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TESTING OF VARIOUS CHIMNEYS AND CHIMNEY CONNECTORS AT THE CMHC-OWNED ARMSTRONG HOUSE

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EXECUTIVE SUMMARY

The performance of six different chimney types and three chimney connector (flue pipe) designs was monitored at a test house on Armstrong Road in Ottawa. The purpose of the testing was to measure the effects of chimney insulation and downsizing, and to collect data that could be used to verify CMHC's FLUESIM computer simulation model.

Tests were carried out on the six 8-metre chimneys in calm weather and near freezing conditions. The chimneys evacuated combustion gases from a 26 kW oil furnace, which was run from a cold start and under slight house depressurization. Unfortunately, the furnace was shown to have large combustion pulsations which added a complex variable to the analysis of data.

Three of the chimneys were 100-mm (inside-diameter) factory built: two highly insulated and one standard A-vent. The three remaining chimneys were a 175-mm A-vent, a 150-mm type-650 and a 160-mm rectangular clay flue masonry chimney.

Test results have shown that all 100-mm chimneys spilled combustion gases for excessive periods of time at furnace start up. The larger chimneys had little startup spillage. The 150-mm and 175-mm factory-built chimneys had ample flow capacity as they carried a 70% surplus of dilution air at steady state conditions.

Except for the very highly insulated chimney, all 5 other chimney types were shown capable of developing their designed insulating value at equilibrium. Mass effect played an important role in reducing "effective insulation" value on all chimneys within 8 minutes of startup, a typical cycling period for oil furnaces.

From a cold start all chimneys formed a wall condensate. Better insulated chimneys had shorter condensation periods and attained operating conditions much faster. Both A-vent chimneys barely managed to get rid of condensation after 8 minutes. In the uninsulated exterior masonry chimney, condensation lasted for periods exceeding 15 minutes.

The 100-mm insulated chimney connector helped maintain a 10 degree higher temperature in 100-mm chimneys, thus slightly improving operating conditions and reducing the condensation period.

RÉSUMÉ

Des essais ont été effectués sur six différents types de cheminées et trois tuyaux à fumée raccordés à une fournaise à l'huile de vingt-six kilowatts. Le but de ces essais était de démontrer l'influence de l'augmentation de l'isolation et de la diminution du diamètre sur la performance des cheminées. De plus la cueillette de données devait servir à la validation de FLUESIM, un modèle informatique pour la simulation du fonctionnement de cheminées.

Les cheminées de huit mètres étaient installées à l'extérieur d'une maison de la SCHL sur le chemin Armstrong à Ottawa. Les essais ont été fait par vents calmes et lorsque la température était près du point de congélation. La fournaise à l'huile était démarrée à froid et sous l'effet d'une légère dépressurisation. Malheureusement, le brûleur était sujet à de grandes pulsations de combustion, ce qui ajoutait une autre variante dans l'analyse des données.

Trois des cheminées préfabriquées étaient de 100-mm: deux fortement isolées et une du type A. Parmi les autres cheminées on en retrouvait une de type A de 175-mm, une de type 650 de 150-mm et une de maçonnerie avec conduit d'argile de 160-mm.

Les résultats des essais ont démontré que toutes les cheminées de 100-mm étaient sujettes, lors de l'allumage, à produire des fuites de gaz de combustion pour des durées excessives. Par ailleurs, les fuites de démarrage étaient presque négligeables avec les plus grosses cheminées. Sous des conditions d'opération stabilisées, les cheminées de 150-mm et de 175-mm ont démontré des capacités de débit 70% plus élevé que le débit de gaz de combustion de la fournaise.

A partir d'un allumage à froid nous avons trouvé de la condensation sur les parois intérieures de toutes les cheminées. Les cheminées les mieux isolées ont eu des périodes de condensation plus courtes et ont atteint des conditions d'opération stables plus rapidement. La condensation n'était pas encore disparue dans les deux cheminées du type A, 8 minutes après l'allumage. La période de condensation n'était pas encore terminée dans la cheminée de maçonnerie 15 minutes après l'allumage.

Le tuyau de fumée isolé de 100-mm a aidé à maintenir des températures moyennes de cheminée supérieures de 10 degrés à celle du tuyau à paroi simple, améliorant ainsi la performance et réduisant la période de condensation.

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1.0 INTRODUCTION

The performance of six different chimney types and three chimney connector (flue pipe) designs was monitored at a test house on Armstrong road in Ottawa, Ontario. The purpose of the testing was to measure the effects of chimney insulation and downsizing, and to collect data that could be used to verify CMHC's FLUESIM computer simulation model.

Most of the test work was performed in April 1989. Additional test work was carried out at IRTA's combustion lab during the summer and at the Armstrong house in September.

The objectives of this study were:

- to monitor performance and collect field data for a variety of chimney and chimney connector designs

- to evaluate the performance of the different chimney and chimney connector combinations

- to investigate the effects of chimney insulation and sizing on venting

- to simulate the performance of these same chimney and chimney connector designs with CMHC's computer simulation program FLUESIM

- to compare the simulated data with the field data and identify discrepancies

- to modify FLUESIM if field and simulated data did not agree satisfactorily

Because of the complex nature of FLUESIM, the last objective was abandoned. Instead it was decided that the FLUESIM initial designers would modularize, streamline and add features to FLUESIM to facilitate the above comparison. At the time of publication of this report, these modifications are still under way.

CMHC and other organizations have been promoting better chimney insulation and smaller chimney diameters as partial solutions to the problems of combustion spillage and chimney condensation. This series of tests was designed to help assess the usefulness of these modified chimney designs.

2.0 TEST PROCEDURE

2.1 Approach

The performance of six chimneys and three chimney connector designs was monitored at the CMHC Armstrong house. The oil furnace already installed at Armstrong was used as the test furnace. Temperatures, pressures and flows were measured on each chimney and chimney-connector combination. Smoke pencils were used to check the duration of spillage of combustion gases at the barometric damper.

Table 1 describes the different chimneys and chimney connectors.

Figure 1 is the test matrix which shows which chimney was tested with which chimney connector. Apart from facilitating comparison with FLUESIM, this matrix allowed the following field data comparison: effect of increasing the insulation on 100-mm chimneys (4" A-vent, 4" high RSI-B, 4" high RSI-A) and on 100-mm chimney connectors, effect of increasing chimney diameter on 100-mm (4") and 175-mm (7") A-vent and 100-mm (4") and 175-mm (7") flue-connectors.

To simulate poor draft conditions, tests were repeated with the house under a 5-pascal depressurization.

The field data was analyzed and compared with simulated data from the FLUESIM program.

A detailed test protocol may be found in Appendix A.

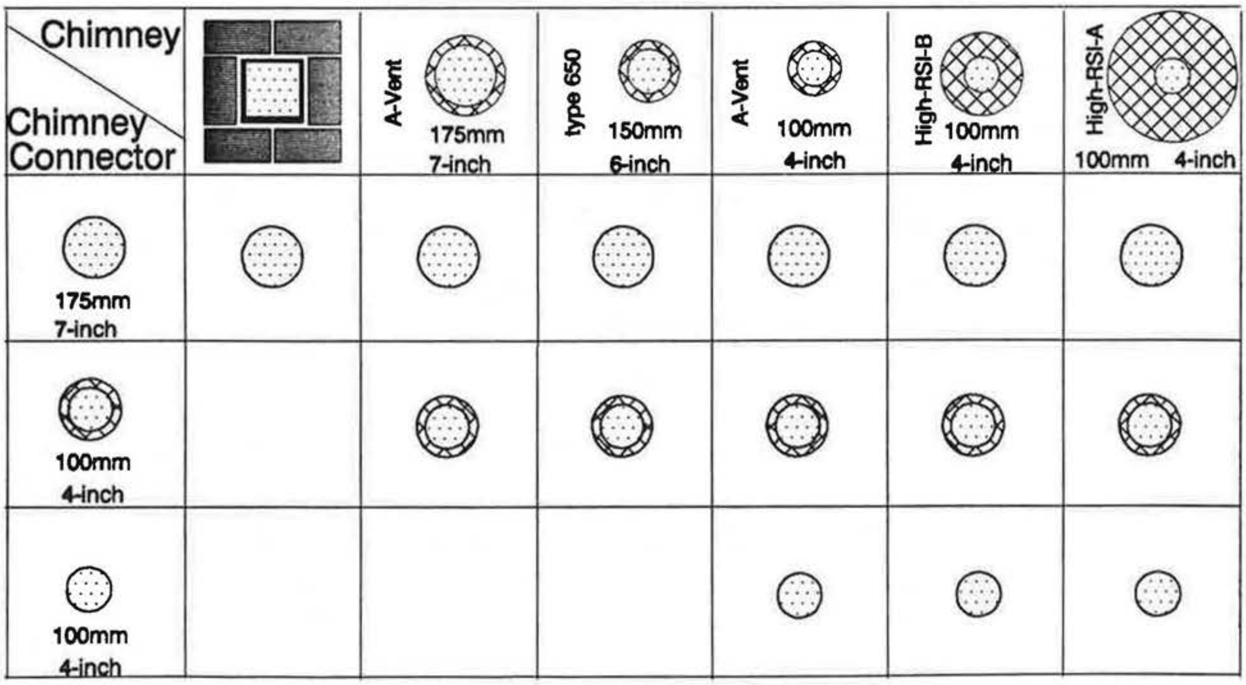
2.2 Weather restrictions

To minimize the influence of weather, testing was done when atmospheric conditions were favourable. There was to be no precipitation, winds had to be lower than 6 km/h and outdoor temperatures had to be close to, or below, freezing. Weather forecasts were checked with the Atmospheric Environment Service (AES) of Environment Canada. The station is located only a few kilometres from the Armstrong test house. The monthly meteorological summary sheets for April 1989 are found in Appendix A.

TABLE 1. DESCRIPTION OF TEST CHIMNEYS AND CHIMNEY CONNECTORS

CHIMNEY size & type	INSULATION material & thickness	RSI - VALUE theoretical or expected	INSULATION DENSITY Kg/m3	INSULATION HEAT CAPACITY J/kg.K	LINER MATERIAL
1. High-RSI-A	fiberglass	3	16 *	657 ***	stainless
100 mm (4-inch)	137 mm (5.5")				steel
2. High-RSI-B	fiberglass	1.5	28 *	657 ***	stainless
100 mm (4-inch)	67 mm (2.7")				steel
3. A-vent	mineral fibre	0.4	400 **	800 ****	stainless
100 mm (4-inch)	25 mm (1")				steel
4. Type 650	mineral wool	1.3	208 **	800 ****	stainless
150 mm (6-inch)	57 mm (2.3")				steel
5. A-vent	mineral fibre	0.4	400 **	800 ****	stainless
175 mm (7-inch)	25 mm (1")				steel
6. Masonry	clay tile	0.4	1900 ***	829 ***	clay tile
160 mm (8-inch nominal)	air space				brick
	brick				
* measured	** from manufacturer		*** ASHRAE	**** estimated	

FIGURE 1. MATRIX SHOWING WHICH CHIMNEY AND CHIMNEY CONNECTOR COMBINATIONS WERE TESTED



3.0 INSTRUMENTATION

3.1 Temperature measurement

The locations of the 10 temperature monitoring points are shown in Figure 2. Type K thermocouples were used. Extensions were shielded to prevent electronic interference.

3.2 Static pressure measurement

a) Static pressure

Static pressure was recorded at the base and exit of each chimney, and before and after the barometric damper (Fig. 2) with differential pressure transducers. The accuracy of the transducers was checked against that of an incline manometer. Data sheets for the transducers are given in Appendix B.

At each pressure measuring point a single pressure tap terminated flush with the inside surface of the chimney or chimney connector, and was connected to the transducers by means of plastic tubing. Pressure transducers were referenced to basement pressure.

b) Sources of error in pressure measurement

i) Verifying the stability of house reference pressures

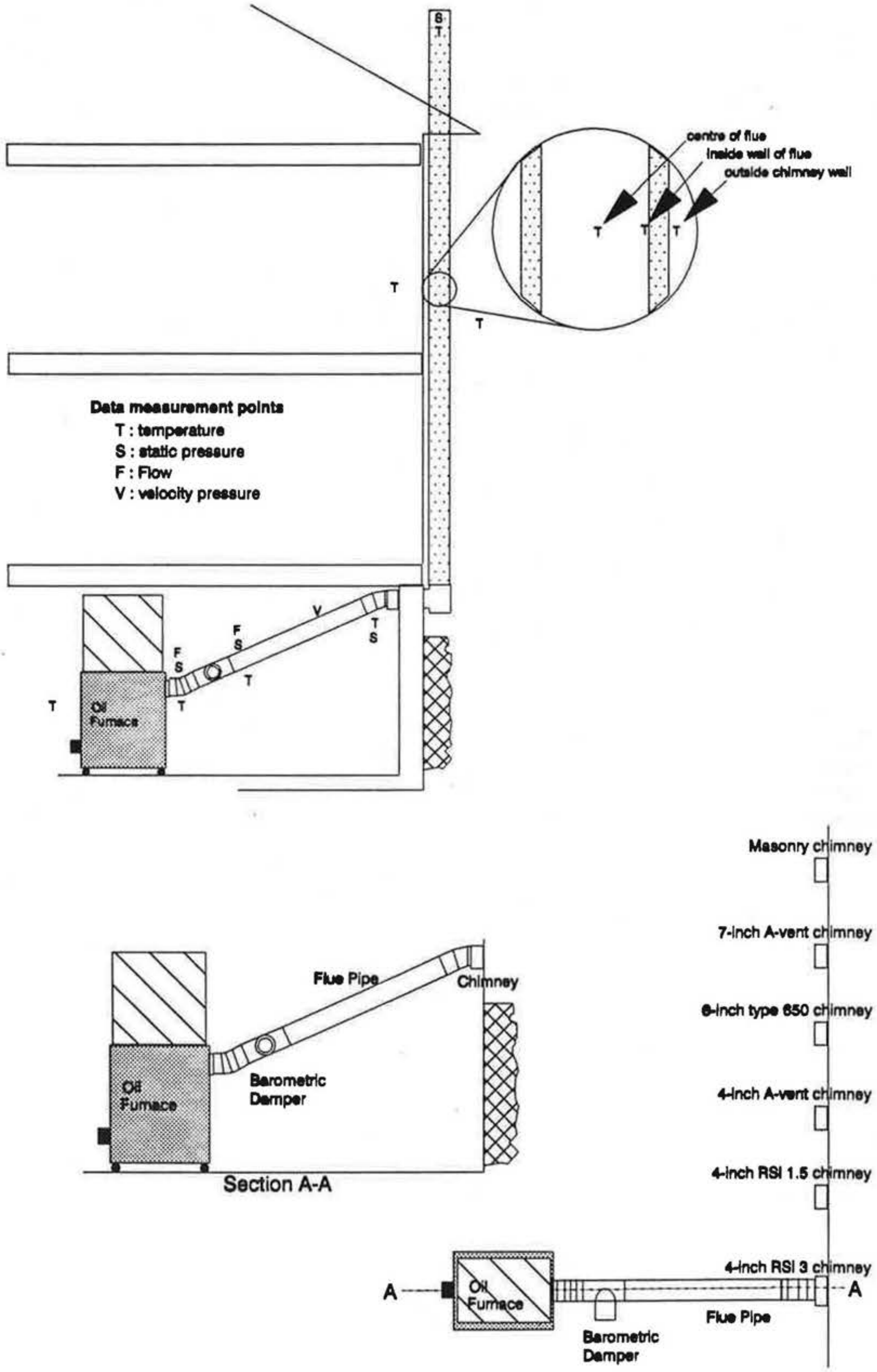
A fifth pressure transducer was used to check the stability of the house's reference pressure. It was checked against an absolute pressure measured in a sealed glass jar. The differential pressure measured between both these points showed only small and gradual variations in basement pressure. They did not exceed 2 Pa over the length of any test. Our basement reference point was stable.

To verify the influence of slight wind on the basement reference pressure, we compared an exterior reference pressure, measured on the windward side of the house, to that of a pressure measured in a sealed glass jar. The differential pressure measured between these points again showed only minor variation. All testing was done on days when wind speed was less than 6 km/h.

ii) Pressure oscillations

Measured static pressures were shown to change very rapidly. We tried dampening pressures at the flue collar, by averaging their reading across the flow instead of taking a single reading, but were unsuccessful. We discovered that the static pressure was in the form of high frequency oscillations and that our readings were random points along the oscillating curve.

FIGURE 2 TYPICAL CHIMNEY INSTALLATION



We later found out that the static pressures were oscillating too rapidly for the 16 msec response time of the pressure transducers. To measure these high frequency vibrations more accurately, we used a dynamic pressure transducer or microphone. The microphone's signal was amplified and displayed on an oscilloscope.

3.3 Flow measurement

a) Furnace flow

To verify FLUESIM's prediction of furnace flow, dilution flow and chimney flow, the concentration of CO_2 in the flue gas was monitored continuously before and after the barometric damper. A reduction of CO_2 after the damper indicated the addition of dilution air. This meant an increase in flow[1]. Unfortunately air leakage into the CO_2 sampling lines considerably lowered the accuracy of the flow measurements.

As an alternative for measuring dilution flow we used two other methods, one using dew-point temperature and the other using before-and-after-damper temperatures. Both methods stem from the basic calculations for oil combustion where the standard volume flow (furnace flow) is theoretically calculated as being 15.83 L/s, given an oil flow rate of 0.82 USGPH (26.4 kg/h) and a CO_2 concentration of 8% at the flue collar (Appendix C).

The dew-point temperature method uses the dew point to find the water-air ratio (from the psychometric chart) of the after damper flue gas. With the before damper water-air-ratios available from the basic combustion calculations we equated flows and water-air-ratios both before and after the damper to calculate dilution flow.

In the before-and-after-damper temperature method we equate the heat content of the flow before the damper to the heat content of the increased flow after the damper. The lower temperature after the damper is proportional to the increased flow from dilution. In this method we also must account for the radiant heat losses from the chimney connectors between the measuring points.

b) Sources of error in flow measurement

Flow was initially measured from the percentage of CO_2 in the flue gas at the flue collar and downstream from the barometric damper. Because of infiltration into the gas sampling lines, this method gave inconsistent data. The calculation of flow at the flue collar

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[1]The CO_2 concentration past the damper cannot be higher than the concentration before the damper. We cannot measure spillage from the damper with this method.

also relies on the accuracy of the CO_2 measurement and determining the accuracy of the oil flow to the burner. This method gave us error readings in the range of 3 L/s on flows from 15 to 30 L/s (Appendix C).

When calculating flow from the dew-point temperature we first locate the point where the flue gases have just finished condensing from the temperature curves (ref. section 5.1.1). This is the dew point and is located at the knee on the wall temperature curve just before the evaporation plateau. We can determine this point within one degree C. There is also some error attributed to the thermocouples. They also were shown to be within one degree C when calibrated against melting ice and boiling water.

When measuring flow from before-and-after-damper temperature difference we rely on the accuracy of two thermocouples. Another source of error is in the estimate of the radiation loss from the chimney connector between measuring points.

Flow calculated from both the dew-point temperature method and the before-and-after-damper temperatures give a surprisingly good correlation (Ref. section 5.1a).

3.4 Data acquisition

Test data were collected by a Sciemetric Labmate Series 7000 and a Hewlett Packard 3421A data acquisition system. Fifteen analog channels on the Sciemetric recorded data at 12-second intervals. The data were saved on diskette in ASCII file form for analysis. The basement, second floor and exterior temperatures were recorded by the Hewlett Packard system on tape and then manually transferred to the worksheet files for analysis.

While each test was being run, data acquisition was monitored on a real-time graph. This instantaneous presentation allowed us to monitor test parameters as the test proceeded. If problems developed they were apparent immediately, and tests could be aborted or problems debugged.

Because of the potential for electrical interference originating from air traffic control systems in the vicinity of the Armstrong house, all leads to the datalogging equipment were shielded and all measuring instruments grounded.

4.0 FIELD PREPARATIONS AT THE ARMSTRONG HOUSE

4.1 Field preparations

a) Inspection of existing chimneys

Six chimneys were used in the study (Ref. Table 1). A 175-mm diameter (7-inch) A-vent and a masonry chimney with a 160-mm (8-inch nominal) square clay flue liner were already installed at the Armstrong House. These exterior chimneys were used in a previous CMHC study. The 175-mm A-vent chimney was replaced because a visual inspection showed that water had penetrated many of its sections. The outer shells were rusted, a few to the point of perforation. Chimney insulation was caked due to moisture penetration.

The brick chimney was in fairly good shape on the exterior with no cracks in the mortar or broken bricks. The clay tile liner had a rather large curvature from top to bottom. There were no noticeable cracks in the clay flue tile liner and no blockages.

b) Installation of new chimneys

The four other chimneys were installed along the exterior wall of the Armstrong house next to the 175-mm (7") A-vent. All six chimneys were side by side, 10 cm apart, and approximately 8.5 m in height, terminating 2 m above the roof. They all entered the basement at the same level. To protect the thermocouples from interference, all metal chimneys were grounded. Figure 2 shows a typical chimney installation.

During installation there was some difficulty joining the custom-built (i.e high RSI) chimney sections together, because there was only a 12 to 25 mm (1/2 to 1 inch) overlap between chimney sections. A 50 mm overlap would have made the chimneys easier to work with.

Exterior joints from all five pre-fab chimneys were sealed with aluminum tape, immediately after installation, to protect against water entry and air infiltration. Unwanted air entry would dilute the gases and cause errors in the calculation of flows, temperatures, etc. The chimney tops remained sealed at all times when there was no testing. This kept rainwater and birds out. We removed several dead birds from the two existing chimneys before the testing. Chimney caps were not installed because chimneys were too close to each another.

c) Preparation of house, furnace and chimney connectors

i) House

The CMHC Armstrong test house is situated on Armstrong Road in Ottawa, a few kilometres south of the Ottawa International Airport. The Armstrong house is a large, two-storey unoccupied research house. It has a half basement where the oil furnace is installed. The house is unheated when it is unoccupied. Since the entire house was not required for the study, a portion was sealed-off, to facilitate heating and to maintain stable temperatures during testing. The basement plus the first and second floor directly above comprised the first area.

ii) Furnace

In order to eliminate chimney connector geometry as a variable, IRTA connected each chimney connector to the furnace and chimney in an identical fashion. To do this, the furnace was fitted with a flexible oil line and it was placed on casters. The furnace could now be moved in front of each chimney being tested.

iii) Chimney connectors

In each test the furnace was connected to the chimney using a straight chimney connector 2.7 meters (9') long. Three different types of chimney connectors were compared in the study: 175-mm (7") and 100-mm (4") single wall chimney connectors and a 100-mm (4") insulated chimney connector. The 100-mm (4") insulated chimney connector had 45 mm (1-3/4") of fibreglass insulation, which should provide an RSI of 1. Chimney connector joints were taped to prevent infiltration of room air.

Adapters were used to connect the chimney connectors to the different chimneys and the furnace flue collar. The adapters were of the short step-type with abrupt transition from smaller to larger diameter.

4.2 One-time tests

a) Adjusting the oil furnace

The Finlay oil furnace installed at Armstrong house uses a conventional Arrow burner rated at 36 kW (123,000 Btu/h) when fitted with a 1.10 USGPH nozzle.

Prior to the testing the furnace was serviced by E. C. Brown Heating and Ventilation. The serviceman relined the fire pot, and adjusted the circulating fan, the burner motor and burner motor shaft. The burner was downsized to 0.85 USGPH which was gave it a 27 kW equivalent.

The serviceman's efficiency test on the furnace gave a flue gas temperature of 227°C at the flue collar and a CO_2 concentration of 9%. The furnace's efficiency was measured at 78%. IRTA's test measurements agreed with those of the serviceman.

b) Verifying the oil nozzle rating

To verify the nozzle rating, we disconnected the furnace's flexible oil line from the oil tank and placed it in a jar of oil which was mounted on a weigh scale. With the furnace operating, we measured the weight of oil consumed over a time interval. The weight was converted to USGPH. A value of 0.82 USGPH was obtained as compared to the nozzle's rating of 0.85. This lowered the furnace's rating to 26 kW. Our measured oil flow rate was used in the mass flow calculations for combustion gas flow.

c) Fan depressurization

The fan depressurization test was performed with a Retrotec blower door to determine the air tightness characteristics of the building. This air tightness data was necessary as input to simulation, and helpful in interpreting the behaviour of some of the chimneys. Testing was performed according to the standard CAN/CGSB-149.10-M86, Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method.

For these tests all the chimney flues were sealed.

A summary of the fan test results is given below. All test data are shown in Appendix D.

<u>Results of air tightness testing:</u>

Testing revealed a rate of 11.8 air changes per hour (ACPH) at 50 pascals. The equivalent leakage area (at 10 Pa) is 0.15 m^2 (1.60 ft^2). The flow coefficients were: n = 0.625 and c = 186.2.

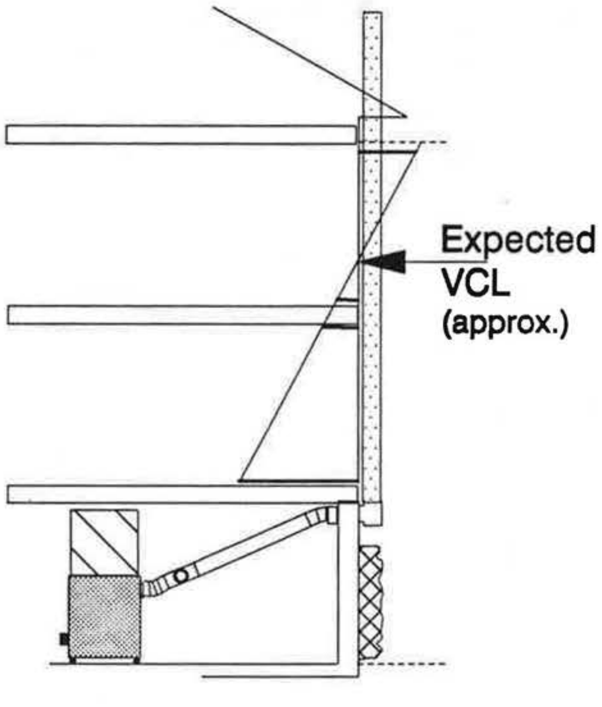
d) Vertical centre of leakage (VCL)

Indoor/outdoor pressure gradients were used to approximate the extent of air leakage occurring along the vertical axis of the building. The vertical centre of leakage is the theoretical location of zero leakage as defined by a zero pressure gradient. Below the VCL air flows into the building and above it air flows out of the building.

The indoor/outdoor pressure differentials measured indicated that the VCL was 3.5 metres above the second storey ceiling. We had expected the VCL to be somewhere around the midpoint of the building, considering the house's large air change rate (refer to previous section). Our VCL measurements were taken in less than ideal conditions, in warmer weather with less than a 10 degree C inside/outside temperature differential.

Doubting our results, we arbitrarily took the VCL as being located halfway between the exterior grade and the top storey ceiling.

FIGURE 3. VERTICAL CENTRE OF LEAKAGE



e) CMHC flue duct testing

Flue duct testing was performed by CMHC. Results are listed in Appendix E. The duct test utilizes an apparatus with a variable speed fan, which controls and measures the volume of air exhausted from a conduit, when the conduit is subjected to incremental pressures. From this information each chimney can be fingerprinted by a pressure-vs-flow curve which describes the aerodynamic behaviour of the chimney.

Flue testing of each chimney was done both with the chimney top open and sealed. Tests with the chimney top open give an indication of the chimney's flow capacity as shown by the flow @ 10 Pa pressure in Table 2. Tests with the chimney top sealed give an estimate of the quantity of cracks in each chimney. The larger the sealed chimney's ELA, the larger the amount of infiltration into the chimney. Chimneys with their joints taped are shown to have lower ELAs and consequently lower infiltration.

The test results were also used to determine the effect of air leakage in reducing the effectiveness of chimney insulation.

TABLE 2.

FLUE DUCT TESTING RESULTS

Chimney		Flow at 10 Pa (open chimney) (L/s)	ELA (cm^2) Blocked chimney joints taped	ELA (cm^2) Blocked chimney joints untaped
1	High-RSI-A			
	100-mm	13.5	2.4	3.2
2	High-RSI-B			
	100-mm	13.7	2.5	3.7
3	A-vent			
	100-mm	11.5	1.8	
4	Type-650			
	150-mm	51.0	2.5	
5	A-vent			
	175-mm	89.7	5.2	6.7
6	Masonry			
	160-mm	80.4	8.6	

5.0 TEST RESULTS

Introduction:

The first section of test results deals with flows and spillage. A chimney must be able to vent all combustion products to the outdoors safely, without any spillage to the indoor environment.

The second section of test results deals with temperatures, condensation and chimney insulation. When a chimney cannot maintain adequate flue gas temperatures, condensation occurs, and this can lead to the rapid deterioration of the chimney.

The third section of the test results covers the pressures associated with the combustion process and how these influence the chimney performance.

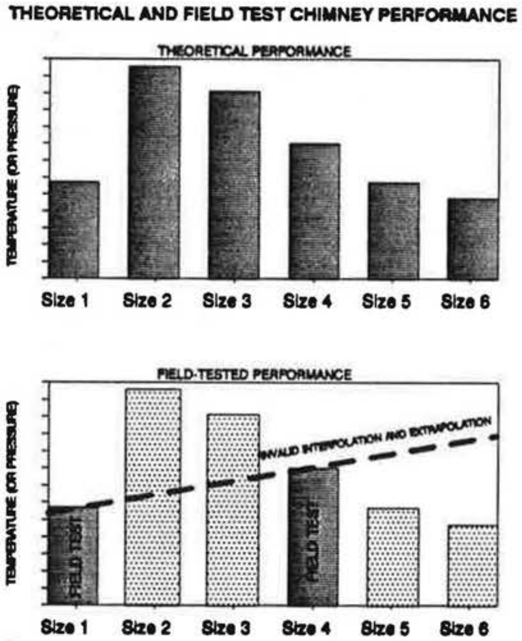


FIGURE 4. Limits on interpolating or extrapolating results

The test design was initially intended to use FLUESIM computer simulations to aid in drawing conclusions on the benefits of increased chimney insulation and downsizing. As FLUESIM proved inappropriate for this analysis, the testing matrix is not complete enough for optimum comparison of insulation and sizing effects. Only two of the installations (100-mm chimneys with 2 insulation levels) permit comparison of increased insulation; only two of the installations (100-mm and 175 mm A-vents) permit comparison of varying chimney size. As demonstrated in Figure 4, two points alone are far from sufficient for permitting interpolation or extrapolation of data with any degree of confidence.

5.1 Flows and spillage

a) Flows

Table 3 and Figure 6 summarize the flow data derived from dew-point temperatures and from the temperature difference of the flue gases before and after the damper. The different methods give slightly different results because they do not measure flow at the same times during the combustion. The dew-point temperature method measures flow as condensation ends (Fig. 5) while the temperature difference method measures flow at 8 minutes. Because condensation in the masonry chimney continued beyond the 12 minute test period, dew-point temperatures were not available for measurement of flow.

The furnace flow is measured from the basic combustion calculations as 15.8 L/s. While the furnace flow changes slightly as efficiency changes, we will assume it to remain constant with all chimneys. Calculated flows for all 100-mm flues (chimney and chimney connectors) show them to operate near capacity i.e. very close to the basic furnace flow with very little room for dilution flow. Flows from some of the 100-mm flues are smaller (Table 3) than the furnace flow because of their prolonged spillage periods.

The 150-mm and 175-mm chimneys showed flows of 27 and 29 L/s respectively when using a 175-mm chimney connector. These flows are 70% larger than the basic 15.8 L/s furnace flow and would indicate that a smaller chimney (possibly 125-mm) could handle the steady-state flow from this furnace without excessive spillage. It would not properly handle startup spillage from <u>this</u> furnace: the 150-mm chimney spilled for 30 seconds with 7" chimney connector (Fig. 7).

These standard volumetric flows translate into standard density velocities of 2.0 m/s for 100-mm chimneys, 1.5 m/s for the 150-mm chimney and 1.2 m/s for the 175-mm chimney.

TABLE 3.

FLOW COMPARISON FROM DEW-POINT AND FROM DELTA-TEMPERATURE							
NO DEPRESSURIZATION		dew point			delta temp		
chimney		chimney connectors			chimney connectors		
		175-mm	100-mm	100-mm	175-mm	100-mm	100-mm
		single-wall	insulated	single-wall	single-wall	insulated	single-wall
1	100-mm High-RSI-A	NA	18.8	19.3	NA	15.6	17.2
2	100-mm High-RSI-B	14.7	16.6	13.8	14.8	16.8	17.6
3	100-mm A-vent	20.5	18.7	17.2	16.9	15.1	16.5
4	150-mm Type-650	28	17.6	NA	27.6	17.7	NA
5	175-mm A-vent	29.6	17.7	NA	28.8	17.4	NA
6	160-mm Masonry	NA	NA	NA	21.5	NA	NA
DEPRESSURIZATION					delta temp		
chimney					chimney connectors		
					175-mm	100-mm	100-mm
					single-wall	insulated	single-wall
1	100-mm High-RSI-A				NA	15.4	16.5
2	100-mm High-RSI-B				14.8	16.2	17.4
3	100-mm A-vent				16.4	15	16.5
4	150-mm Type-650				24.5	17.7	NA
5	175-mm A-vent				24.9	16.4	NA
6	160-mm Masonry				15.2	NA	NA

FIGURE 5. Dew Point Measurements

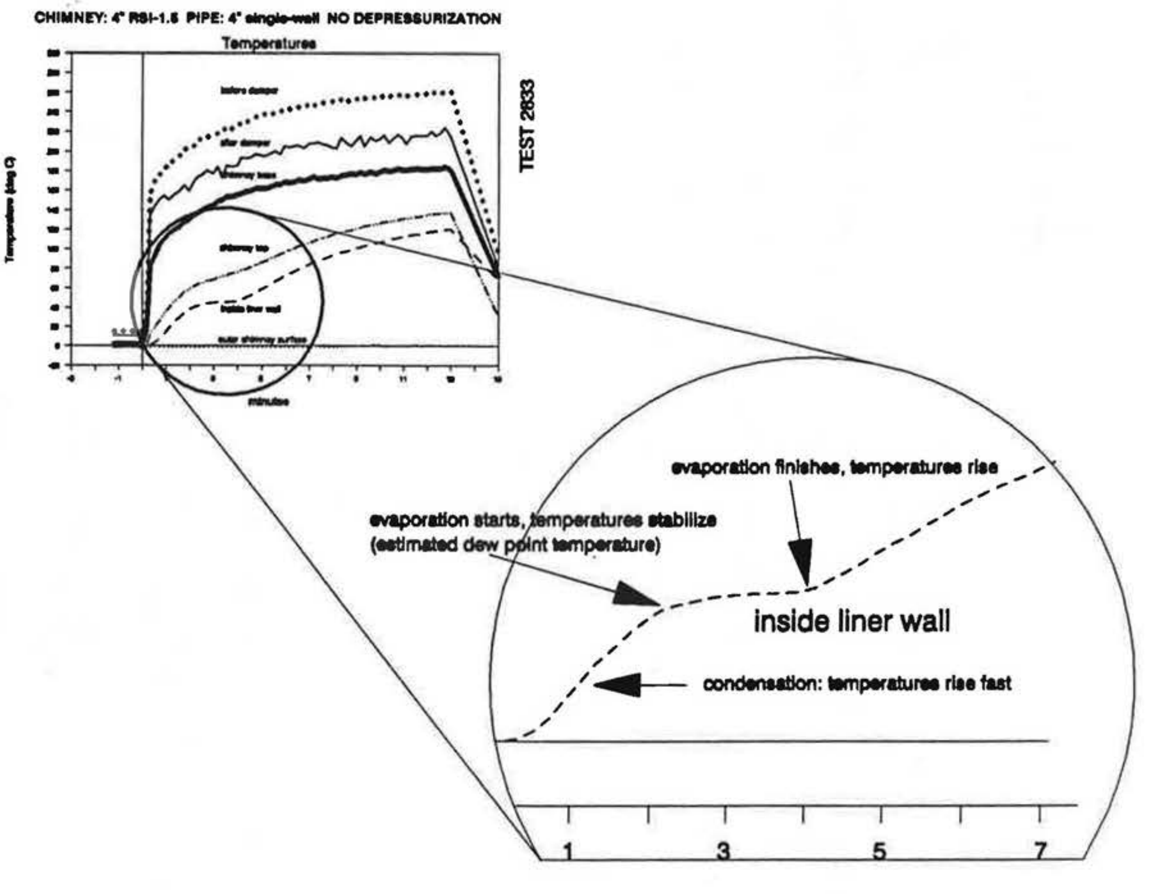


FIGURE 6.

