reported in (6) above. The result showed that there was no flow reversal when the diverter was blocked. The tracer gas concentration for each of the clam shells is shown in Fig.21. A similar test with reverse injection/sampling of the tracer gas in clam shell No.1 was also conducted. No reverse flow occurred. The total off-cycle sensible loss of all four clam shells was calculated to be 2.30%. The flue gas mass flow rate and the off-cycle sensible loss rate are shown in Figs.22 and 23. The results show good agreement with those obtained in (6) above where the diverter was kept open and the flow was reversed in one of the clam shells.

6. DISCUSSION

The results of the off-cycle sensible heat loss from the various tests described above are tabulated below for ease of comparison:

DIVERTER & STACK	INLET DAMPER	TRACER GAS TEST Sampling	$L_{S,OFF}$(%)
Open	Open	Stack	4.32
	Open	Each HX	4.99
	Closed	Stack	1.91
	Closed	Each HX	2.20(Est.)
Sealed & Stack Restricted	Open	Stack	5.45 (5.95 by optional ASHRAE 103 procedure)
	Closed	Stack	1.56 (1.75 by optional ASHRAE 103 procedure)
	Closed	Each HX	2.30

From the above table and the figures and results discussed in (1) to (7) above, it appears that the tracer gas test can be conducted by either sealing the diverter and restrict the stack (as requested by Lennox) or by keeping the diverter open. However, the different flow pattern in the No.1 heat exchanger (reverse flow when the inlet damper was closed and the diverter was open) indicated that the test should be performed as close to the actual installed condition as possible. That is, the tracer gas test should be tested with the diverter open. Another point expressed in the comments (see Introduction section) was that an atmospheric furnace without an inlet damper may have a flue draft factor less than 1 if tested by the tracer gas method. This would indicate that some form of correction should be applied to the result from the tracer gas test on unit with burner box inlet damper in order to account for the savings attributable to the use of an inlet damper. If, as in Eqn.1, the computation of the effective loss factor K_L is done with the measured values of the $L_{S,OFF}$ by the tracer gas method for both the damper open and the damper closed conditions during the cool-down period, the required correction would be automatic. Another point raised was that the insulation of the diverter and the stack causes more flow through the stack during the off-cycle since the heat stored in has less chance of been dissipated to the air around the diverter and the stack. This heat would keep the inside surface temperature of the diverter and the stack higher as compared to an un-insulated set-up, and the higher temperature would cause more draft. It is felt that even though the argument may be valid, the testing with tracer gas for both the damper open and closed cases would bias the results in the same direction. That is, $L_{S,OFF}$ would be higher for both cases. Also, the DoE (and ANSI/ASHRAE 103-1982 and 103-1988) test procedure specifies the insulation of the draft diverter and the test stack during the cool-down and heat-up tests.

In summary, it is seen from the test results that the burner box inlet damper will reduce the off-cycle sensible loss. To give credit for energy savings by this type of furnaces, the following test procedures were considered as possible methods for testing furnaces that have an integral burner box inlet damper to restrict the combustion air flow during the off-cycle.

1. The present DoE and ANSI/ASHRAE 103-1982 optional tracer gas procedure for systems equipped with power burners or direct vent and not equipped with stack dampers.

2. Tracer gas method conducted with the diverter open and the inlet damper closed

during the off-cycle as described in this report. The resulting total off-cycle sensible loss is then divided by the off-cycle sensible loss computed by the ANSI/ASHRAE 103 procedure for atmospheric furnace without the inlet damper ($D_F = 1$) to obtain a loss factor K_L' as given in equation 1a of this report. This loss factor is then input to the ASHRAE calculation procedure in place of D_F.

3. Tracer gas method conducted with the diverter open and the inlet damper closed as well as open during the off-cycle. The off-cycle sensible loss (damper closed is then divided by the off-cycle sensible loss (damper open) to obtain an effective loss factor K_L as defined by equation 1 in this report.

As mentioned previously, method 1 is the method requested by Lennox in the waiver petition. However, the method requires that the tracer gas test be conducted with the diverter sealed and the stack restricted. As described previously in this report, the physical flue gas flow patterns inside the heat exchanger clam shell are not the same for the diverter open versus diverter sealed conditions. Therefore, even though the resulting values of the losses are close for the two conditions for the unit under test, it was decided that method 1 should not be used.

As can be seen, the procedures in method 2 and method 3 are very similar. However, there was concern (as described in the Introduction section of this report) that D_F may be less than 1 for the damper-open case. This would indicate that dividing the tracer gas measured loss by the ANSI/ASHRAE 103-1982 computed loss where D_F is assumed to be 1 would give undue credit to the energy saving of the furnace resulting from the use of an inlet damper because of a smaller K_L' value caused by a larger denominator in the ratio. Also, as a practical matter, the measurement of the tracer gas concentration in the first minute of the off-cycle is difficult to obtain because of the rapid decrease of the mass flow rate of the stack or the flue gas during the first minute after cool-down is started. The gas temperature also decreases rapidly in this time interval. The time delay in the gas sample line and the slower response of the gas analyzer as compared with the temperature measurement (by thermocouple), when coupled with the transient state of the gas flow, makes the precise and careful matching of the tracer gas concentration to the temperature a very tedious process when performed on a routine basis. Since the total loss over the whole off-cycle period (13.3 minutes for furnace) is required in Eqn.1a (because the denominator, $L_{S,OFF}$, from the ANSI/ASHRAE 103-1982 calculation procedure is over the whole period), this matching process can not be avoided. Because of the two reasons just described, method 3 becomes the preferred method. The first concern that D_F may be smaller than 1 even with the inlet damper held open is eliminated because the tracer gas test results are used for both the inlet damper closed and open cases. The second problem was solved by computing the tracer gas losses and the ratio for K_L by the following two methods and comparing the results:

Method A. Tracer gas measured off-cycle sensible loss computed by integrating the loss rate $Q_{S,OFF}$ over the entire 13.3 minutes interval.

Method B. Tracer gas measured off-cycle sensible loss computed by integrating the loss rate $Q_{S,OFF}$ over a one minute interval starting at 5 minutes into the cool-down phase. The resulting values for the damper closed and damper open cases are used to obtain the K_L value. That this procedure will work can be seen from the two curves in Fig.11 of this report. In Fig.11 it is seen that the two loss curves would maintain a fairly constant ratio if the value of one is divided by the other. Also, the variation of the loss values become much slower at the 5 to 6 minutes interval than at the first two minutes. (see also Fig.10 for the mass flow and Fig.12 for the temperature variations.)

The resulting K_L from the two methods of computation is shown in the following table based on several sets of test data:

K_L = Sum of $Q_{S,OFF}$(damper closed) / Sum of $Q_{S,OFF}$(damper open)

By sum over 13.3 minutes	By sum over 1 minute (between minute 5 and 6)	Remark
0.46	0.39	cyclic operation
0.45	0.38	,,
0.48	0.43	,,
0.44	0.38	,,
0.49	0.43	start from Steady-state
0.54	0.45	start from Steady-state

From the above table it is seen that the two methods give fairly consistent results, though the second column gives a lower value (by 0.05 to 0.09). However, considering the possible in-accuracy involved in the first minute matching of the data points as shown in the result in Test 1, and the fact that a penalty is taken when the damper-open case is based on a D_F not equal to 1, and that the ANSI/ASHRAE 103 optional tracer gas procedure also used the data at a point in the 5 to 6 minutes interval for the computation of the flue draft factor D_F, the much easier method B is therefore the preferred method.

Note that in the above table, the last two rows of data are labelled as starting from steady-state operation. This will generally give a slightly higher value of the off-cycle sensible loss because the beginning temperature for cool-down is higher when starting from steady-state. However, as can be seen, the ratio K_L remains comparable with those under cyclic operation (13.3 minutes cool-down following 4 minutes heat-up). Since the steady-state temperature is the same for both damper closed and damper open cases (damper is open when burner is on), starting the tracer gas test after the steady-state conditions are reached would be a more equatable way for the two cases. This is also the starting condition for tracer gas test in the ANSI/ASHRAE 103-1982 optional tracer gas procedure.

7. RECOMMENDED TEST PROCEDURE

Based on the test results presented and the discussion above, the following test procedure is recommended for the performance testing of the Lennox G20 type atmospheric furnace by the tracer gas method:

1. Perform the standard steady-state, cool-down, and heat-up test as specified in the ANSI/ASHRAE 103-1982 and the applicable sections for an atmospheric furnace with an integral draft diverter in Sections 9.1.1 to 9.1.4, 9.5.1, and 9.6.1. Note that during part of the test, the draft diverter will be sealed and

insulated, and the stack restricted, and also insulated as specified in Section 7.2.2.1 and Fig.3-A in the Standard. Keep the burner box inlet damper open during the whole period of the test.

2. After the heat-up test in 1 is run for four minutes, turn the burner off and run another cool-down for 5 to 10 minutes. Keep the inlet damper open. During this cool-down period, un-block the integral draft diverter and remove the stack restriction. This would general take less than five minutes to accomplish.

3. At the end of the 5 to 10 minutes cool-down period in 2 (and after the diverter and the stack restrictions are removed), turn the burner on and run the furnace until steady-state is again reached as specified by Section 9.1.1 of the ANSI/ASHRAE 103-1982 standard. Open the sampling line of the tracer gas test set-up to the ambient during this period and record the background concentration C_B of the tracer gas used (one data point is generally enough).

4. At the end of the steady-state, turn the burner off for another 10 minutes cool-down period. Continue to keep the inlet damper open. Within one minute after the unit is shut off to start the cool-down test, start the injection of the tracer gas with a known concentration C_I at a constant flow rate V_T into the lower part of the stack near the test plane where the stack thermocouple grid is located. Monitor the flow rate V_T with an instantaneously reading flow meter. Follow the accuracy requirement as specified in Sections 9.4.1 and 9.4.2 and Appendix D of ANSI/ASHRAE 103-1982. Within one minute after the tracer gas injection is started, connect the gas sampling line to the tracer gas analyzer to sample the concentration of the tracer gas at a plane inside and near the top exit of the stack. Measure the transport delay time which is equal to the time between the insertion of the sampling line and the initial response of the CO analyzer. Add to this transport time the time required for the analyzer used to reach 90% of its steady-state value as specified in the analyzer's operation manual. This is the time delay needed to match the concentration measurement to the temperature measurement in the calculation of the off-cycle loss. Make sure that well mixed sample is collected by the use of a multi-hole sampling tube as suggested in Appendix D of ANSI/ASHRAE 103-1982. Continue the tracer gas injection and sampling until the required concentration and temperature data are collected and recorded between 5 and 7 minutes after the beginning of cool-down. Determine the temperature of the tracer gas entering the flow meter (T_T) and the barometric pressure P_B.

5. At 5 minutes after the unit is shut off to start the cool-down test, measure and record the percent volumetric concentration of tracer gas present in the diluted stack gas sample, C_T. At the same time, measure the stack gas temperature, $T_{S,OFF}$, using the thermocouple grid in the test plane (see Test Set-up). The data measurement and recording should be done every 5 seconds for the next 1 to 2 minutes. The exact length of time required for the data measurement is equal to the tracer gas sample delay time plus 1 minute. Stop the tracer gas injection and sampling after the required data are measured and recorded.

6. At the end of the 10 minutes of the cool-down period in 4, disconnect the gas sampling line from the stack and sample the ambient air to clear the line. Turn on the burner and run the furnace until steady-state is again reached.

7. At the end of the heat-up to steady-state in 6, turn the burner off for another cool-down period. Let the inlet damper close the way it is designed. Repeat the test of step 4 to step 5. Keep the tracer gas injection rate, V_T, the same if possible. However, V_T may have to be changed to a lower rate to keep the sample concentration stay within the range of the gas analyzer used.

8. At the end of the data measurement period (between 5 and 7 minutes into cool-down) in 7, stop the injection and stop the test.

9. The total time for the test (step 1 to step 8) is less than 200 minutes which is about twice the time required for the regular steady-state, cool-down and heat-up test run.

10. The off-cycle stack gas mass flow rate and the sensible loss rate are calculated by the equations 2 and 3 in the Test Results section of this report. The gas density, ρ, in Eqn.2 in lb_m per cu. ft. is approximated by the equation given in Section 11.4.1 of ANSI/ASHRAE 103-1982. The one minute off-cycle sensible loss, $L_{S,OFF}$, are computed by summing up the values of the off-cycle loss rate, $Q_{S,OFF}$, computed for the one minute interval (starting at 5 minutes into the cool-down) for both the damper open and the damper closed cases based on tracer gas test of steps 4 and 5, and 7 and 8. Calculate an effective loss factor by the following equations:

$$K_L = (L_{s,off} \text{ when damper closed}) \,/\, (L_{s,off} \text{ when damper open}) \qquad (4)$$

$$L_{s,off} = \sum_{t=5}^{6} (Q_{S,OFF} \cdot \Delta t) \qquad (5)$$

where $L_{s,off}$ = one minute sum total of the measured $Q_{S,OFF} \cdot \Delta t$ (Δt = time step when data were recorded) as measured and computed by equations 2 and 3 of this report and summed over a one minute interval starting at 5 minutes into the cool-down period

11. Input the value of K_L in the ANSI/ASHRAE 103-1982 calculation procedure (or the computerized procedure in the ANSI/ASHRAE 103-1988 computer program) together with the data measured in steps 1 and 2, and compute the necessary efficiency values. Note that in order for the computer program to make use of the computed K_L value, the input values for the variables NSYS, OPTEST and DP in the ANSI/ASHRAE 103-1988 standard should be set to the values of 2, 0, and K_L, respectively for the indoor installation case. For the isolated combustion system (ICS), the value for NSYS should be set to 10.

At the request of DoE, the above recommended test procedure was also written in a format conforming to the DoE Test Procedures for Furnaces and the ANSI/ASHRAE 103-1982 Standard. It is included as Appendix B in this report.

It should be noted that the test data (steady-state, cool-down, and heat-up) to be used in conjunction with the computed K_L value in step 11 for the computation of the efficiency values are collected with the inlet damper open during the 45 minutes cool-down period in step 1. This is because that the factor K_L is applied to the "damper-open" off-cycle sensible loss to arrive at a value for the "damper-closed" off-cycle sensible loss in the ANSI/ASHRAE 103-1988 computer program. This can be shown in the following equation:

$$K_L = L_{S,OFF} \text{ (DC measured) } / L_{S,OFF} \text{ (DO measured)}$$
$$= L_{S,OFF} \text{ (DC calculated) } / L_{S,OFF} \text{ (DO calculated)}$$

therefore, $L_{S,OFF}$ (DC calculated) = $K_L \cdot L_{S,OFF}$ (DO calculated)

In the above equation, DC and DO indicate damper-closed and damper-open, respectively.

Following the procedure described in step 11, calculations were made with the test data obtained during this study. The following table shows the efficiency values with the computed K_L for the furnace tested in this report:

DIVERTER	DAMPER	INSTALLATION	Eff_{SS}	AFUE	K_L
Open	Open	Indoor	80.9	72.91	1
Open	Open	ICS	80.9	71.79	1
Open	Closed	Indoor	80.9	76.89	0.43
Open	Closed	ICS	80.9	76.70	0.43
Closed	Closed	Indoor	81.1	77.87	0.19(=D_F)*
Closed	Closed	ICS	81.1	77.94	0.19(=D_F)*

* conducted in accordance with the ASHRAE optional tracer gas procedure (the same as requested by the Lennox Petition for Waiver), except that the cool-down started after 4 minutes heat-up (not from steady-state condition). Here D_F = 0.19 is the flue draft factor.

In the above table, the last two rows marked with an asterisk (*) was computed by using the gas concentration data and temperature at the time 5.5 minutes into the cool-down period in the ANSI/ASHRAE 103 optional tracer gas procedure as specified in the Standard for a power burner. For that test, the diverter was sealed and the stack was restricted. It is seen that the resulting AFUE values differ by 1.0 to 1.2 percentage points to the one by the recommended method described above. It should be noted that the above efficiency values were computed by assuming an assigned jacket loss of 0% for the indoor case and 1.7% for the isolated combustion system (ICS) case (an option given in ANSI/ASHRAE 103) since no jacket loss measurement was made. Also, the results are from tests conducted at different days and weeks apart on a furnace that has gone through a lot of tracer gas test runs. They are therefore listed for comparison and reference purposes only.

In the above table, it is seen also that the resulting AFUE values for the inlet damper closed case are 76.72% for a furnace with indoor installation and 76.50% for an isolated combustion system. The AFUE value for an indoor installation system is slightly higher than an isolated combustion system. There are several factors in the calculation procedure which influence the AFUE values for the two systems. These factors include the assumed air temperature at the burner inlet (70 F for indoor and 42 F for ICS) which affects the on- and off-period sensible heat loss, the tightness of the inlet damper during off-period which affects the off-period sensible loss, and the assumptions of no jacket loss for an indoor installation and no infiltration loss for an ICS system. A detailed discussion on the effects of these factors on the AFUE values of an indoor and an ICS system, and the way they offset each other to result in a near identical AFUE value for the two systems, is given in Appendix C of this report.