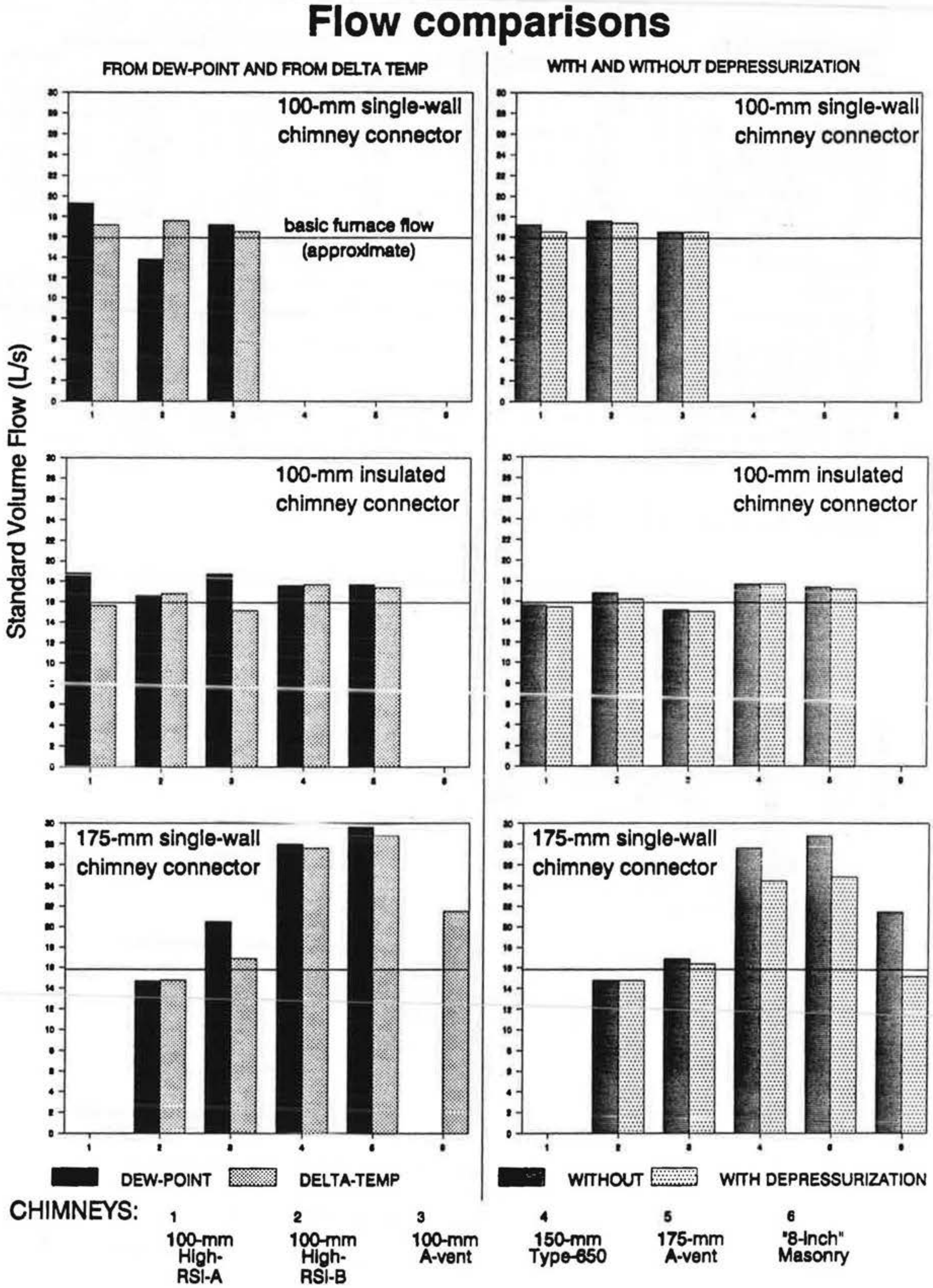
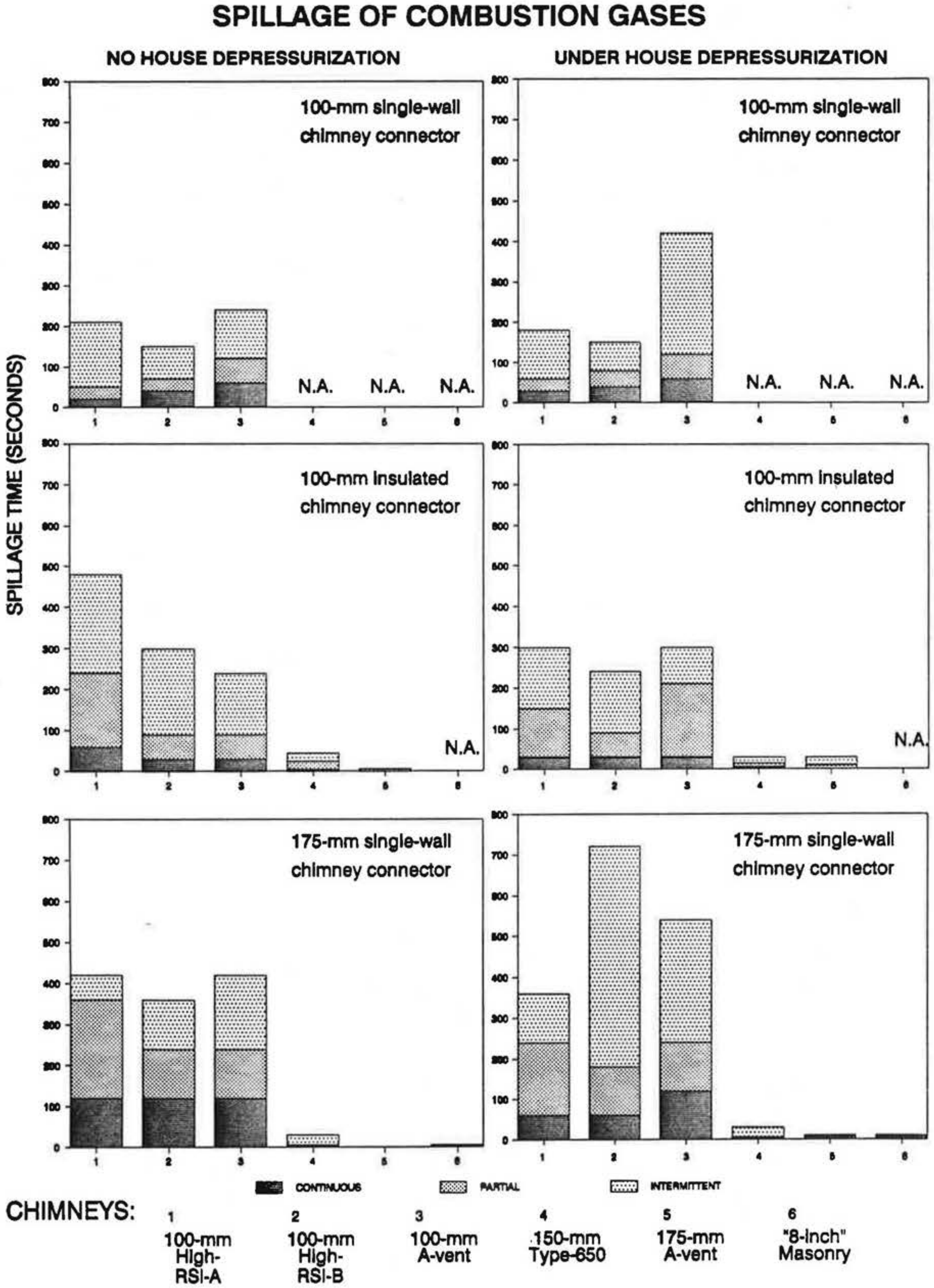

Flow comparisons
FROM DEW-POINT AND FROM DELTA TEMP
WITH AND WITHOUT DEPRESSURIZATION
Standard Volume Flow (L/s)
100-mm single-wall chimney connector
basic furnace flow (approximate)
100-mm insulated chimney connector
175-mm single-wall chimney connector
DEW-POINT
DELTA-TEMP
WITHOUT
WITH DEPRESSURIZATION
CHIMNEYS:
1 100-mm High-RSI-A
2 100-mm High-RSI-B
3 100-mm A-vent
4 150-mm Type-650
5 175-mm A-vent
6 "8-Inch" Masonry

FIGURE 7.


SPILLAGE OF COMBUSTION GASES
NO HOUSE DEPRESSURIZATION
UNDER HOUSE DEPRESSURIZATION
SPILLAGE TIME (SECONDS)
100-mm single-wall chimney connector
100-mm insulated chimney connector
175-mm single-wall chimney connector
N.A.
CONTINUOUS
PARTIAL
INTERMITTENT
CHIMNEYS:
1 100-mm High-RSI-A
2 100-mm High-RSI-B
3 100-mm A-vent
4 150-mm Type-650
5 175-mm A-vent
6 "8-inch" Masonry

b) Spillage of combustion gases

i) Categorizing spillage

Spillage of combustion gases was identified with a smoke pencil, and the duration of any spillage after furnace start-up was timed. Because we identified different degrees of spillage, we decided to categorize these according to some measure of importance. Light backpuffing is not as serious a problem as continuous spillage. The following categories were selected:

- continuous: There is continuous spillage out of the damper. No room air is being drawn into the damper.
- partial: The damper is continuously oscillating between spillage and air intake.
- intermittent: Occasional spillage from time to time.

Note: 1) Our system was equipped with a barometric damper in very good operating condition. It shut firmly in place, leaving a very small perimeter crack under zero or positive gas pressure differential. This provided little opportunity for spillage. This is not always the case in houses. Identical pressure conditions with a poorly operating damper could easily result in much higher spillage.

2) It is our opinion that intermittent, and probably partial, spillage during the tests are both caused primarily by combustion oscillations.

ii) Field data

During each test total spillage times were recorded. These are shown on Figure 7. The lower part of the stacked graph shows the duration of continuous spillage, the middle partial spillage and at the top the duration of intermittent spillage.

All 100-mm (4-inch) diameter chimneys were shown to spill combustion products into the house for unacceptably long periods with complete spillage occurring for periods longer than 25 seconds. The type of chimney connector did not seem to affect the spillage patterns of the 100-mm (4-inch) chimneys. There seemed to be no definite pattern as to how the depressurization affected the duration of spillage.

The 150-mm Type-650 chimney had only short periods of continuous spillage, but partial and intermittent spillage lasted for periods up to half a minute and more after start up.

Spillage on the 175-mm (7-") A-vent and the masonry chimney was limited to less than 10 seconds and even then the spillage was only partial and intermittent.

SPILLAGE FROM THE 100-MM FLUES LEADS US TO BELIEVE THAT THEIR CAPACITY IS INSUFFICIENT TO HANDLE THE FLOW FROM THIS 26-kW OIL FURNACE, WHILE 150-MM AND 175-MM FLUES WERE EASILY ABLE TO HANDLE THIS FLOW.

5.2 Temperatures, condensation and thermal resistance

a) Test temperatures

i) Temperature variations between chimneys

Six of the ten recorded temperatures are graphed (Fig. 8a and 9a). Omitted for the sake of clarity are two interior ambient temperatures, the exterior temperature and the flue gas temperature at the chimney's midpoint. Temperature curves for each test may be found in Appendix F.

The duration of each test was approximately 15 minutes (Fig. 8a). Temperatures were recorded 3 minutes before furnace startup to check recordings and verify operating conditions. At time 0, the furnace was turned on; temperatures rose sharply and then tapered off as they approached equilibrium.

The "chimney top" and "inside liner wall" temperatures were slower to reach equilibrium. Flue gas temperatures generally reached 90% to 95% of their steady state conditions within 12 minutes, except in chimneys with a heavy thermal mass, such as the masonry chimney.

Figure 10 summarize the "chimney top" temperatures at 8 minutes after startup. The two horizontal lines at 60 and 80°C, represent the zone where condensation is evaporating. If the core (or flue centre) gas temperature at the chimney top is in this zone, the condensate may not have totally evaporated. If it is below 60°C, condensation may still be occurring.

<u>THE VERY HIGHLY INSULATED RSI-A CHIMNEY DID NOT SHOW ANY IMPROVEMENT IN TEMPERATURE OVER THE HIGHLY INSULATED RSI-B CHIMNEY, 8 MINUTES AFTER STARTUP (Fig. 10).</u> This observation agrees with the calculated thermal resistance values of the chimneys: high RSI-A = 1.6 and high RSI-B = 1.3 (ref. section 5.2 c).

When touching the exterior wall of the high RSI-A chimney we could feel hot spots, suggesting poor distribution of the insulation pads.

<u>THE HIGHLY INSULATED RSI-B CHIMNEY SHOWS A NOTICEABLE IMPROVEMENT OVER THE LESSER INSULATED A-VENT IN MAINTAINING HIGH TEMPERATURES AND PREVENTING CONDENSATION OF COMBUSTION GASES</u>.

FIGURE 8a

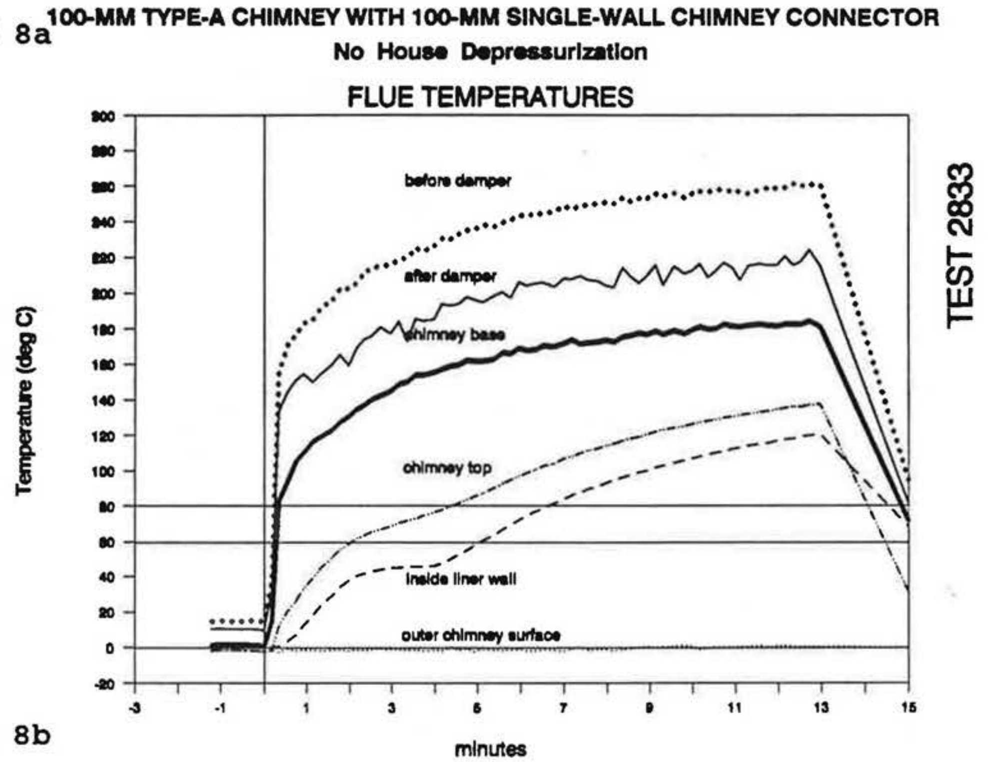


FIGURE 8b

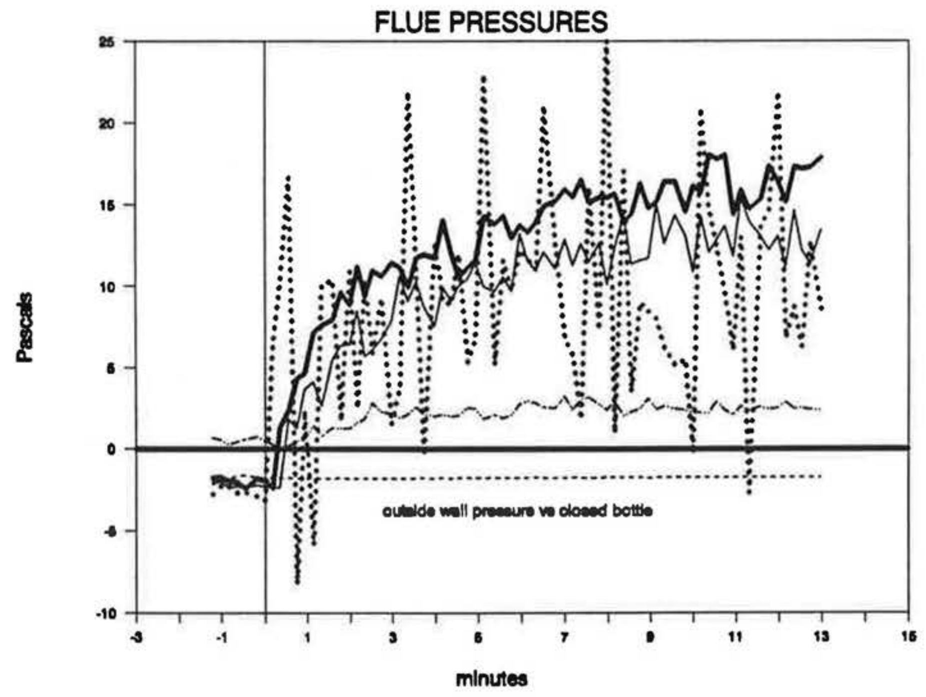


FIGURE 9a 150-MM TYPE-650 CHIMNEY WITH 175-MM SINGLE-WALL CHIMNEY CONNECTOR

No House Depressurization

TEST 4009

FLUE TEMPERATURES

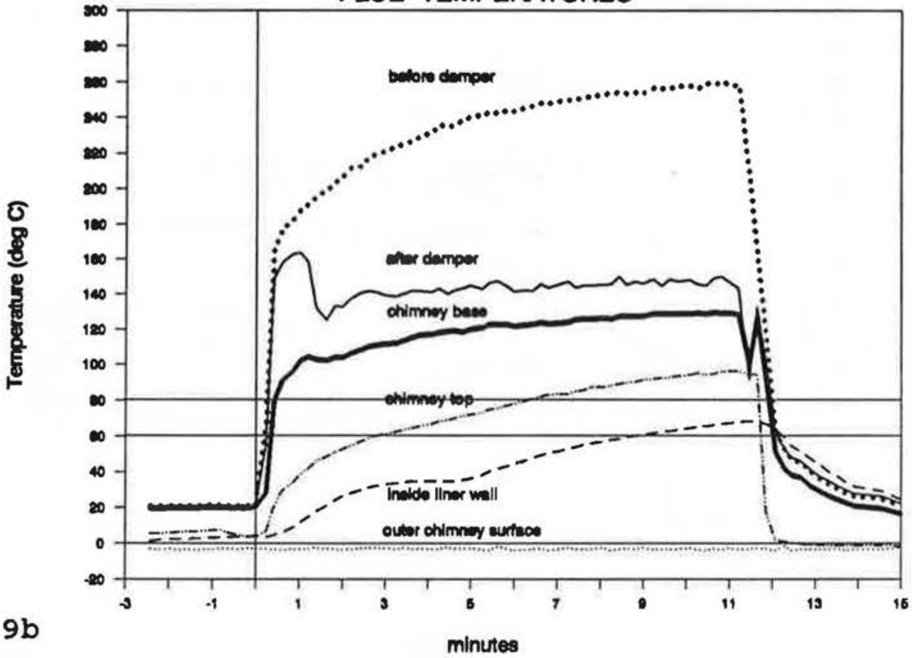


FIGURE 9b

FLUE PRESSURES

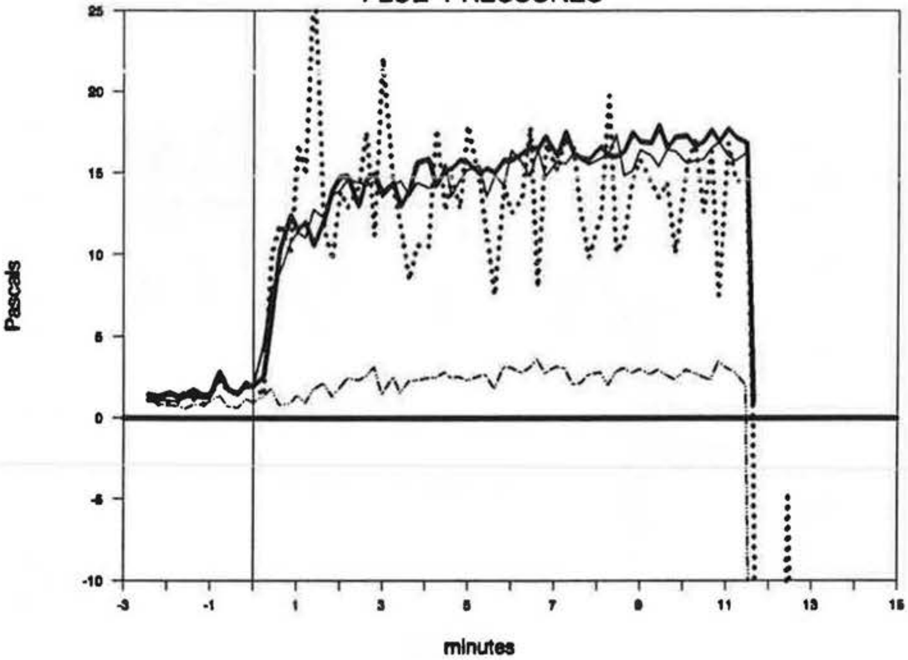


FIGURE 10

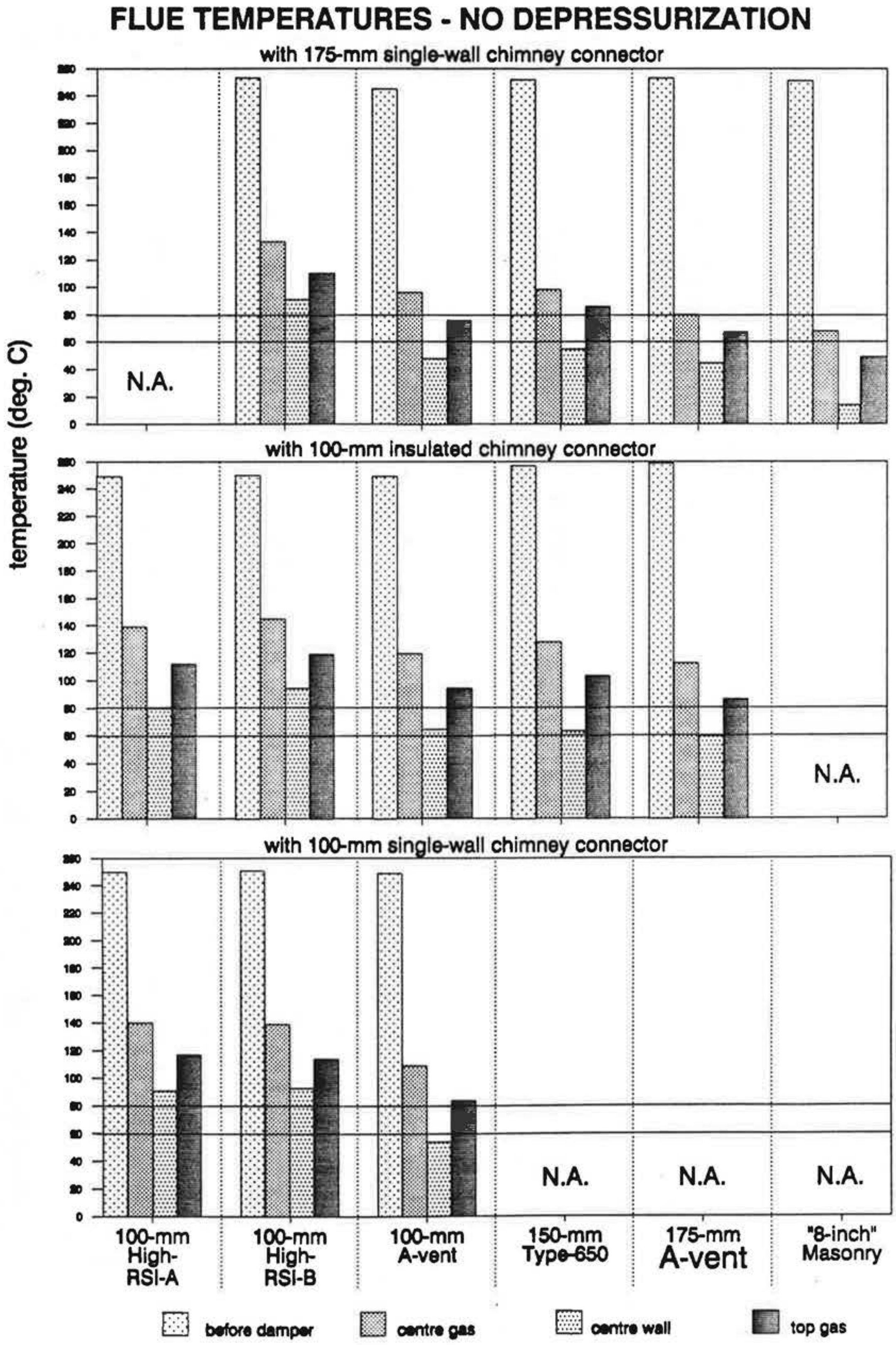
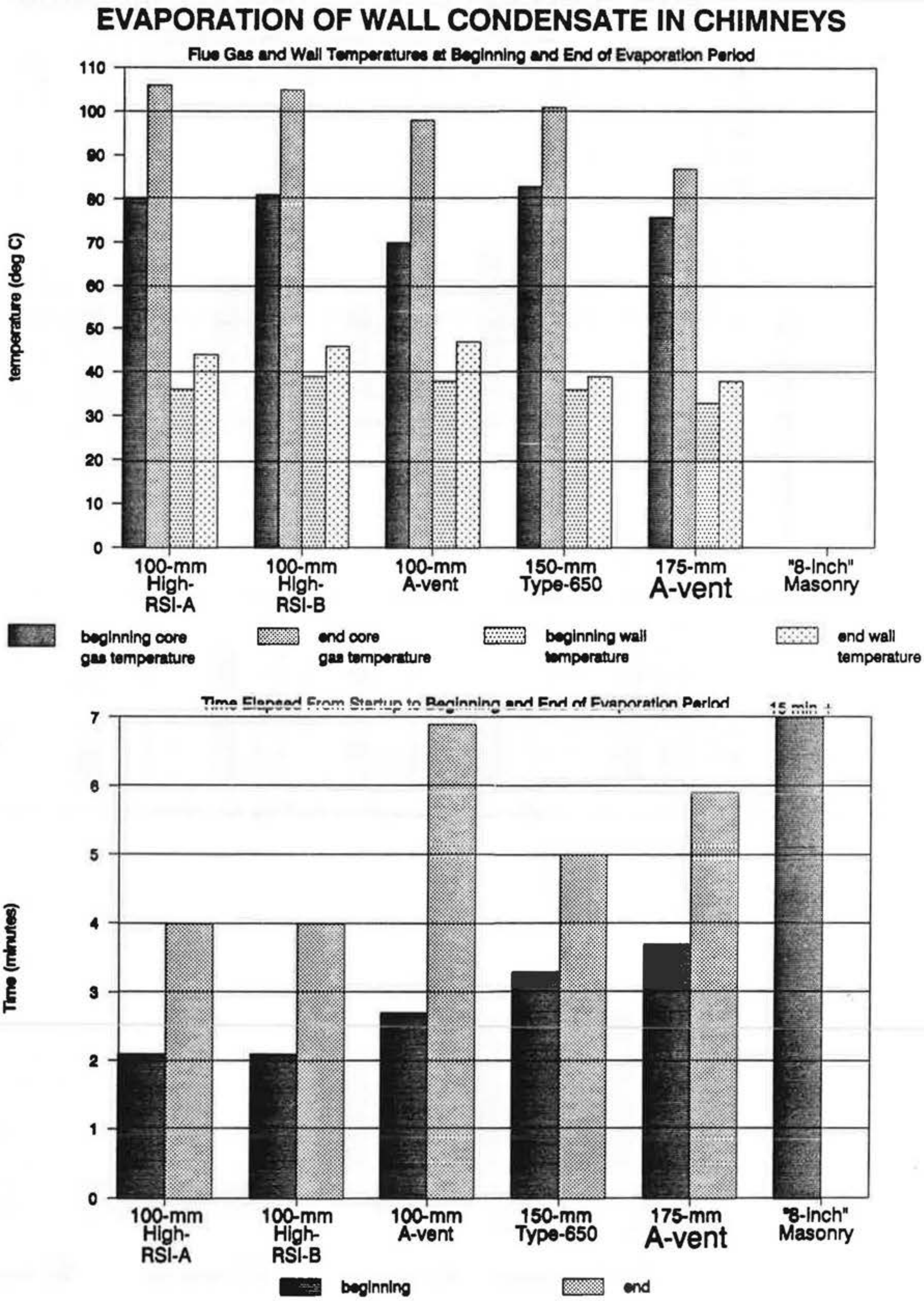

FLUE TEMPERATURES - NO DEPRESSURIZATION
with 175-mm single-wall chimney connector
with 100-mm insulated chimney connector
with 100-mm single-wall chimney connector
temperature (deg. C)
N.A.
100-mm High-RSI-A
100-mm High-RSI-B
100-mm A-vent
150-mm Type-650
175-mm A-vent
"8-inch" Masonry
before damper
centre gas
centre wall
top gas

FIGURE 11


EVAPORATION OF WALL CONDENSATE IN CHIMNEYS
Flue Gas and Wall Temperatures at Beginning and End of Evaporation Period
temperature (deg C)
0
10
20
30
40
50
60
70
80
90
100
110
100-mm High-RSI-A
100-mm High-RSI-B
100-mm A-vent
150-mm Type-650
175-mm A-vent
"8-Inch" Masonry
beginning core gas temperature
end core gas temperature
beginning wall temperature
end wall temperature
Time Elapsed From Startup to Beginning and End of Evaporation Period
Time (minutes)
0
1
2
3
4
5
6
7
100-mm High-RSI-A
100-mm High-RSI-B
100-mm A-vent
150-mm Type-650
175-mm A-vent
"8-Inch" Masonry
beginning
end

ii) Temperatures associated with insulated chimney connectors

The 100-mm chimneys were tested with three chimney connectors: 100-mm single-wall, 100-mm insulated and 175-mm single-wall. The 100-mm single-wall chimney connector maintained 15 degrees higher temperatures at the chimney base than did the larger 175-mm single-wall chimney connector. The insulated 100-mm chimney connector maintained the average temperature of chimney gases some 10 degrees higher than the single-wall chimney connector.

iii) Temperature drop due to dilution flow

On the three larger-diameter chimneys, dilution of combustion gases is noticeable by the sudden drop in temperature on the "after damper" curve (Fig. 9a). The barometric damper was set to open at 15 Pa.

On the smaller 100-mm (4") chimneys, the chimney operates below this 15-Pa draft but pressure pulsations make the damper flutter. The small amounts of dilution provided by these draft fluctuations can be seen by the oscillations in the "after damper" temperature curves (Fig. 8a).

iv) Effect of depressurization on temperature

A 5 Pa depressurization does not seem to change the temperatures in the 100-mm (4") flues. The smaller chimneys are shown to operate with a draft smaller than the 15 Pa required to open the damper, with the consequence that the system remains closed to the depressurized surroundings. There does not seem to be a significant increase in spillage under depressurized conditions.

On the three larger flues (with the 175-mm chimney connector), which operate generally at a draft greater than 15 Pa, the 5-Pa depressurization has the effect of decreasing dilution into the chimney (Table 3), thus slightly increasing temperatures.

b) Condensation

The cessation of condensation of combustion gases is noticeable by the flat portion of the "inside liner wall" temperature curve a few minutes after furnace startup (Fig. 5, 8a and 9a). Because of the heat released during condensation, wall temperatures rise rapidly during the first two minutes. This rapid rise of wall temperature is followed by a flat portion, due to the stabilization of temperatures during evaporation of the condensate. When all the water is re-evaporated, temperatures once again start to rise.

Figure 11 shows the core gas temperatures at the chimney top associated with re-evaporation. It also indicates the duration of the condensation period and the time required for each chimney to re-evaporate the wall moisture. Better insulated chimneys show a slight advantage over the other chimneys. With a cold startup, in a 0°C outside temperature, the masonry chimney does not reach its re-evaporation phase within 15 minutes of startup. Using an insulated chimney connector to deliver warmer gases to the chimney base will decrease both the quantity and duration of condensation in a chimney.

In domestic applications for oil and gas furnaces where the cycle periods are less than 8 minutes, we must question whether condensation does not affect the performance of even the better insulated chimneys. Where cycle periods become longer (or for woodburning applications where periods are long but temperatures are lower) better insulated chimney increase performance by maintaining shorter condensation periods and warmer temperatures.

<u>BETTER INSULATED CHIMNEYS AND CHIMNEY CONNECTORS WOULD REDUCE THE QUANTITY AND DURATION OF CHIMNEY CONDENSATION ASSOCIATED WITH FURNACE CYCLING. THIS REDUCED CONDENSATION RESULTS IN REACHING HIGHER CHIMNEY TEMPERATURES MORE QUICKLY AND IMPROVES CHIMNEY PERFORMANCE.</u>

c) Chimney RSI values

i) Measured vs theoretical

To measure the insulation value of the chimneys, we heated them until they reached equilibrium temperatures. In this state, the axial heat flow through the chimney wall and insulating materials is also in equilibrium. The materials are no longer absorbing any heat. This process took roughly 30 minutes for chimneys with low thermal mass and an hour and more for the chimneys with high thermal mass.

Table 4 lists theoretical and measured chimney RSI values for the different chimney types. The 8-minute operating cycle was much too short for chimneys to come to equilibrium. Over these short periods the chimneys with the larger thermal mass (i.e. A-vents, masonry) had a lower "effective RSI"[2] because of the mass effect.

<u>SYSTEMS OPERATING ON LONGER HEATING CYCLES ALLOW CHIMNEYS TO APPROACH EQUILIBRIUM TEMPERATURES, THUS PUTTING TO BETTER USE THE CHIMNEYS INSULATING VALUE</u>

ii) How chimney infiltration affects "effective RSI" values

To determine the degree to which air leakage through chimney joints affected insulation values, chimneys were retested under three infiltration rates. Table 4 shows how infiltration can decrease the "effective RSI" values of chimneys. Maximum chimney heat losses due to infiltration can reach 30% of the total heat loss. These maximum infiltration tests were done by removing the tape from around the chimney joints (ref. Table 2).

<u>INFILTRATION INTO CHIMNEYS LOWERS A CHIMNEYS "EFFECTIVE RSI" VALUE AND DECREASES CHIMNEY PERFORMANCE.</u>

5.3 Pressure

a) Test pressures

Static pressures were found to change rapidly in response to combustion pulsations. Our initial recordings of static pressure were not sensitive enough to trace the exact shape of the pressure

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[2]The RSI of any material is a steady-state measurement. In this text, we use the term "effective RSI" to indicate the apparent thermal resistance of a material before equilibrium is reached. Its value is lower than the true RSI due to the mass effect: the larger the thermal mass, the greater the flue gas heat loss to the material before thermal equilibrium is reached.

oscillations whose high frequencies were later measured in the 125 to 330 Hz range (Ref. Appendix H). Audible and visual observations of the operating furnace detected low frequencies with peak amplitudes recurring at more than 10-second intervals. These low frequencies would become more important when assessing combustion gas spillage.

Figures 8b and 9b show the four measured test pressures: before and after the barometric damper, and at the chimney base and top. At time of 0 minute the furnace is turned on. Pressures rise sharply and then flatten off as the temperatures reach equilibrium and the draft is established. Pressures are recorded for 15 minutes during the tests.

The "before damper" oscillations were shown to have an amplitude in excess of 25 Pa (Appendix H). Pressures variations measured upstream from the damper were much smaller, their amplitude being cut by the action of the barometric damper. The "chimney top" static pressures are again lower due to friction losses in the chimney.

b) Pressure measurements under house depressurization

Tests done with the 5-pascal depressurization show that the flue pressures are affected most when the damper is open (at flue pressures above 15 Pa) and only slightly affected when the damper is closed (at flue pressures below 15 Pa).

TABLE 4.

CHIMNEY INSULATION								
CHIMNEY		INSULATION		RSI - VALUE			"EFFECTIVE RSI"	HEAT LOSS
	size & type	material & thickness	density Kg/m3	theoretical	measured at equilibrium (joints taped)	measured at equilibrium (joints untaped)	after 8 minutes operation	from maximum infiltration %
1	High-RSI-A	fiberglass	16	3	1.65	1.40	0.42	26
	100 mm	137 mm (5.5")						
2	High-RSI-B	fiberglass	28	1.5	1.26	1.10	0.26	33
	100 mm	67 mm (2.7")						
3	A-vent	mineral fibre	400	0.4	0.25	NA	0.14	NA
	100 mm	25 mm (1")						
4	Type 650	mineral wool	208	1.3	NA	NA	0.38	NA
	150 mm	57 mm (2.3")						
5	A-vent	mineral fibre	400	0.4	0.41	0.38	0.29	29
	175 mm	25 mm (1")						
6	Masonry	clay tile	1900	0.4	NA	NA	0.20	NA
	160 mm	air space						
		brick						

6.0 DISCUSSION

a) Further research work needed

Further research in sizing chimneys should use a variable non-pulsating heat source with a matrix of flue types and sizes. Most of the work could be done in the lab.

Further research work of this nature should investigate the optimum insulation levels and insulation characteristics of flues meant to service short cycling oil or gas furnaces. This work should include masonry chimneys.

Further research should study the role of infiltration on chimney thermal resistance and performance.

While the nature of the pressure oscillations is complex and has been researched to a great extent we suggest that any future work investigate the relationship of the combustion generated oscillations to the spillage of combustion gas in the house (ref. Appendix H).

b) The FLUESIM program was designed with the intention of simulating the operational parameters (temperature, pressure, flow, spillage of combustion gases...) for different flue designs used with oil or gas furnaces. This approach provided the potential of designing and testing, on paper, new or innovative chimney designs. Design changes could be evaluated quickly and economically.

IRTA performed a few of the FLUESIM simulations (Appendix I) but was not very successful in matching its field data to the simulated data.

FLUESIM is presently undergoing modifications which are intended to accelerate its execution speed and to permit safer and easier access to its algorithms for modifications. On a 386-16MHz computer, the FLUESIM simulation of test 3420 lasts 16 minutes. On an XT running at 4.77 MHz this same test took 1 hour and 45 minutes. Ideally we should be expecting an execution time of less than 2 minutes, otherwise this discourages the trial of numerous variations.

Work should be continued on developing a flue simulator program because it can greatly reduce costs associated with chimney research. The FLUESIM program should have its execution speed greatly increased to encourage its use. Its structure should be modularized to easily accept the modifications shown necessary by results of field testing.

8.0 CONCLUSIONS

1- The three 100-mm factory-built chimneys showed excessive spillage when operated on a 26 kW furnace with combustion pulsations. The 150-mm and 175-mm factory-built chimneys and the 160-mm masonry chimney had only minimal spillage.

2- Mass effect played an important role in reducing "effective insulation" value on all chimneys within 8 minutes of start up, a typical cycling period for oil furnaces.

4- Better insulated chimneys had shorter condensation periods and attained operating condition much faster.

5- Insulated chimney connectors contributed to increase chimney performance.

6- The duration of condensation in the uninsulated masonry chimney was excessive.

7- Low-frequency combustion pulsations can contribute to indoor air pollution.

8- FLUESIM proved inappropriate for use in these studies, due to its complexity of structure (preventing easy modification) and its long execution times.

APPENDIX A

TEST PROTOCOL (WEATHER SUMMARY)

APPENDIX A - TEST PROTOCOL

A.1 Restrictions

a) Weather

So that weather would not influence measurements, testing was done when atmospheric conditions were favourable. Weather forecasts were checked at the Atmospheric Environment Service (AES) of Environment Canada. The station is located only a few miles from the Armstrong test house. The monthly meteorological summary sheets for April 1989 are included at the end of this Appendix. The following restrictions were placed on the testing.

Wind speed less than 6 kilometres per hour: Wind speeds were monitored both from the AES weather station and with the help of a cup anemometer on site. The cup anemometer is handy in identifying the short term variations in the wind speeds, which generally do not show up in the AES averages. Most of the testing was done with the wind speeds less than 6 k/h.

Stable and cold outdoor temperatures: The masonry and two A-vent chimneys were to be tested with exterior temperatures below freezing. The other 3 chimneys were to be tested with temperatures below 5°C. The unusually cold temperatures of the April 1989 test period permitted most of the testing to be done with temperatures below freezing.

No precipitation during testing: The chimneys were all tested without chimney caps because they were installed to close to permit putting on some of the larger caps. To ensure that no rain water enters the chimney insulation through the top chimney sections, testing would not be done if it was raining.

No solar gain for three hours prior to testing: Testing was performed in the evenings and at night. This prevented chimneys materials from storing solar heat which could influence test results.

b) House preparations for testing

Indoor house temperature restrictions: When testing was performed house temperatures were maintained between 17 and 22°C.

When necessary the house was cooled with a depressurization fan. Electric heaters were used to maintain minimum temperatures when testing. Fans circulated house air and reduced overheating of the basement, where the furnace is located.

Instrumentation was housed in a temperature controlled room to isolate it from the house's temperature variations which could increase measurement errors.

Chimney liner and heat exchanger temperatures: Chimney liners and furnace heat exchanger temperatures were kept at temperatures below 22°C at the start of each test. If the heat exchanger and chimney were hot from a previous test, they were cooled by a fan drawing cool exterior air down the chimney and through the furnace.

House indoor/outdoor pressure difference at 1 pascal: During several of the tests the house indoor/outdoor pressure difference was above the suggested 1 Pascal limit. Initially it was discussed that if this happened, the pressure could be equalized by providing fresh air intake in the basement to lower the house's neutral pressure plane. This could be done by opening up some of the chimney flues. When this was later tried, we realized that the chimneys were not very helpful because they opened up only at the upper level, not in the basement and did little to equalize pressures. We would have needed a fresh air intake at the basement level. In several of the tests the house pressure differential was larger than the suggested 1 Pascal limit but it did not exceed 3 Pascals.

A.2 Steady state tests

The purpose of the steady state tests was to record base information on the performance of each chimney. This test consisted in running the furnace from a cold start and recording operating parameters such as temperatures, flows and pressures until the chimney's steady state condition was reached. The duration of spillage of combustion gases from the barometric damper was also recorded. The following test protocol was used in the testing.

- Ensure that restrictions for weather and interior house conditions are met.

- Data was recorded for three minutes prior to testing. This allowed us to verify the recording and noise level. A check on pressure readings told us whether the chimney flow was upward or whether it was backdrafting.

- The indoor/outdoor pressure differential was recorded.

- The furnace circulation fan ran continuously. Several fans were used to circulate house air.

- The furnace was started and its start time was marked on the hard copy of the recording.

- Pressure, temperature and flow data was recorded.

- At the start of the test a smoke pencil was used to check for spillage at the barometric damper. The duration and intensity of the spillage was recorded.

- Tests were run for 12 minutes. This period of time allowed most flue liners to reach 90% of maximum value. When testing was done to determine the thermal resistance of the various chimneys, flue were heated for 30 to 60 minutes. During this period the top chimney temperature would reach 99% of its maximum value.

- The furnace was turned off. The house, furnace and chimney were cooled to the initial test conditions.

A.3 Tests with depressurization

These tests proceeded in the same fashion as the steady state tests except that the chimney was depressurized prior to the start of the test. A 30 Pascals depressurization was used to initiate a cold backdraft down the chimney. The depressurization was then slowly reduced to 5 Pascals for the test. If the 5 Pascals was not sufficient to maintain initial flue backdrafting then the pressure was increased to 7.5 or 10 Pascals. In a few cases a pressure of 10 Pascals was required to obtain startup backdraft.

Environment Canada / Environnement Canada
Atmospheric Environment Service / Service de l'environnement atmosphérique

MONTHLY METEOROLOGICAL SUMMARY
SOMMAIRE MÉTÉOROLOGIQUE MENSUEL

MONTH/MOIS APRIL / AVRIL 1989

AT/À OTTAWA INTERNATIONAL AIRPORT / AEROPORT INTERNATIONAL D'OTTAWA

LAT: 45 ° 19 'N LONG: 75 ° 40 'W ELEVATION/ALTITUDE: 114.0 METRES (ASL)/MÈTRES (NMM) STANDARD TIME USED/HEURE NORMALE UTILISÉE: EASTERN/DE L'EST

DATE	Temperature/Température: Maximum/Maximale °C	Minimum/Minimale °C	Mean/Moyenne °C	Degree-Days/Degrés-Jours: Heating/De chauffe Base 18.0°C	Growing/De croissance Base 5.0°C	Cooling/De réfrigération Base 18.0°C	Rel. Humidity/Humidité rel.: Maximum/Maximale %	Minimum/Minimale %	Thunderstorm/Orage	Precipitation/Précipitations: Rainfall/Pluie (hauteur) mm	Snowfall/Neige (hauteur) cm	Total Precip./Précip. totale mm	Snow on Ground/Neige au sol cm	Wind/Vent: Average Speed/Vitesse moyenne km/h	Prevailing Direction/Direction dominante	Max 2 min Mean Speed & Direction/Vitesse moyenne max. sur 2 min & direction km/h	Bright Sunshine/Insolation effective Hours/Heures
1	5.4	-2.3	1.6	16.4			100	45			0.8	0.8	9	14.6	NW	NNW* 26	5.2
2	7.5	-3.9	1.8	16.2			87	41		0.6		0.6	2	10.9	S	S 22	6.7
3	6.1	1.9	4.0	14.0			100	87		3.4		3.4		7.4	ENE	E 13	0.0
4	7.4	2.7	5.1	12.9	0.1		100	93		9.6		9.6		13.7	E	E 28	0.0
5	14.6	3.1	8.9	9.1	3.9		93	59		TR		TR		10.4	SSW	SW* 19	4.8
6	8.9	1.9	5.4	12.6	0.4		93	65						8.7	WNW*	WNW 15	3.3
7	5.3	-1.7	1.8	16.2			87	52			TR	TR		19.1	WNW	W 30	4.5
8	5.9	-3.5	1.2	16.8			80	24						10.9	NNW	W 19	12.2
9	8.7	-3.9	2.4	15.6			80	26		TR	TR	TR		10.0	SSW	WSW* 26	8.8
10	3.4	-5.0	-0.8	18.8			74	27			TR	TR		11.5	WSW	W 20	4.9
11	5.5	-3.6	1.0	17.0			93	30			TR	TR		8.9	W	WNW* 15	9.2
12	8.2	-4.3	2.0	16.0			86	31						10.7	SSW	SSE 20	8.3
13	4.8	-0.5	2.2	15.8			93	56		2.0	1.4	3.8		10.4	SSW	E 22	2.0
14	9.9	-3.0	3.5	14.5			93	40						8.0	SW	SSW 19	8.7
15	11.0	3.4	7.2	10.8	2.2		100	61		1.4		1.4		9.3	E*	SSW* 19	1.1
16	12.7	2.9	7.8	10.2	2.8		100	54		TR		TR		5.7	SSE	SSE* 11	5.0
17	16.4	0.5	8.5	9.5	3.5		100	39		2.8		2.8		11.7	SSE*	WNW 26	5.3
18	7.1	-4.1	1.5	16.5			86	31						15.0	NW	NW 28	8.0
19	9.6	-2.9	3.4	14.6			100	29						9.6	W	WSW 20	10.6
20	11.5	-0.3	5.6	12.4	0.6		80	19						11.1	W	NW* 22	13.1
21	12.4	-1.9	5.3	12.7	0.3		64	19						15.6	NNW	WNW 37	12.4
22	3.1	-4.0	-0.5	18.5			54	18						22.6	NNW	NNW 32	11.7
23	6.7	-3.7	1.5	16.5			69	39						18.9	NW	NNW* 26	6.8
24	12.5	-0.7	5.9	12.1	0.9		69	20						19.4	WNW	WNW 30	11.8
25	13.2	0.7	7.0	11.0	2.0		59	26						8.3	NNW*	N* 15	12.7
26	16.4	2.1	9.3	8.7	4.3		60	25						13.9	NNW	W 30	11.9
27	11.6	2.2	6.9	11.1	1.9		65	37		TR		TR		16.3	NNW	NW 30	5.5
28	10.6	1.4	6.0	12.0	1.0		60	32						12.1	WNW	NNW 22	8.7
29	14.5	-0.6	7.0	11.0	2.0		71	28		0.2		0.2		10.8	E	E 19	5.2
30	17.5	6.7	12.1	5.9	7.1		93	59		1.6		1.6		8.3	SSW	W 20	4.2
31																	
MEAN/MOYENNE	9.6	-0.7	4.5	TOTAL 405.4	TOTAL 33.0	TOTAL 0	83	40	TOT	TOTAL 21.6	TOTAL 2.2	TOTAL 24.2		12.1	PREVAILING/DOMINANTE WNW	MAXIMALE WNW 37	TOTAL 212.6
NORMAL/NORMALE	10.7	0.3	5.6	374.5	64.2	0.4			1	59.5	8.2	69.1		16.8	E		176.9

DEGREE-DAY SUMMARY/SOMMAIRE DE DEGRÉS JOURS

Below 18°C/Au-dessous de 18°C	This Year/Année en cours	Previous Year/Année précédente	Normal/Normale	Above 5°C/Au-dessus de 5°C	This Year/Année en cours	Previous Year/Année précédente	Normal/Normale
TOTAL FOR MONTH/TOTAL DU MOIS	405.4	360.7	374.5	TOTAL FOR MONTH/TOTAL DU MOIS	33.0	46.5	64.2
ACCUMULATED SINCE JULY 1/ACCUMULÉE DEPUIS LE 1er JUILLET	4506.6	4363.7	4471.9	ACCUMULATED SINCE APRIL 1/ACCUMULÉE DEPUIS LE 1er AVRIL	33.0	46.5	64.2

Days with total precipitation/Jours avec précipitations totales (mm): 0.2 or more/ou plus	1.0 or more/ou plus	5.0 or more/ou plus	10.0 or more/ou plus	25.0 or more/ou plus	Days with snowfall/Jours avec chute de neige (cm): 0.2 or more/ou plus	1.0 or more/ou plus	5.0 or more/ou plus	10.0 or more/ou plus	25.0 or more/ou plus
9	6	4	0	0	2	1	0	0	0

UDC 551.506.1 (713.84) Note/Avis

1. Climatological Day/Journée climatologique 01 01 E ST – 01 00 E ST
2. Normal/Normale 1951-1980
3. TR = Trace
4. M = Missing/Manquant
5. No entry/Pas de valeur = No occurrence/Pas d'événement
6. * Indicates first of more than one prevailing direction and/or maximum 2 minute mean speed (see page 4)/Indique la première de plusieurs des directions dominantes et/ou la vitesse moyenne maximale sur 2 minutes (voir page 4).
7. C = Calm/Calme
8. Price: single issue $2.75 ; annual (Jan. to Dec.) $27.30 /Prix: numéro individuel $2.75 ; annuel $27.30 (janv. à déc.)
9. Sunshine data from the experimental farm./Données d'ensoleillement de la ferme experimentale.

Canada

—2—

COMPARATIVE RECORDS AT: OTTAWA INTERNATIONAL AIRPORT — MONTH APRIL — 19 89
RELEVÉS COMPARATIFS À: AEROPORT INTERNATIONAL D'OTTAWA — MOIS AVRIL

Temperature/Température — ° Celsius
Precipitation/Précipitation — Millimetres/millimètres (mm)
Rainfall/Hauteur de pluie — Millimetres/millimètres (mm)
Snowfall/Hauteur de neige — Centimetres/centimètres (cm)
Wind speed/Vitesse du vent — Kilometres/h / kilomètres/h (km/h)
Station pressure/Pression à la station — Kilopascals (kPa)

	THIS MONTH / CE MOIS-CI		PREVIOUS YEAR / ANNÉE PRÉCÉDENTE		NORMAL / NORMALE	RECORD FOR THE MONTH / RECORD POUR LE MOIS: HIGHEST EVER / MAXIMUM ABSOLU			LOWEST EVER / MINIMUM ABSOLU			NO OF YEARS / NO D'ANNÉES
	VALUE / RELEVÉ	DAY / JOUR	VALUE / RELEVÉ	DAY / JOUR		VALUE / RELEVÉ	DAY / JOUR	YEAR / ANNÉE	VALUE / RELEVÉ	DAY / JOUR	YEAR / ANNÉE	
HIGHEST TEMPERATURE (MAXIMUM) / TEMPÉRATURE MAXIMALE	17.5	30	15.6	4		29.8	18	1976				51
LOWEST TEMPERATURE (MINIMUM) / TEMPÉRATURE MINIMALE	-5.0	10	-2.6	19					-16.7	4	1954	51
MEAN MONTHLY TEMPERATURE / TEMPÉRATURE MENSUELLE MOYENNE	4.5		6.0		5.6	9.9		1987	1.1		1943	51
TOTAL MONTHLY RAINFALL / HAUTEUR TOTALE MENSUELLE DE PLUIE	21.6		87.4		59.5	124.1		1984	9.1		1975	51
TOTAL MONTHLY SNOWFALL / HAUTEUR TOTALE MENSUELLE DE NEIGE	2.2		2.4		8.2	29.5		1975	0.0		1941	51
TOTAL MONTHLY PRECIPITATION / PRÉCIPITATION TOTALE MENSUELLE	24.2		91.6		69.1	124.3		1984	20.8		1941	51
NO OF DAYS WITH MEASURABLE PRECIPITATION / NOMBRE DE JOURS AVEC PRÉCIPITATION MESURABLE	9		17		12	18		1951*	8		1975*	40
GREATEST RAINFALL IN ONE DAY / HAUTEUR DE PLUIE MAXIMALE EN UNE JOURNÉE	9.6	4	24.0	28		42.4	15	1956				51
GREATEST SNOWFALL IN ONE DAY / HAUTEUR DE NEIGE MAXIMALE EN UNE JOURNÉE	1.4	13	1.4	8		26.7	3	1975				51
GREATEST PRECIPITATION IN ONE DAY / PRÉCIPITATION MAXIMALE EN UNE JOURNÉE	9.6	4	24.0	28		42.4	15	1956				51
MAXIMUM RAINFALL RECORDED IN: / HAUTEUR DE PLUIE MAXIMALE ENREGISTRÉE EN												
5 MINUTES	0.5	4	1.0	3		2.0	4	1974*				22
10 MINUTES	0.5	4	1.5	3		3.8	22	1974				22
15 MINUTES	1.1	4	1.7	3		5.1	22	1974				22
30 MINUTES	1.6	4	2.5	3		5.8	22	1974				22
60 MINUTES	2.7	4	4.4	3		7.7	11	1978				22
24 CONSECUTIVE HOURS / HEURES CONSÉCUTIVES	9.6	4	28.5	28/29		42.4	15	1956				51
MEAN WIND SPEED (km/h) / VITESSE MOYENNE DU VENT (km/h)	12.1		14.4		16.8	21.7		1967	12.0		1989	51
MAXIMUM SPEED (2 min. mean) (km/h) / VITESSE MAXIMALE (moyenne sur 2 min.) (km/h)	WNW 37	21	WNW 35	21		SW 76	6	1985				40
MAXIMUM GUST SPEED (km/h) / POINTE DU VENT MAXIMALE (km/h)	NNW 48	22*	ENE 59	29		W 97	18	1954				40
TOTAL HOURS OF SUNSHINE / TOTAL DES HEURES INSOLATION	212.6		142.4		176.9	236.7		1977	115.1		1951	51
MEAN STATION PRESSURE (kPa) / PRESSION MOYENNE À LA STATION (kPa)	100.08		99.59		99.97	100.26		1964	99.36		1961	29
GREATEST STATION PRESSURE (kPa) / PRESSION MAXIMALE À LA STATION (kPa)	101.28	12	101.40	2		102.31	13	1985				29
LEAST STATION PRESSURE (kPa) / PRESSION MINIMALE À LA STATION (kPa)	98.62	7	97.54	18					96.36	2	1970	29

CLIMATOLOGICAL DATA THIS MONTH FOR THE PAST TEN YEARS
DONNÉES CLIMATOLOGIQUES CE MOIS-CI POUR LES DIX DERNIÈRE ANNÉES

YEAR / ANNÉE	MAXIMUM TEMP / TEMP MAXIMALE	MINIMUM TEMP / TEMP MINIMALE	MEAN TEMP / TEMP MOYENNE	RAINFALL / HAUTEUR DE PLUIE	SNOWFALL / HAUTEUR DE NEIGE	TOTAL PRECIP / PRECIP TOTALE	MEAN WIND SPEED / VITESSE MOYENNE DES VENTS	MAXIMUM WIND SPEED / VITESSE MAXIMALE DES VENTS	SUNSHINE HOURS / HEURES INSOLATION	HEATING DEGREE-DAYS / DEGRÉS-JOURS DE CHAUFFE	GROWING DEGREE-DAYS / DEGRÉS-JOURS DE CROISSANCE	COOLING DEGREE-DAYS / DEGRÉS-JOURS DE RÉFRIGÉRATION
1980	19.3	-6.2	6.7	94.8	3.4	99.3	13.9	ENE 35	164.5	340.3	71.4	0.0
1981	23.3	-7.6	6.7	58.2	1.0	59.0	17.0	WNW 69	205.9	339.0	84.1	0.0
1982	23.4	-15.1	4.1	53.8	2.2	56.8	19.3	W 52	211.6	417.9	72.2	0.0
1983	19.0	-7.5	4.2	64.3	23.5	91.1	15.2	E 41	138.3	414.3	38.2	0.0
1984	23.6	-2.9	7.5	124.1	0.2	124.3	14.0	WSW 50	187.6	316.7	85.8	0.0
1985	27.3	-8.6	5.5	30.4	17.6	52.4	16.3	SW 76	194.4	375.2	85.9	0.0
1986	26.9	-6.8	9.0	33.6	2.6	36.0	13.0	WNW 43	220.1	271.9	138.8	0.1
1987	28.6	-8.5	9.9	65.6	7.8	73.8	14.8	NNW 48	212.0	262.5	152.5	3.8
1988	15.6	-2.6	6.0	87.4	2.4	91.6	14.4	WNW 35	142.4	360.7	46.5	0.0
1989	17.5	-5.0	4.5	21.6	2.2	24.2	12.1	WNW 37	212.6	405.4	33.0	0.0

Note/Avis
1. Climatological Day/Journée climatologique 01 01 E S.T. – 01 00 E S.T.
2. Normal/Normale 1951-1980
3. Extremes for period of record/Extrêmes pour la période de registre
4. Maximum rainfall recorded in: may overlap calendar days/Hauteur de pluie maximale enregistrée en: peut-être pour plus d'une journée du calendrier
5. ** Indicates most recent occurrence/indique le plus récent
6. * Indicates first of more than one occurrence/indique le premier de plusieurs

DRY-BULB TEMPERATURES AT: OTTAWA INTERNATIONAL AIRPORT — MONTH APRIL — 19 89
TEMPÉRATURES DU THERMOMÈTRE SEC À: AEROPORT INTERNATIONAL D'OTTAWA — MOIS AVRIL

Date	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	01	01	01	00	-02	-02	-01	-06	00	04	06	04	07	10	25	35	44	52	40	26	26	19	04	04
2	-16	-17	-26	-25	-29	-31	-35	-14	03	09	33	47	59	67	70	64	62	51	52	47	52	56	45	40
3	36	34	22	22	22	25	31	33	36	44	48	49	53	56	57	58	58	52	51	47	45	43	42	40
4	38	34	33	33	31	30	30	30	30	32	34	38	45	46	43	47	51	68	68	70	64	69	73	72
5	71	63	63	56	58	52	47	55	80	96	108	131	141	124	138	122	119	115	102	84	79	74	67	53
6	43	37	27	25	22	19	19	22	32	43	53	66	68	68	82	78	81	83	78	71	68	63	56	47
7	40	36	29	18	18	17	15	17	17	19	18	22	23	39	46	44	45	41	26	20	08	-01	-08	-11
8	-13	-16	-16	-27	-33	-28	-34	-27	-12	00	08	19	27	40	42	47	50	48	46	33	23	22	08	-06
9	-12	-15	-22	-23	-29	-35	-37	-25	05	22	41	53	65	68	71	80	78	74	50	33	16	-04	-06	-18
10	-23	-30	-38	-40	-50	-46	-39	-35	-37	-27	-14	-06	05	03	05	12	24	26	24	16	06	-08	-12	-16
11	-17	-20	-27	-26	-26	-30	-35	-33	-19	-07	06	10	21	30	29	39	40	39	38	25	06	-04	-11	-19
12	-20	-14	-16	-29	-38	-42	-33	-23	01	21	26	46	49	62	71	72	72	73	65	60	57	57	47	33
13	21	20	15	17	23	28	44	47	41	33	34	40	15	30	36	44	12	43	40	36	19	15	14	14
14	03	-03	-09	-14	-15	-20	-23	-08	15	39	58	64	66	86	86	99	87	80	73	68	61	65	65	68
15	57	50	47	46	42	36	43	51	57	63	68	68	67	77	91	103	106	101	94	87	75	71	64	61
16	56	50	43	42	37	36	37	41	50	55	57	64	83	98	106	108	116	120	113	89	74	64	58	44
17	46	29	20	21	09	07	12	35	61	99	127	149	151	155	162	156	155	155	129	121	110	100	95	73
18	49	26	06	-04	-23	-26	-37	-34	-38	-32	-20	-02	15	36	49	60	67	68	59	46	40	20	11	02
19	-02	-11	-11	-22	-18	-26	-26	-16	01	34	52	62	75	80	76	82	83	81	77	73	65	63	47	46
20	37	28	24	14	07	02	00	15	28	49	62	82	88	92	99	110	110	106	101	90	72	62	42	39
21	23	29	09	23	12	-12	-08	11	43	70	88	103	108	109	121	103	101	84	65	43	28	16	05	-02
22	-08	-19	-27	-30	-33	-37	-35	-30	-32	-20	-12	-06	00	15	14	19	22	20	08	02	-02	-08	-13	-15
23	-17	-20	-21	-24	-28	-34	-34	-24	-06	08	18	32	44	44	45	55	52	61	55	50	43	35	36	29
24	17	-05	02	-01	-06	-06	-04	05	22	36	59	78	85	94	104	115	119	117	110	100	84	73	67	65
25	52	45	33	27	21	15	08	16	27	39	50	83	85	102	107	120	121	124	127	114	102	96	89	71
26	54	57	53	49	36	26	29	57	68	98	99	115	125	143	146	157	156	158	148	132	111	95	81	69
27	64	57	53	50	40	37	31	61	63	72	78	88	105	100	105	109	110	101	95	85	71	55	42	34
28	26	22	20	16	18	17	17	19	23	30	37	56	68	69	81	89	96	95	95	88	76	61	54	46
29	35	25	23	13	-02	01	14	30	49	71	82	97	103	118	127	138	139	139	137	131	123	118	111	106
30	95	79	68	76	74	72	71	77	85	110	121	141	158	162	158	165	165	167	165	154	140	129	115	101
31																								

Note/Avis
1. Climatological Day/Journée climatologique 01 01 E S.T. — 01 00 E S.T.
2. Hours are L.S.T./Les heures sont à l'heure normale de la localité
3. Unit/Unité = 0.1°C

WINDS (km/h) AT: OTTAWA INTERNATIONAL AIRPORT — MONTH APRIL 1989
DES VENTS (km/h) À: AEROPORT INTERNATIONAL D'OTTAWA — MOIS AVRIL

Date	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Peak Gust / Rafale max	Hour/Date / Heure/Date (L.S.T.)
1	NNW 15	NNW 15	NW 15	NW 17	NW 19	NW 22	NNW 20	NW 17	NNW 22	NNW 26	NW 20	NNW 20	NW 26	NW 24	NNW 20	NW 11	NW 7	C	SW 6	SSW 4	W 9	W 7	WSW 4	WNW 6	NNW* 37	0905
2	W 9	WNW 7	C	SSW 6	SSW 6	SSW 7	SSW 6	C	S 11	S 9	S 11	S 22	SSW 19	SSW 20	SSW 20	S 19	S 13	S 19	SSE 11	S 17	ESE 6	E 7	E 6	ESE 11	SSW 37	1618
3	ESE 9	E 4	ENE 6	ENE 4	ENE 6	SE 7	S 7	SSE 7	SE 7	SE 6	SE 7	ESE 9	ESE 11	ESE 11	E 11	E 13	E 9	ENE 9	ENE 4	ENE 7	ENE 6	ENE 7	E 4	E 6		
4	E 11	E 9	E 11	E 11	ENE 15	E 11	ENE 13	E 17	ENE 19	E 19	E 19	ENE 22	E 24	E 28	E 20	E 13	E 6	SW 4	SW 7	SW 11	SSW 7	SSW 7	SW 6	SW 19	E 43	1109
5	WSW 11	SSW 13	SW 4	S 4	S 4	SSE 7	S 9	S 11	S 11	SSW 11	SSW 17	SW 19	SW 19	SW 17	SW 13	SSW 11	SSW 11	SSW 11	SSW 9	SSW 7	SSW 7	SSW 7	SSW 11	SSW 4	SSW 33	1132
6	SSW 4	SSW 6	SSW 4	WSW 4	SW 7	SW 4	SW 4	WSW 6	WSW 9	NW 11	W 9	W 11	WNW 15	WNW 13	WNW 13	WNW 11	NNW 7	N 11	NW 11	NNE 6	N 11	N 9	N 11	NW 13		
7	NW 22	WNW 20	WNW 24	WNW 19	WNW 22	W 22	W 22	W 24	W 28	W 30	W 30	WNW 24	W 22	WNW 19	WNW 19	WNW 19	WNW 19	WNW 19	WNW 15	WNW 13	W 6	WNW 6	NW 7	N 11	W 44	0832
8	N 6	N 4	N 7	NNW 9	NNW 7	NNW 7	NNW 9	NNW 11	NNE 13	N 13	NNW 15	NNW 17	W 15	W 19	WNW 15	WNW 17	NW 19	WNW 17	WNW 17	W 7	NW 7	WNW 6	C	SSW 6		
9	SSW 4	C	N 4	N 7	N 7	NNE 9	NNE 7	NE 6	ENE 6	E 4	N 4	SSW 4	W 7	WSW 9	SSW 6	SSW 7	SW 11	SSW 6	SW 17	WSW 26	W 22	W 24	W 26	WSW 19	W 46	2044
10	WSW 17	WSW 17	SW 11	SW 7	SSW 6	W 6	WSW 7	W 11	NW 15	WNW 19	W 11	W 20	SW 15	WNW 17	WSW 11	SW 13	WSW 9	W 17	W 15	WSW 4	SW 7	SSW 6	SW 7	WSW 9	W 33	0914
11	W 13	WNW 15	W 15	WNW 15	W 9	WNW 11	W 9	W 9	W 9	WSW 7	W 13	NW 9	WNW 9	WNW 11	WNW 15	C	SSW 9	C	SSE 4	S 6	SSW 7	SSW 7	SSW 6	SSW 6		
12	SSW 6	SSW 7	SW 6	SSW 6	SSW 6	SSW 6	SSW 6	SSW 6	WSW 9	SW 9	WSW 7	S 11	S 11	SSE 20	SSW 19	SSW 7	S 13	S 13	S 6	S 17	ESE 15	E 19	E 19	E 17		
13	E 17	E 22	E 13	ESE 9	ESE 9	SE 15	S 9	SSW 11	SSW 9	SW 15	SSW 17	SW 15	WNW 13	WSW 11	SSE 7	WSW 6	SE 6	SSE 9	SSE 7	SSW 6	NNW 6	S 9	C	S 7		
14	SW 4	SW 6	SW 7	WSW 4	WSW 4	WSW 4	SW 4	C	SW 4	SSW 7	S 11	SSW 13	S 15	S 15	SSW 19	S 17	S 15	SW 17	SSW 13	S 6	ESE 7	C	ESE 4	C		
15	E 11	E 9	E 7	E 4	E 6	NE 6	C	S 6	SSW 9	SW 9	SW 7	SSW 13	SSW 13	SSW 15	SSW 19	S 19	S 15	S 15	S 11	C	SSE 7	SSE 9	SSE 7	SSE 6		
16	S 6	SE 2	C	ESE 7	SSE 2	C	NNE 6	NE 7	ENE 9	ENE 7	E 7	ENE 4	C	C	SW 7	SSW 7	SSE 4	SSW 9	S 7	SSE 11	SSE 11	SSE 9	SSE 9	SSE 6		
17	SSE 9	SSE 7	SSE 6	SSE 6	SE 7	SE 7	ESE 7	SE 7	SSE 7	SE 9	SE 17	S 20	S 20	S 13	S 17	SSW 11	S 6	SW 19	WSW 13	WSW 15	WSW 7	SW 7	W 13	WNW 26	WNW 32	2303
18	NW 26	NNW 24	NNW 26	NNW 22	NNW 22	NNW 24	NW 28	NW 22	NW 22	WNW 11	W 13	C	WNW 13	WNW 13	WNW 11	WSW 13	W 15	NW 15	WNW 11	NW 11	C	SSW 7	SSW 7	SSW 4	NNW 37	0225
19	SW 6	W 4	WSW 4	WSW 4	W 4	WNW 4	WNW 7	WNW 11	WNW 11	WNW 15	WNW 15	W 15	W 13	W 11	W 13	WSW 20	W 19	WNW 11	NW 9	WSW 13	SSW 4	SW 6	W 7	WSW 6	NW 35	1518
20	W 13	SW 4	W 4	W 7	WNW 11	W 6	W 9	W 11	NW 15	NW 13	WNW 11	NW 15	W 19	NNW 7	WNW 20	NW 22	WNW 22	WNW 20	NW 19	N 6	NNE 7	ESE 4	C	C	NW 43	1712
21	C	C	NE 7	WSW 4	E 4	C	C	C	SW 4	WNW 6	WSW 11	NW 19	NW 22	NW 35	NW 33	WNW 28	WNW 37	NNW 32	NNW 24	NNW 32	NNW 22	NNW 20	NNW 19	N 15	NW 46	1251
22	N 11	NW 11	NW 11	NW 13	NW 15	NNW 17	NW 19	NNW 28	NNW 30	NNW 24	NNW 28	NNW 26	NNW 26	NNW 22	NNW 22	WNW 22	NW 30	N 30	NW 26	N 24	NNW 32	NNW 24	NNW 30	N 22	NNW 48	2208
23	N 24	N 22	NNW 13	N 20	NW 22	NNW 19	NW 15	NW 20	NW 17	NW 17	WNW 20	WNW 22	NW 17	NNW 26	NNW 24	NW 19	NW 19	NW 22	NW 26	NNW 17	NNW 15	NNW 9	NNW 19	NW 13	WSW 41	1121
24	NW 7	W 11	WSW 7	W 13	W 15	W 15	WNW 17	W 19	WNW 7	WNW 22	WNW 28	WNW 30	WNW 30	WNW 28	WNW 28	WNW 26	W 26	NW 24	NW 22	NW 20	NNW 15	NW 15	NNW 13	NNW 9	WNW 48	1303
25	NNW 13	W 9	WNW 9	WNW 11	NW 11	N 13	NNW 13	N 13	NNW 11	NW 9	W 9	N 15	N 15	NNW 6	NW 9	W 7	C	WNW 7	C	WNW 4	W 4	E 6	SSE 4	SW 4		
26	C	NNW 4	C	N 9	NW 7	WNW 9	WNW 9	NW 9	NW 9	NNW 15	N 15	N 19	NNW 15	NNW 20	WNW 15	WNW 26	W 26	W 30	NNW 22	N 17	NNE 17	NNE 15	NNE 15	NE 11	WNW 41	1502
27	ENE 7	NE 4	C	C	WSW 7	W 6	W 4	WNW 11	N 19	W 17	W 24	NNW 24	WNW 20	WNW 17	NNW 11	NNW 24	NW 30	NNW 22	NNW 26	NNW 24	NNW 26	NW 28	N 22	N 19	NNW 44	1853
28	NNW 22	N 20	NNW 13	NNW 19	N 15	NW 15	NNW 19	NNW 20	NNW 11	N 15	NNW 11	W 9	WNW 13	WNW 17	WNW 6	WNW 11	WSW 4	N 6	WNW 4	W 6	W 6	WNW 4	NNE 11	NE 13		
29	NE 11	NNE 9	NNE 11	NE 11	NNE 9	NE 11	NE 9	ENE 15	ENE 11	ENE 9	ENE 11	E 15	E 19	E 13	E 13	ESE 15	E 9	E 9	E 11	ENE 7	E 7	E 7	NE 7	ENE 7		
30	E 7	ESE 6	W 20	NNW 7	NNE 11	ENE 9	NE 9	ESE 17	E 15	ESE 7	C	E 7	SSE 9	WSW 6	SSW 6	SSW 7	SW 4	SW 6	SSW 7	S 7	SSW 9	SSW 7	SSW 7	SSW 7		
31																										