8. TEST RESULTS FROM ETL

At the request of DoE, the Lennox G20 furnace was sent to the ETL Testing Laboratories, Inc., a commercial testing laboratory, for an independent test of the furnace. The above NIST recommended tracer gas test procedure was used by ETL for the test. The results of the ETL test, and the results obtained at NIST, are listed in the following table for comparison:

	Eff_{SS}, %	K_L	AFUE(ICS), %
ETL	81.6	0.546	76.63
NIST	80.9	0.430	76.70
NIST	81.2	0.450	77.10

The first NIST entry in the above table was a relist of the result reported in the previous section. The second NIST entry was from a test conducted at NIST just before the furnace was sent to ETL.

It is seen from the above table that the test data obtained at ETL differed from those obtained at NIST in the AFUE values by 0.1 to 0.5 percentage points with a larger variation in the K_L values. There are also some differences in the stack temperature measurements. It is felt that these are the variations that would be expected when a furnace (in well used condition) is tested at two different laboratories.

9. SUMMARY OF TEST RESULT

From the result of testing at NIST, it is seen that for a moderately tight inlet damper (K_L = 0.4 to 0.5), there is only a small difference between an ICS system and an indoor system in the AFUE value (0.1 to 0.2 percentage points) tested by the NIST recommended tracer gas procedure.

The same result also showed up when the furnace was tested by the optional tracer gas method in the interim waiver requested and granted to Lennox. In this case the indoor system is only slightly lower (by 0.07 percentage points; AFUE = 77.94% for ICS and 77.87% for indoor).

For the Lennox furnace tested at NIST, the AFUE values by the two test procedures differ by 1.2 percentage points (for an ICS system: 76.70% by NIST procedure versus 77.94% by the interim waiver procedure). However, the test procedure requested by Lennox requires the blocking of the draft diverter during the tracer gas test with the inlet damper closed. As was shown and discussed previously in this report, when the diverter was not blocked after the burner was shut off, there was reverse air flow through the heat exchanger four minutes into the cool-down period. This flow entered the top plenum of a side clam-shell through the diverter opening, circulated down the side clam-shell, flowed up the adjoining clam-shell containing the pilot light, and exited up the stack. It is likely this flow replaced part of the flow going through the small cracks and openings of the closed burner box inlet damper. It was also shown previously that when the diverter was blocked, this reverse flow did not occur. For a moderately tight inlet damper, the flow through the openings in the damper or through the diverter gave approximately the same off-period loss. However, for a very tight damper, the flow through the diverter opening might be a greater source of the off-period loss. In other word, the flow through the diverter opening, not the tightness of the inlet damper, might be the limiting factor on the effectiveness of an inlet damper. On a furnace with a draft diverter, if the diverter opening is blocked during the tracer gas test and the inlet damper is very tight in design, the actual flow through the heat exchanger is likely to be under-estimated, resulting in a smaller measured off-period loss.

Another problem with blocking the diverter during the tracer gas test is that a blocked diverter is likely to over-estimate the cool-down flue gas temperatures measured 1.5 minutes and 9 minutes after the burner is shut off, since with the diverter blocked and the stack insulated, the only flow through the test stack will be the small amount of air through the heat exchanger. The gas temperature measured at the test plane will tend to decrease at a slower rate due to the insulation on the stack than the flue gas temperature at the heat exchanger plenum exit which is cooled down by the near room temperature air on the air side of the heat exchanger. This will result in a lower flue gas temperature at the exit plenum than at the stack. Since the temperature measured at the stack with the damper closed, the diverter sealed and the stack insulated and restricted is used as the flue gas temperature in the ASHRAE optional tracer gas test procedure (requested by Lennox as the test procedure), the actual flue gas temperature is likely to be over-estimated and the result from the computation procedure will be in error. This is likely to be especially important for a unit equipped with a very tight inlet damper, since the stack temperature during cool-down is likely to be even higher, resulting in a greater error.

Based on the discussions above, NIST believes that the test procedure specified in Lennox's waiver request is inappropriate and the Recommended Test Procedure described in this report is the appropriate procedure for furnaces with inlet dampers. Furthermore, NIST believes that for this type of furnace with a moderate tight inlet damper, there is little difference (i.e. 0.1 to 0.2 percentage points) in the AFUE rating between indoor and ICS applications.

10. CONCLUSION

An atmospheric furnace with an integral draft diverter and an electro-mechanical burner box inlet damper was tested by the tracer gas method for the development of a test procedure. Tests were conducted under two conditions: with the diverter open during tracer gas test, and with the diverter sealed and the stack restricted and insulated during tracer gas test. Test results indicated that the flue gas flow patterns inside the heat exchanger were different for the two conditions. There was reverse flow in one of the clam shells when the diverter was open, but no flow reversal when the diverter was sealed. The off-cycle sensible loss which was a measure of the effectiveness of the burner box inlet damper gave similar value for both conditions. However, because of the change in flow pattern, the test procedure recommended in this report requires that the tracer gas test should be conducted with the diverter open since this is the condition when the furnace is operated in the field. The NIST recommanded test procedure does not agree with the one requested by the Lennox Industries, Inc. in its Petition for Waiver, which requested that the tracer gas test be performed with the diverter sealed and the stack restricted.

11. REFERENCE

1. Lennox Industries, Inc. Petition for Waiver submitted to the Department of Energy, August 1, 1989.

2. ANSI/ASHRAE 103-1982, "Methods of Testing for Heating Seasonal Efficiency of Central Furnaces and Boilers". ASHRAE, Atlanta, GA

3. ANSI/ASHRAE 103-1988, "Methods of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers". ASHRAE, Atlanta, GA

4. Kelly, G.E., Chi, J., Kuklewicz, M.E., "Recommended Testing and Calculation Procedures for Determining the Seasonal Performance of Residential Central Furnaces and Boilers". NBSIR 78-1543, March 1978.

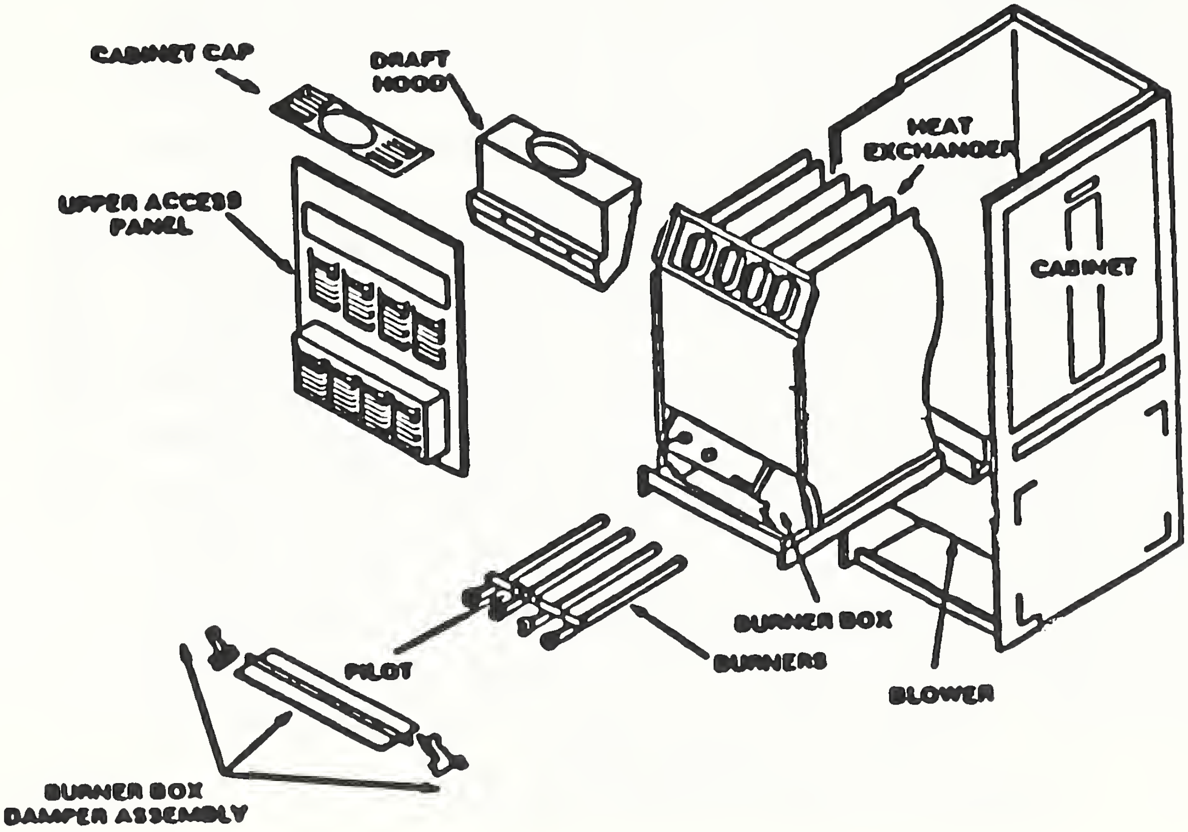


Figure 1. Schematic of the test furnace and burner box inlet damper

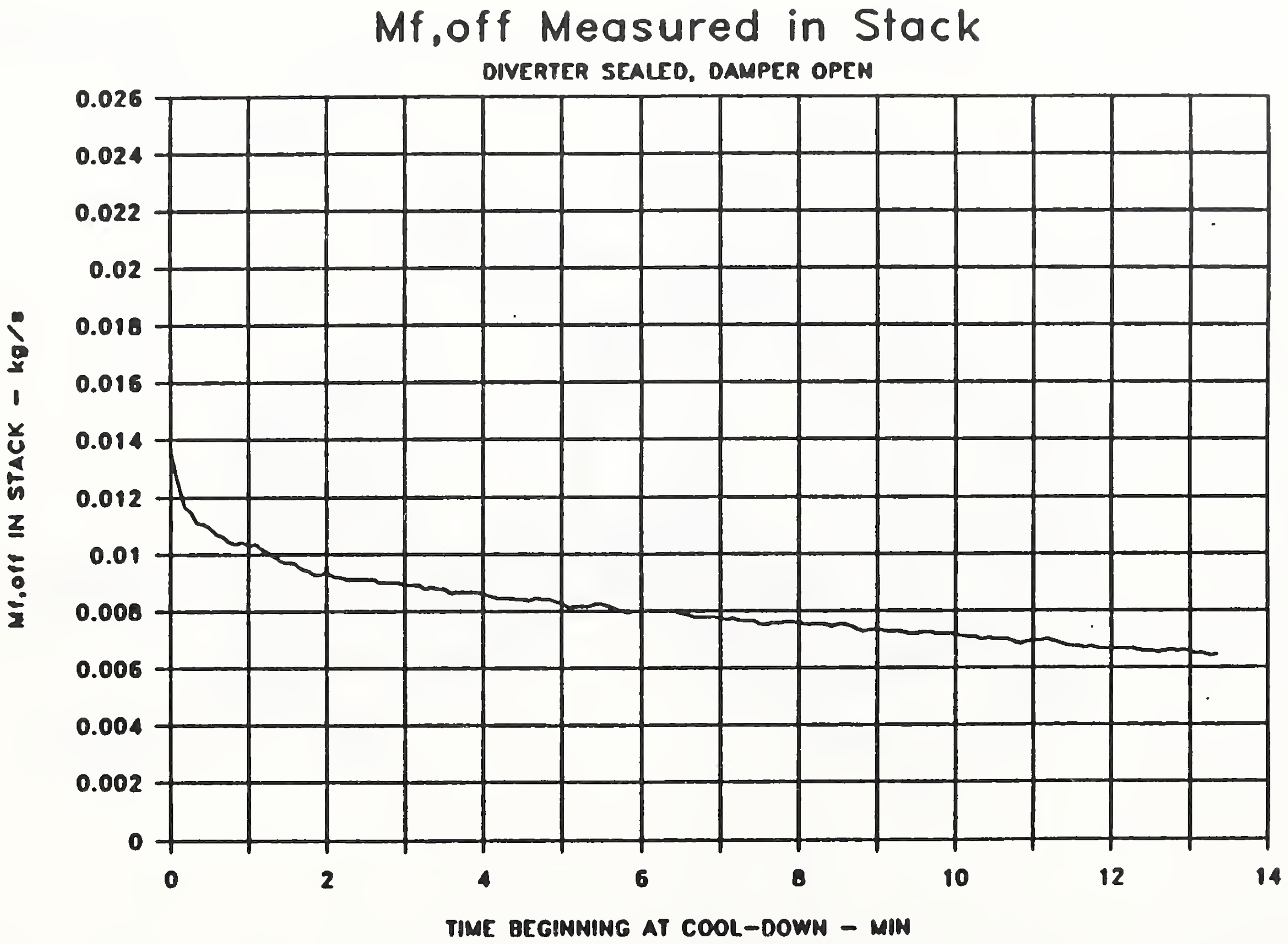


Figure 2. Off-cycle flue gas mass flow rate during cool-down test - diverter sealed; inlet damper open

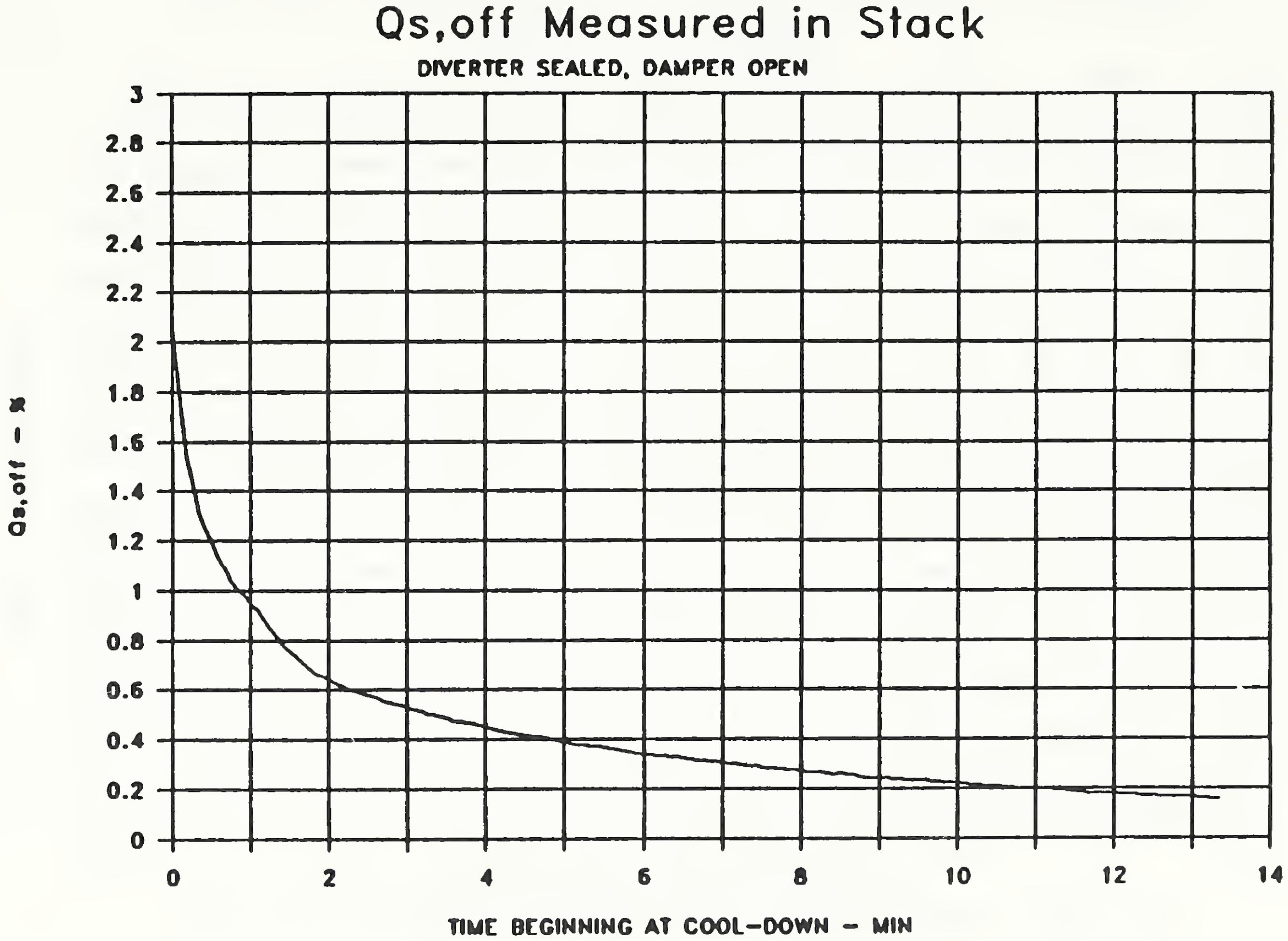


Figure 3. Off-cycle sensible heat loss rate during cool-down test - diverter sealed; inlet damper open

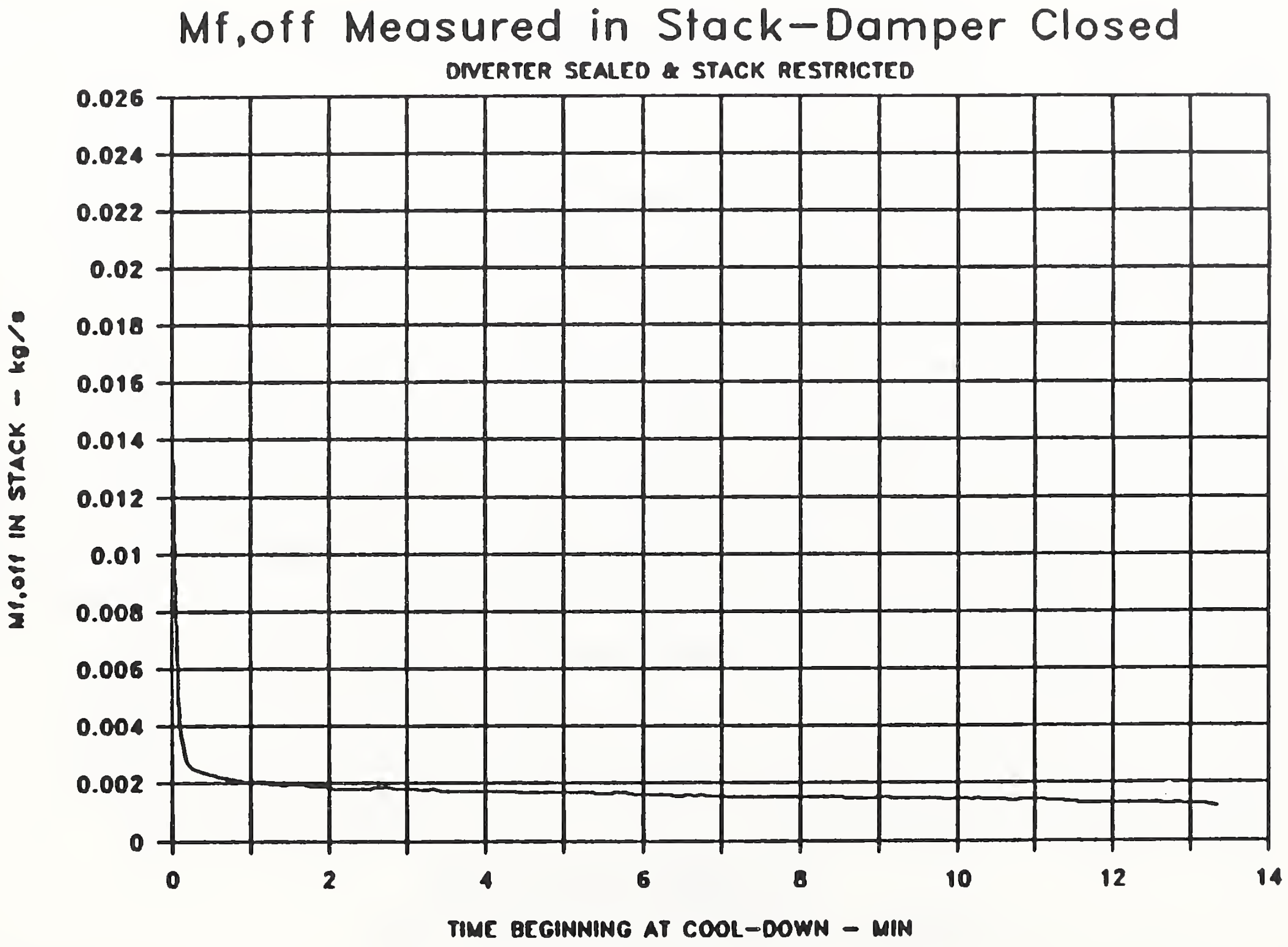


Figure 4. Off-cycle flue gas mass flow rate during cool-down test - diverter sealed; inlet damper closed

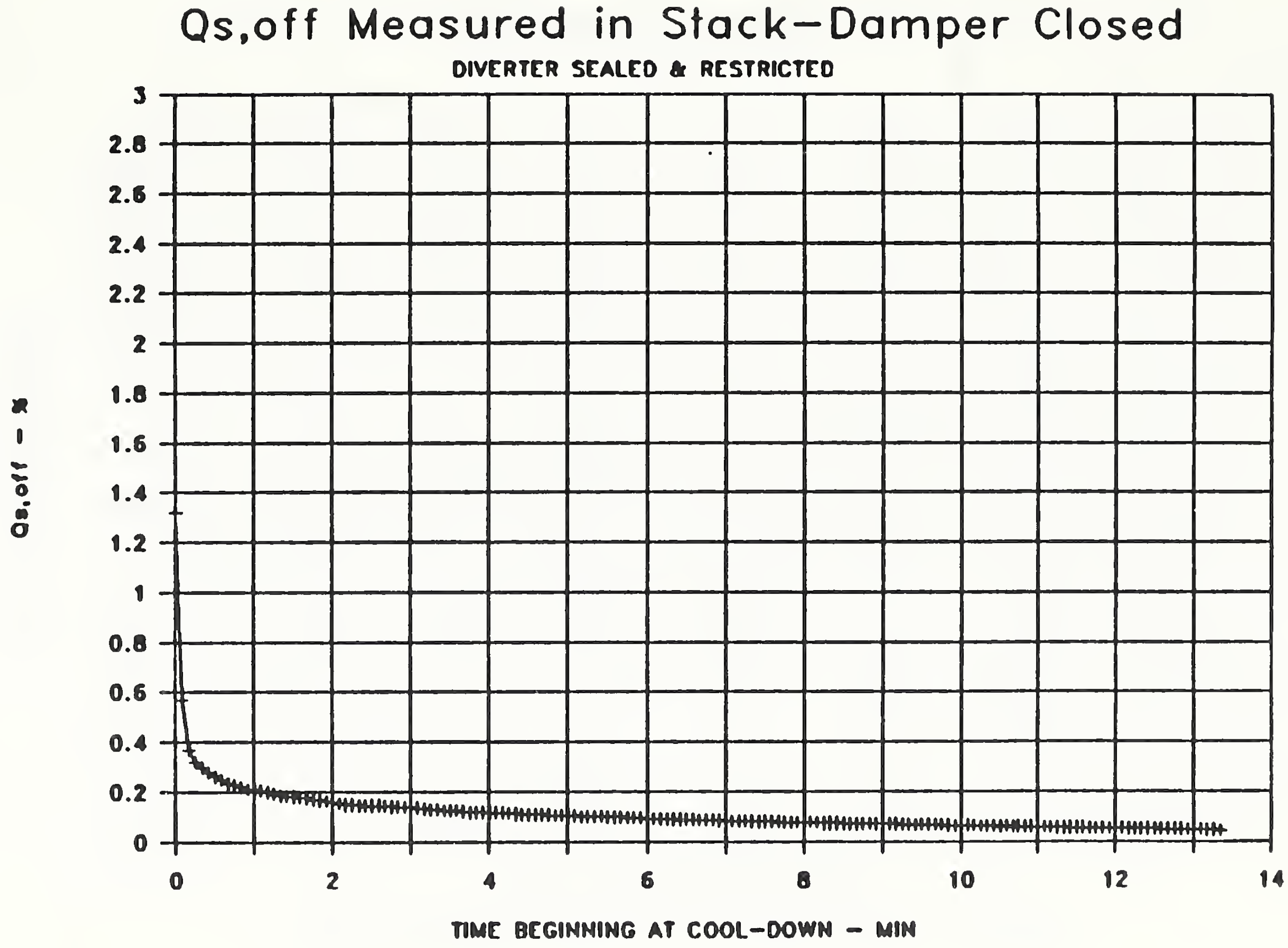


Figure 5. Off-cycle sensible heat loss rate during cool-down test - diverter sealed; inlet damper closed

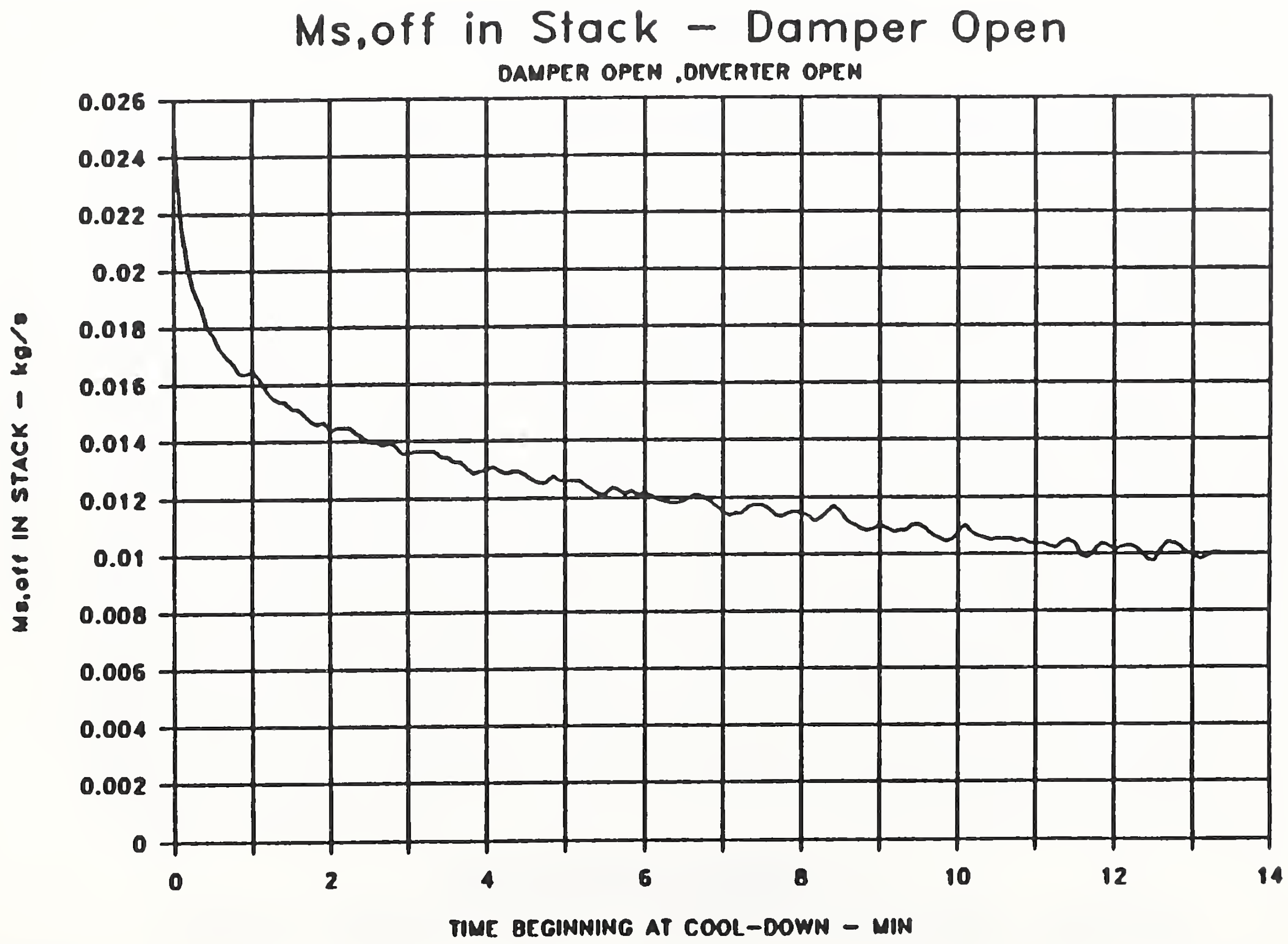


Figure 6. Off-cycle stack gas mass flow rate during cool-down test - diverter open; inlet damper open

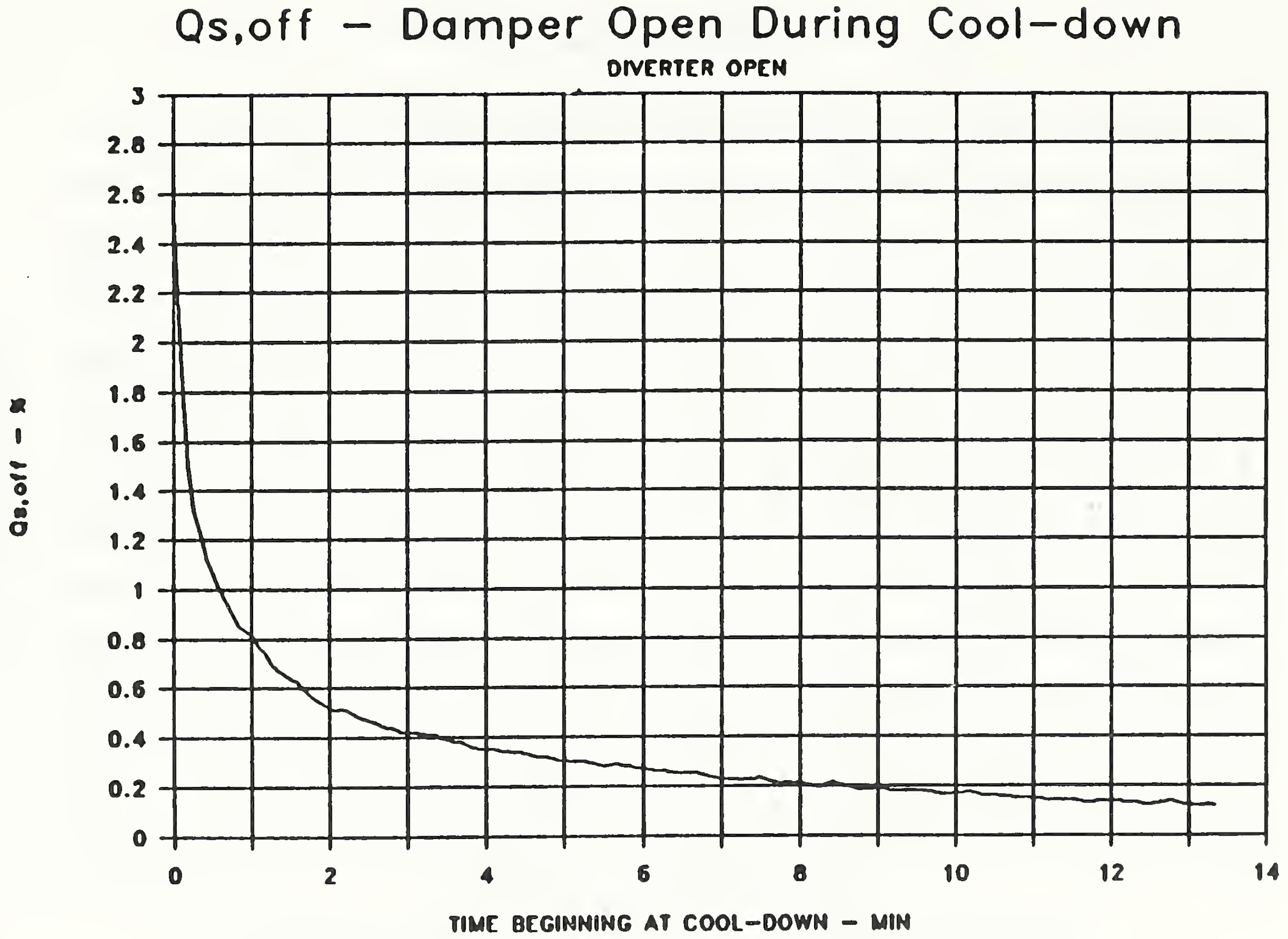


Figure 7. Off-cycle sensible heat loss rate during cool-down test - measured in stack - diverter open; inlet damper open