Note/Avis
1. Climatological Day/Journée climatologique 01 01 E S.T. – 01 00 E S.T.
2. Hours are L.S.T./Les heures sont à l'heure normale de la localité
3. Unit/Unité = 1.0 km/h
4. C = Calm/Calme
5. M = Missing/Manquant
6. * Indicates first of more than one occurrence of the same speed/Indique le premier de plusieurs de la même vitesse

OTTAWA INTERNATIONAL AIRPORT / AEROPORT INTERNATIONAL D'OTTAWA — MONTH / MOIS: APRIL / AVRIL 19 89

Date	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	S	S	S	S	S	S	S	S	S															
2																R	R	R	R	R	R	R		
3		R	R	R		R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R			
4								R	R	R	R	R	R	R	R	R	R						R	
5																	R							
6																								
7											S	S	S	S										
8																								
9																			R		S	S	S	
10									S	S					S	S								
11					S	S																		
12																								
13									R	R	R	R	R/S	R/S	R/S	R	R/S	S			R/S	R/S		
14																								
15						R	R	R	R	R	R	R	R	R										
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30	R	R	R	R																				
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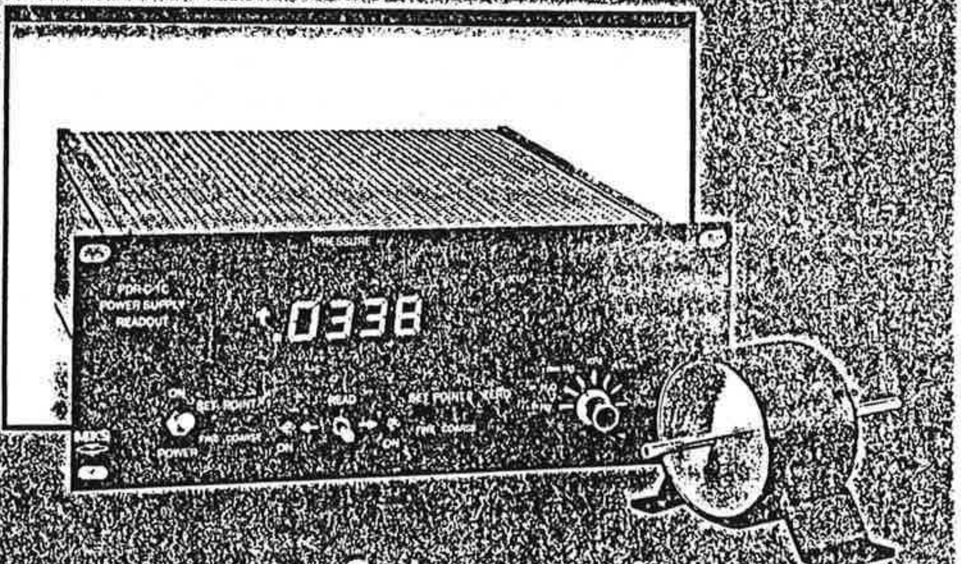
LEGEND / LEGENDE

R = Rain Drizzle	Pluie Bruine
Z = Freezing Precipitation	Verglas
S = Snow	Neige
A = Hail	Grêle

APPENDIX B

INSTRUMENTATION

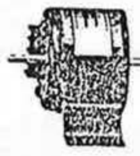
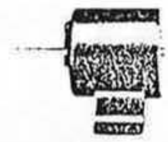
Differential Pressure Transducers



& Accessories

MKS
INSTRUMENTS INC

200 Series Differential Transducer Specifications

			
TYPE		225AD	229HD
Pressure ranges (mmHg Full Scale) (Other engineering units optional)		standard: 0.2, 1, 10, 100, 1000 mmHg options: 0.2, 1, 10, 100, 1000 cmH_2O 0.1, 0.25, 0.5, 5, 50, 500 inH_2O	standard: 0.2, 1, 10, 100, 1000 mmHg options: 0.2, 1, 10, 100, 1000 cmH_2O 0.1, 0.25, 0.5, 5, 50, 500 inH_2O
Resolution		0.01% F.S.	0.01% F.S.
Accuracy (non-linearity, hysteresis and non-repeatability)		0.5% F.S. (± temperature coefficients)	0.5% F.S bidirectional or unidirectional (Code A) 0.3% F.S. bidirectional or unidirectional (Code B) 0.3% R unidirectional only (Code C)
Temperature coefficients	Zero	0.1% F.S./°C	0.1% F.S./°C (Code A); 0.05% F.S./°C (Code B); 0.05% F.S./°C (Code C)
	Span	0.04% Reading/°C	0.04% Reading/°C
Operating temperature range		0° to 50°C	0° to 50°C
Time constant		Standard: <16 msec Optional: <500 msec (SP045-88)	Standard: <20 msec Optional: <500 msec (SP045-88)
Materials exposed to gases	Px side	Inconel	Inconel
	Pr side	Inconel, Ceramic, Forsterite, Palladium, Glass	Inconel, Ceramic, Forsterite, Palladium, Glass
Volume	Px side	1.3 cc	1.3 cc
	Pr side	9.8 cc	9.8 cc
Overpressure limit		120% of sensor Full Scale, or 20 psi (140 kPa), whichever is greater	120% of sensor Full Scale, or 20 psi (140 kPa), whichever is greater
Line pressure (maximum)		40 psig (275 kPa)	40 psig (275 kPa)
Input required		+ 11 to + 30 VDC @ 25 mA ripple ≤ 0.5 V peak to peak	Two wire 4-20 mA @ 24-32 VDC, into ≤500 Ω load Bidirectional calibrations (codes A & B) Output is 4 mA at negative Full Scale to 20 mA at positive Full Scale (4 mA = − F.S., 12 mA = 0 ΔP, 20 mA = + F.S.) Unidirectional calibrations (code C): Output is 4 mA at zero to 20 mA at positive Full Scale (4 mA = 0 ΔP, 20 mA = + F.S.)
Output		0 to 5 VDC Unidirectional	
RFI Suppression		Standard on all Models	Standard on all Models
Fittings	Standard	3/16 inch (4.6 mm) tubulation	3/16 inch (4.6 mm) tubulation
	Optional	N/A	N/A
Additional standard features		Low cost, powered by common DC power sources	Two-wire, 4-20 mA Differential Transducer

Beckman Industrial

MADE IN U.S.A.

Model 755 Oxygen Analyzer

Beckman Industrial™

MADE IN U.S.A.

Beckman Industrial™
Process Instruments Division
600 S. Harbor Blvd.
La Habra, CA 90631

GENERAL SPECIFICATIONS*

Standard Range Options (% Oxygen Fullscale)

0 to 1, 0 to 2.5, 0 to 5, 0 to 10;
0 to 5, 0 to 10, 0 to 25, 0 to 50;
0 to 10, 0 to 25, 0 to 50, 0 to 100;
20 to 21, 19 to 21, 16 to 21, 11 to 21;
99 to 100, 98 to 100, 95 to 100, 90 to 100;
50 to 100, 60 to 100, 80 to 100, 90 to 100.

Response Time (90% of Fullscale)

Factory-set for 20 seconds; Adjustable from 5 to 25 seconds.

Reproducibility

±0.01% oxygen or ±1% of fullscale, whichever is greater.

Ambient Temperature Limits

Maximum: 120°F (49°C) except for 80°F (27°C) for 99% to 100% range.
Minimum: −20°F (−29°C), except 60°F (16°C) for 99% to 100% range.

*Zero Drift***

±1% fullscale (±2% of fullscale for 99% to 100% range) per 24 hours, provided that ambient temperature does not change by more than 20 Fahrenheit degree (11.1 Celsius degrees).

±2.5% of fullscale per 24 hours with ambient temperature change over entire range.

*Span Drift***

±1% fullscale (±2% of fullscale for 99% to 100% range) per 24 hours, provided that ambient temperature does not change by more than 20 Fahrenheit degrees (11.1 Celsius degrees).

±2.5% of fullscale per 24 hours with ambient temperature change over entire range.

SAMPLE SPECIFICATIONS

Sample Dryness

Sample dewpoint below 110°F (43°C), sample free of entrained liquids.

Sample Temperature Limits

Maximum: 150°F (66°C)
Minimum: 50°F (10°C)

Operating Pressure Limits

Maximum: 10 psig (69 kPa gauge pressure)
Minimum: 660 mm Hg absolute (88.1 kPa absolute pressure)

*Sample Flow Rate****

Maximum: 500 cc/min
Minimum: 50 cc/min
Recommended: 250 ±20 cc/min.

Materials in Contact with Sample Gas

316 Stainless Steel, Glass, Titanium, Pallaney, 7†, Epoxy Resin, Viton-A††, Platinum, Nickel.

ELECTRICAL SPECIFICATIONS

Supply Voltage and Frequency

120 V ± 10 V, 50/60 Hz
240 V ± 10 V, 50/60 Hz } Selectable when ordered

Power Consumption

300 watts maximum.

Outputs

Standard: Field-selectable voltage output of 0 to 10 mV, 0 to 100 mV, 0 to 1 V, or 0 to 5 VDC.

Optional: Isolated current output of 4 to 20 mA, 0 to 20 mA, or 10 to 50 mA is obtainable through plug-in of appropriate circuit board.

PHYSICAL SPECIFICATIONS

NOTE

For explosion-proof version see Beckman Instructions 015-555780.

Case Mounting

Panel mounting (surface or stanchion accessory).

Case Classification

General Purpose.
Enclosure meets NEMA-4.

Air Purge (optional)

ISA S12.4 or NFPA 496 (1974) Type Z purge. (See Page iii).

ALARMS SPECIFICATIONS

Options

High-Low Alarm.

Alarm Contact Ratings

5 amperes, 120 VAC, resistive load
3 amperes, 120 VAC, inductive load
3 amperes, 30 VDC, inductive load
1 ampere, 240 VAC, resistive load

Setpoint

Adjustable from 1% to 100% of fullscale.

Deadband

Adjustable from 1% to 20% of fullscale.
Factory-set to 10% of fullscale.

OSHA

The Model 755 Oxygen Analyzer (General Purpose Enclosure) has been designed to meet the applicable requirements of the U.S. Occupational Safety and Health Act (OSHA) of 1970 if installed in accordance with the requirements of the National Electrical Code (NEC) of the United States in non-hazardous areas, and operated and maintained in the recommended manner.

*All performance specifications based on recorder output.

**Zero and span drift specifications based on following conditions: operating pressure constant; ambient temperature change from initial calibration temperature, less than 20 Fahrenheit degrees (11.1 Celsius degrees); deviation from set flow held to within ±10% or ±20 cc/min, whichever is smaller.

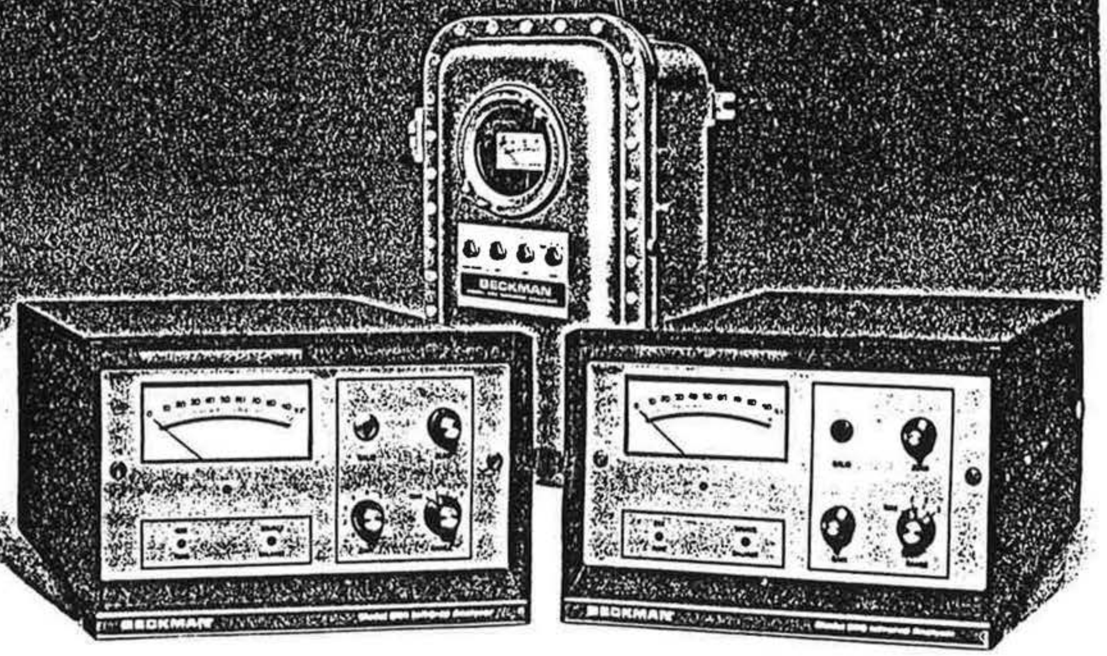
***Deviation from set flow should be held to within ±10% or ±20 cc/min, whichever is smaller. If so, zero and span drift will be within specifications, provided that operating pressure remains constant.

†Trademark of William Nys Co.

††Trademark of E.I. du Pont de Nemours & Co.

BECKMAN

Models 864/865 Non-Dispersive Infrared Analyzers



SPECIFICATIONS

	MODEL 864	MODEL 865
Precision	1% of fullscale	1% of fullscale
Noise	1% of fullscale	1% of fullscale
Zero Drift **	±1% of fullscale per 24 hours	±1% of fullscale per 24 hours
Span Drift **	±1% of fullscale per 24 hours	±1% of fullscale per 24 hours
Response Time (Electronic)	Variable, 90% in 0.5-second to 26 seconds, field-selectable	Variable, 90% in 0.5-second to 26 seconds, field-selectable
Maximum Sensitivity	500 p/10^6 fullscale carbon monoxide 350 p/10^6 fullscale carbon dioxide	50 p/10^6 fullscale carbon monoxide *(pressurized cell)* 10 p/10^6 fullscale carbon dioxide *(pressurized cell)*
Materials in Contact with Sample:		
Windows	Sapphire, quartz, irtran	Sapphire, quartz, irtran
Cells	Stainless steel, gold-plated stainless steel	Stainless steel, gold-plated stainless steel
Tubing	FEP Teflon*	FEP Teflon *(general purpose)* 316 Stainless steel *(explosion proof)*
Fittings	316 Stainless steel	316 Stainless steel
O-Rings	Viton-A*	Viton-A*
Sample Flow Rate	Nominal 500 to 1000 cc/min	Nominal 500 to 1000 cc/min
Sample Pressure	Maximum 15 psig (101 kPa) *(higher pressures used in pressurized cell applications)*	Maximum 15 psig (101 kPa) *(higher pressures used in pressurized cell applications)*
Ambient Temperature Range**	30°F to 120°F (–1°C to +49°C)	30°F to 120°F (–1°C to +49°C)
Analog Output:		
Standard (Potentiometric)	0 to 10 mV, 0 to 100 mV, 0 to 1 V, 0 to 5 VDC *(field selectable)*	
Optional (Current)	4 to 20 mA, 10 to 50 mADC *(field selectable)*	
Optional (Linear Potentiometric)	0 to 10 mV, 0 to 100 mV, 0 to 1 V, 0 to 5 VDC *(field selectable)*	
Optional (Linear Current)	4 to 20 mA, 10 to 50 mADC *(field selectable)*	
Power Requirements	115 ±15V rms 50/60 ±0.5 Hz 230 watts	115 ±15V rms, 50/60 ±0.5 Hz, 200 watts average, 500 watts maximum
Enclosure	General purpose for installation in weather-protected area	194501 – General purpose for installation in weather-protected area. 194502 – Explosion-proof, Class I, Groups B, C, and D, Division 1.
Overall Dimensions	8-11/16 inches (220 mm) H 13-1/8 inches (333 mm) W 22-3/8 inches (569 mm) D	194501 – 8-11/16 inches (220 mm) H 13-1/8 inches (333 mm) W 27-3/8 inches (696 mm) D 194502 – See Figure 2-3
Instrument Weight	50 pounds (23 kg)	194501 – 61 pounds (28 kg) 194502 – 155 pounds (70 kg)
Shipping Weight	65 pounds (29 kg)	194501 – 81 pounds (37 kg) 194502 – 185 pounds (83 kg)

*Trademark of E. I. du Pont de Nemours & Co.
**Performance specifications based on ambient temperature shifts of less than 20°F (11°C) at a maximum rate of 20°F (11°C) per hours, without need to recalibrate.

COMPLIANCES: The general purpose Models 864 and 865 are constructed to meet the applicable requirements of the Occupational Safety and Health Act of 1970 if installed in accordance with the requirements of the National Electrical Code (NEC) in non-hazardous areas and operated and maintained in the recommended manner.

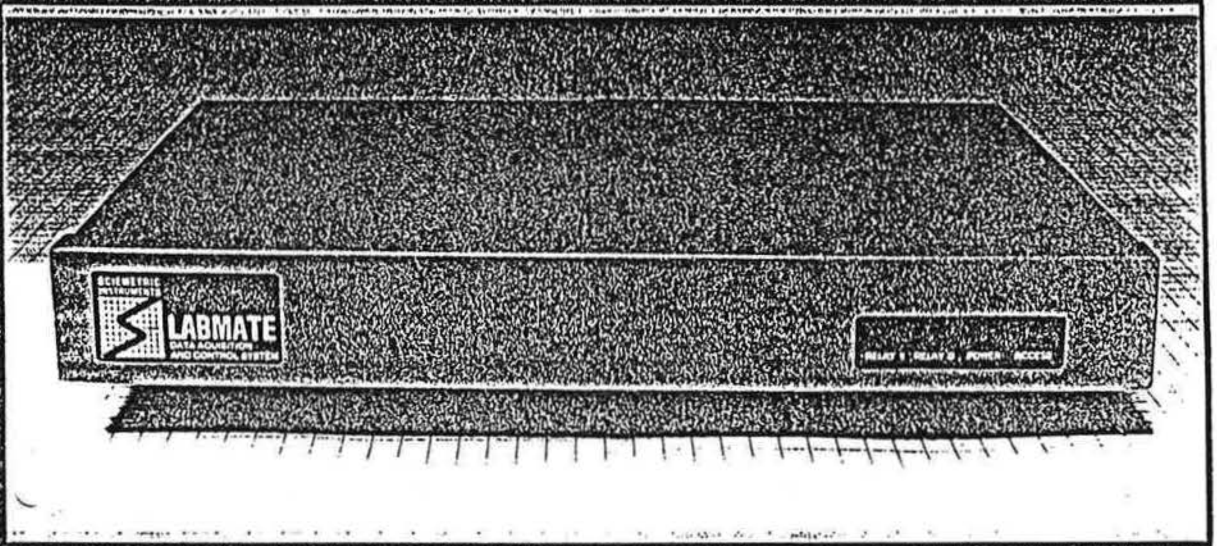
The Model 864 is certified by Canadian Standards Association (CSA) as complying with the applicable standards for protection against electrical shock and fire hazards in non-hazardous (ordinary) locations.

The air purge accessory for the Models 864 and 865 is designed for application with user-supplied components to comply with National Fire Protection Association (NFPA) 496-1974† to reduce the classification within an enclosure from Division 2, normally non-hazardous, to non-hazardous. This principle is recognized in the National Electrical Code (NEC)-1981 in articles 500-1 and 501-3 (a).

The explosion-proof Model 865 is approved by Factory Mutual Research (FM) for use in Class I Groups B, C, and D, Division 1 hazardous locations and will be deemed "approved" within the meaning of the U.S. Occupational Safety and Health Act of 1970, if installed in accordance with the requirements of the National Electrical Code (NEC) for such locations and operated and maintained in the recommended manner.

†The standard is not applicable to applications involving the introduction of flammable samples into the enclosure. See DANGER notice on inside front cover.

THE LABMATE



an easy solution to the most individual and demanding research and industrial applications.

Simply plug the appropriate interface card into your computer, connect the **Labmate**, and run the various software packages that are available.

Transform your PC into a powerful data acquisition and control station today.

Base-Unit Features

*16 analog input channels (32 single-ended for voltage)
*Built-in programmable amplifier gains: 1, 10, 100, 500
*2 analog outputs (current or voltage/switch selectable)
*8 digital inputs
*8 digital outputs
*3 event counters/timers
*2 relay outputs

THE LABMATE

ANALOG INPUTS

Number of channels: 16 multifunction/differential [Note 1] or 32 single-ended for voltage only
A/D converter : 12 bit-plus-sign, dual slope, integrating
Conversion rate : Typically: 10 channels per second Worst case: 7.5
Measurable signal types: Volts — DC or AC Resistance — Ω
Current — mA Frequency — Hz
***any channel, any order, any range, totally software selectable**

DC VOLTAGE

Input impedance : single-ended: 5 M Ω, differential 10 M Ω

Ranges	Gain	Full-Scale	Resolution
	1	± 5.0 V	1.22 mV
	10	± 0.5 V	0.12 mV
	100	± 50 m V	12 μV
	500	± 10 m V	2.4 μV

Accuracy : 0.1% + 2 digits

AC VOLTAGE

Ranges	Gain	Full-Scale	Resolution
	1	10.0 Vp-p	1.22 mV RMS
	10	1.0 Vp-p	0.12 mV RMS

Accuracy : 1% + 2 digits

RESISTANCE

Measurement modes: 2-wire or 3-wire, software selectable

3-Wire Ranges	Full-Scale	Resolution
	200 Ω	0.05 Ω
	20000 Ω	5 Ω
	200000 Ω	50 Ω

Accuracy : 0.3% + 2 digits (3-wire)

DC CURRENT

Ranges [Note 2]	Full-Scale	Resolution
	± 0.5 mA	0.12 μA
	± 5.0 mA	1.20 μA

Accuracy : 0.5% + 2 digits

FREQUENCY

Waveform Types : any shape, internal amplification and squaring
Measurement method: pulse-period measured with binary counters and computer clock signal
Trigger-point : Zero-crossing detector
Ranges : DC to 10000 Hz, 255 ranges, 16-bit counter
Resolution : 4 μS per bit on 0.26 sec maximum period range [Note 3]

DIGITAL INPUTS

Number of inputs : 8, TTL compatible
Conditioning : Internal pull-up resistors
Logic "0" voltage : -0.5 to 0.8 V
Logic "1" voltage : 2.0 to 5.0 V

COUNTER INPUTS

Number of counters : 3
Counter size : 16 bit binary
Counting rate : DC to 2 MHz, RC filter dependent
Input signal filtering : Schmitt triggers and RC filters

ANALOG OUTPUTS

Number of channels: 2
D/A converters : 12-bit, multiplying
Output types : Voltage or current, switch selectable
Voltage output : minimum load resistance: ± 10 V : 2000 Ω
± 5 V : 1000 Ω
Current output : current internally sourced from +12 V supply
Protection : outputs fused and diode clamped

Ranges	Mode	Full-Scale	Resolution
	Unipolar DCV	+ 5 V	1.2 μV
		+ 10 V	2.4 μV
	Bipolar DCV	± 2.5 V	1.2 μV
		± 5 V	2.4 μV
		± 10 V	4.8 μV
	Unipolar mA	0.20 mA	4.8 μA

Accuracy : 0.1% + 2 digits

DIGITAL OUTPUTS

Number of outputs : 8, TTL compatible
Bit selection : Read or write any bit individually
Logic "0" output : +0.5 V maximum
Logic "1" output : +2.4 V minimum

RELAY OUTPUTS

Number of relays : 2
Contact arrangement: SPDT
Contact rating : 1.5 A @ 120 VAC (inductive)
3.0 A @ 120 VAC (resistive)
Protection : common contact fused
Status indication : front panel LED's

COMPUTER INTERFACE

Base unit : memory-mapped/dedicated bus interface with switch-selectable address.
Interface options : RS-232C, IBM PC, APPLE II/II+/IIe, compatibles, Commodore PET and C64.

SOFTWARE

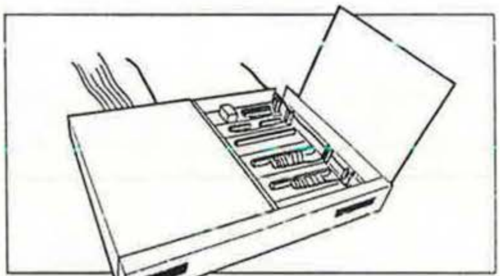
Optional software packages are available for IBM PC, APPLE, and Commodore computers. Sophistication ranges from BASIC/PASCAL subroutine packages to fully automated, menu-driven data collection and control software

GENERAL SPECIFICATIONS

Power requirements : 12-14 VDC input power @ 1.0 A maximum
Connection method : Screw terminals included with base unit
Operating temperature range: 5°C to 40°C
Relative humidity : 8 to 80%
Storage temperature : -30°C to 60°C

Size	Height	Width	Depth
	60 mm	450 mm	365 mm
	2.4 inches	17.7 inches	14.4 inches

Base unit weight : 4 kg



NOTES

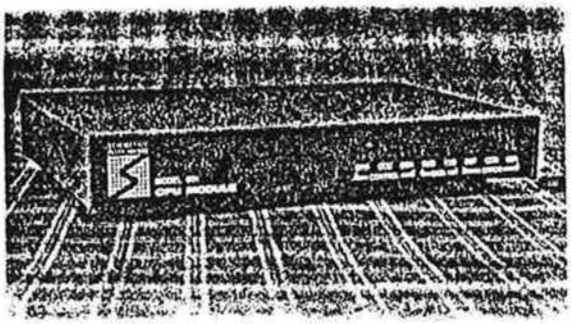
1. When thermocouples are measured, two of the 16 differential channels are used by the system (auto-zero and cold-junction compensation).
2. Higher currents (e.g., 4..20 mA) are measured using precision shunts and the DCV function. Screw terminal block includes built-in shunt solder-pads
3. Specifications based on 1 MHz clock frequency.

MANUFACTURED BY
SCIEMETRIC INSTRUMENTS
27 NORTHSIDE ROAD, NEPEAN, ONTARIO K2H 8S1
(613) 596-3995

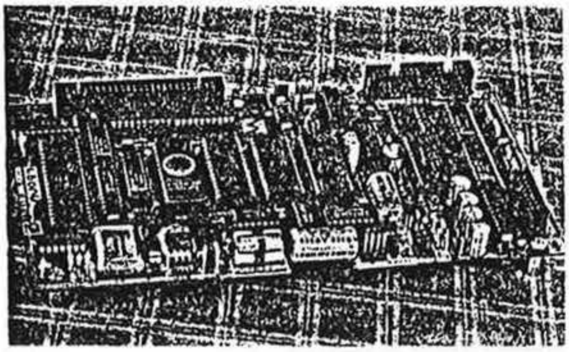
SCIEMETRIC INSTRUMENTS

DATA ACQUISITION AND CONTROL FOR PERSONAL COMPUTERS

CPU MODULE AND INTELLIGENT SERIAL INTERFACE MODEL 901



Cabinet Version



Single Card Version

HARDWARE FEATURES

- CMOS microprocessor
- 32K EPROM for system FIRMWARE
- Up to 24K RAM for CPU and User data
- Internal real-time clock
- Industry standard RS232C serial interface
- Operates from standard +12 VDC power source
- Watchdog timer ensures reliable operation
- Compatible with Sciemetric Models: 81, 161, 321, 641, LABMATE, 323, and 8082A
- Modem compatible

SOFTWARE FEATURES

- Powerful ASCII-based intelligent command set
- Stand-alone measurement, averaging and storage
- Automatic amplifier autozeroing
- Automatic thermocouple compensation
- Interrupt driven RS232 communication

APPLICATIONS

- Process monitoring and control
- Stand-alone data logging
- Energy management
- Research and Engineering
- Product testing
- Laboratory measurement and control

FUNCTIONAL DESCRIPTION

The MODEL 901 is a microprocessor-based intelligent interface for Sciemetric data acquisition and control products. The MODEL 901 provides an advanced, easy-to-use, software command set to access as many as 8 measurement and control modules, which are connected to the 901 using a standard Sciemetric daisy-chained cable. The 901 controls all input/output functions, communications, command interpretation and execution, data scaling and conversion to Engineering units.

All required software is resident in the 901 EPROM. This *firmware* is designed to keep the User-interface simple — while maintaining maximum power and flexibility for data collection and control. The host computer or terminal communicates with the MODEL 901 through the RS232 port. On-board DIP switches allow the User to select all serial communication parameters such as baud rate, number of data/stop bits, and the handshake mode.

A user-friendly interactive mode can be selected when the 901 is operated with a *dumb* terminal or from a personal computer acting as a terminal (e.g., using Crosstalk on an IBM PC).

The battery-backed real time clock precisely times all measurement functions, and can be read or reset by the User at any time — providing seconds, minutes, hours, date, month, year and day-of-week. The MODEL 901 also contains a special *watchdog* timer circuit — which automatically reboots the central processor should it ever *"hang"* and fail to execute the operating program.

Reliable low-level voltage measurements and thermocouple measurements are ensured since the 901 automatically measures the autozero and reference temperature values on a periodic basis. Floating-point numerical support handles amplifier gain compensation, thermistor linearization and conversion to °C, and complete thermocouple cold junction compensation and linearization — all transparent to the User.

POWERFUL COMMANDS

Over 40 commands are defined in the MODEL 901 — supporting measurement and control functions, automatic command list processing, real time clock access, and general processor module operation. The command set was designed to be as straightforward as possible, allowing even first-time Users fast efficient access to the installed system. Example commands include:

DCV	DC volts measurement
TCP	Thermocouple measurement
TIMES	Read real time clock
DIN	Digital input status (on/off)
DOUT	Set the state of a digital output
COUNTER	Read a digital counter
@SCAN	Start scanning the automatic list
@DUMP	Dump internal stored data

STAND-ALONE OPERATION

A powerful aspect of the MODEL 901 is the ability to stand-alone and automatically execute up to 64 commands, compute averages, maximums or minimums, and save the results in memory — without a host computer connected. Stored data can be dumped out the serial port or cleared at any time. The standard 901 unit has capacity for 2000 data samples.

Direct commands can also be processed even while the internal scan list is active. The 901 will execute the new command and report the results immediately.

Should the 901 reboot while an automatic list is executing (by pressing the RESET button or from a watchdog timer time-out), the command list and any data collected so-far will be preserved — as long as power is maintained. When the 901 reboots, auto-scanning and data averaging will continue from where it left off. Also, since the 901 operates from a standard +12 volt power source, full battery backup may be achieved for days or weeks using a standard 12-volt rechargeable power-pack.

ERROR HANDLING

The MODEL 901 includes extensive error detection and reporting software. Over 30 error messages are defined covering conditions from *Signal out of range* to *Syntax error*. Errors are reported as either error-numbers or as English error messages, selectable by the User. If an error is detected during an automatic-list measurement, the data value will be ignored, and the error number stored.

SIMPLE PROGRAMMING

Virtually any computer which has an RS232 port is compatible with the MODEL 901, and programming is easy when using common computer languages such as BASIC, FORTRAN, C, PASCAL, or ASSEMBLER.

As an example with BASIC on an IBM PC, the following program opens a file to a serial port (baud rate 9600, no parity, 8 data bits, 1 stop bit), sends a command to measure the DC voltage on channel 1, and reads the answer back from the 901 into the variable VOLTS:

```
OPEN "COM1:9600,N,8,1" AS #1
PRINT #1, "DCV 1.0"
INPUT #1, VOLTS
```

PACKAGING

The MODEL 901 is available either as a modular card, or mounted inside a steel cabinet. As a single-card product, the 901 can be integrated into OEM-type applications where a number of measurement and control units will form the working system. The optional cabinet for the 901 provides power and RS232 interface connectors on the rear panel, and also provides 8 front-panel status LEDS.