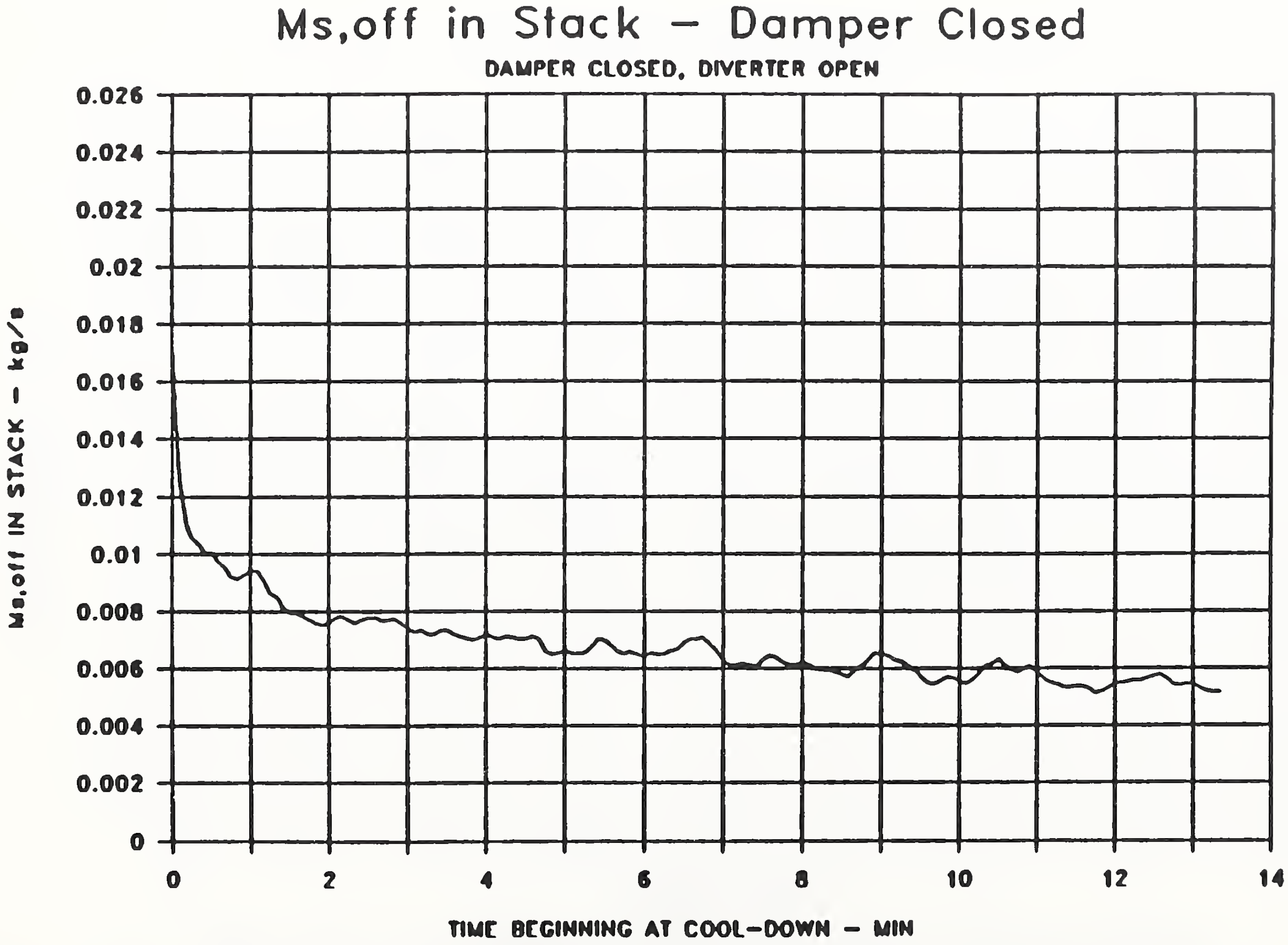


Figure 8. Off-cycle stack gas mass flow rate during cool-down test - diverter open; inlet damper closed

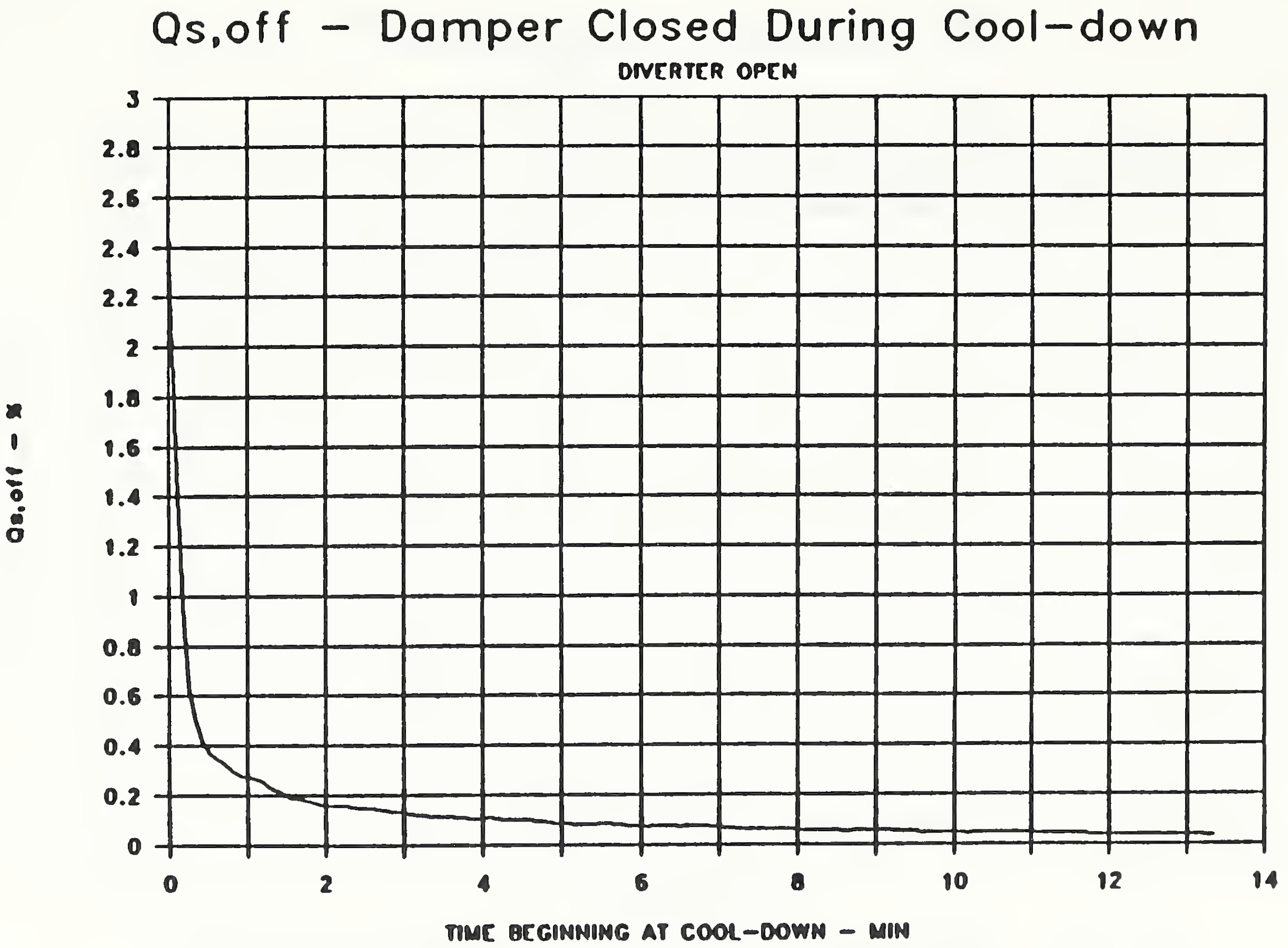


Figure 9. Off-cycle sensible heat loss rate during cool-down test - measured in stack - diverter open; inlet damper closed

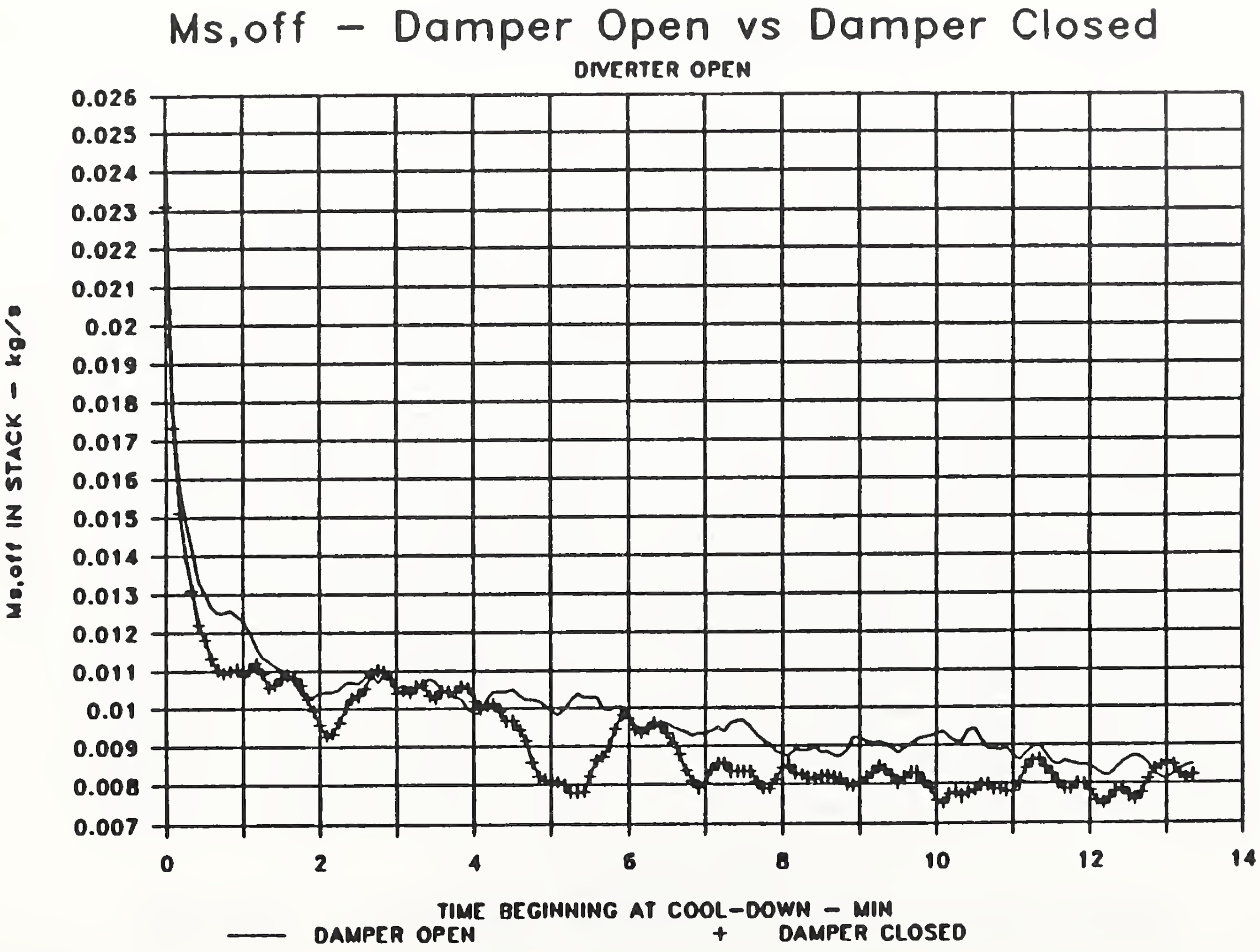


Figure 10. Comparison of stack gas mass flow rate during cool-down - inlet damper open vs. closed - diverter open

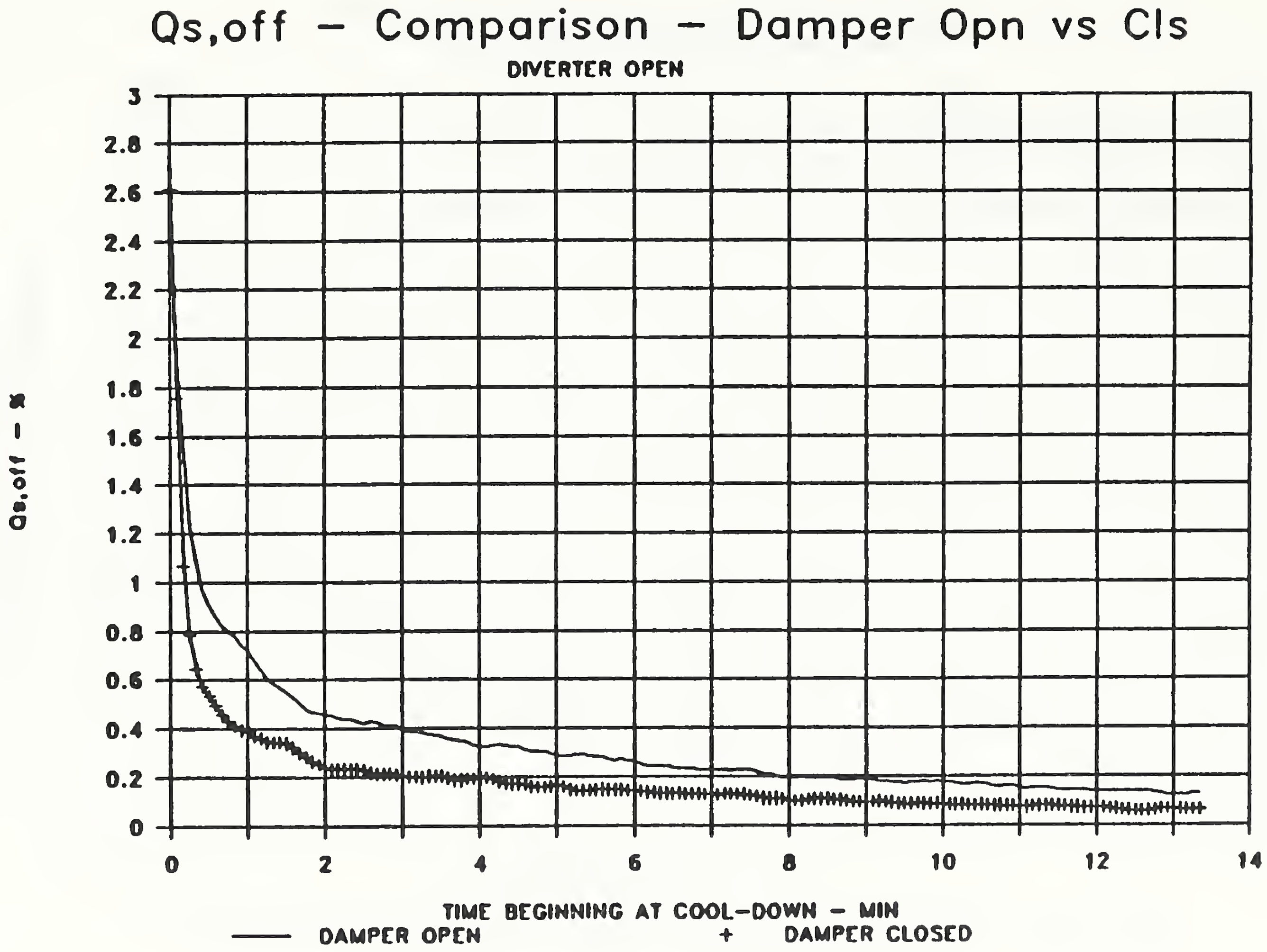


Figure 11. Comparison of off-cycle sensible loss rate during cool-down - inlet damper open vs. closed - diverter open

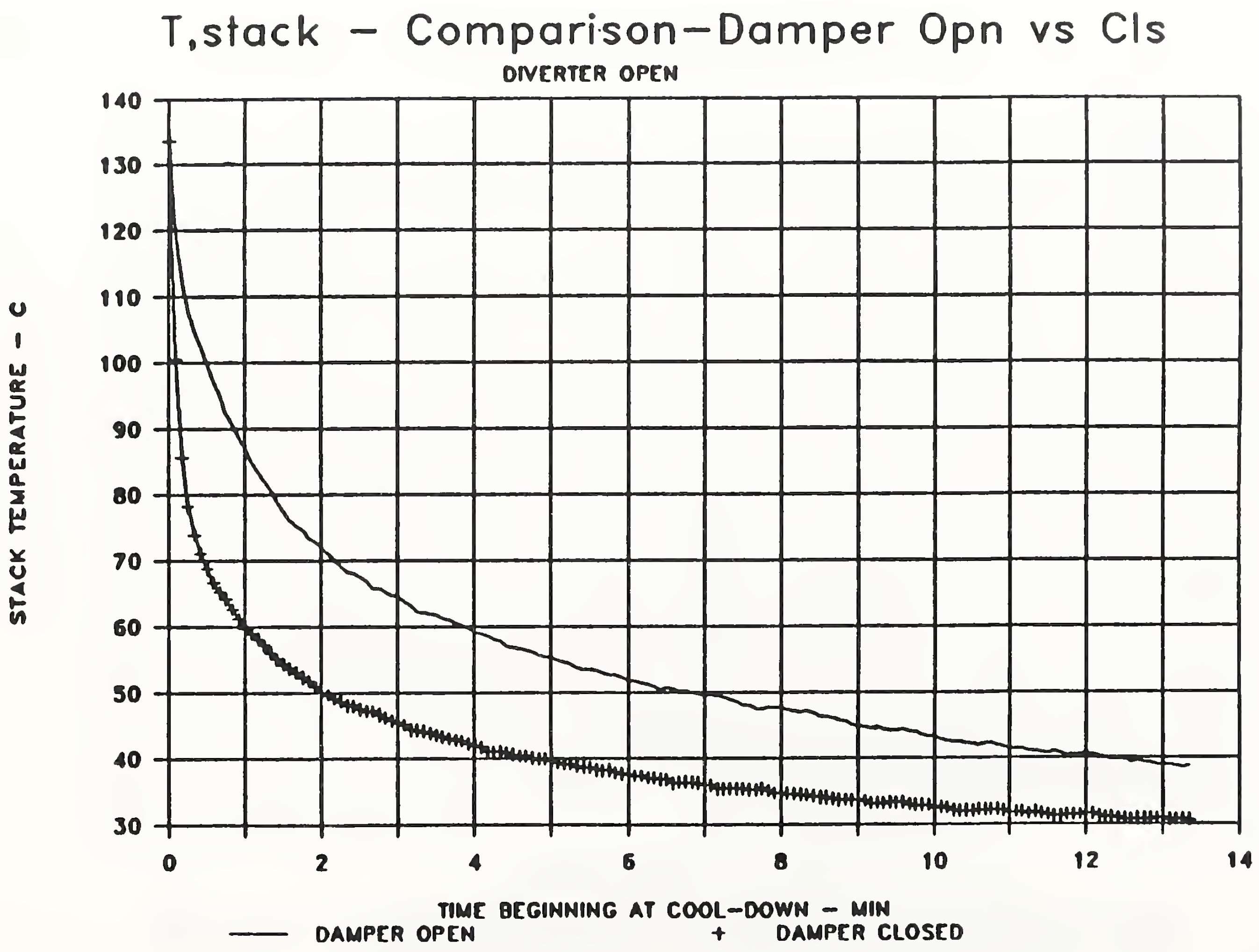


Figure 12. Comparison of stack gas temperature during cool-down - inlet damper open vs. closed - diverter open

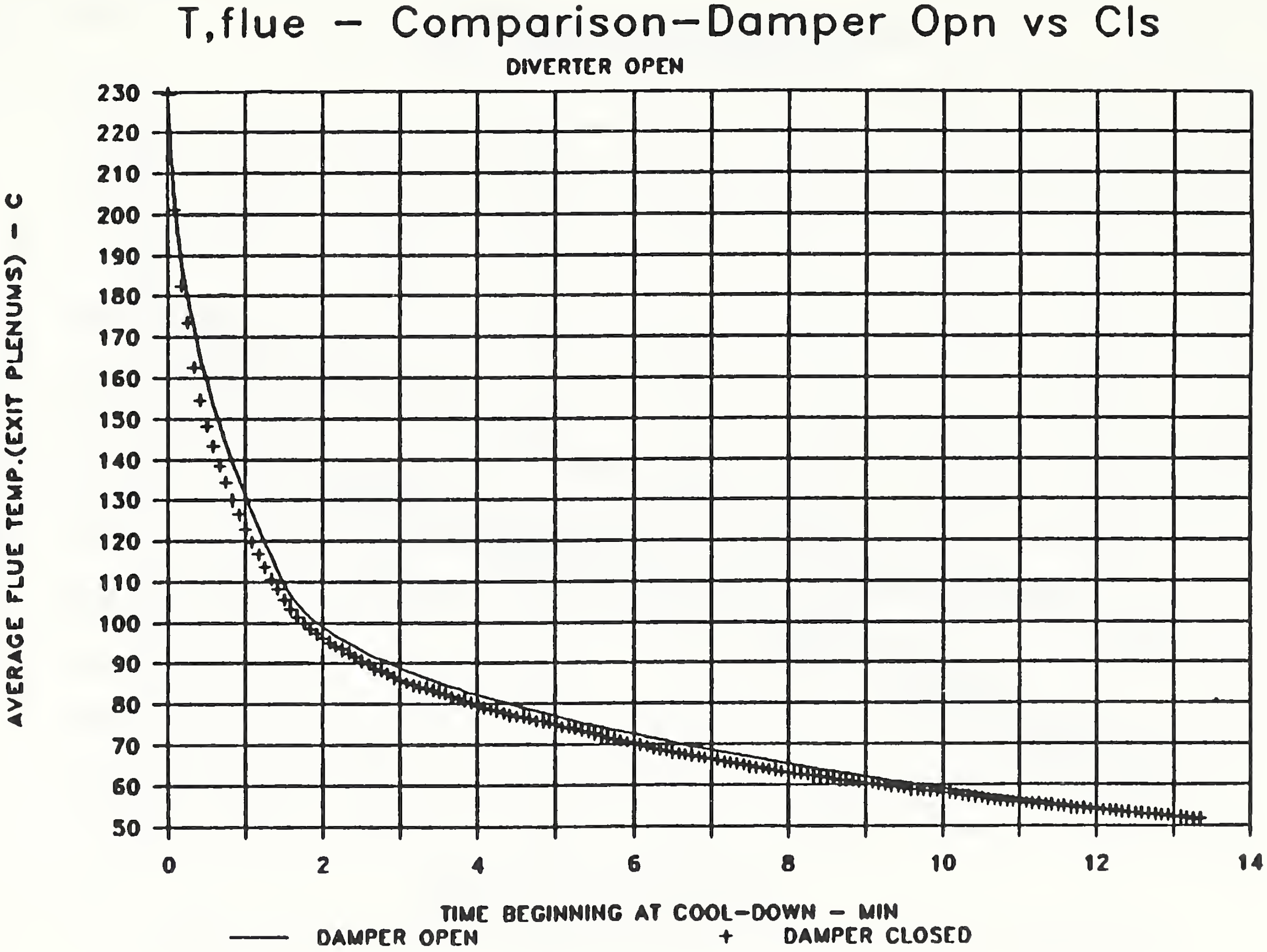


Figure 13. Comparison of average flue gas temperature during cool-down - inlet damper open vs. closed - diverter open

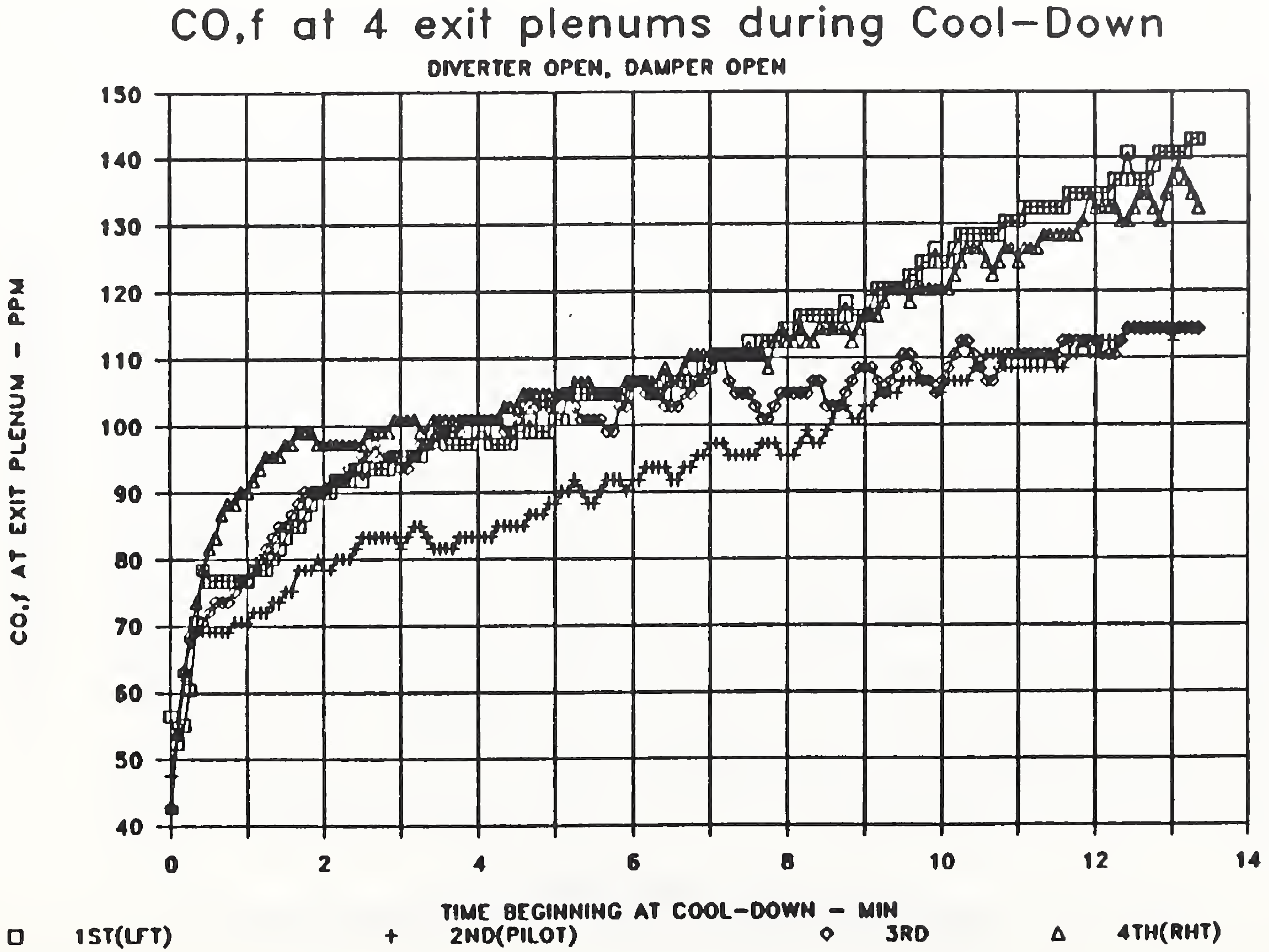


Figure 14. Tracer gas (CO) concentrations at each clam shell exit during cool-down test - diverter open; inlet damper open

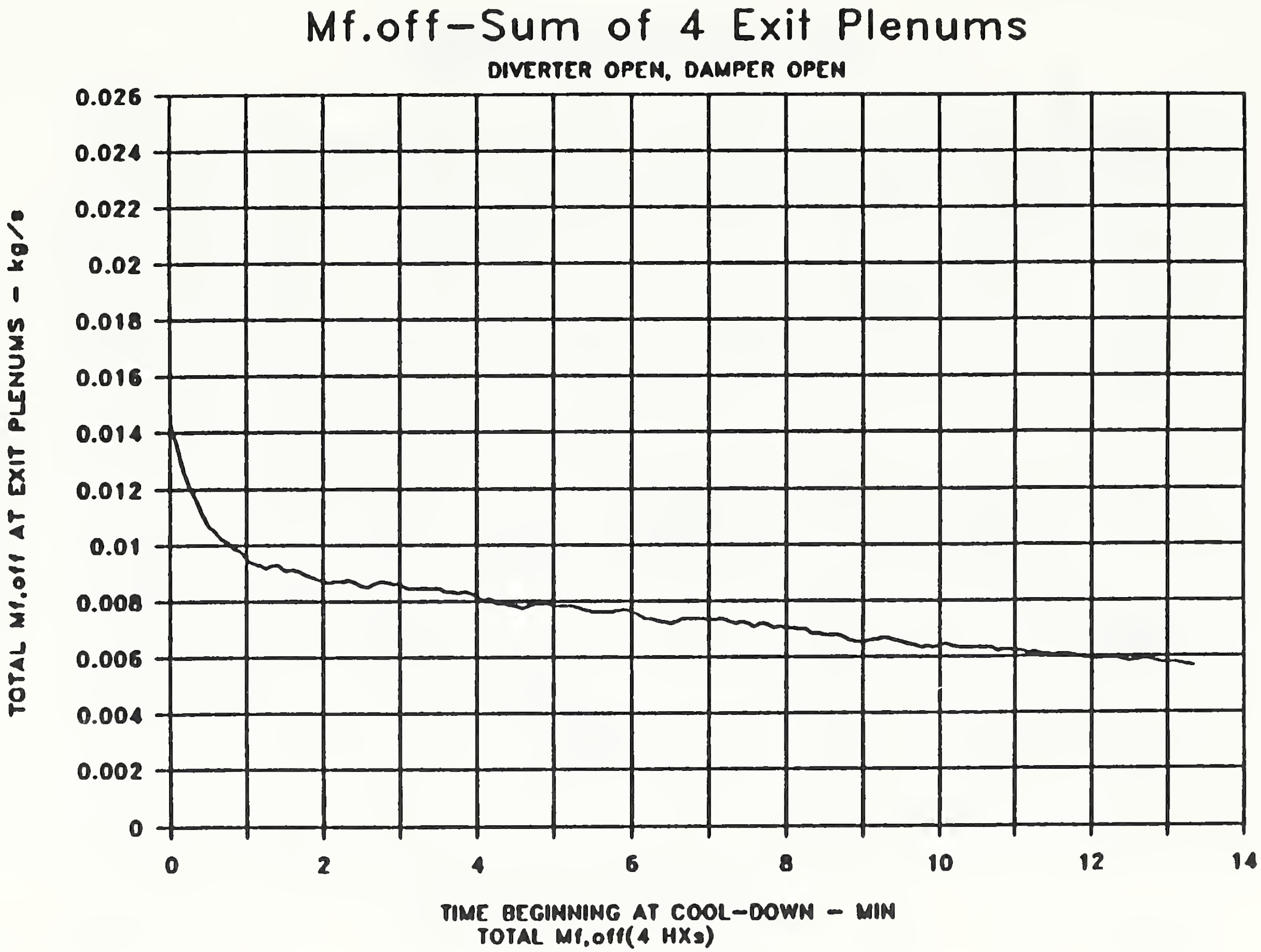


Figure 15. Sum of flue gas mass flow rates measured at each clam shell exit during cool-down - diverter open; inlet damper open

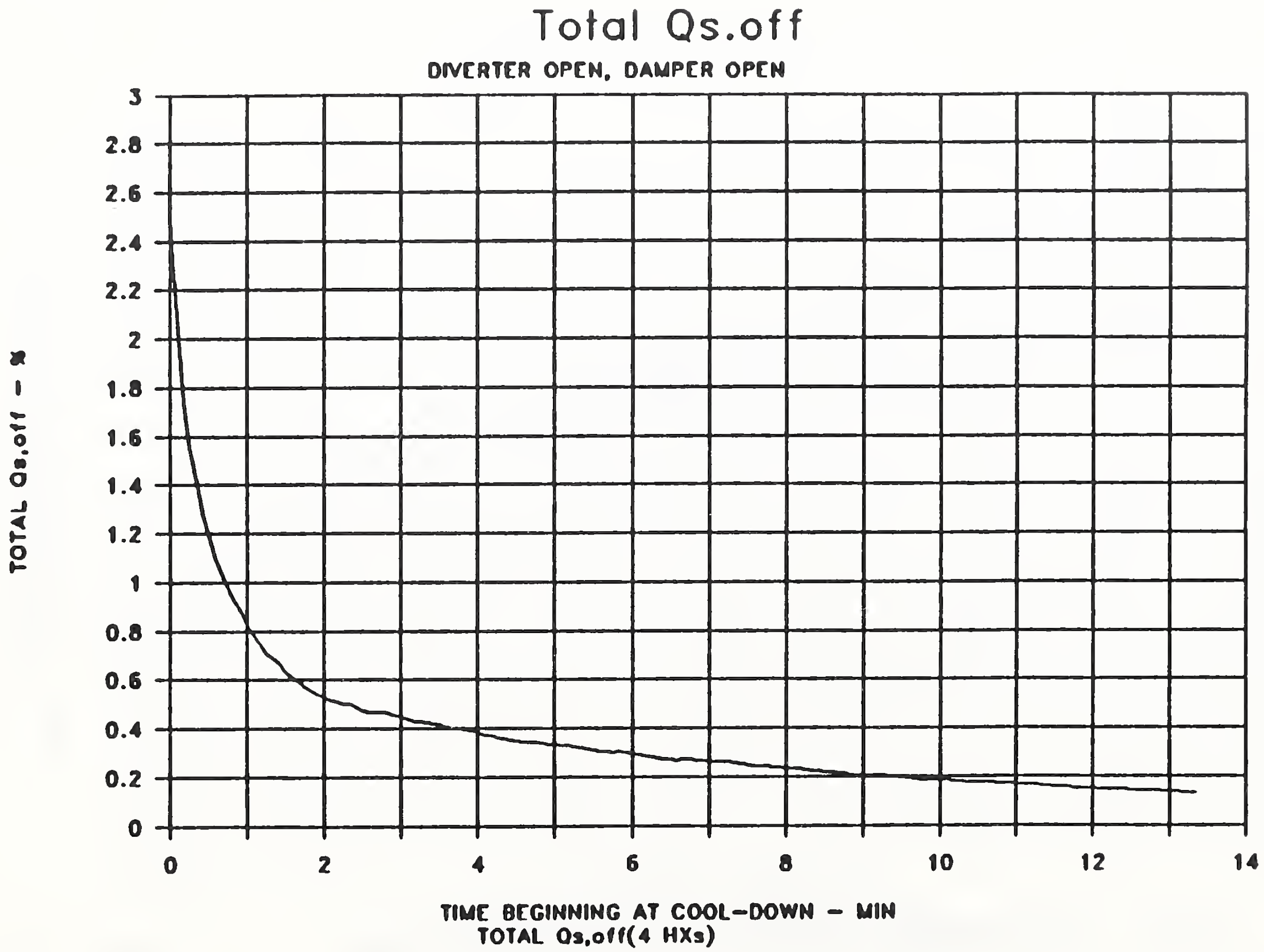


Figure 16. Sum of off-cycle sensible loss rates measured at each clam shell exit during cool-down test - diverter open; inlet damper open