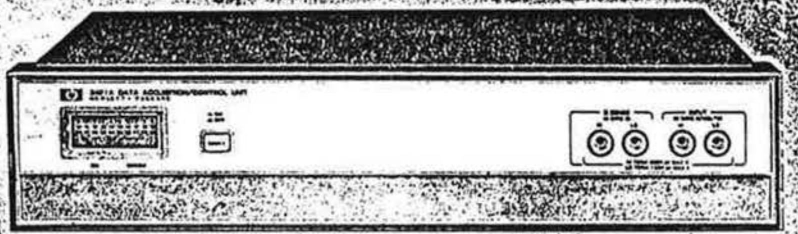
SPECIFICATIONS

Operating temperature	0°C — 60°C
Storage temperature	-30°C — 60°C
Operating relative humidity	8% — 80%
Typical power required	12-14 VDC, 0.4 A
Maximum power required	12-14 VDC, 1 A
Size (circuit board, cm)	10.9 × 21.3
Size (cabinet, cm)	4.3 × 18.2 × 24.4

Specifications subject to change without notice

Manufactured in Canada by
SCIEMETRIC INSTRUMENTS INC.
27 Northside Road, Nepean, Ontario, Canada K2H 8S1 (613) 596-3995

3421A Data Acquisition/ Control Unit



Operating, Programming, and Configuration Manual

APPENDIX C

CALCULATION OF COMBUSTION GAS FLOW FROM CO_2

(FLOW CURVES USING CO_2)

COMBUSTION OF FUEL OIL IN FURNACE

Given:

$kgoil \equiv 1 \cdot kg$ define kgoil as 1 kg

$C \equiv 0.8642 \cdot \frac{kg}{kgoil}$ define Carbon content of fuel

$H \equiv 0.1331 \cdot \frac{kg}{kgoil}$ define Hydrogen content of fuel

$S \equiv 0.0027 \cdot \frac{kg}{kgoil}$ define Sulphur content of fuel

1. Compute kg of O2 required per kg of fuel oil

   Element x molecular-weight ratio = kg O2 required

$$kgO2forC \equiv C \cdot \frac{32}{12} \qquad kgO2forC = 2.305 \cdot \frac{kg}{kgoil}$$

$$kgO2forH \equiv H \cdot \frac{16}{2} \qquad kgO2forH = 1.065 \cdot \frac{kg}{kgoil}$$

$$kgO2forS \equiv S \cdot \frac{32}{32} \qquad kgO2forS = 0.003 \cdot \frac{kg}{kgoil}$$

$$kgO2for1kgoil \equiv kgO2forC + kgO2forH + kgO2forS$$

$$kgO2for1kgoil = 3.372 \cdot \frac{kg}{kgoil}$$

2. Compute kg of air required for perfect combustion

kg of Nitrogen associated with required Oxygen

$$massratioN2O2inair \equiv \frac{0.768}{0.232}$$

$$kgN2for1kgoil \equiv kgO2for1kgoil \cdot massratioN2O2inair$$

$$kgN2for1kgoil = 11.163 \cdot \frac{kg}{kgoil}$$

$$kgairfor1kgoil \equiv kgO2for1kgoil + kgN2for1kgoil$$

$$kgairfor1kgoil = 14.535 \cdot \frac{kg}{kgoil}$$

---

3. Compute the mass of products of combustion

Fuel constituent + Oxygen = Product of combustion

$$kgCO2 \equiv C + kgO2forC \qquad kgCO2 = 3.169 \cdot \frac{kg}{kgoil}$$

$$kgH2O \equiv H + kgO2forH \qquad kgH2O = 1.198 \cdot \frac{kg}{kgoil}$$

$$kgSO2 \equiv S + kgO2forS \qquad kgSO2 = 0.005 \cdot \frac{kg}{kgoil}$$

$$kgfluegasfor1kgoil \equiv kgCO2 + kgH2O + kgSO2 + kgN2for1kgoil$$

$$kgfluegasfor1kgoil = 15.535 \cdot \frac{kg}{kgoil}$$

4. Convert flue-gas mass to volume @ STP

$molwtCO2 \equiv 44 \cdot kg$ $molwtH2O \equiv 18 \cdot kg$ $molwtN2 \equiv 28 \cdot kg$ $molwtSO2 \equiv 64 \cdot kg$

$kgmolvolume \equiv 22400 \cdot litre$ $molwtAIR \equiv 28.95 \cdot kg$

kg molecular volume = molecular volume / molecular mass

$$kgmolvolCO2 \equiv \frac{kgmolvolume}{molwtCO2} \qquad kgmolvolCO2 = 509.091 \cdot \frac{litre}{kg}$$

$$kgmolvolH2O \equiv \frac{kgmolvolume}{molwtH2O} \qquad kgmolvolH2O = 1.244 \cdot 10^{3} \cdot \frac{litre}{kg}$$

$$kgmolvolSO2 \equiv \frac{kgmolvolume}{molwtSO2} \qquad kgmolvolSO2 = 350 \cdot \frac{litre}{kg}$$

$$kgmolvolN2 \equiv \frac{kgmolvolume}{molwtN2} \qquad kgmolvolN2 = 800 \cdot \frac{litre}{kg}$$

Volume at standard temperature of 20 deg C

= kg molecular volume of product x mass of product

$$volCO2for1kgoil \equiv kgmolvolCO2 \cdot kgCO2 \qquad volCO2for1kgoil = 1.613 \cdot 10^{3} \cdot \frac{litre}{kgoil}$$

$$volH2Ofor1kgoil \equiv kgmolvolH2O \cdot kgH2O \qquad volH2Ofor1kgoil = 1.491 \cdot 10^{3} \cdot \frac{litre}{kgoil}$$

$$volSO2for1kgoil \equiv kgmolvolSO2 \cdot kgSO2 \qquad volSO2for1kgoil = 1.89 \cdot \frac{litre}{kgoil}$$

$$volN2for1kgoil \equiv kgmolvolN2 \cdot kgN2for1kgoil$$

$$volN2for1kgoil = 8.93 \cdot 10^{3} \cdot \frac{litre}{kgoil}$$

$$volwetfluegas \equiv volCO2for1kgoil + volH2Ofor1kgoil \ldots$$
$$+ volSO2for1kgoil + volN2for1kgoil$$

$$volwetfluegas = 1.204 \cdot 10^{4} \cdot \frac{litre}{kgoil}$$

$$voldryfluegas \equiv volCO2for1kgoil \ldots$$
$$+ volSO2for1kgoil + volN2for1kgoil$$

$$voldryfluegas = 1.0545 \cdot 10^{4} \cdot \frac{litre}{kgoil}$$

---

5. Compute the CO2 content of the flue gas

$$percentCO2wet := 100 \cdot \frac{volCO2for1kgoil}{volwetfluegas} \qquad percentCO2wet = 13.403$$

$$percentCO2dry := 100 \cdot \frac{volCO2for1kgoil}{voldryfluegas} \qquad percentCO2dry = 15.298$$

---

6. compute the air required for i% excess air

i := % excess air

$$totalair := \left[1 + \frac{i}{100}\right] \cdot kgairfor1kgoil \qquad totalair = 14.535 + 0.145i \cdot \frac{kg}{kgoil}$$

$$excessair := \frac{i}{100} \cdot kgairfor1kgoil \qquad excessair = 0.145i \cdot \frac{kg}{kgoil}$$

---

7. compute the weight of the products of combustion

totalmass := kgfluegasfor1kgoil + excessair **totalmass = 15.535 + 0.145i**

---

8. compute the volume of the combustion products and the %CO2

$$volwetfluegas\_xs := volwetfluegas + excessair \cdot \frac{kgmolvolume}{molwtAIR}$$

$$volwetfluegas\_xs = (1.204*10^{4} + 112.461*i)\ \frac{litre}{kgoil}$$

$$voldryfluegas\_xs := voldryfluegas + excessair \cdot \frac{kgmolvolume}{molwtAIR}$$

$$voldryfluegas\_xs = (1.0545*10^{4} + 112.46*i)\ \frac{litre}{kgoil}$$

$$percentCO2wet\_xs := 100 \cdot \frac{volCO2for1kgoil}{volwetfluegas\_xs}$$

$$percentCO2dry\_xs := 100 \cdot \frac{volCO2for1kgoil}{voldryfluegas\_xs}$$

$$percentCO2dry\_xs := 100\ \frac{1613}{(10545 + 112.46i)}$$

FORMULA TO CALCULATE % EXCESS AIR (i) FROM % CO2 DRY: . . .

$$i := \frac{1434}{\%\ CO2\ dry} - 93.97$$

9. compute combustion gas flow

$$oilflow := 0.7312 \cdot \frac{g}{sec} \qquad oilflow \equiv .000732 \cdot \frac{kgoil}{sec}$$

$$wetgasflow := volwetfluegas\_xs \cdot oilflow$$

from section 8.

$$volwetfluegas\_xs = 1.2036 \cdot 10^{4} + 112.4614i \cdot \frac{litre}{kgoil}$$

$$wetgasflow = \left(12036 + 112.461 * \left(\frac{1434}{\%\ CO2\ dry} - 93.97\right)\right) * .000732\ \frac{litre}{sec}$$

$$12036 \cdot oilflow = 8.8104 \cdot \frac{kg}{sec} \qquad 112.461 \cdot oilflow = 0.0823 \cdot \frac{kg}{sec}$$

$$1434 \cdot 112.461 \cdot oilflow = 118.049 \cdot \frac{kg}{sec} \qquad 93.97 \cdot 112.461 \cdot oilflow = 7.736 \cdot \frac{kg}{sec}$$

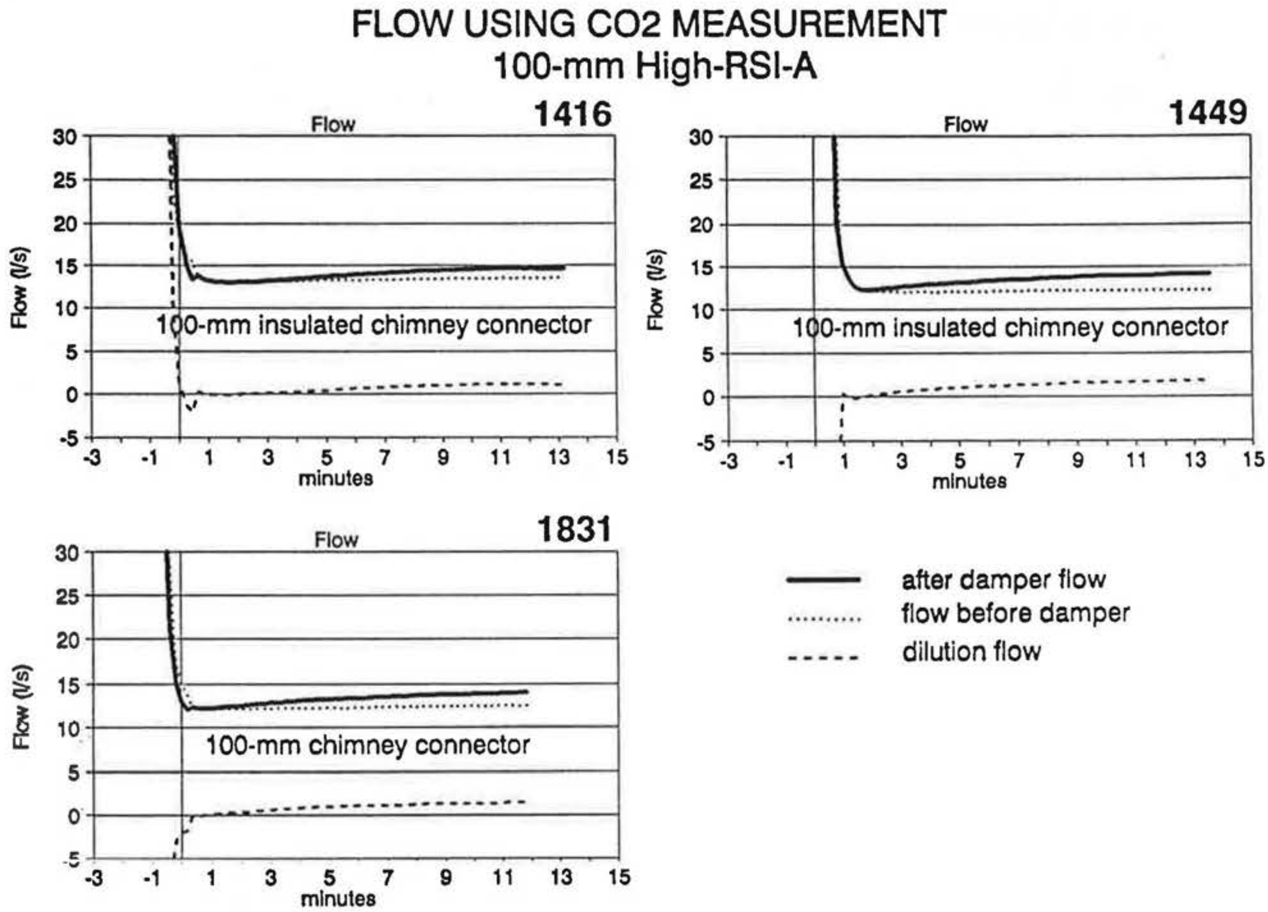
$$wetgasflow = \left(8.810 + \left(\frac{118.05}{\%\ CO2\ dry} - 7.736\right)\right)\ \frac{litre}{sec}$$

TYPICAL CALCULATION OF WET GAS FLOW IN litres/sec

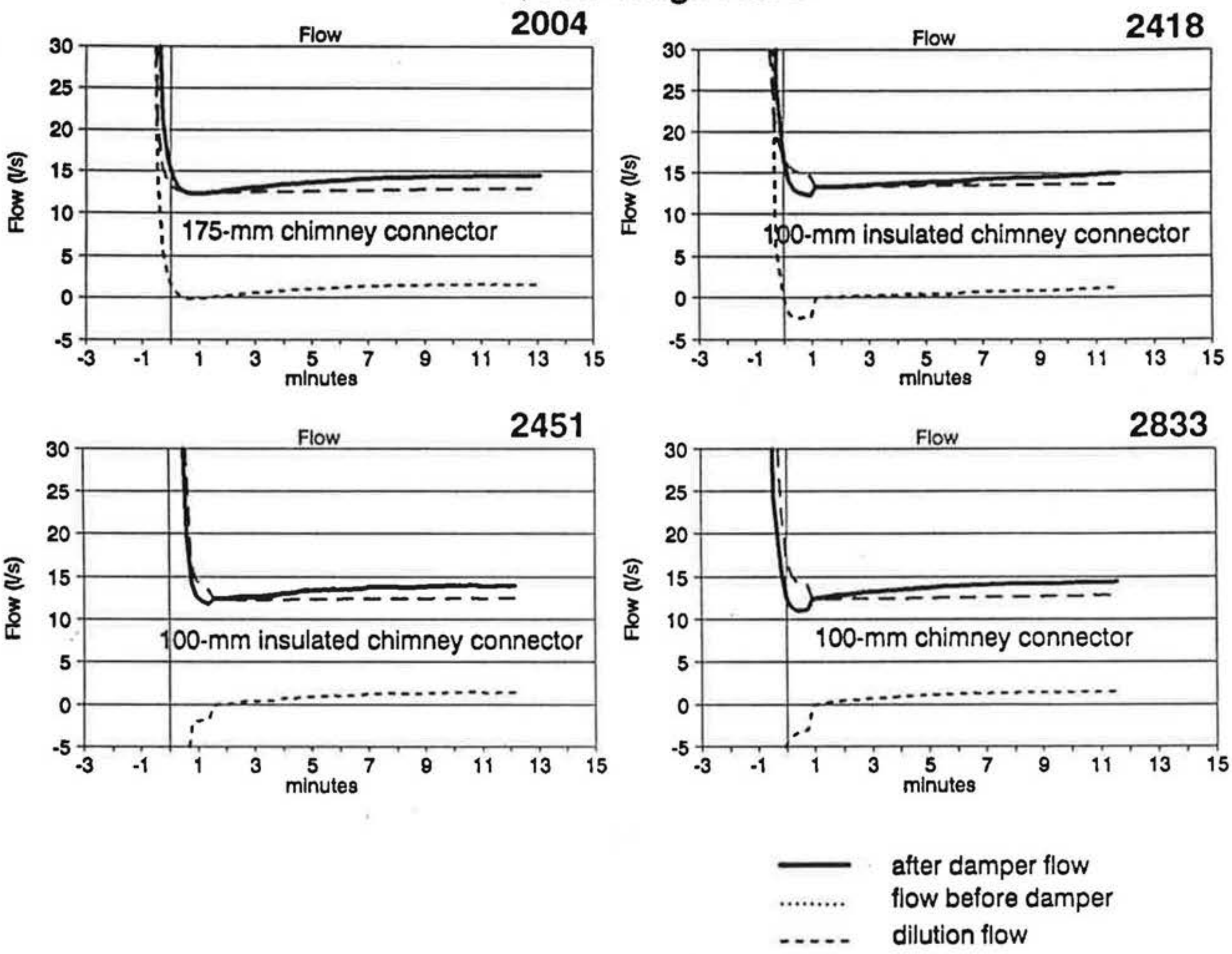
CO2dry := 8

$$\text{wetgasflow} := \left[8.810 + \left[\frac{118.05}{\text{CO2dry}} - 7.736\right]\right] \cdot \frac{\text{litre}}{\text{sec}}$$

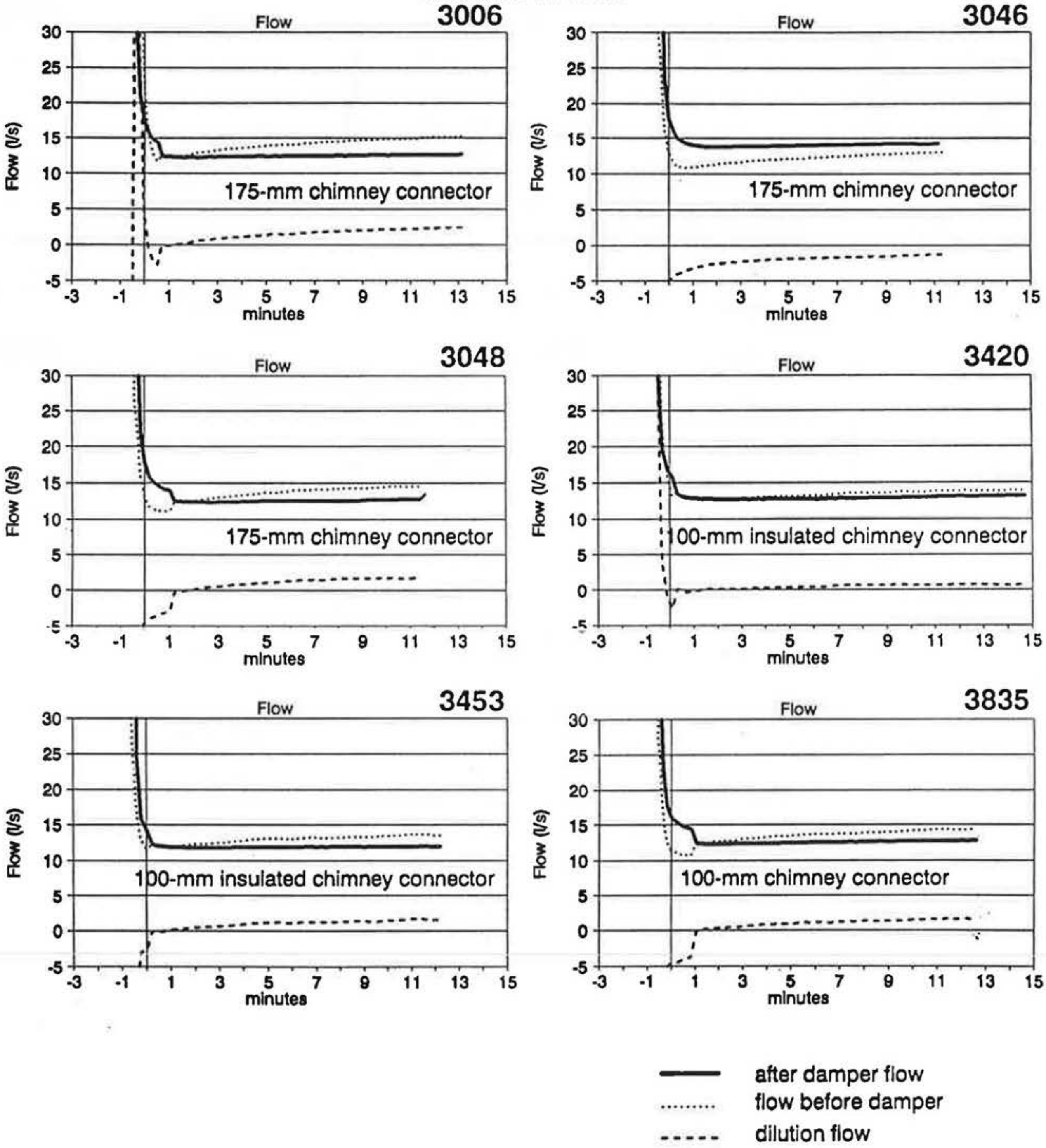
$$\text{wetgasflow} = 15.83 \cdot \frac{\text{litres}}{\text{sec}}$$


FLOW USING CO2 MEASUREMENT
100-mm High-RSI-A
Flow
1416
100-mm insulated chimney connector
1449
100-mm insulated chimney connector
1831
100-mm chimney connector
Flow (l/s)
minutes
after damper flow
flow before damper
dilution flow

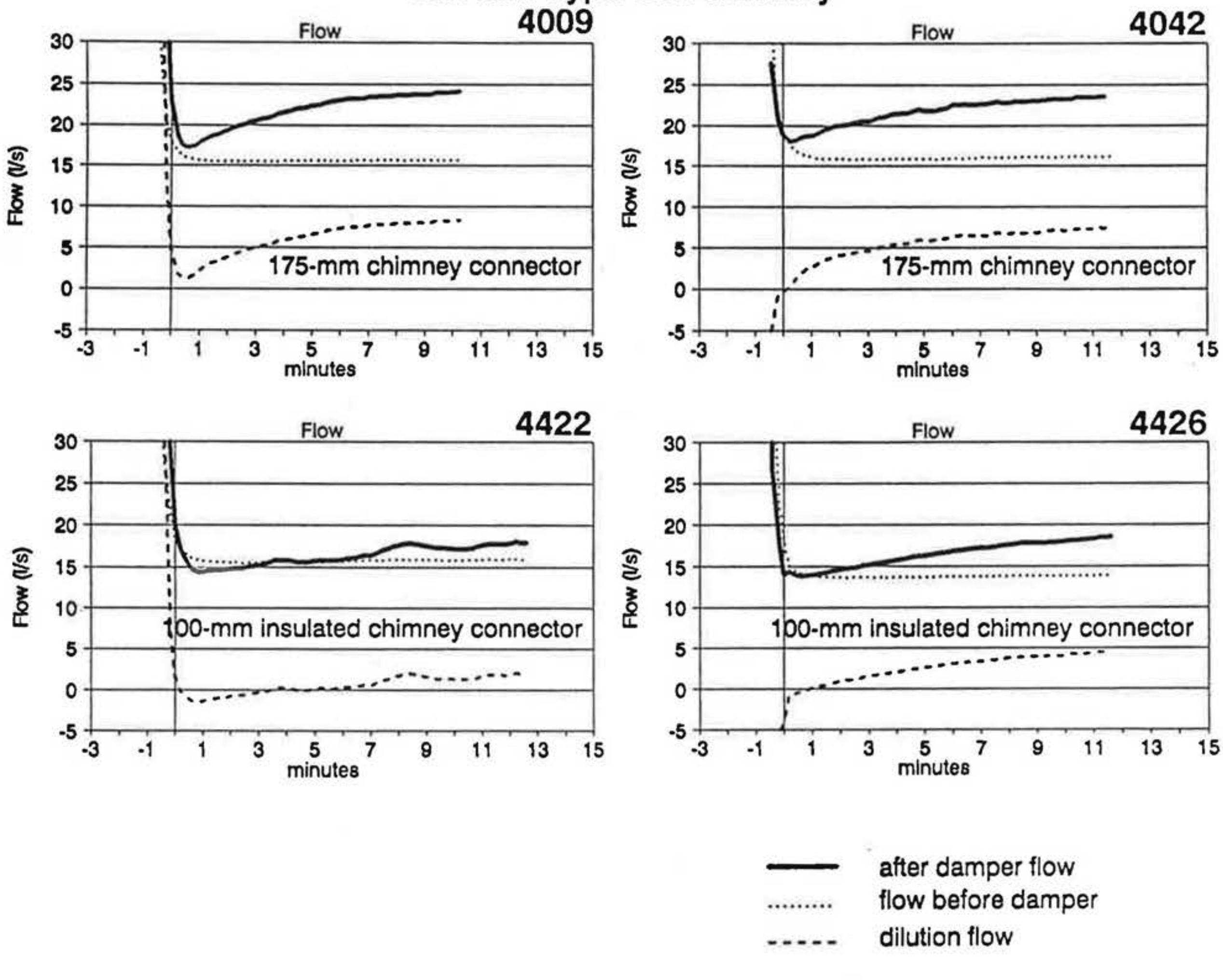
FLOW USING CO2 MEASUREMENT
100-mm High-RSI-B



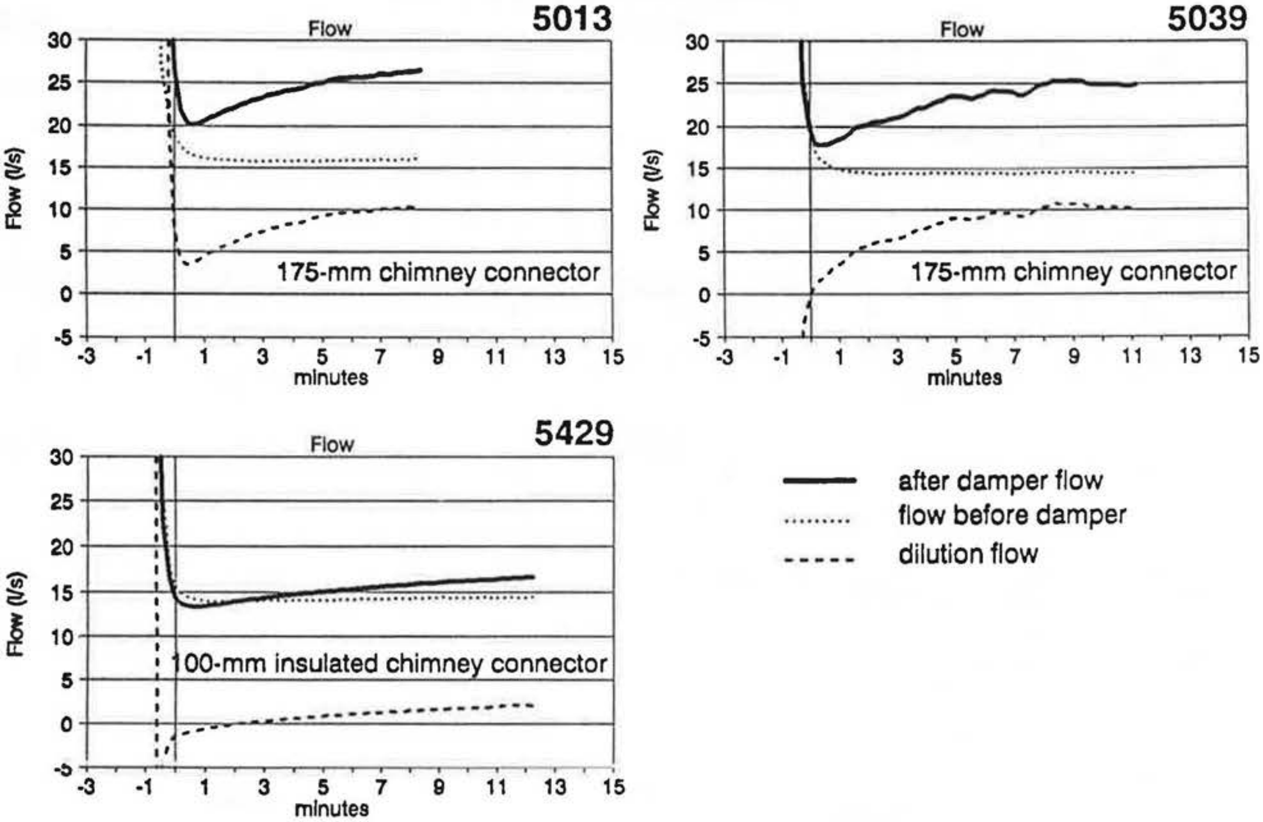
FLOW USING CO2 MEASUREMENT
100-mm A-vent

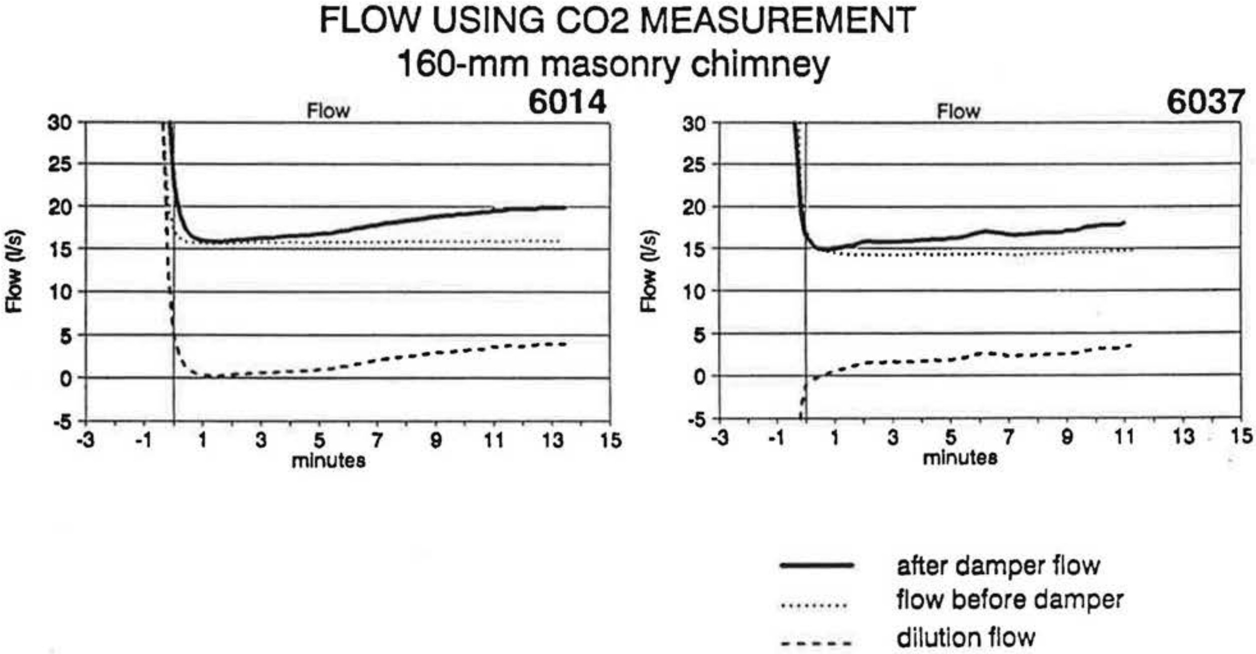


FLOW USING CO2 MEASUREMENT
150-mm Type-650 chimney



FLOW USING CO2 MEASUREMENT
175-mm A-vent




FLOW USING CO2 MEASUREMENT
160-mm masonry chimney
6014
Flow
Flow (l/s)
minutes
6037
Flow
Flow (l/s)
minutes
after damper flow
flow before damper
dilution flow

APPENDIX D

FAN DEPRESSURIZATION TEST DATA

IRTA

AIR LEAKAGE ANALYSIS
700-HA1

CMHC ARMSTRONG HOUSE
APRIL 11,1989

SQ.FT.= 2161 CU.FT.= 10876

TEMP.IN= 68F OUT= 41F

RANGE= 20 = no Plate

PRE-TEST #2

HOUSE (Pa)	FLOW (Pa)	FLOW (cfm)	ERROR (%)
50	29	2147	-0.0
45	26	2027	0.7
40	22	1855	-0.7
35	19	1717	-0.0
30	15	1542	-1.2
25	13	1405	0.9
20	10	1223	1.0
15	7	1013	0.1
11	5	848	-0.9

TOTAL AREA OF ALL CRACKS AND HOLES
1.60 SQ.FT.= 230.76 SQ.IN.

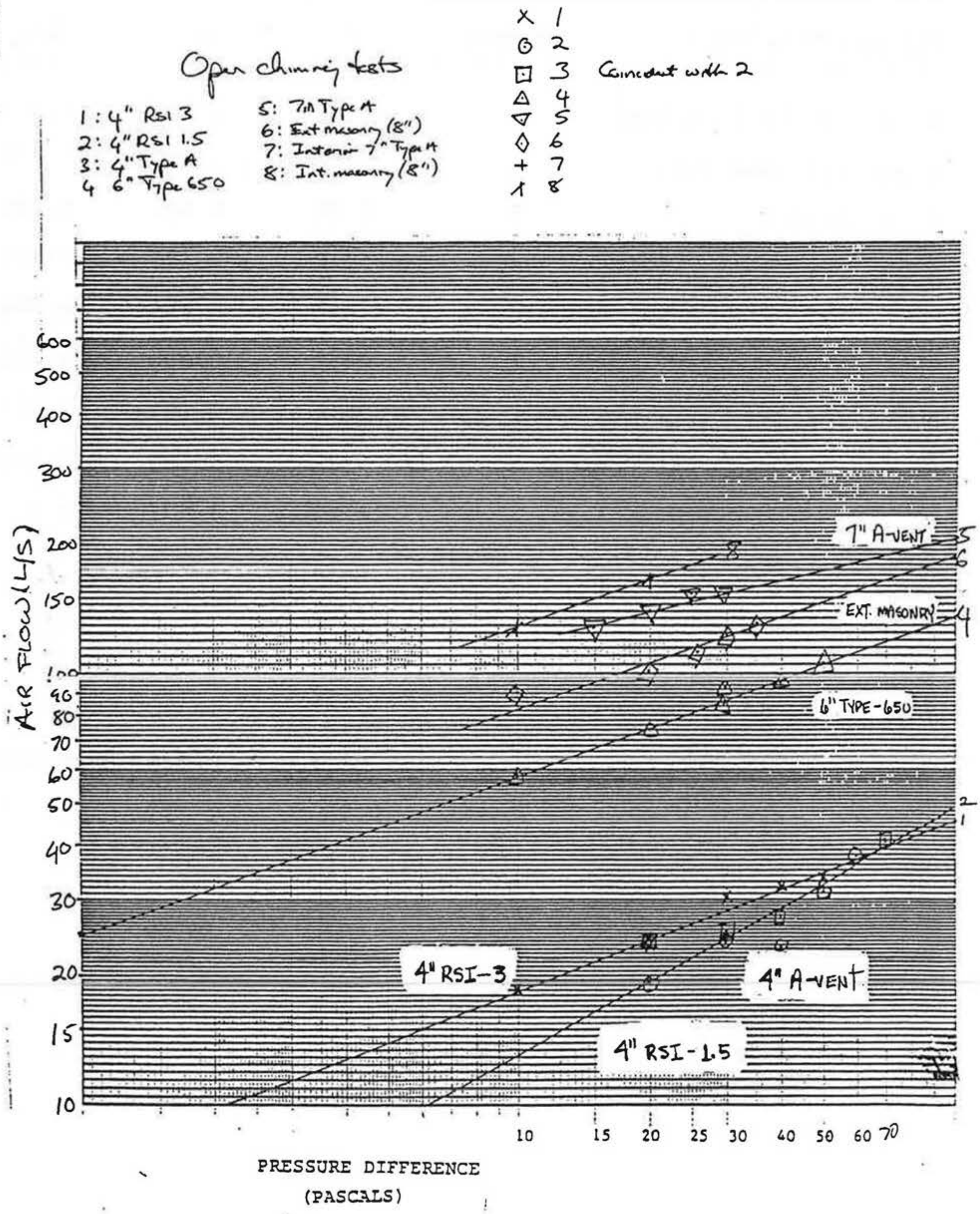
AIR CHANGES/HR.@ 50.00 Pa.= 11.85
CORR.= 99.95
STND. ERROR= 0.91
LBL ELA @4Pa. = 0.87 SQ.FT.
L.R.= 10.07 SQ.IN./100 SQ.FT.
C= 186.18 n= 0.6252

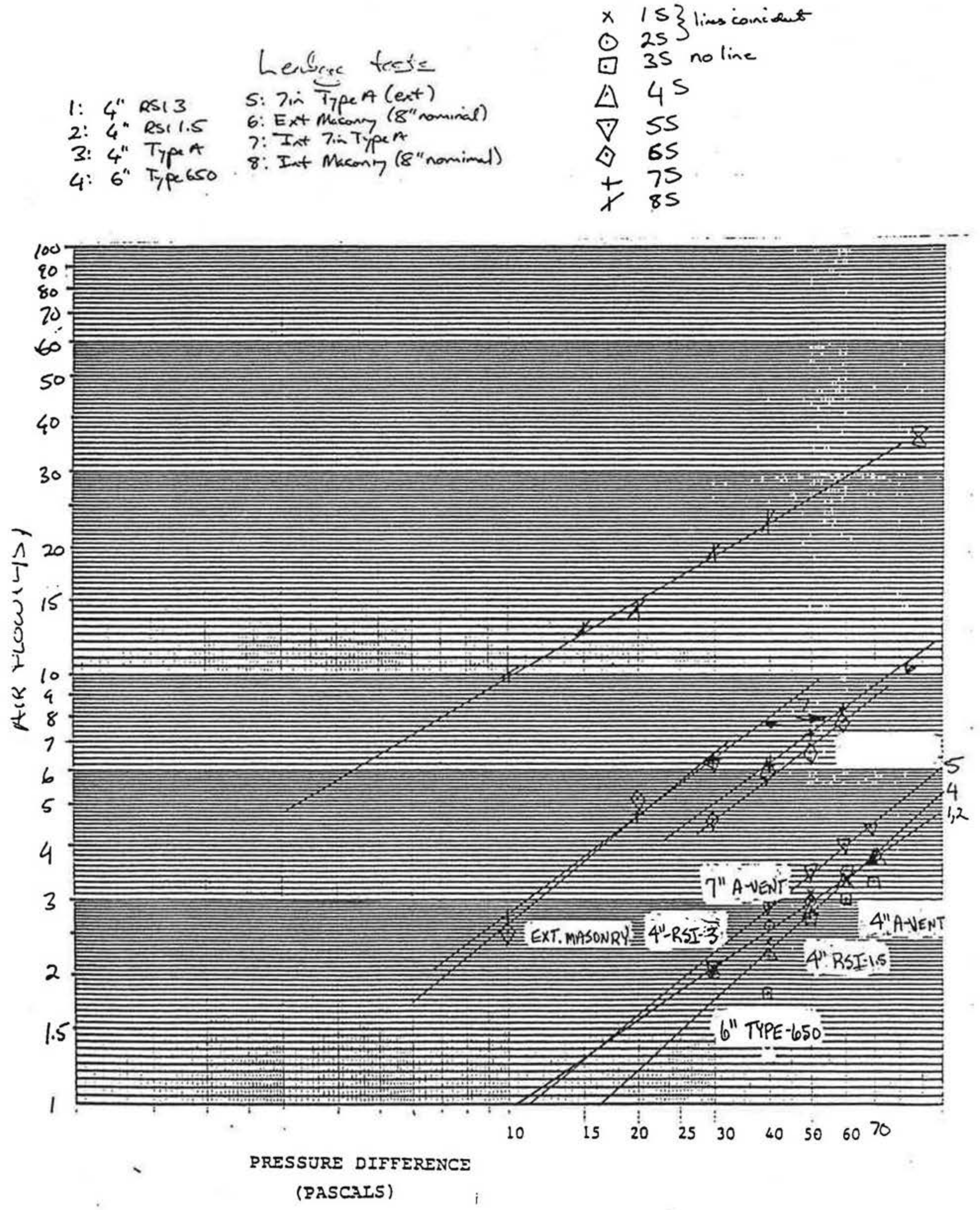
APPENDIX E

CMHC'S PRESSURE VS FLOW MEASUREMENTS (DUCT TEST RIG)