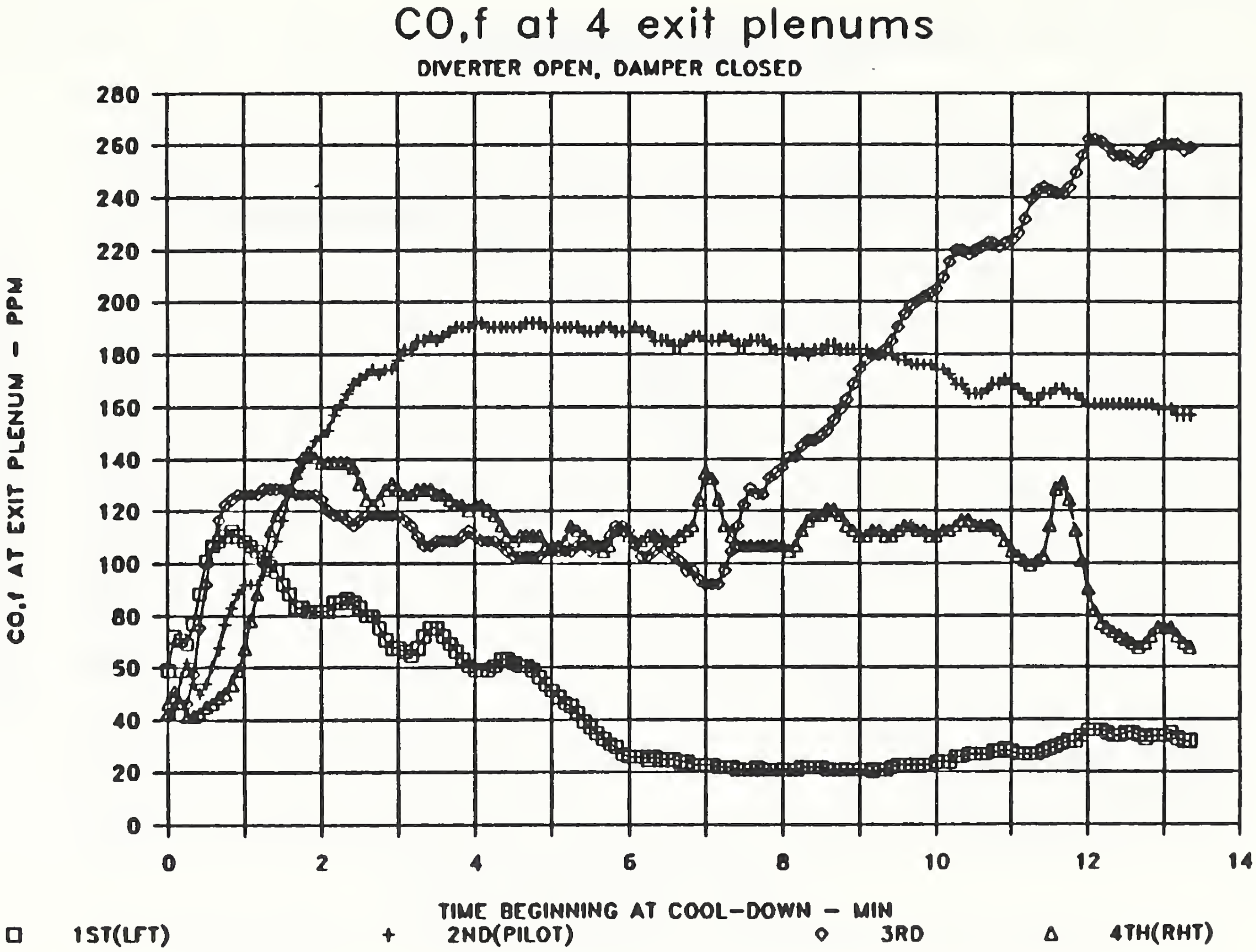


Figure 17. Tracer gas (CO) concentrations at each clam shell exit during cool-down test - diverter open; inlet damper closed

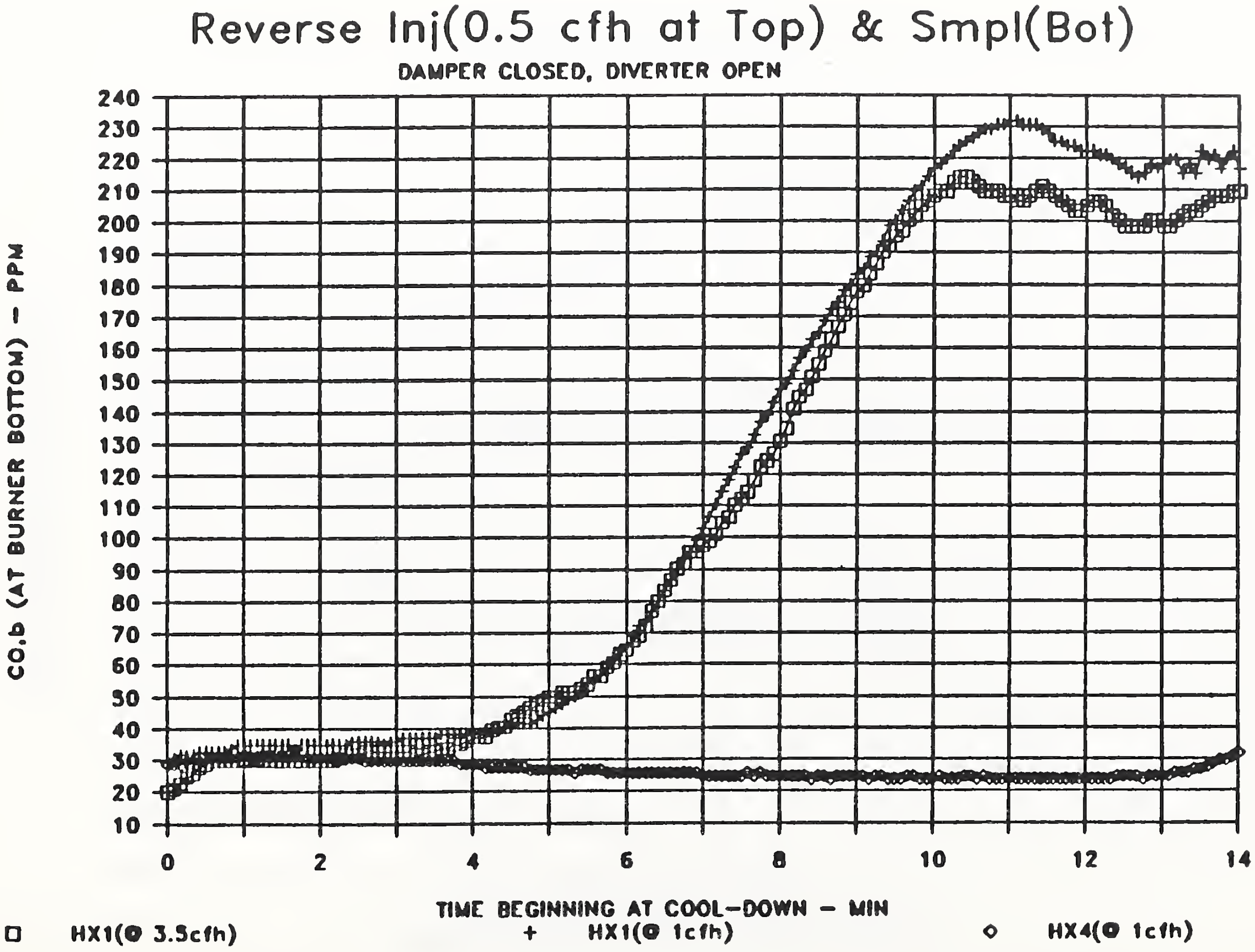


Figure 18. Flow reversal test - tracer gas (CO) concentrations at burner level with injection at clam shell exit during cool-down test - clam shells 1 and 4 - diverter open; inlet damper closed

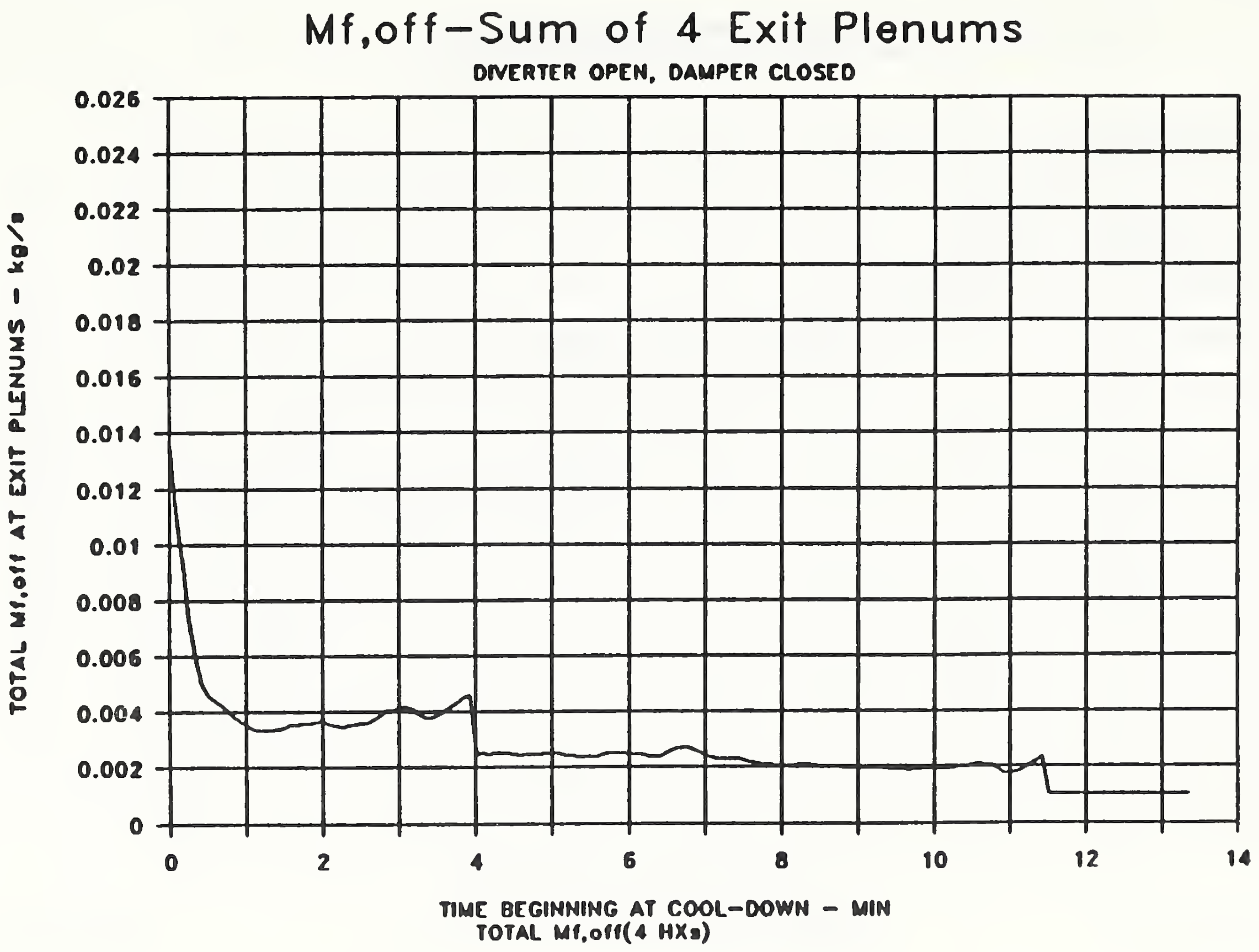


Figure 19. Sum of flue gas mass flow rates measured at each clam shell exit during cool-down - diverter open; inlet damper closed

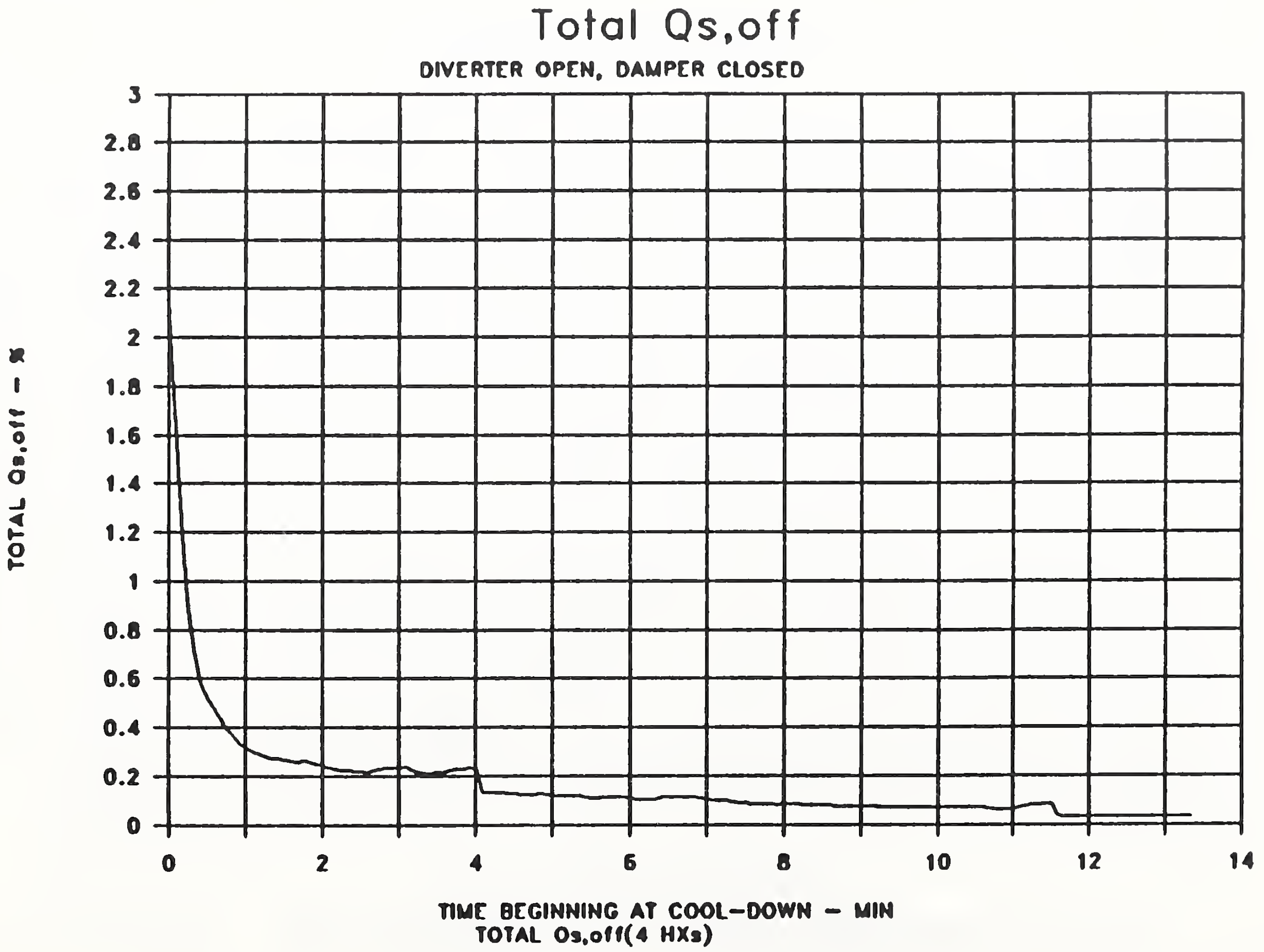


Figure 20. Sum of off-cycle sensible loss rates measured at each clam shell exit during cool-down test - diverter open; inlet damper closed

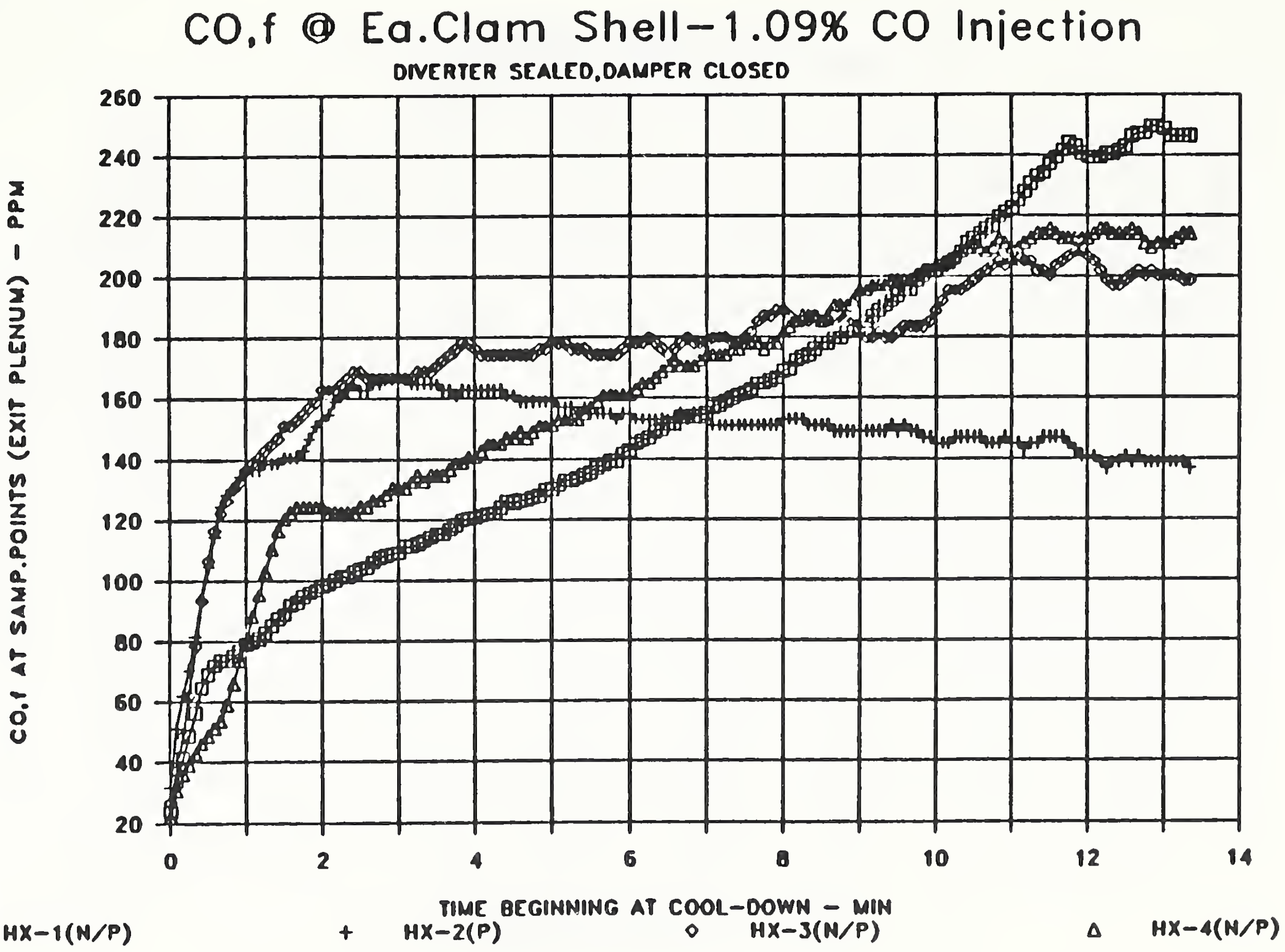


Figure 21. Tracer gas (CO) concentrations at each clam shell exit during cool-down test - diverter sealed; inlet damper closed

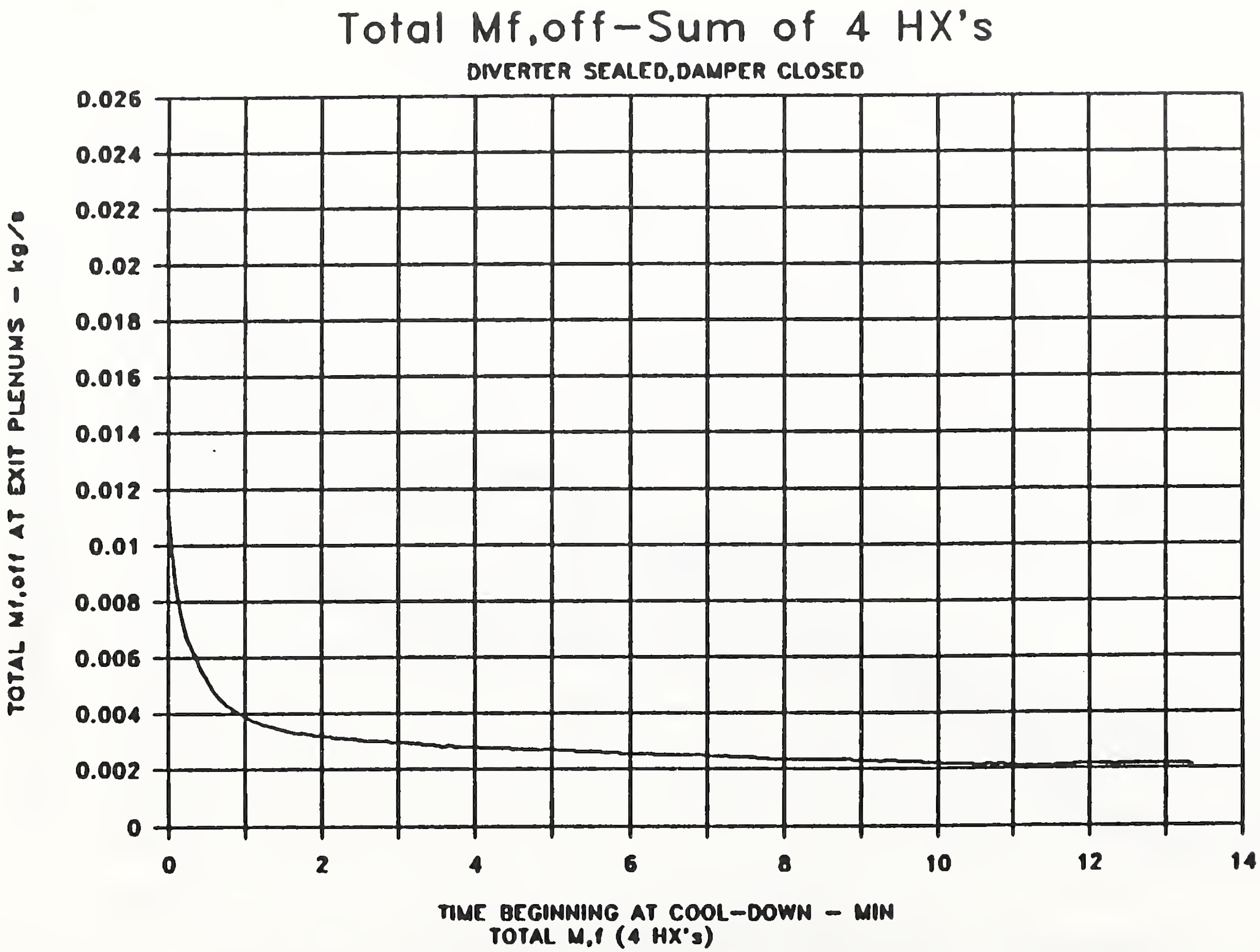


Figure 22. Sum of flue gas mass flow rates measured at each clam shell exit during cool-down - diverter sealed; inlet damper closed

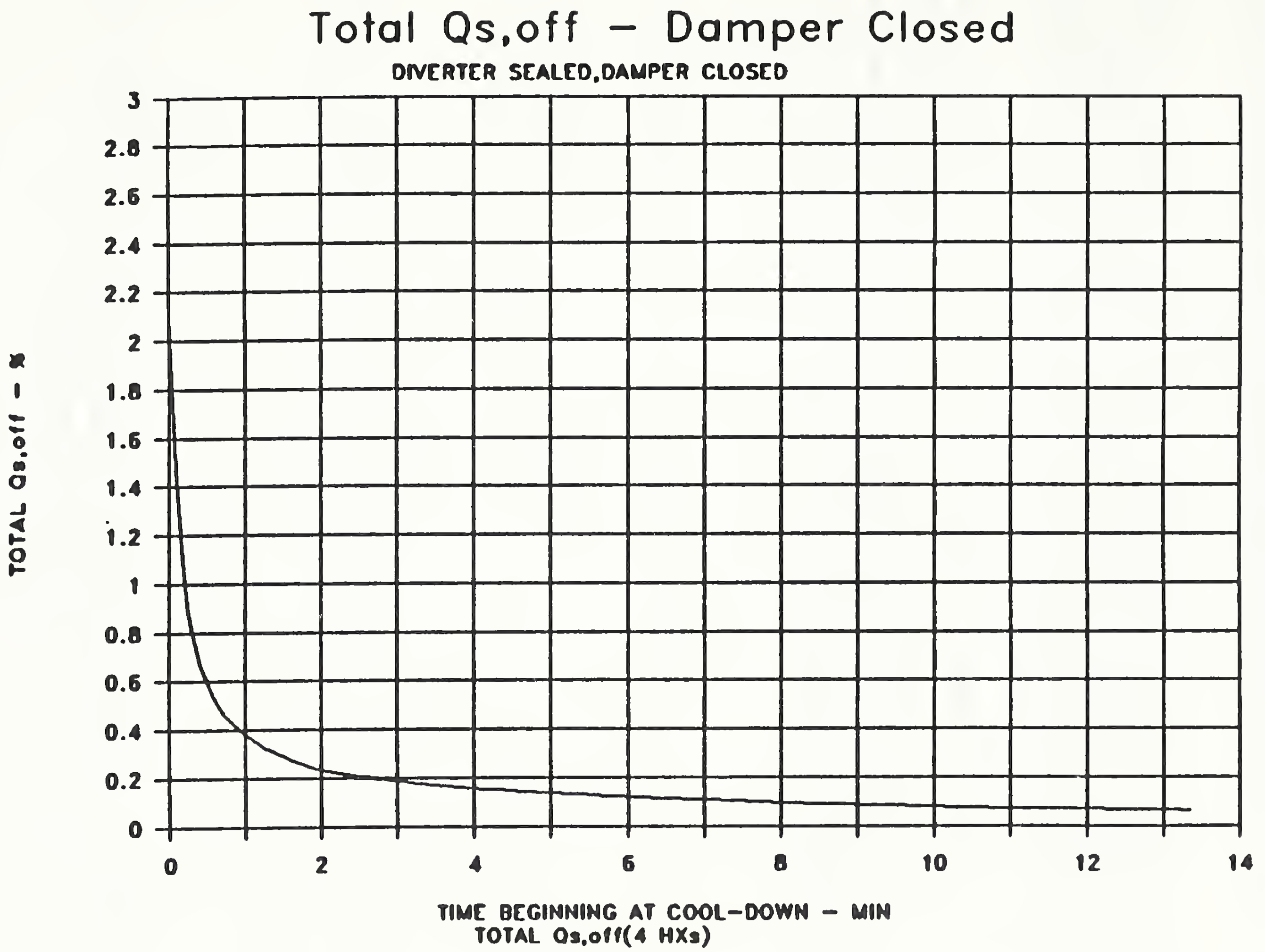


Figure 23. Sum of off-cycle sensible loss rates measured at each clam shell exit during cool-down - diverter sealed; inlet damper closed

APPENDIX A

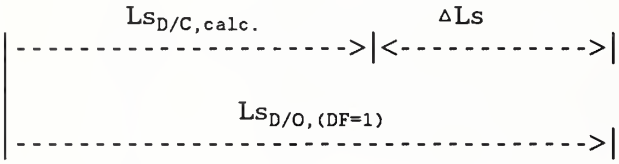
DEFINITION OF AN EFFECTIVE LOSS FACTOR, K_L

In this Appendix, all the loss terms are assumed to be off-period sensible heat losses, and are denoted by the variable name Ls. The conditions under which the losses are defined are attached to Ls as subscripts.

Assuming that the off-period sensible heat losses for an atmospheric furnace with a burner box inlet damper are $Ls_{D/O}$ when the inlet damper is held open during the off-period, and $Ls_{D/C}$ when the inlet damper is closed during the off-period, where the subscripts D/O and D/C indicate damper open and damper closed conditions, respectively, a fractional reduction in the off-period loss due to the function of the inlet damper can be defined as:

$$R = (Ls_{D/O} - Ls_{D/C}) \; / \; Ls_{D/O} = 1 - Ls_{D/C} \; / \; Ls_{D/O} \qquad \text{(A-1)}$$

If the calculated off-period sensible loss by the ANSI/ASHRAE 103-1988 procedure for the furnace with an open inlet damper is $Ls_{D/O,(DF=1)}$, where the flue draft factor D_F is assumed to be 1, the calculated reduction in the off-period sensible loss when the inlet damper is closed can be computed from equation (A-1) as (see the figure below):



$$\begin{aligned} \Delta Ls &= Ls_{D/O,(DF=1)} \cdot R = Ls_{D/O,(DF=1)} \cdot (1 - Ls_{D/C} \; / \; Ls_{D/O}) \\ &= Ls_{D/O,(DF=1)} - Ls_{D/O,(DF=1)} \cdot (Ls_{D/C} \; / \; Ls_{D/O}) \qquad \text{(A-2)} \end{aligned}$$

The calculated off-period sensible loss when the inlet damper is closed is, therefore, from the above figure and equation (A-2):

$$\begin{aligned} Ls_{D/C,calc.} &= Ls_{D/O,(DF=1)} - \Delta Ls \\ &= Ls_{D/O,(DF=1)} \cdot (Ls_{D/C} \; / \; Ls_{D/O}) \qquad \text{(A-3)} \end{aligned}$$

The ratio $Ls_{D/C}$ to $Ls_{D/O}$ in equation (A-3) can be obtained from the tracer gas test results, where $Ls_{D/C}$ and $Ls_{D/O}$ are computed from the measured tracer gas concentration and stack gas temperature data, each over a 13.3 minutes cool-down off-period following a 3.87 minutes heat-up period.

Defining an effective loss factor K_L as,

$$K_L \equiv Ls_{D/C} / Ls_{D/O}\Big|_{\text{measured by tracer gas method over 13.3 minutes off-cycle period}}$$

$$\approx (Ls_{D/C} / Ls_{D/O})\Big|_{\text{measured between minutes 5 and 6 after the burner-off}} \qquad \text{(A-4)}$$

the off-period sensible loss when the inlet damper is closed in the off-period can be calculated as, from equations (A-3) and (A-4):

$$Ls_{D/C,\text{calc.}} = K_L \cdot Ls_{D/O,(DF=1)} = Ls_{D/C}\Big|_{\text{rating}} \qquad \text{(A-5)}$$

Equation (A-5) shows that the off-period sensible loss when the inlet damper is closed during the off-period can be calculated with data from the standard ANSI/ASHRAE 103-1982 test with the inlet damper held open during cool-down, if an effective loss factor, K_L, is obtained from two tracer gas tests during the off-period, one with the inlet damper closed and one with the inlet damper open.

Now, the off-cycle flue gas flow rate is, for unit using indoor air for combustion, from Ref. 3:

$$M_{F,OFF} = D_F \cdot M_{F,ON} \cdot [(T_{F,OFF} - T_{RA}) / (T_{F,SS} - T_{RA})]^{0.56}$$

$$\cdot [(T_{F,SS} - T_{RA} + 530) / (T_{F,OFF} - T_{RA} + 530)]^{1.19} \qquad \text{(A-6)}$$

and the off-cycle sensible heat loss is:

$$Ls = (100)(0.24) / (Q_{IN} \cdot t_{ON}) \cdot \int_0^{t_{OFF}} M_{F,OFF} \cdot (T_{F,OFF} - T_{RA}) \cdot dt \qquad \text{(A-7)}$$

Substituting equation (A-6) into equation (A-7):

$$Ls = D_F \cdot [(100)(0.24) \cdot M_{F,ON} \cdot (T_{F,SS} - T_{RA} + 530)^{1.19} / (T_{F,SS} - T_{RA})^{0.56}$$

$$\cdot \int_0^{t_{OFF}} (T_{F,OFF} - T_{RA})^{1.56} / (T_{F,OFF} - T_{RA} +530)^{0.56} \cdot dt] \qquad \text{(A-8)}$$

Equation (A-8) is the equation in the ANSI/ASHRAE 103-1982 calculation procedure for the computation of the off-period sensible loss when the flue gas draft factor, D_F, is not equal to 1. When $D_F = 1$, the terms in the brackets in equation (A-8) give the off-period sensible loss for an atmospheric furnace without inlet damper and using indoor combustion air as calculated in the ASHRAE 103-1982 procedure.

Now, in equation (A-8), if the terms in the brackets are computed with test data from the standard ANSI/ASHRAE 103-1982 test for an atmospheric furnace with an integral draft diverter but with the inlet damper held open during the cool-down test period, the value would be equal to $Ls_{D/O,(DF=1)}$. In addition, if the value for D_F is replaced with K_L, the value of Ls calculated by equation (A-8) would be equal to the $LsD/C|_{\text{rating}}$ in equation (A-5), and the required efficiency values for the inlet damper closed condition also would be calculated by the ANSI/ASHRAE 103-1982 calculation procedure (or by its computer program). Since the input to the ANSI/ASHRAE 103-1988 computer program provided an input variable D_P for the value of D_F, setting $D_P = K_L$ together with the standard steady-state, cool-down and heat-up test data (obtained with the inlet damper held open during the cool-down phase of the test) would give the required input data to calculate the rating efficiencies for the inlet damper closed condition.