Armstrong Summary of 25 April Tests 14 June 89
****

Chimney/Flue Pipe	Number	C	n	R^2
4 in. highly insulated	1	3.45	0.580	0.998
4 in. mid-insulated	2	3.39	0.589	0.998
4 in. A-vent	3	2.90	0.581	0.999
6 in. 650 (all 6 points)	4	17.0	0.462	0.987
(1st 4 points)		14.7	0.515	0.999
7 in. A-vent	5	34.6	0.399	0.981
8 in. masonry	6	25.5	0.463	0.999
Reducer (7"-4") (All points)		9.20	0.481	0.989
(Last 4 pts.)		8.85	0.507	0.997
Enlarger (4"-7")		-2.24	0.702	0.995
4 in. Insulated Flue Pipe		6.02	0.551	0.999
4 in. Uninsulated Flue Pipe		5.85	0.534	0.996
7 in. Flue Pipe --Not Possible--		-	-	-
Open Heater End		-78.7	0.536	0.999
Furnace Leakage		0.357	0.750	0.981


Open chimney tests
1: 4" RSI 3
2: 4" RSI 1.5
3: 4" Type A
4 6" Type 650
5: 7in Type A
6: Ext masonry (8")
7: Interior 7" Type A
8: Int. masonry (8")
× 1
⊙ 2
⊡ 3 Coincident with 2
△ 4
▽ 5
◇ 6
+ 7
⅄ 8
7" A-VENT
EXT. MASONRY
6" TYPE-650
4" RSI-3
4" A-VENT
4" RSI-1.5
AIR FLOW (L/S)
10
15
20
30
40
50
60
70
80
90
100
150
200
300
400
500
600
10 15 20 25 30 40 50 60 70
PRESSURE DIFFERENCE
(PASCALS)


Leakage tests
1: 4" RSI 3
2: 4" RSI 1.5
3: 4" Type A
4: 6" Type 650
5: 7in Type A (ext)
6: Ext Masonry (8" nominal)
7: Int 7in Type A
8: Int Masonry (8" nominal)
x 1S } lines coincident
⊙ 2S
⊡ 3S no line
4S
5S
6S
+ 7S
8S
AIR FLOW (L/S)
7" A-VENT
EXT. MASONRY
4"-RSI-3
4" A-VENT
4" RSI-1.5
6" TYPE-650
5
4
1,2
6
7
PRESSURE DIFFERENCE
(PASCALS)

Armstrong House 20 September 1989 Tests

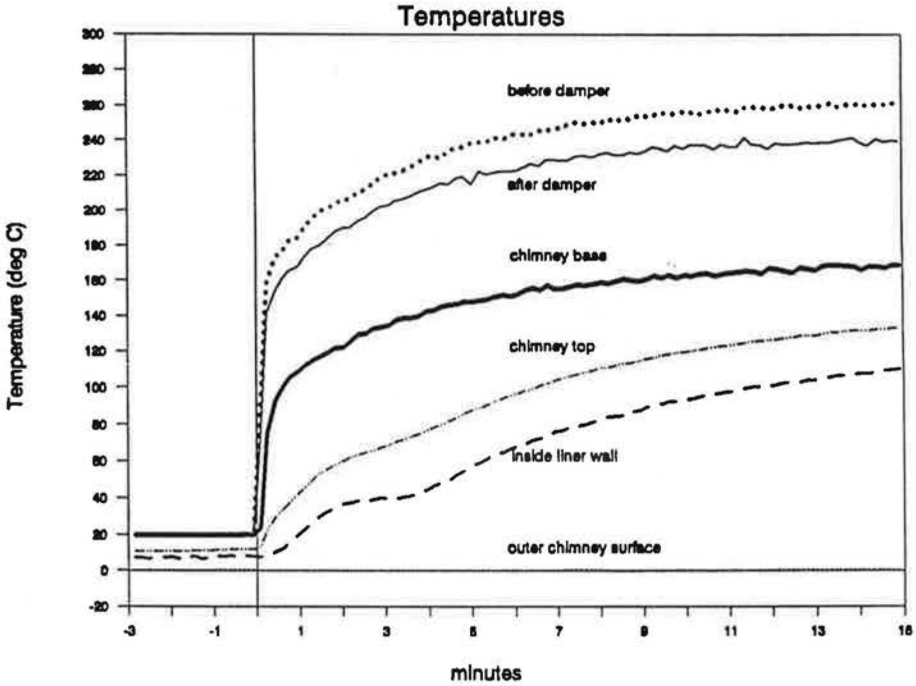
	C	n	R^2	ELA_{10} (cm^2)
Chimney #1				
- as found	0.121	0.691	0.99	2.4
- bottom taped	0.089	0.736	0.95	1.9
- joints, bottom untaped	0.184	0.640	0.99	3.2
Chimney #2				
- as found	0.135	0.669	0.99	2.5
- bottom taped	0.099	0.729	0.99	2.1
- joints, bottom untaped	0.199	0.666	0.99	3.7
Chimney #5				
- as found	0.373	0.538	0.85	5.2
- joints untaped	0.168	0.995	0.99	6.7

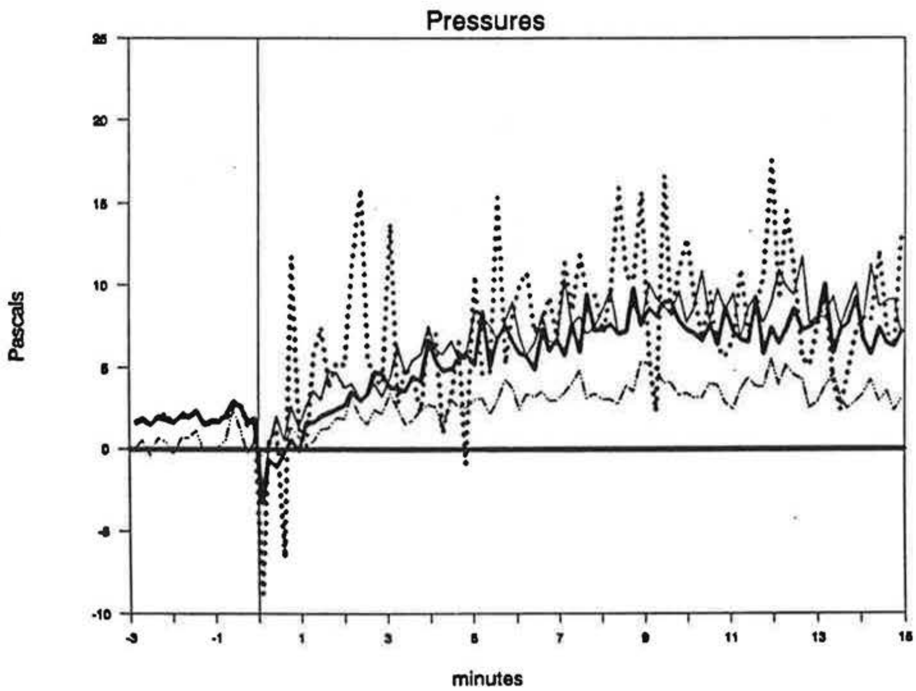
APPENDIX F

PRESSURE AND TEMPERATURE CURVES

CHIMNEY: 4" RSI-3 PIPE: 7" single-wall NO DEPRESSURIZATION

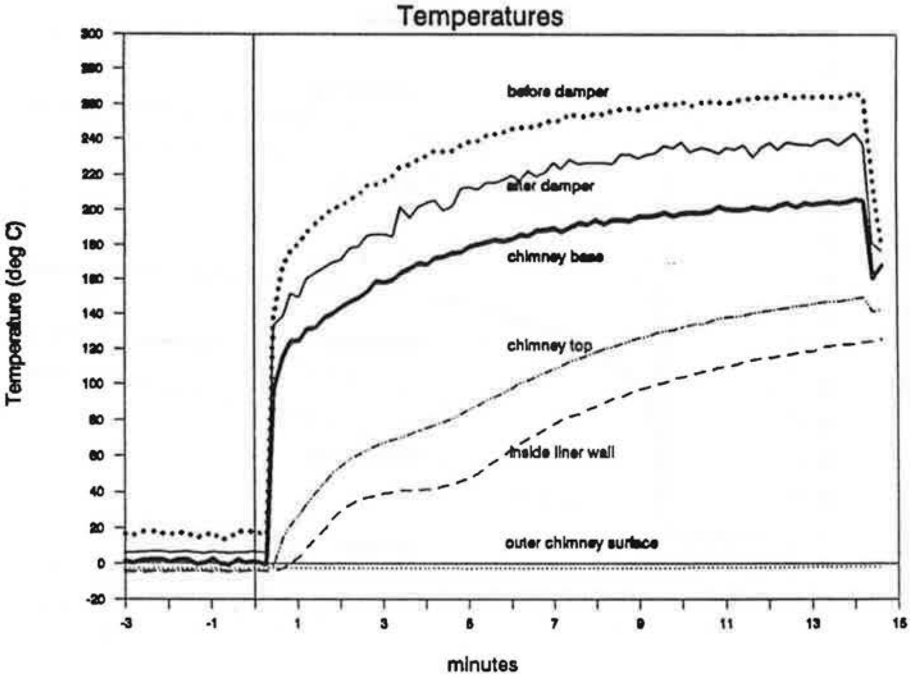
TEST 1003

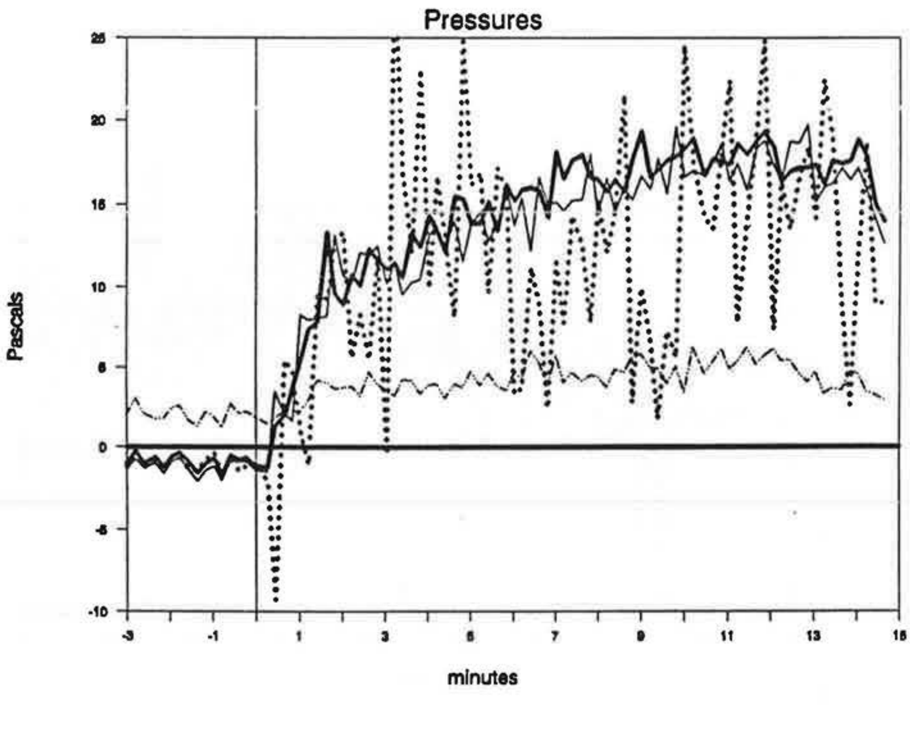




CHIMNEY: 4" RSI-3 PIPE: 4" Insulated NO DEPRESSURIZATION

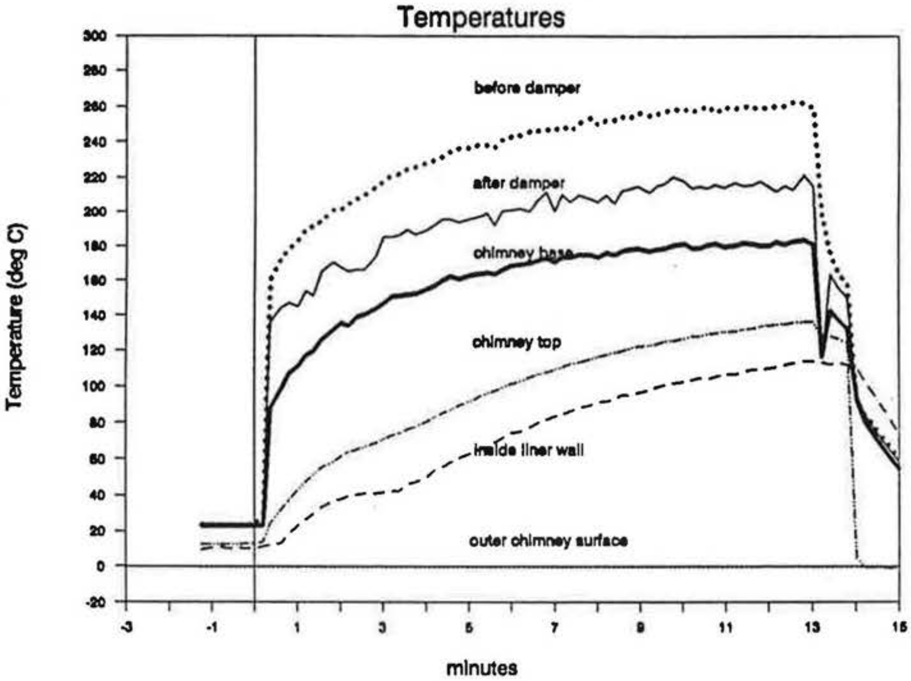
TEST 1416

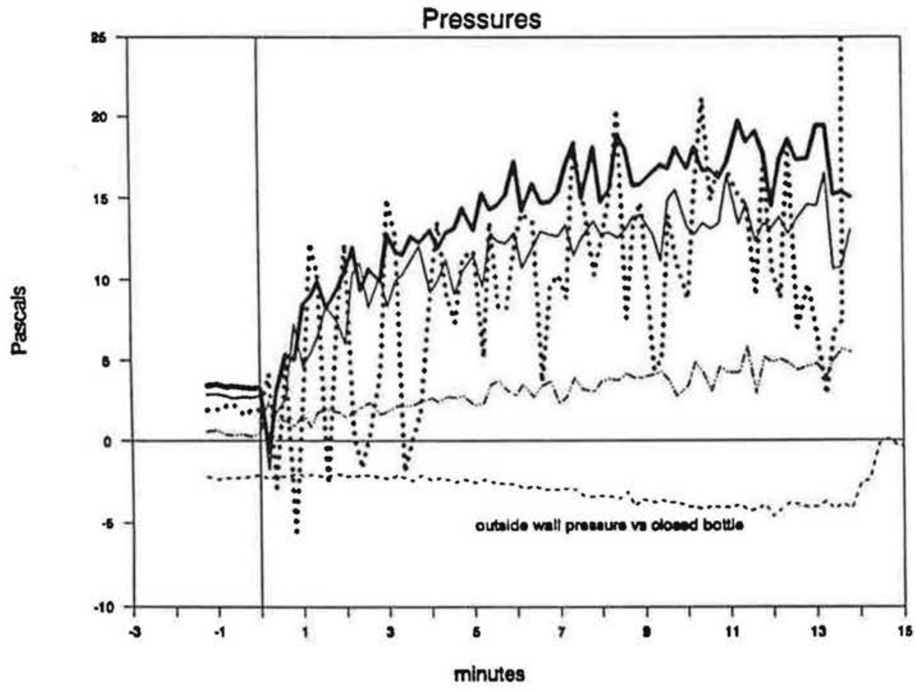




CHIMNEY: 4" RSI-3 PIPE: 4" single-wall NO DEPRESSURIZATION

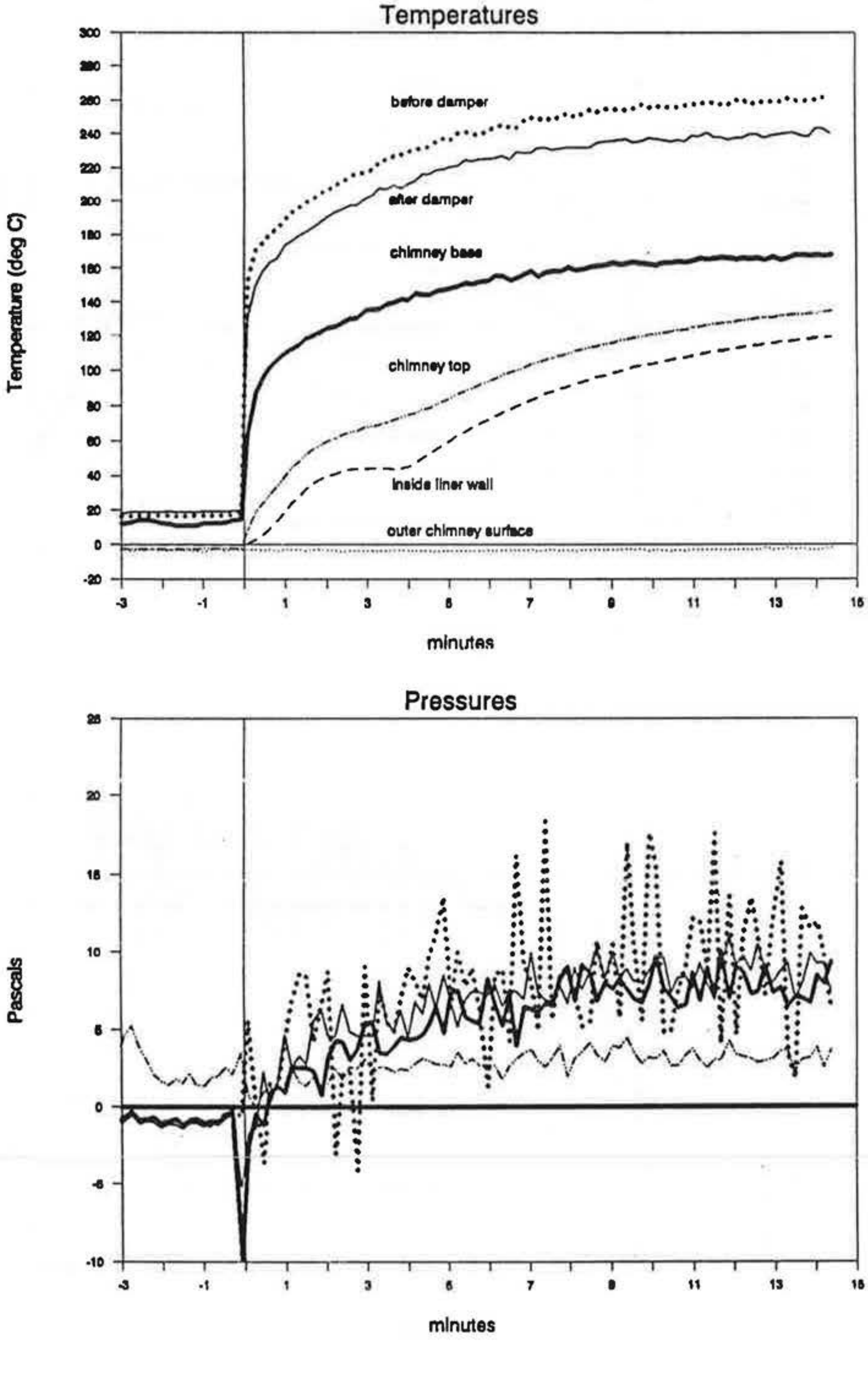
TEST 1831





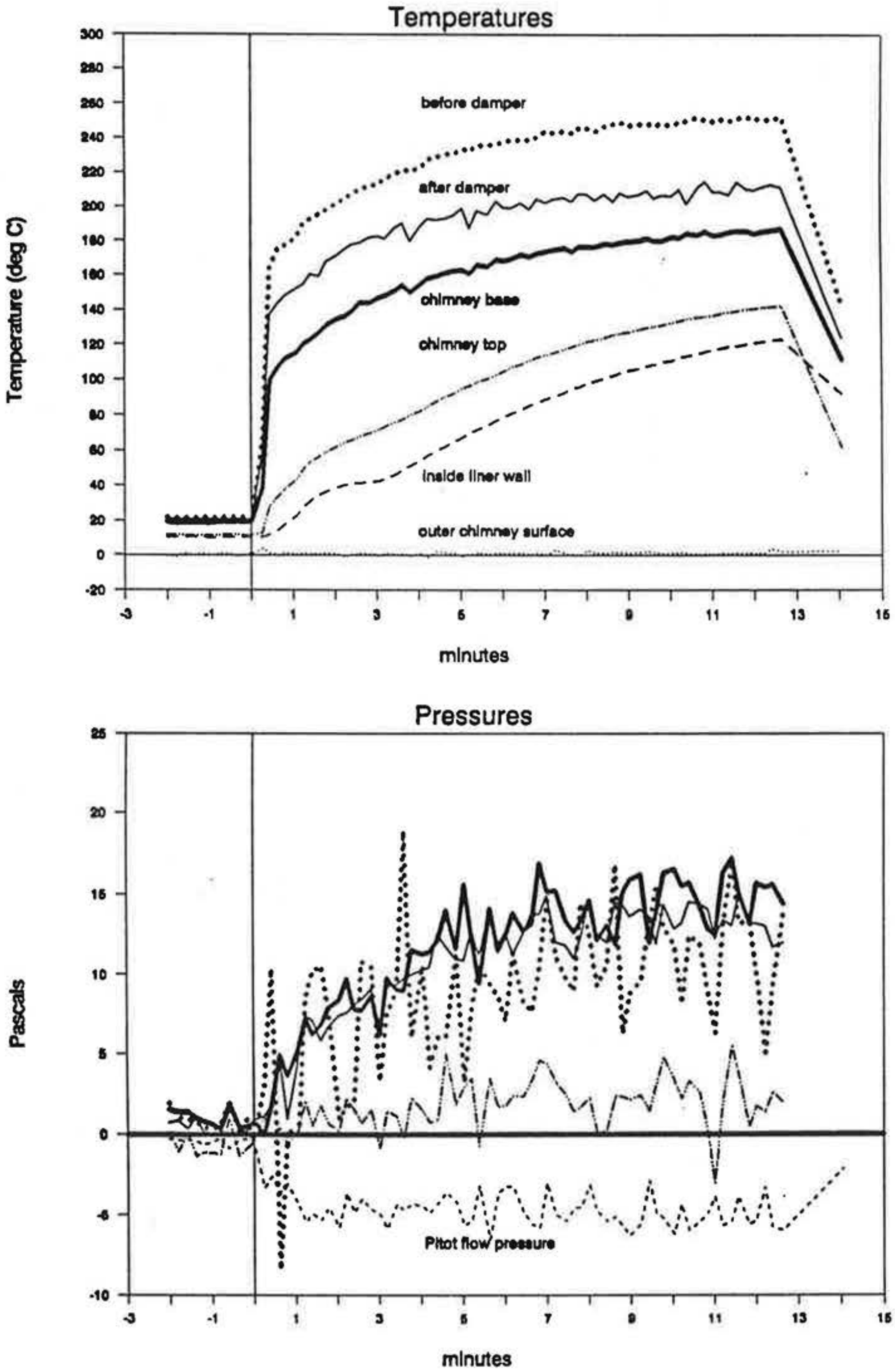
CHIMNEY: 4" RSI-1.5 PIPE: 7" single-wall NO DEPRESSURIZATION

TEST 2004



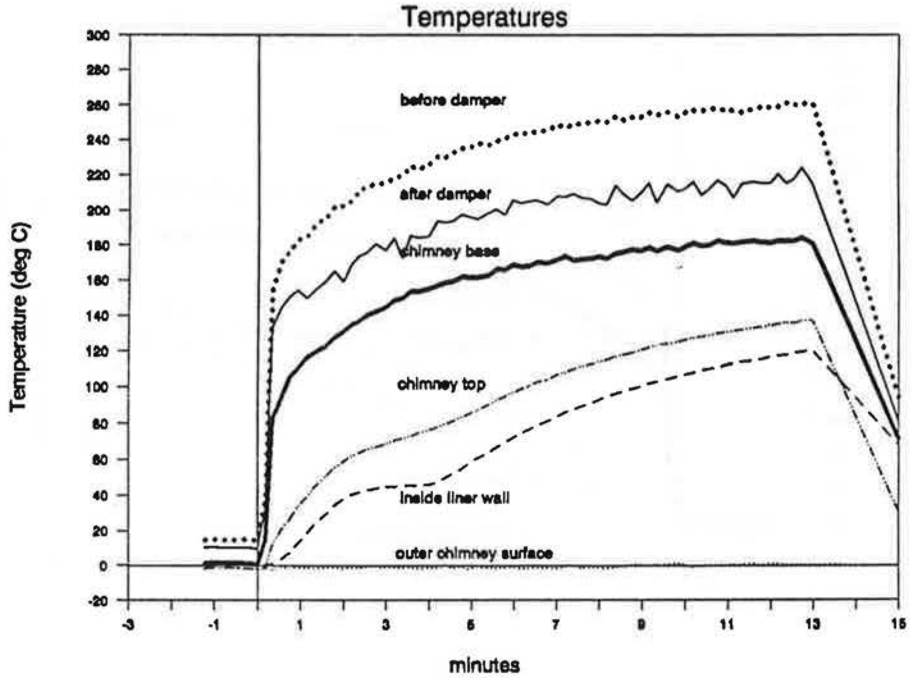
TEST 2451

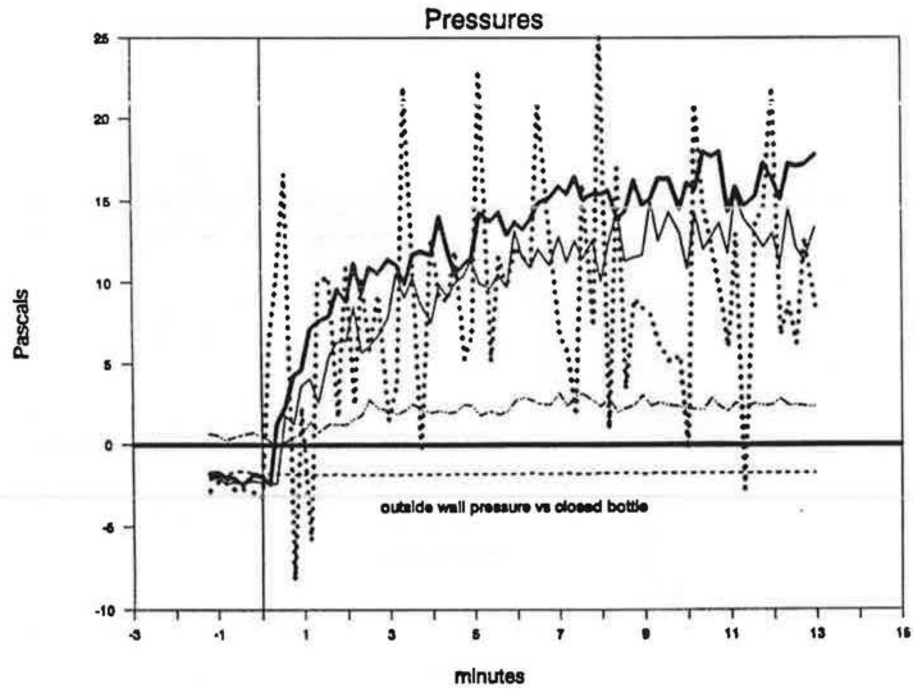
CHIMNEY: RSI-1.5 PIPE: 4" Insulated NO DEPRESSURIZATION



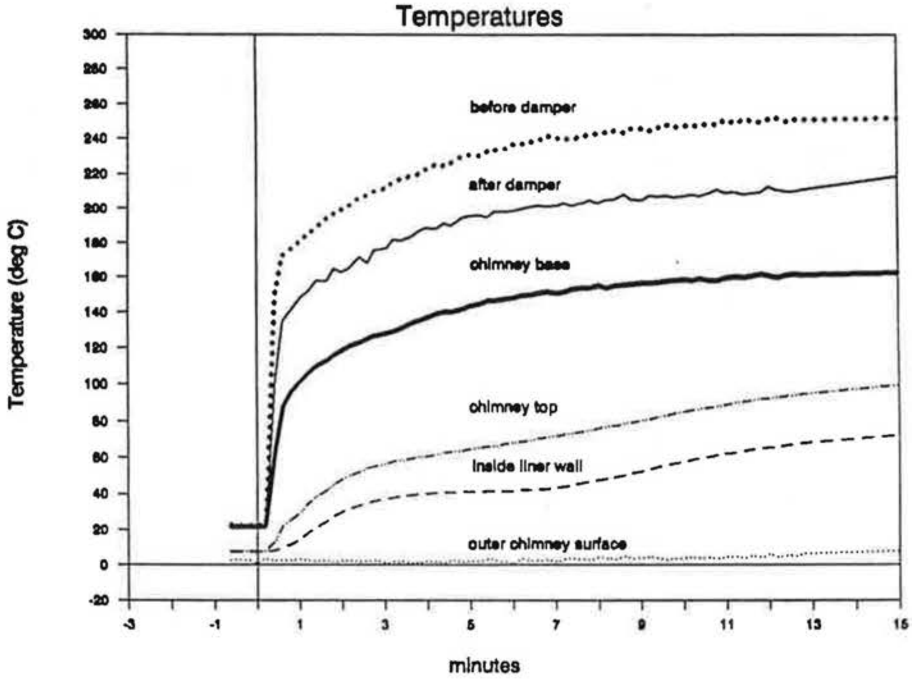
CHIMNEY: 4" RSI-1.5 PIPE: 4" single-wall NO DEPRESSURIZATION

TEST 2833

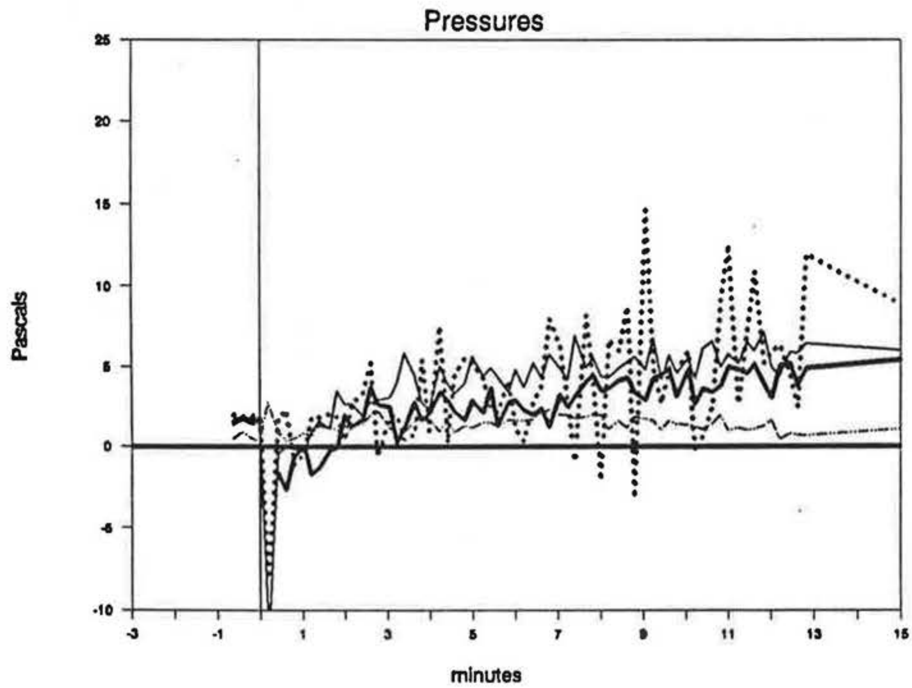




CHIMNEY: 4" A-vent PIPE: 7" single-wall NO DEPRESSURIZATION

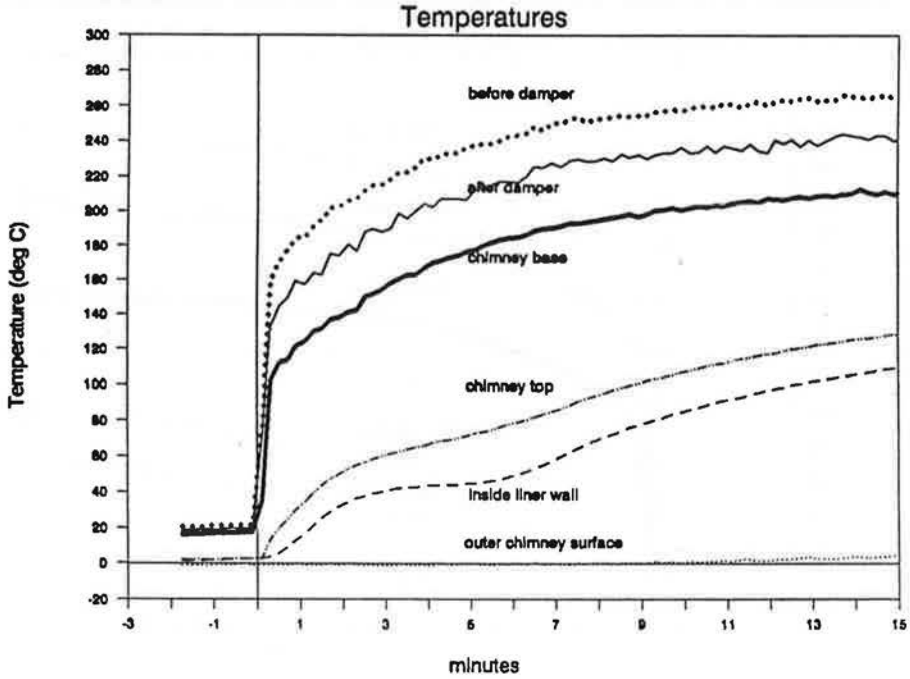


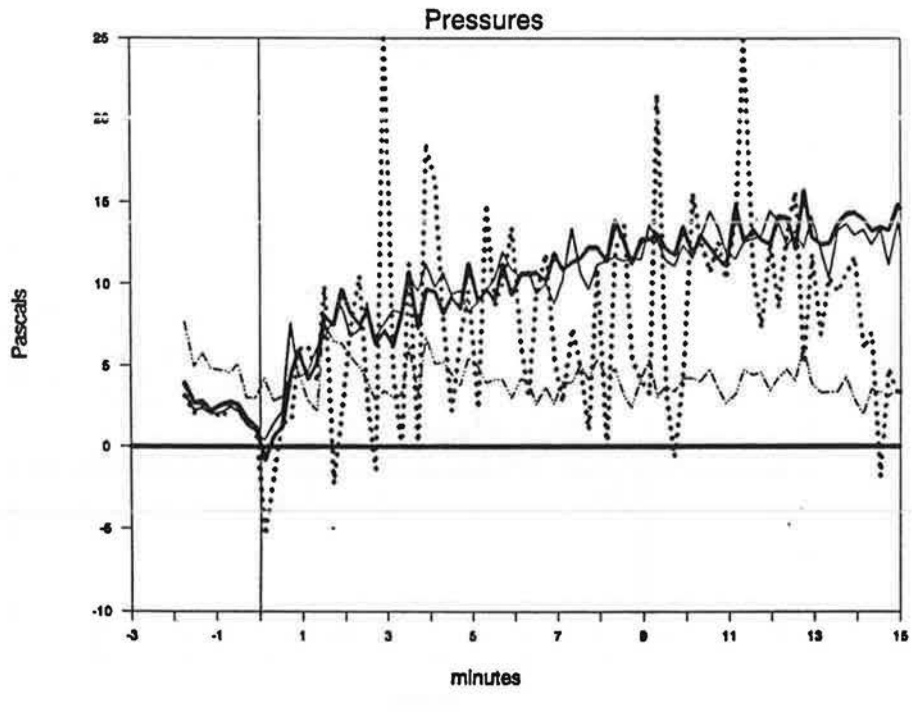
TEST 3048



CHIMNEY: 4" A-vent PIPE: 4" insulated NO DEPRESSURIZATION

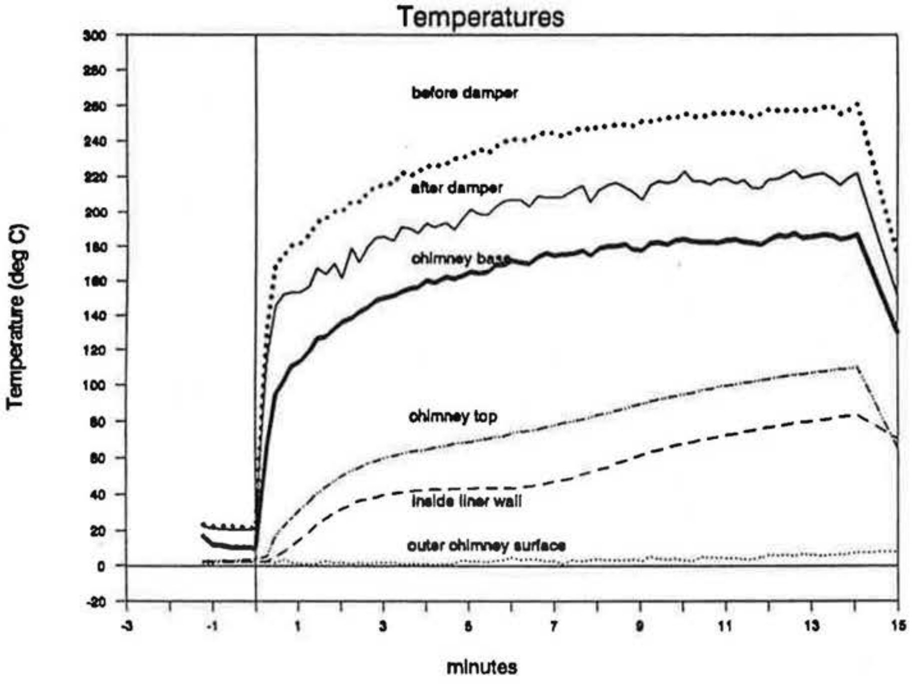
TEST 3420

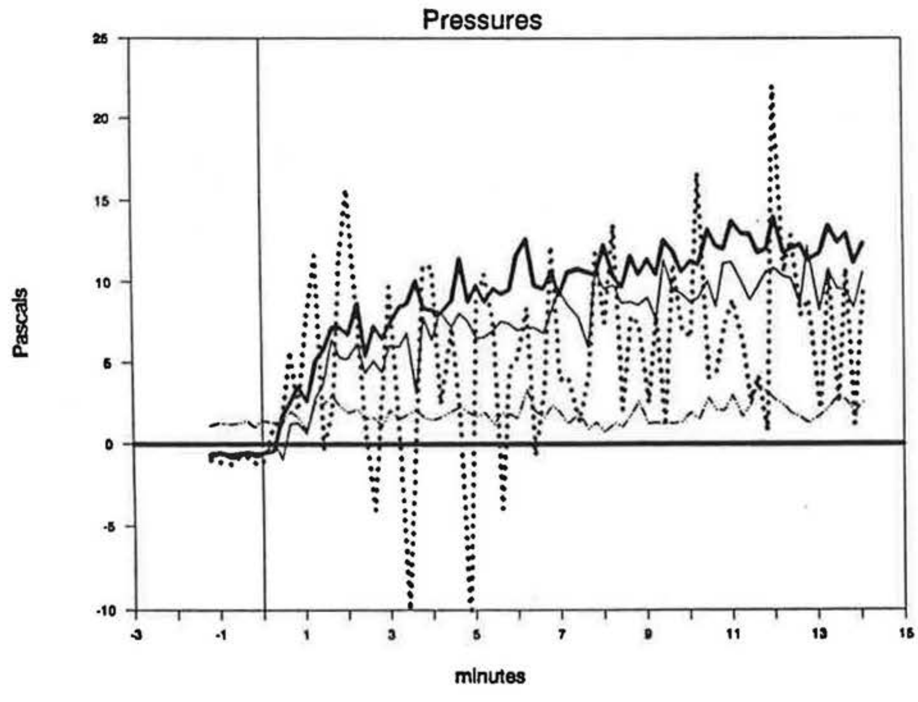




CHIMNEY: 4" A-vent PIPE: 4" single-wall NO DEPRESSURIZATION

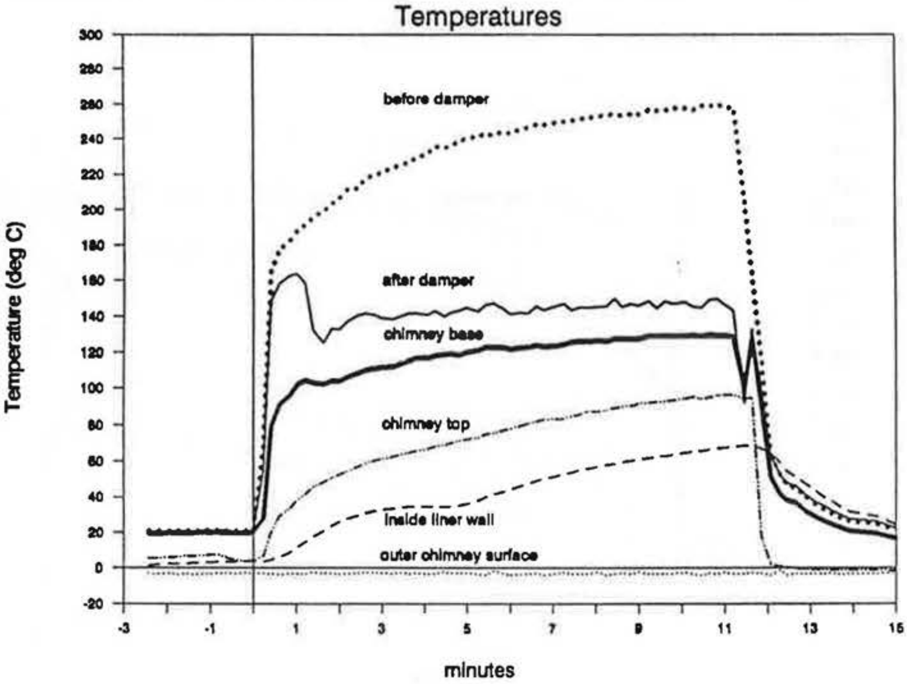
TEST 3835

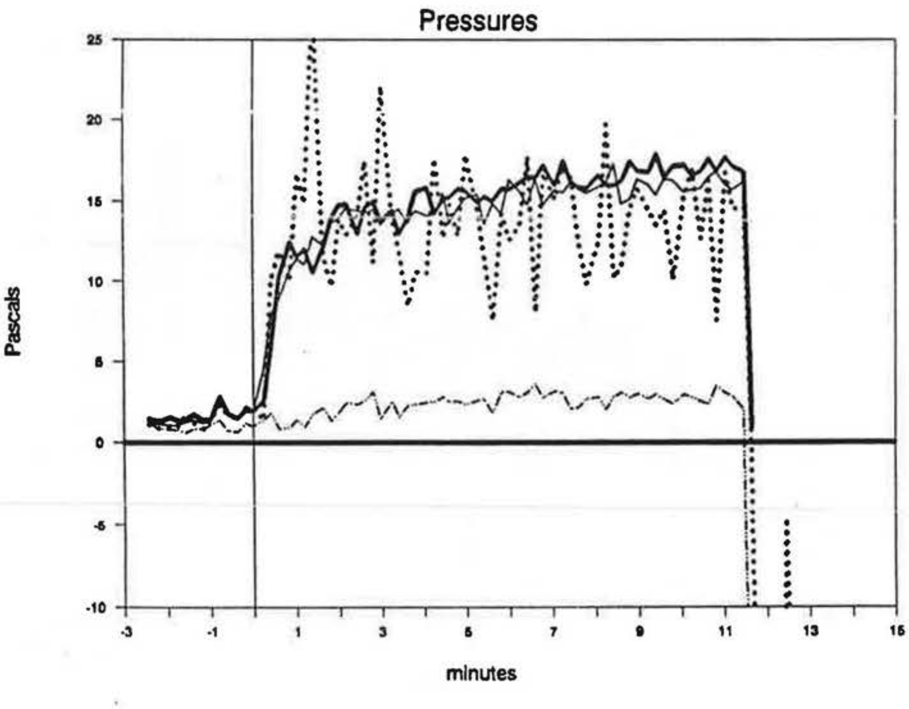




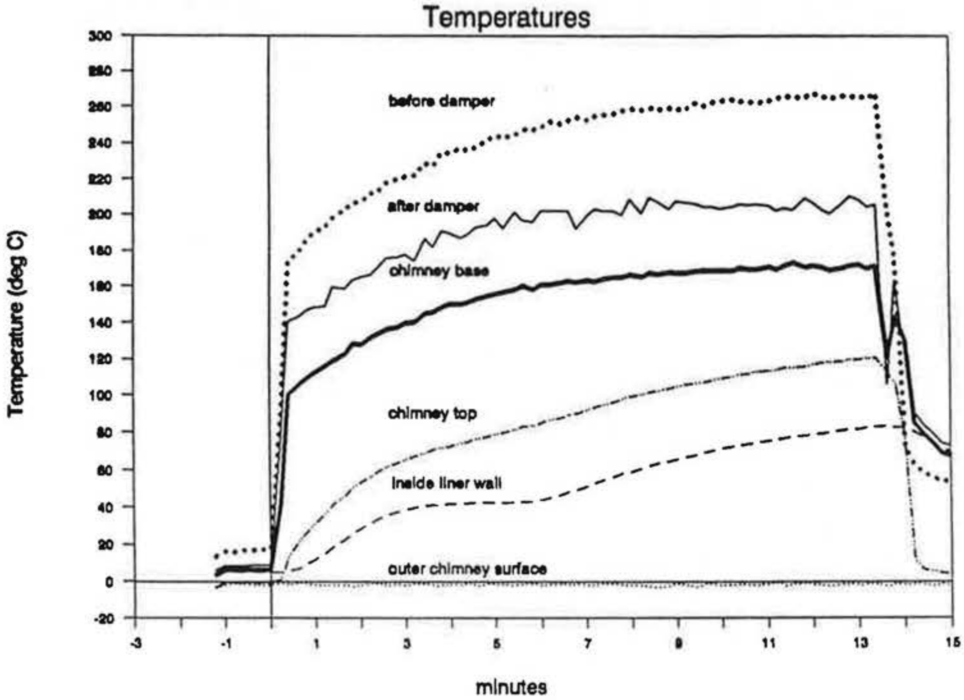
CHIMNEY: 6" type-650 PIPE: 7" single-wall NO DEPRESSURIZATION

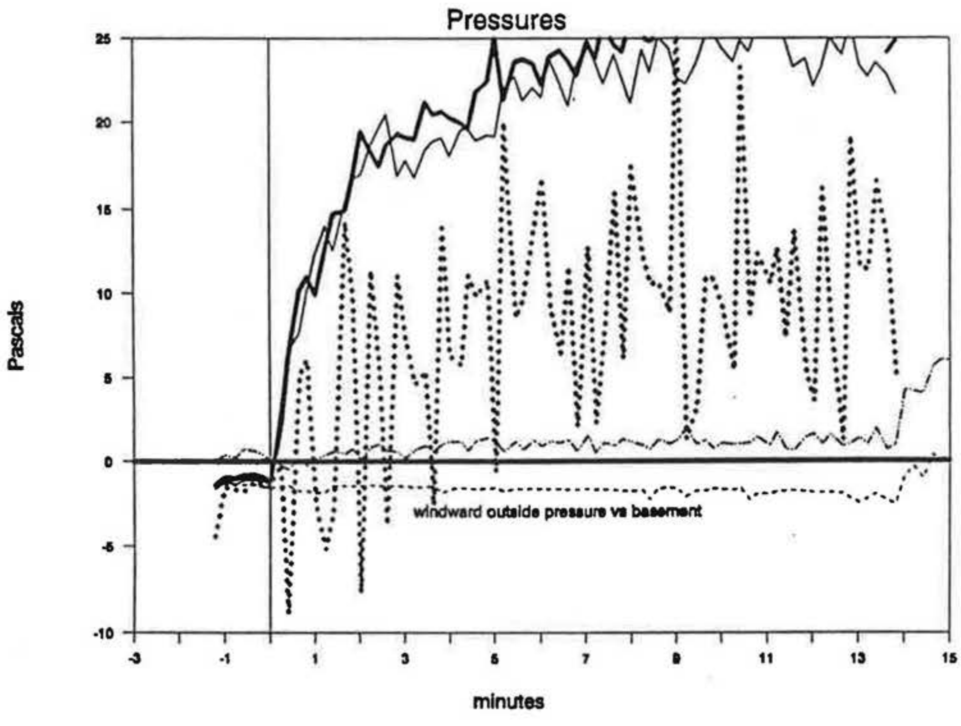
TEST 4009





CHIMNEY: 6" type-650 PIPE: 4" insulated NO DEPRESSURIZATION

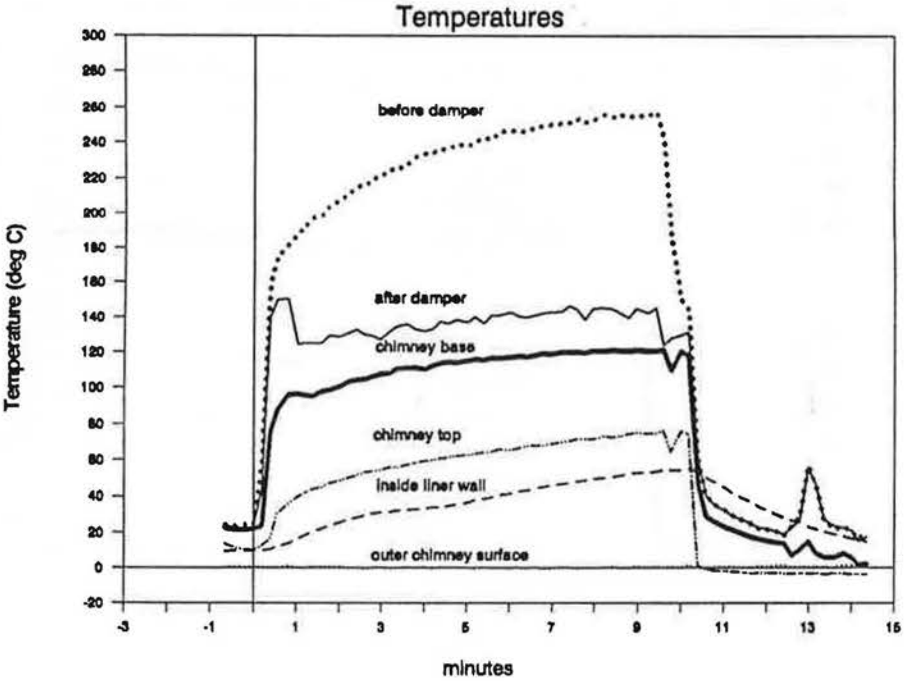


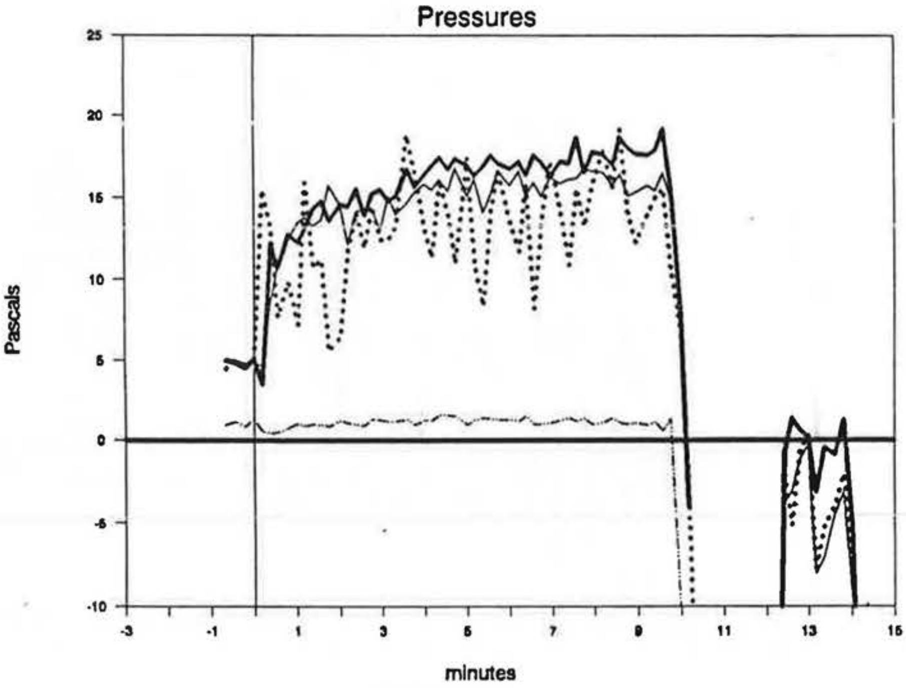


TEST 4425

CHIMNEY: 7" A-vent PIPE: 7" single-wall NO DEPRESSURIZATION

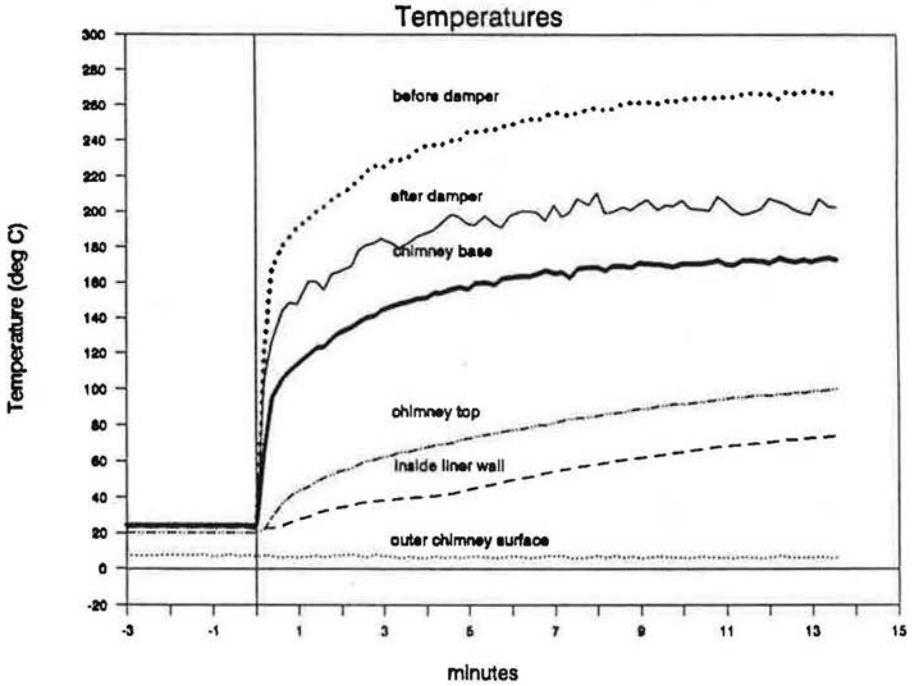
TEST 5013

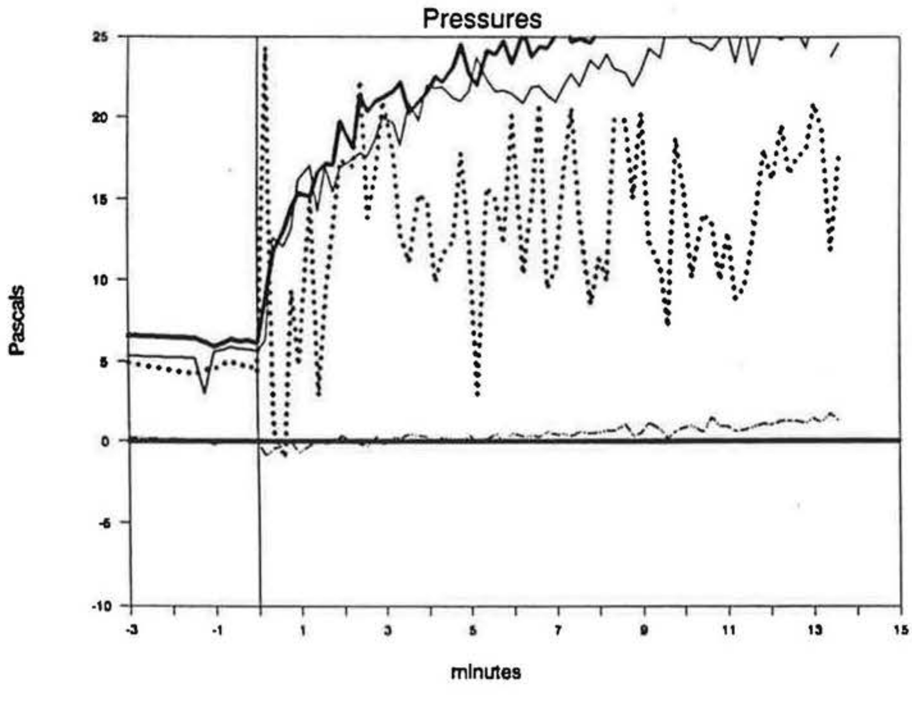




CHIMNEY: 7" A-vent PIPE: 4" Insulated NO DEPRESSURIZATION

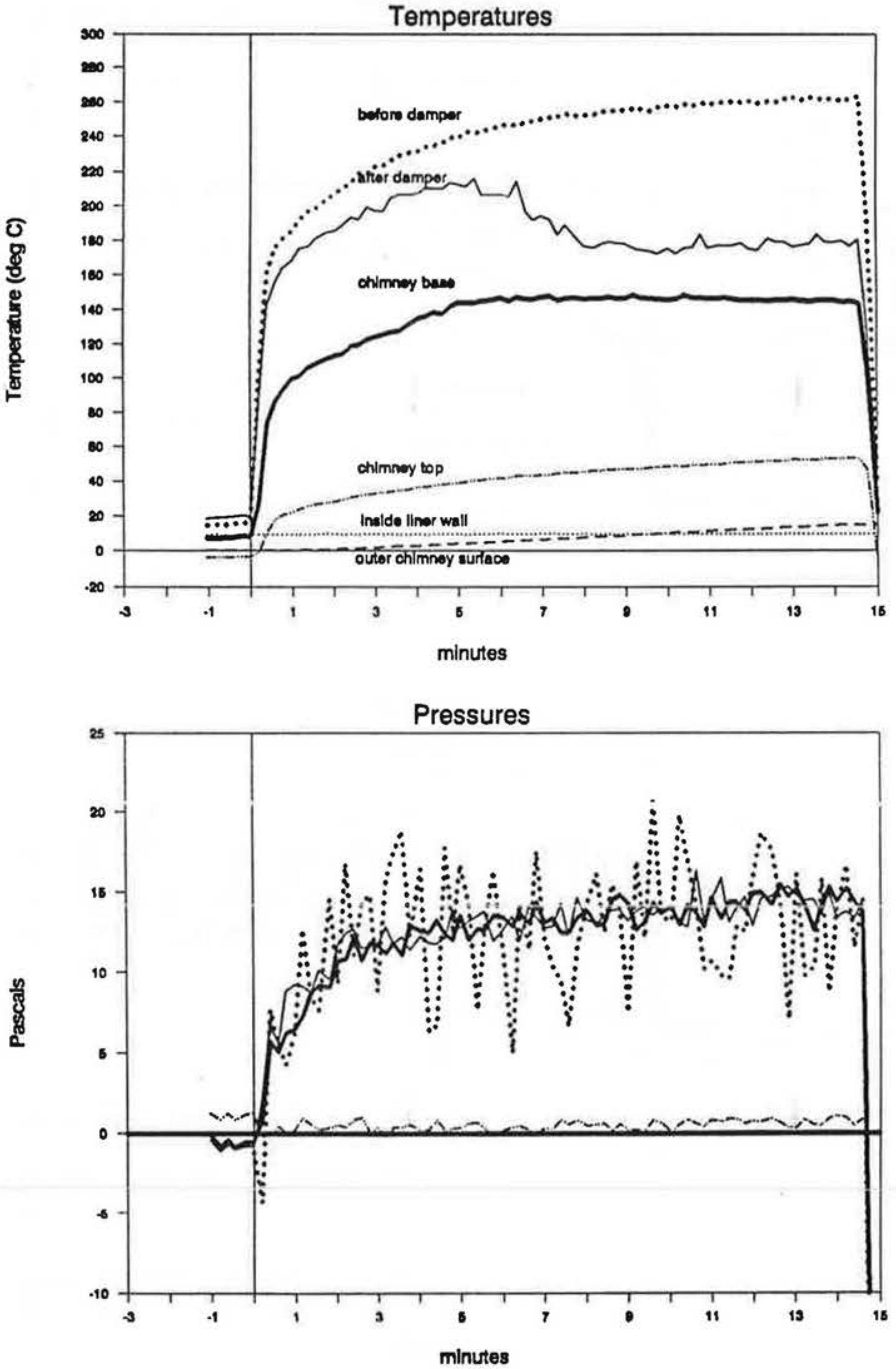
TEST 5429





CHIMNEY: 8" masonry PIPE: 7" single-wall NO DEPRESSURIZATION

TEST 6014



APPENDIX G

CALCULATIONS OF CHIMNEY RSI VALUES

Verification of chimney RSI values from field data

RSI-1.5 chimney, not sealed in basement (test 0109)

$ri := .050 \cdot m$ — ri = inside diameter of chimney

$ro := .117 \cdot m$ — ro = outside diameter of chimney

$L := 8.79 \cdot m$ — L = length of chimney flue

$to := 18.7 \cdot C$ — to = outside temperature

$t1 := 189.6 \cdot C$ — t1 = gas temperature at base of chimney

$t2 := 172.9 \cdot C$ — t2 = gas temperature at top of chimney

$te := 255 \cdot C$ — te = flue gas temperature at furnace exit

$ti := 44.8 \cdot C$ — ti = house ambiant temperature

$\delta t1 := t1 - to$ — $\delta t1$ = temperature difference at base

$\delta t2 := t2 - to$ — $\delta t2$ = temperature difference at top

$\delta t1 = 170.9 \cdot C$ — $\delta t2 = 154.2 \cdot C$

$$\delta tm := \frac{\delta t1 - \delta t2}{\ln\left[\frac{\delta t1}{\delta t2}\right]}$$

δtm = mean temperature difference

$\delta tm = 162.407 \cdot C$

$qt := 7056 \cdot W$ — qt = total flue gas energy loss

$$q := qt \cdot \frac{t1 - t2}{te - ti}$$

q = proportion of total flue gas energy lost within the chimney flue

$q = 560.586 \cdot W$

for thermal condution loss through a right circular cylinder

$$k := \frac{\ln\left[\frac{ro}{ri}\right]}{2 \cdot \pi \cdot L \cdot \left[\frac{\delta tm}{q}\right]}$$

k = thermal conductivity

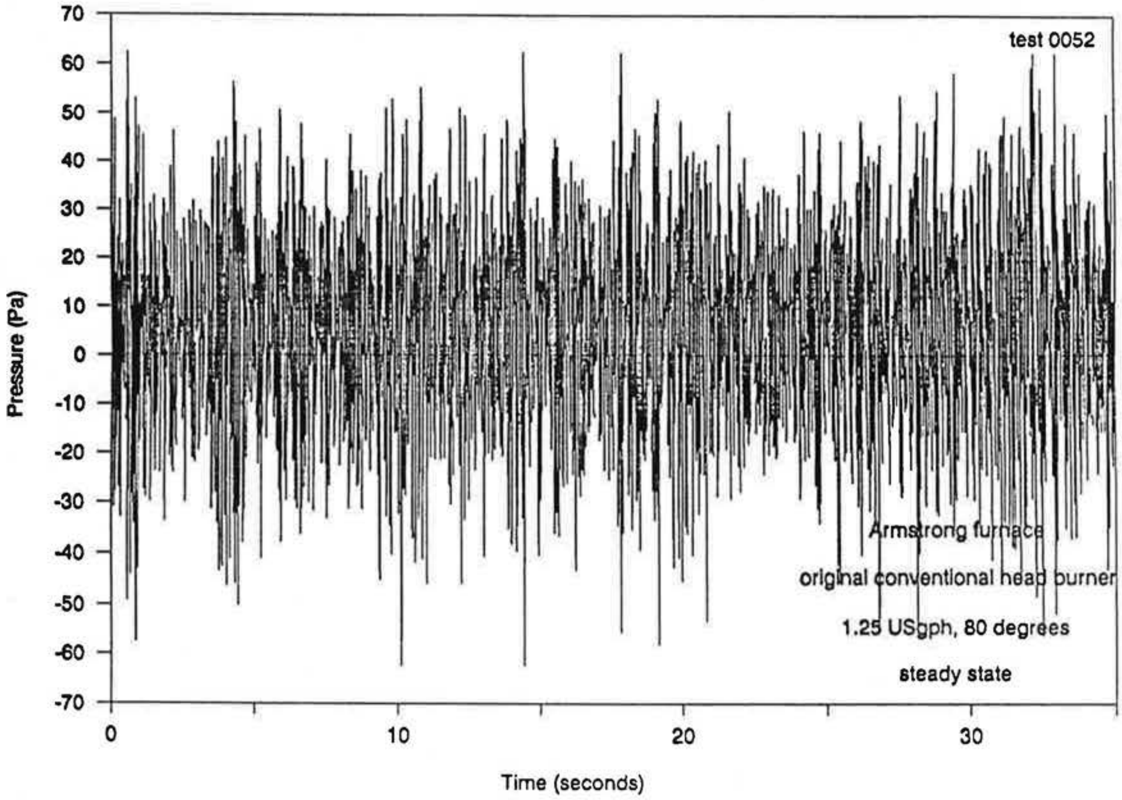
$\delta x := ro - ri$ — δx = thickness of chimney flue

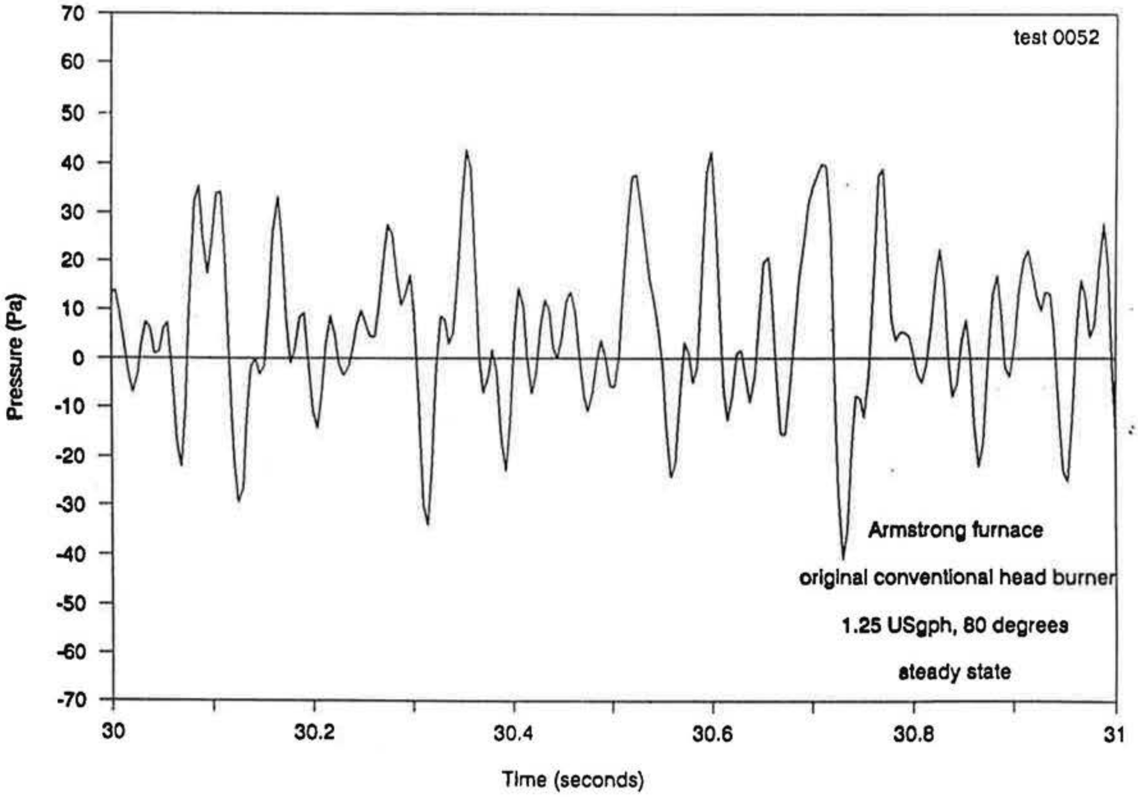
$U := \frac{k}{\delta x}$ $\quad RSI := \frac{1}{U}$ $\quad RSI = 1.26 \cdot \frac{C}{W} \cdot m^2$