APPENDIX B

REVISION TO ANSI/ASHRAE 103-1982 FOR A TRACER GAS PROCEDURE ON AN ATMOSPHERIC FURNACE WITH INTEGRAL DRAFT DIVERTER AND A BURNER AIR INLET DAMPER

(1) The title of Section 8.9 of ANSI/ASHRAE Standard 103-1982 to be deleted and replaced with the following title:

8.9 Methods for Determining Draft Factors D_P, D_F, and D_S and **Off-Cycle Loss Factor K_L.**

(2) Sections 8.9.2 of ANSI/ASHRAE Standard 103-1982 to be deleted and replaced with the following:

8.9.2 Optional Methods for Determining Draft Factors D_P, D_F, and D_S for Systems Equipped with Power Burners or Draft Inducers, **and Method for Determining Off-Cycle Loss Factor K_L for Atmospheric Systems with an Integral Draft Diverter and with an Electro-mechanical Device at the burner air inlet that Restricts the Flow Through the Heat Exchanger in the Off-Cycle.** Draft factors D_P, D_F, and D_S are to be determined as described in 9.4 **and loss factor K_L are to be determined as described in 9.6.** The tracer gas chosen for this task should have a density which is less or approximately equal to the density of air. Use a gas that is of a different chemical species or different concentration from the flue gas to be measured and unreactive with the environment to be encountered.

(3) Add the following section 8.9.2.3 to ANSI/ASHRAE Standard 103-1982:

8.9.2.3 On atmospheric systems with an integral draft diverter and an electro-mechanical device at the burner air inlet that restricts the flow through the heat exchanger in the off-cycle, determine K_L (the ratio of off-cycle sensible heat loss tested with the electro-mechanical device closed during the off-cycle to the off-cycle sensible heat loss tested with the electro-mechanical device held open during the off-cycle) during two additional 10-minute duration cool-down tests. Conduct these two additional cool-down tests after the cool-down and heat-up tests described in 9.2 and 9.3 are completed. During a short burner off period before the two additional cool-down tests but after the completion of the heat-up test described in 9.3, remove the blocking over the draft relief opening and the restriction over the test stack outlet but keep the insulation over the rest of the draft diverter surface on(see 9.1.1.6). Conduct the first additional cool-down test by first running the unit until steady-state conditions are reached, (see 9.1) and then shutting the unit off with the electro-mechanical device adjusted or bypassed so that the device is held open during the resulting cool-down period. After the cool-down period, conduct the second additional cool-down test by again running the unit until steady-state conditions are reached, and then shutting the unit off but with the electro-mechanical device operating as designed during the resulting cool-down period. Measure the stack gas mass flow rate ($m_{S,OFF}$) and the stack gas temperature during the two additional cool-down periods described above starting at five minutes into the cool-down period using the procedure described in 9.6.5, and compute (as described in 11.4.4) the off-cycle sensible heat losses over the one minute interval between five and six minutes into the cool-down period using 9.6.

(4) Section 9.2.1.1 of ANSI/ASHRAE Standard 103-1982 to be deleted and replaced with the following:

9.2.1.1 Turn off the main burner after steady-state testing is completed, and measure the flue gas temperature by means of the thermocouple grid described in 7.5 at 1.5 ($T_{F,OFF}(t_3)$) and 9.0 minutes ($T_{F,OFF}(t_4)$) after burner shut off. Bypass the damper control in units employing stack dampers and integral draft diverter or draft hood so that the damper remains open during the cool-down test.
On atmospheric systems with an integral draft diverter and equipped with an electro-mechanical device at the burner air inlet that restricts the flow through the heat exchanger in the off-cycle, bypass or adjust the control for the device electrically or mechanically so that the device remains open during the cool-down test.

(5) Add the following sections 9.6, and 9.6.1 to 9.6.8 to ANSI/ASHRAE Standard 103-1982:

9.6 Tracer Gas Test Procedures for Determining Off-Cycle Loss Factor K_L for Atmospheric Systems with Integral Draft Diverter and Equipped with an Electro-Mechanical Device at the Burner Air Inlet that Restricts the Flow Through the Heat Exchanger in the Off-Cycle.

9.6.1 As described in 9.4.1.

9.6.2 After the completion of the heat-up test in 9.3, turn the burner off and remove the blocking over the draft diverter and the restriction in the test stack that are installed during the steady-state test in 9.1.1.6. Do not remove the insulation covering the draft diverter surfaces (see 9.1.1.6). In the mean time, sample and feed the ambient air to the tracer gas analyzer and record the background concentration C_B of the tracer gas to be used for the test (one data point is generally enough).

9.6.3 Turn the burner on until steady-state conditions are again achieved as specified in 9.1.1.1. Turn the burner off for a 10-minute cool-down period. Adjust or bypass the electro-mechanical device so that it remains open during this cool-down period. Within one minute after the unit is shut off to start the cool-down test, begin feeding a tracer gas with a known and certified concentration C_{Tm} at a constant flow rate V_T into the lower part of the test stack just above the test plane where the stack thermocouple grid is located (see 8.2.1.5.1). Periodically measure the value of V_T with an instantaneously reading flow meter having an accuracy of ± 3 percent of the quantity measured and maintain that value of tracer gas flow rate at less than one percent of the air flow rate through the test stack.

9.6.4 Within one minute after the tracer gas flow is started, connect the tracer gas sampling line to the sampling probe located at a plane inside and near the top exit of the test stack. Measure the transport delay time which is equal to the time between the connecting of the sampling line and the initial response of the tracer gas analyzer. Add to this transport time the time required for the analyzer to reach 90% of its steady-state value as specified in the analyzer's operation manual. The sum of these two values is the tracer gas sample delay time, t_{DELAY}, needed to match the concentration measurement to the temperature measurement in the off-period loss calculation. Make sure that a well mixed sample is collected by using a multi-hole sampling probe as recommended in Appendix D, Section B.

9.6.5 At five minutes after the unit is shut off to start the cool-down test, measure and record the percent volumetric concentration of tracer gas present in the stack gas sample, C_T, at the location specified in 9.6.4. At the same time, measure the stack gas temperature, $T_{S,OFF}$, using the thermocouple grid in the test plane (see 8.2.1.5.1). The data measurement and recording should be done at a time interval, Δt, of five seconds for the next two to three minutes. The exact length of time required for the data measurement is equal to the tracer gas sample delay time (see 9.6.4) plus one minute. (Even though only one minute of data is required for the computation of the off-cycle loss, the longer time is needed to take into account the time delay between the concentration data and the temperature data). Stop the tracer gas injection and sampling after the required data are measured and recorded. Disconnect the tracer gas sampling line from the sample probe and sample the ambient air to clear the line.

9.6.6 At the end of the 10-minute cool-down period, turn on the burner until steady-state conditions are again achieved as specified in 9.1.1.1. Turn the burner off for another 10-minute cool-down period. Let the electro-mechanical device close the way it is designed to. Repeat the test steps of 9.6.3 through 9.6.5 except that the electro-mechanical device is to remain closed. Note that the tracer gas feeding rate, V_T, may have to be adjusted to a lower rate to keep the sample concentration within the range of the gas analyzer used.

9.6.7 The rate of the stack gas flow through the stack, the off-cycle sensible loss rate, and the loss factor K_L are calculated by the equations in 11.4.4.

(6) Add the following section 11.4.4 to ANSI/ASHRAE Standard 103-1982:

11.4.4 Tracer gas procedure for determining the off-cycle loss factor K_L for atmospheric furnaces with integral draft diverter and equipped with an electro-mechanical device at the burner air inlet that restricts the flow through the heat exchanger during the off-cycle. Calculate the off-cycle loss factor, K_L, defined as the ratio of the off-cycle sensible heat loss with the electro-mechanical device closed during the off-cycle to the off-cycle sensible heat loss with the electro-mechanical device held open during the off-cycle:

$$K_L = (Q_{S,OFF} \text{ with device closed}) \,/\, (Q_{S,OFF} \text{ with device open})$$

where $$Q_{S,OFF} = \sum_{t=5}^{6} (q_{S,OFF}) \cdot (\Delta t/60)$$

= one minute sum-total of the measured $q_{S,OFF} \cdot \Delta t$ (Δt = time-step in seconds when data are recorded) over a one minute interval starting at five minutes into the cool-down period

Δt = time interval between measurement as defined in 9.6.5, second

60 = unit conversion factor to convert time in second to minute

and $q_{S,OFF} = C_P \cdot m_{S,OFF} \cdot (T_{S,OFF} - T_{RA})$

where $q_{S,OFF}$ = off-cycle sensible loss rate, Btu/min
C_P = specific heat capacity of the stack gas, Btu/$lb_m \cdot$°F
$T_{S,OFF}$ = measured stack temperature at time t as defined in 9.6.5, °F
T_{RA} = room ambient temperature as defined in 11.2.4, °F

and $m_{S,OFF} = [(C_{Tm} - C_T)/(C_T - C_B)] \cdot \rho_F \cdot V_T$

where $m_{S,OFF}$ = mass flow rate at time t of the stack gas during the off-cycle, lb_m/min
C_{Tm} = concentration by volume of measurable tracer gas in a certified standard tracer gas mixture, percent
C_T = concentration by volume of tracer gas present in the stack gas sample, measured at time t + t_{DELAY}, in accordance with 8.9, percent
t_{DELAY} = tracer gas sample delay time as defined in 9.6.4, seconds
C_B = room background concentration by volume of the tracer gas used as defined in 9.6.2, percent
V_T = flow rate of tracer gas through the stack measured in accordance with 8.9, ft^3/min
ρ_F = density of the stack gas as defined in 11.4.1, lb_m/ft^3

(7) Add the following section to ANSI/ASHRAE Standard 103-1982:

11..7 Additional Requirements for Atmospheric Furnaces with Integral Draft Diverter and Equipped with an Electro-Mechanical Device at the Burner Air Inlet that Restricts the Flow Through the Heat Exchanger in the Off-Cycle.

For furnaces with an integral draft diverter and equipped with an electro-mechanical device at the burner air inlet and installed as an isolated combustion system (ICS), the System Number and the draft factor D_F are defined as:
System Number = 10
$D_F = K_L$
where
K_L = off-cycle loss factor, as defined in 11.4.4

APPENDIX C

OFFSETTING FACTORS IN ON- AND OFF-CYCLE HEAT LOSSES FOR ICS AND INDOOR SYSTEMS

Ignoring the on-period latent loss and jacket loss for a furnace with an integral diverter which provides the relief air during the on and off cycles, there are two types of losses for the on as well as the off cycle. They are referred to in the DoE/ASHRAE furnace/boiler test procedure as the sensible loss and the infiltration loss.

The on-period sensible loss, $L_{S,ON}$, is due to the heating of combustion products and excess combustion air from room temperature to the flue gas temperature. The higher the flue gas temperature, the less energy is transferred to the circulation air in the heat exchanger, and the higher the sensible loss. For the Lennox unit, $L_{S,ON}$ is equal to 7.083 % for a system installed indoor and 7.517 % for an isolated combustion system (ICS). The higher loss for the ICS case results from correcting the on-period flue gas temperature for the fact that the assumed outdoor air temperature is 42 F. As a result, the ICS system losses more sensible heat than the indoor system, for a net increase of on-period sensible loss of <u>0.434</u> percentage points over the indoor system.

The on-period infiltration loss, $L_{I,ON}$, for furnaces using indoor air for combustion, is due to the heating of the on-period combustion and relief air from outdoor temperature of 42 F to room temperature of 70 F. The energy required is $L_{I,ON}$. In the test procedure, a fraction equal to 0.7 of the total combustion and draft relief air is charged against the furnace as a result of increased infiltration in the residence. For the Lennox furnace tested, $L_{I,ON}$ is equal to 0.962 %. For an ICS system, infiltration loss is assumed to be 0. Therefore, the indoor system has a net increase in on-period infiltration loss of <u>0.962</u> percentage points over the ICS system.

Taking the on-period losses together, it shows that the indoor system has a net on-period loss that is 0.962 - 0.428 = <u>0.528</u> percentage points more than the ICS system. Note that the on period losses are not affected by the inlet damper.

The off-period sensible loss, $L_{S,OFF}$, is due to the heating of the off-period draft air passing through the furnace heat exchanger to a temperature above the indoor temperature. This loss is affected by the operation of the inlet damper. The tighter the damper is, the less will be this sensible loss. For an ICS system, this loss is higher than an indoor system due to the fact that the assumed 42 F air entering the heat exchanger affects the mass flow rate through the heat exchanger. The computation for the off-period sensible loss is fairly complex. For the Lennox furnace tested, $L_{S,OFF}$ for an ICS system is computed to be approximately 1.37 times greater than an indoor system for a K_L value ranging from 1.0 to 0.1. The following table lists the value of $L_{S,OFF}$ computed:

K_L	$L_{S,OFF}$ - %		RATIO,	NET DIFFERENCE - %,	REMARK
	ICS	INDOOR	ICS/INDOOR	(ICS - INDOOR)	
1.00	8.787	6.404	1.3721	2.383	Damper open
0.43	3.778	2.754	1.3718	1.024	NIST test of Lennox furnace
0.10	0.896	0.660	1.3576	0.236	Assumed tight damper

It is seen from the above table that as the inlet damper becomes tighter, the net difference in $L_{S,OFF}$ between the ICS system and the indoor system become smaller.

The off-period infiltration loss, $L_{I,OFF}$, like the on-period infiltration loss, is due to the heating of the off-period draft and relief air from the outdoor air temperature to the indoor air temperature. The computation procedure is also more involved and the 0.7 factor also applies, as in the on-period computation. This loss also depends on the tightness of the inlet damper, but to a much lesser degree than the off-period sensible loss since the relief air through the diverter is included together with the draft air through the furnace heat exchanger. For an ICS system, this loss is again assumed to be zero. The following table shows the value of $L_{I,OFF}$ for K_L of from 1.0 to 0.1.

K_L	$L_{I,OFF}$ - %		Net Difference - %,	REMARK
	ICS	INDOOR	(ICS - INDOOR)	
1.00	0	2.432	-2.432	Damper Open
0.43	0	2.021	-2.021	NIST test of Lennox furnace
0.10	0	1.675	-1.675	Assumed tight damper

In the above table, the $L_{I,OFF}$ decreases as the K_L value becomes smaller because of the lower stack temperature and lower mass flow rate.

In addition to the sensible and infiltration losses described above, there is a jacket loss of 1% • 1.7 = 1.7% assumed for an ICS system. For an indoor system, the jacket loss is assumed to be zero. Combining all the losses, the following table shows the net difference in the losses between an ICS system and an indoor system:

K_L	0.99•(SENS.+INFIL.LOSS)		JACKET LOSS		NET SENS.LOSS		DIFF.IN NET SENS.LOSSES
	ICS	INDOOR	ICS	INDOOR	ICS	INDOOR	(ICS - INDOOR)
1.00	16.141	16.712	1.7	0	17.84	16.71	1.13
0.43	11.182	12.691	1.7	0	12.88	12.69	0.19
0.10	8.217	10.169	1.7	0	9.92	10.17	-0.25

In the above table, the factor 0.99 is a correction factor for the effect of the pilot light on the on and off period sensible and infiltration losses. It is seen from the above table that although the individual losses for the ICS system and the indoor system are quite different, the net difference in losses between the two systems, except for the inlet damper open case (K_L = 1.00), is very small. This explains why the resulting AFUE values are very close between the two systems for the case where K_L = 0.43 (AFUE =76.70% for ICS and 76.89% for indoor).

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An atmospheric furnance with an integral draft diverter and an electro-mechanical burner box inlet damper was tested by the tracer gas method for the development of a test procedure. Tracer gas tests were conducted under two conditions: with the diverter open, and with the diverter sealed and the stack restricted. Test results indicated that the flue gas flow patterns inside the heat exchanger were different for the two conditions. There was reverse flow in one of the clam shells when the diverter was open, but no flow reversal when the diverter was sealed. The off-cycle sensible loss which was a measure of the effectiveness of the burner box inlet damper gave similar value for both conditions. Because of the change in flow pattern and the fact that the furnace normally operated in the field with the diverter open, a recommended test procedure was developed which requires that the tracer gas test should be conducted with the diverter open. A calculation procedure was developed to compute the annual fuel utilization efficiency for the type of furnaces that employ a burner box inlet damper or flue damper for off-cycle loss reduction.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

ANSI/ASHRAE 103; atmospheric burner; burner air inlet damper; DoE test procedure; flue draft factor; loss factor; off-cycle loss; optional procedure for power burner; tracer gas test

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