APPENDIX H

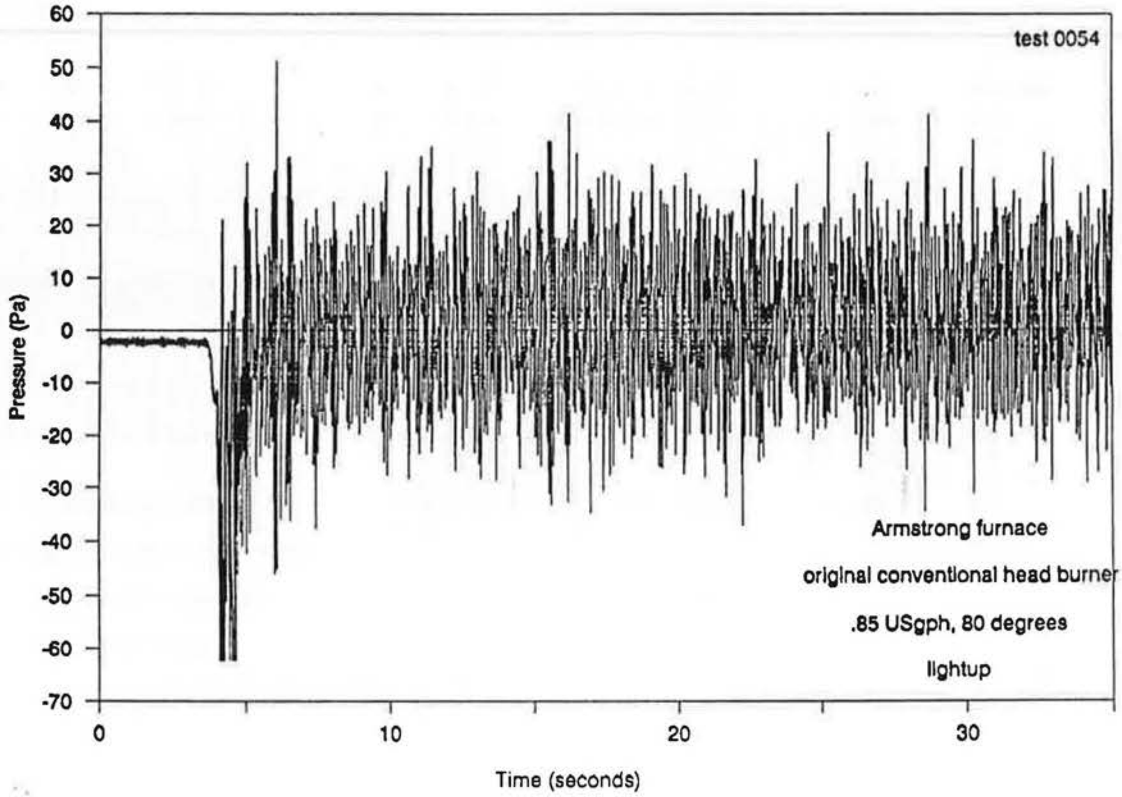
MEASURING PRESSURE OSCILLATIONS IN THE ARMSTRONG OIL FURNACE

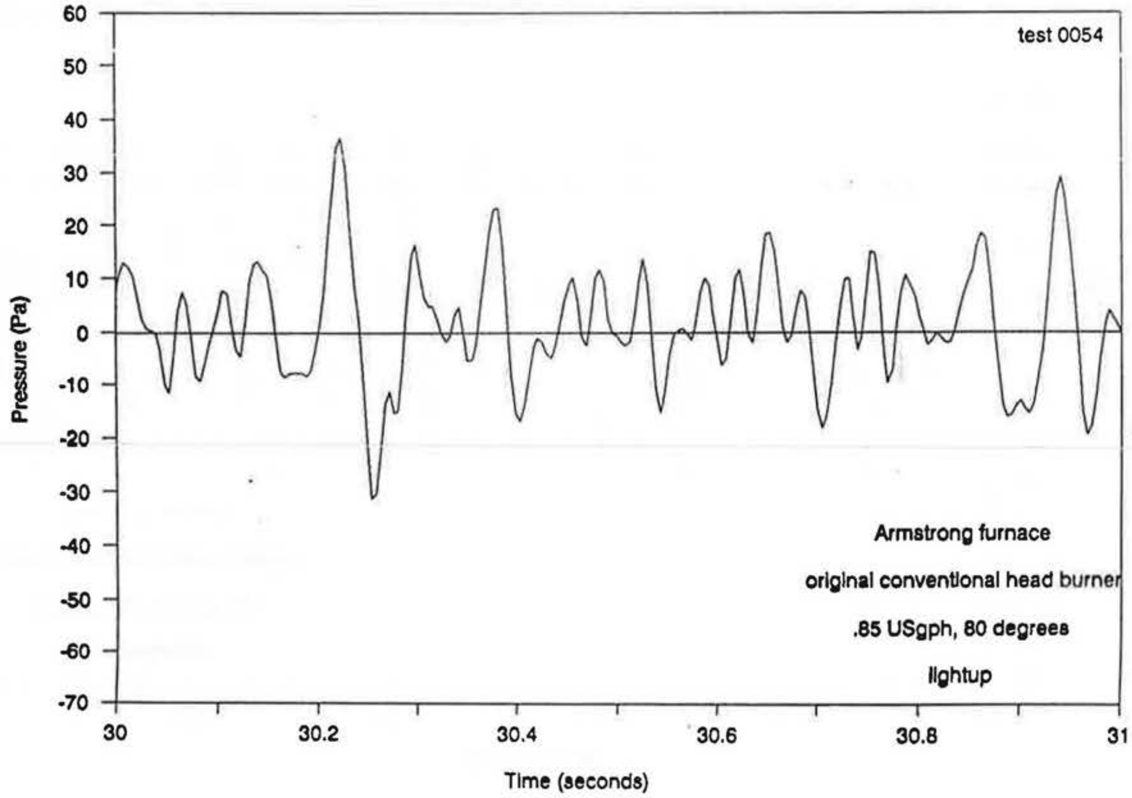
Combustion chamber pulsations





Combustion chamber pulsations





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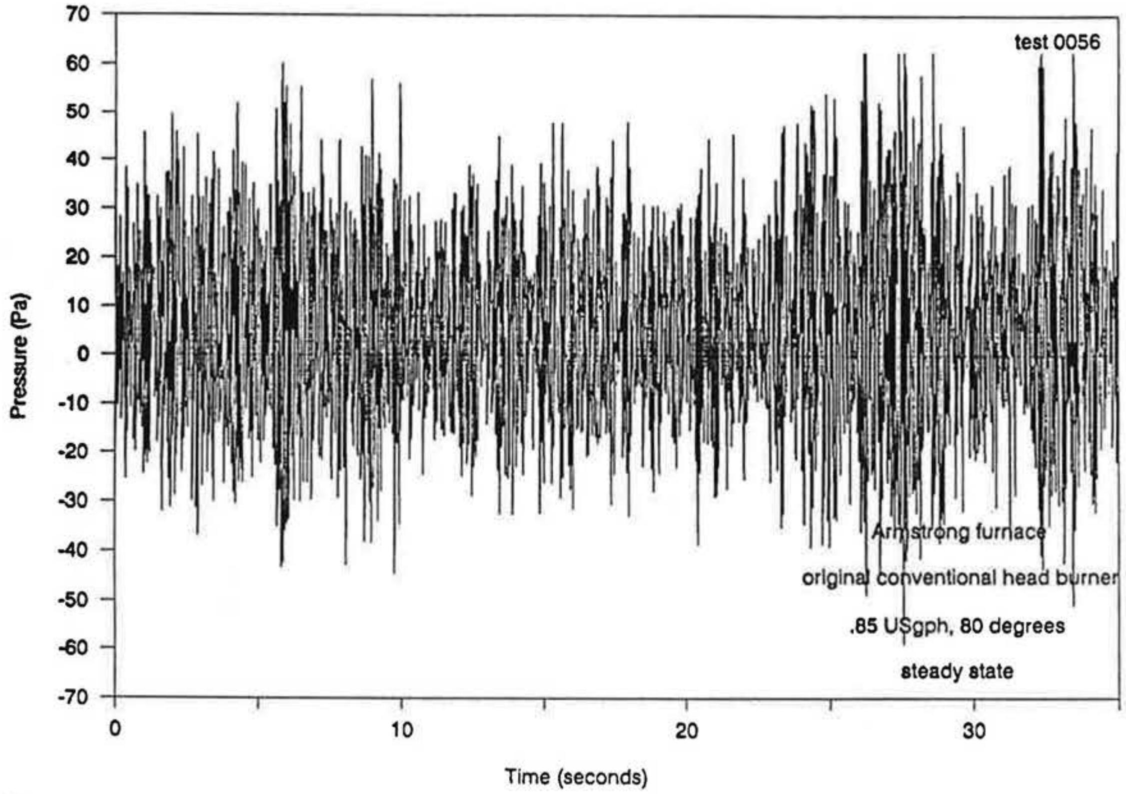

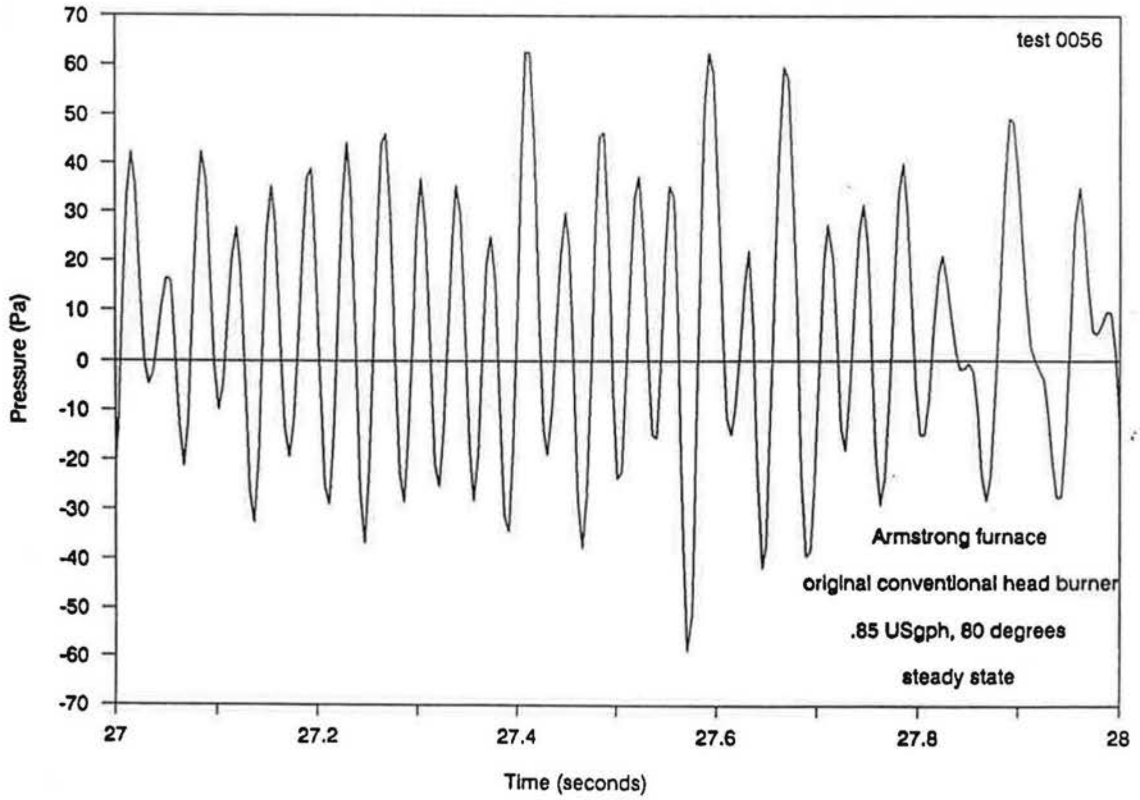

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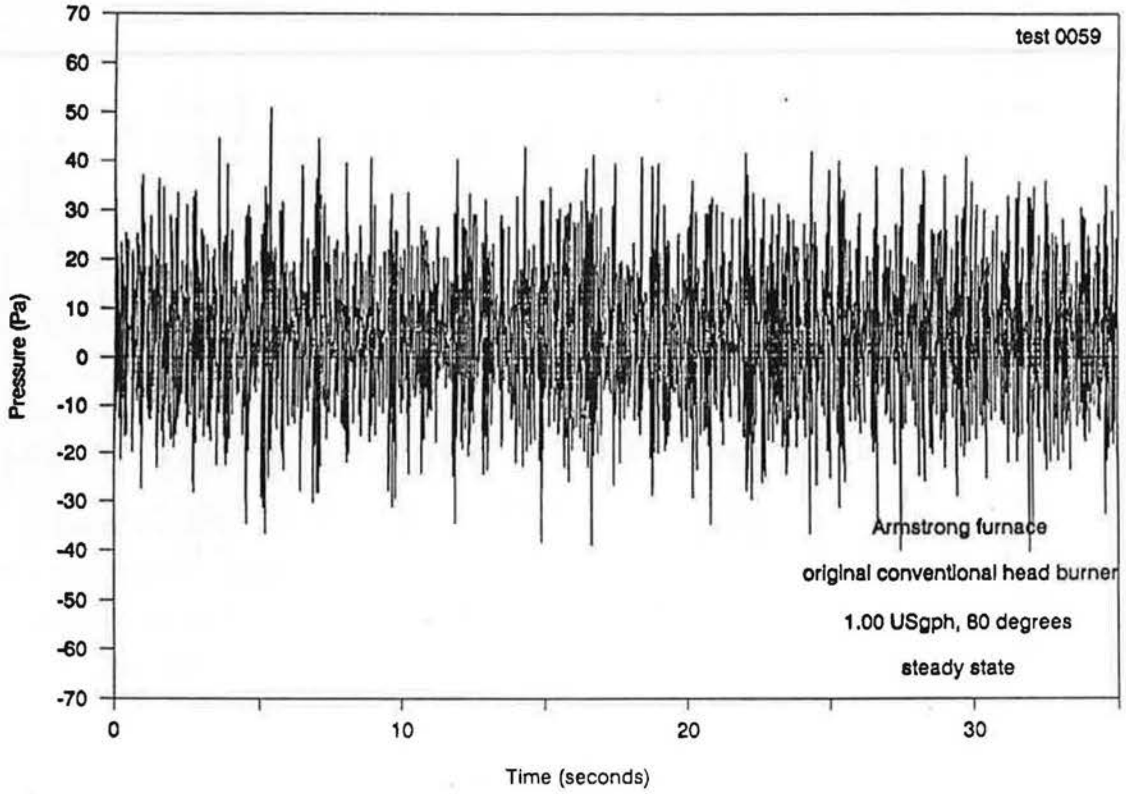
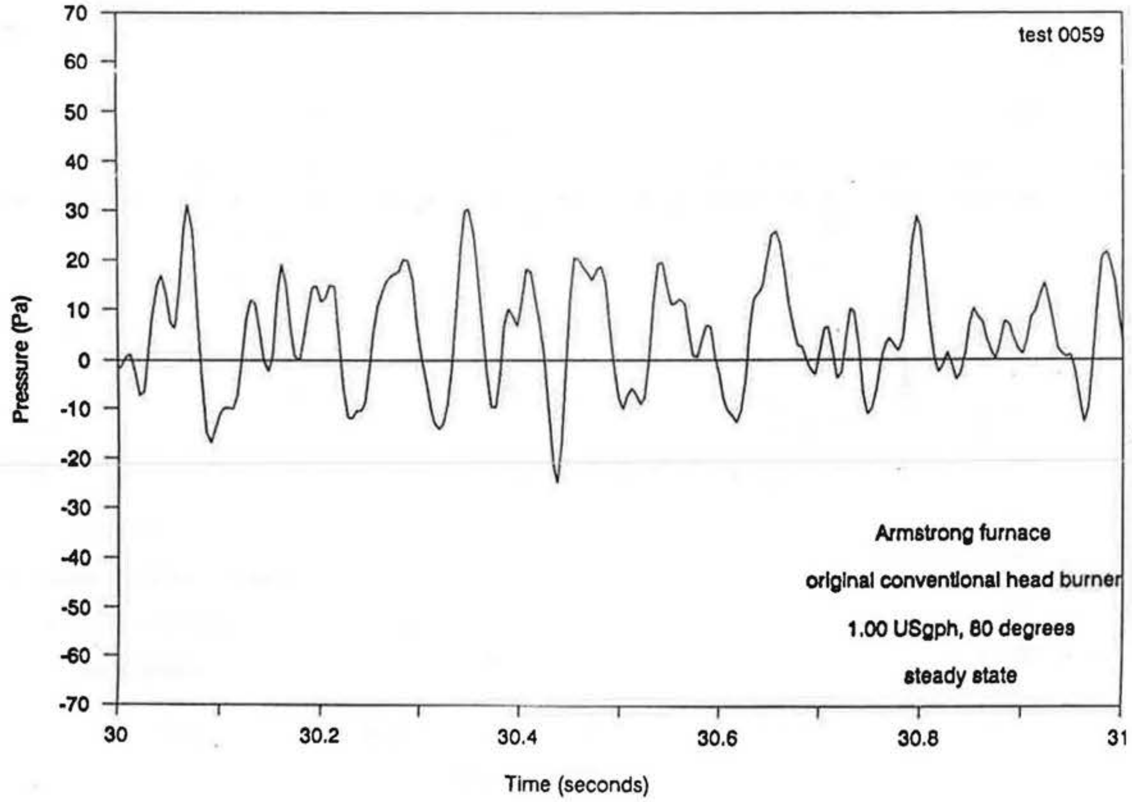
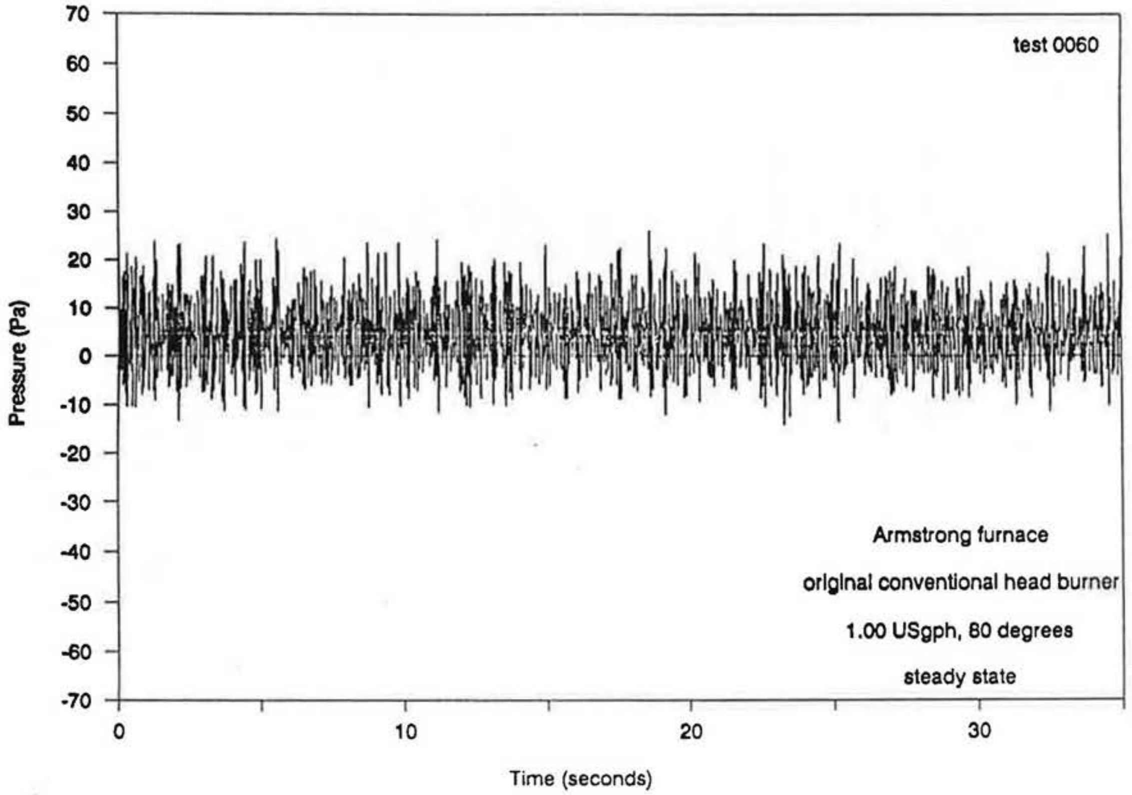
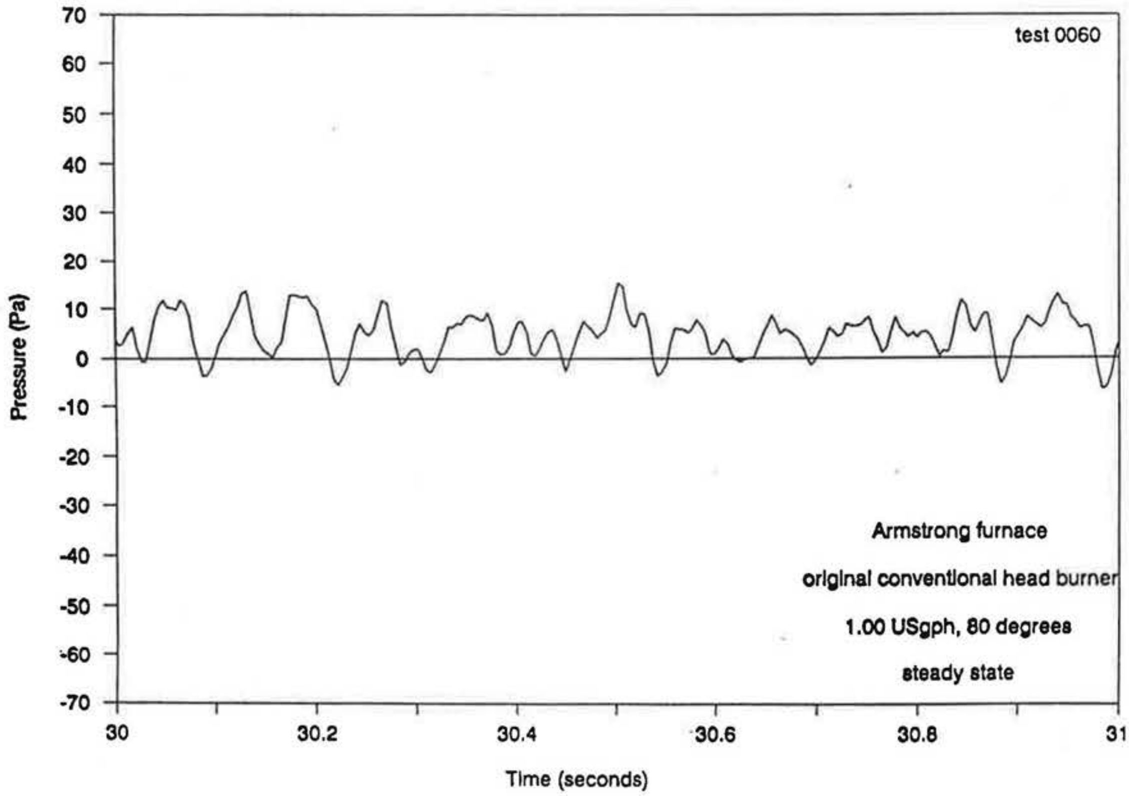


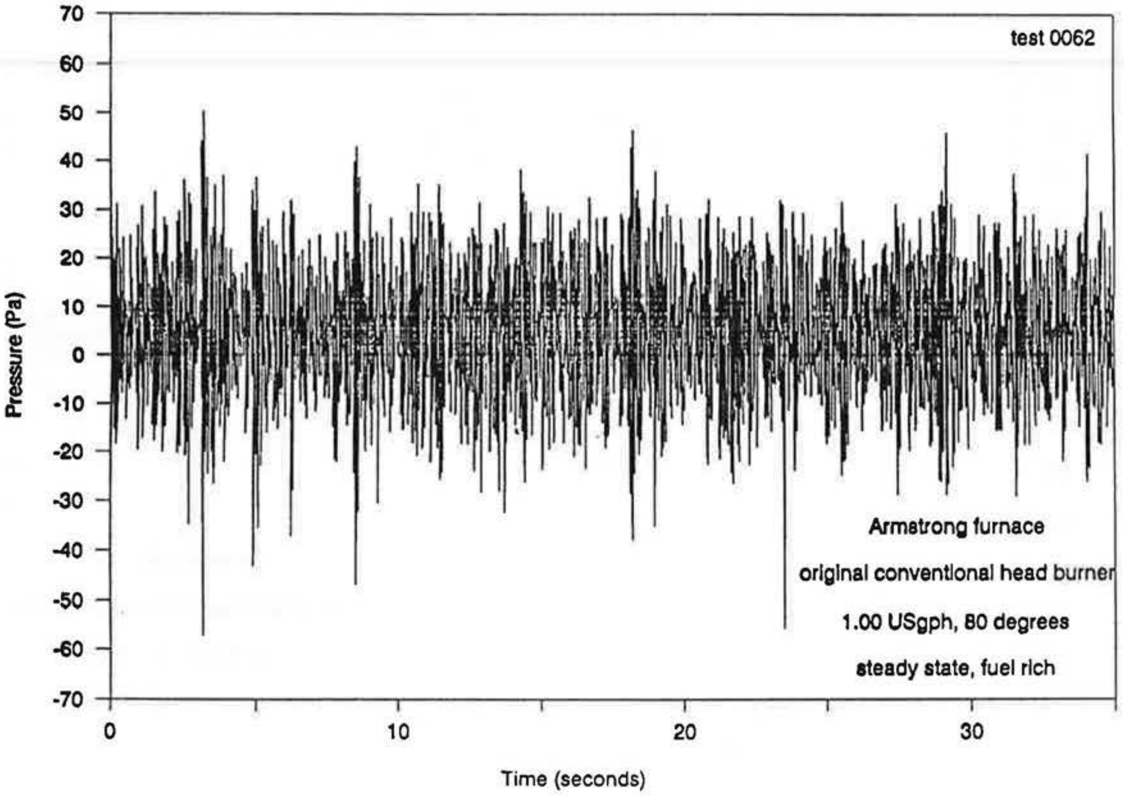


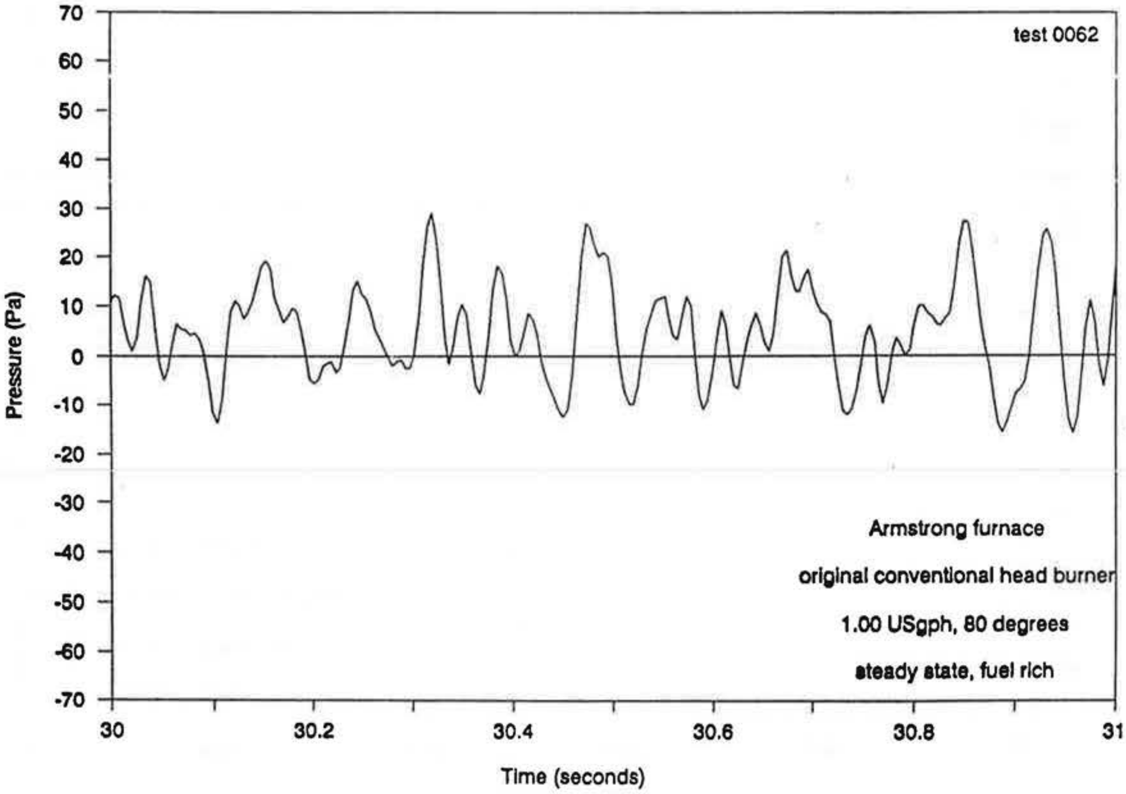
Pulsations at the furnace flue collar





Combustion chamber pulsation





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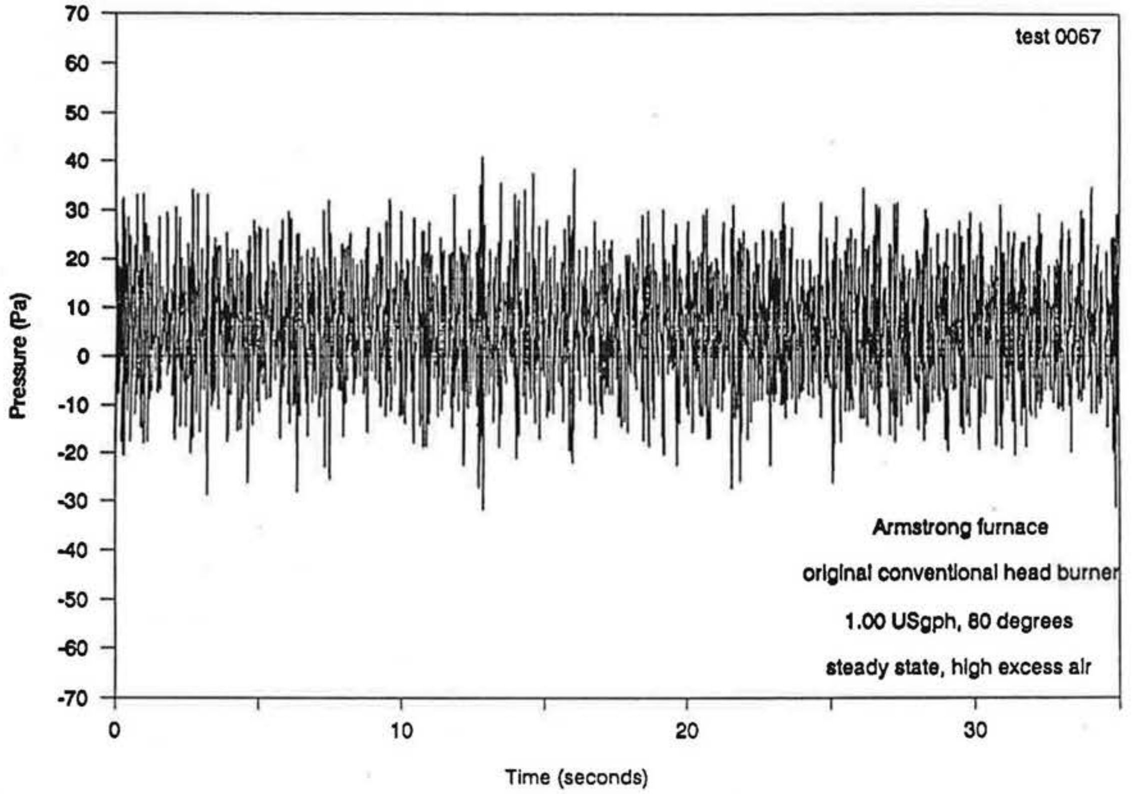

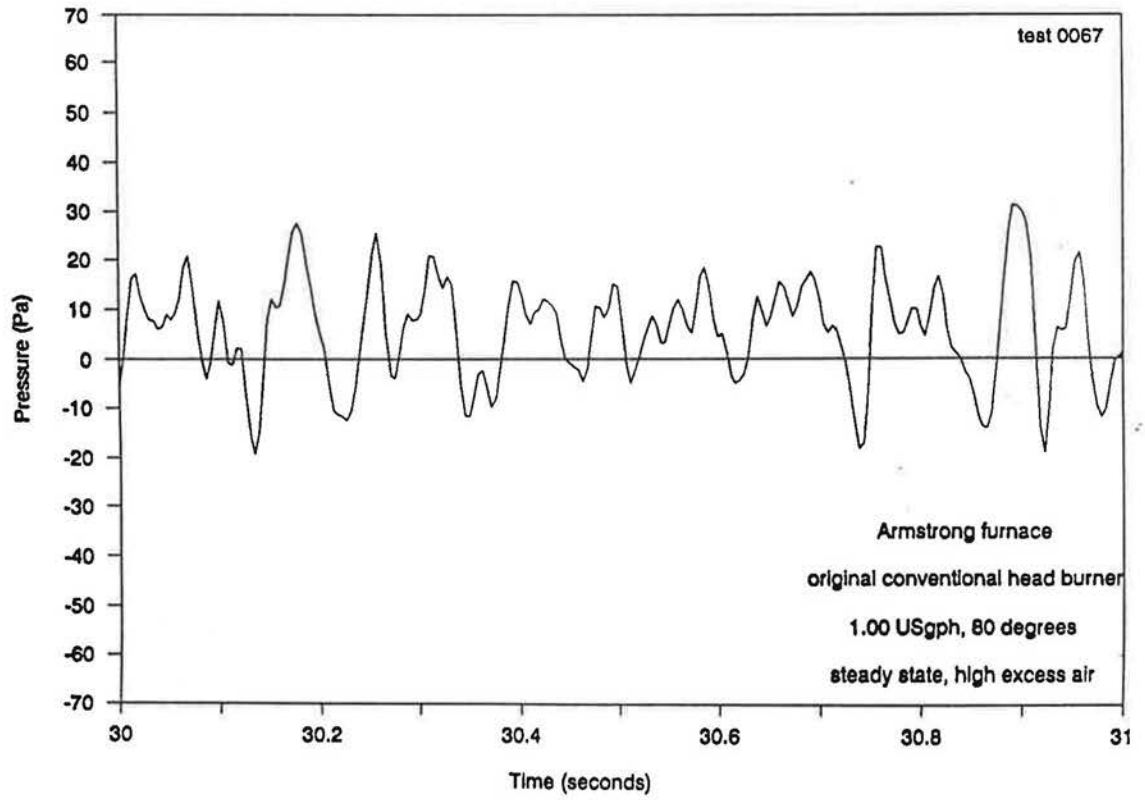

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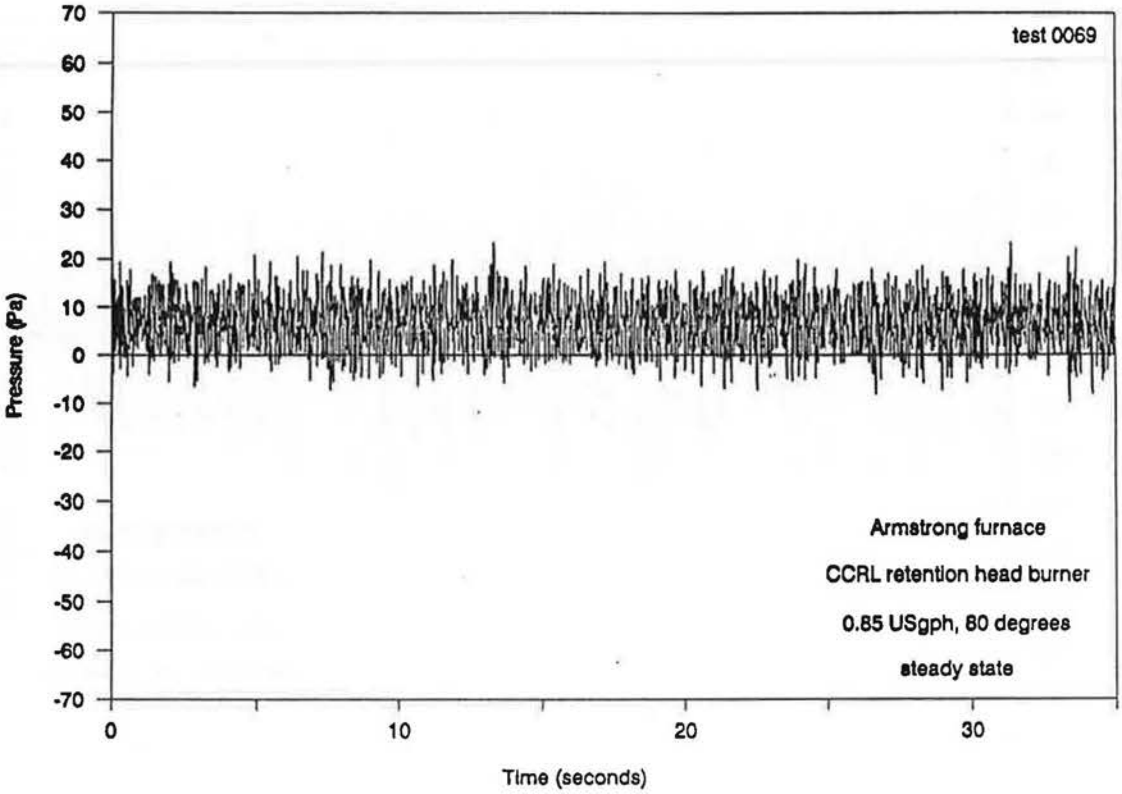

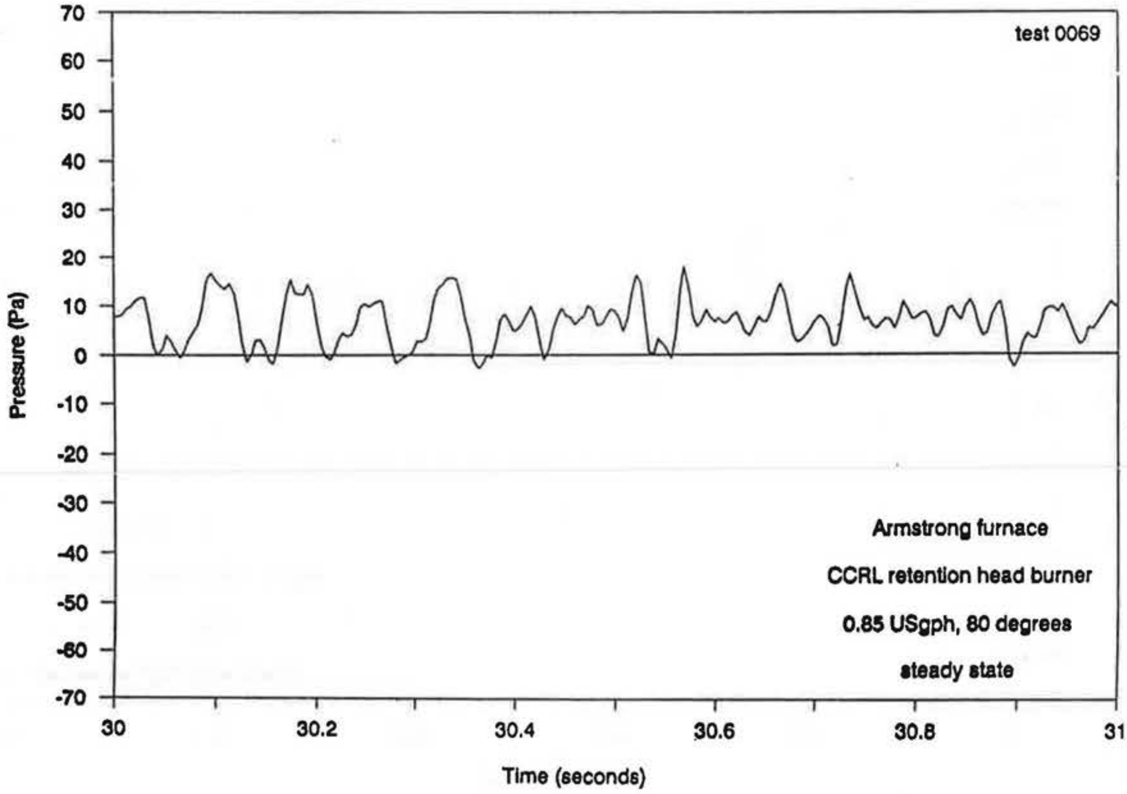

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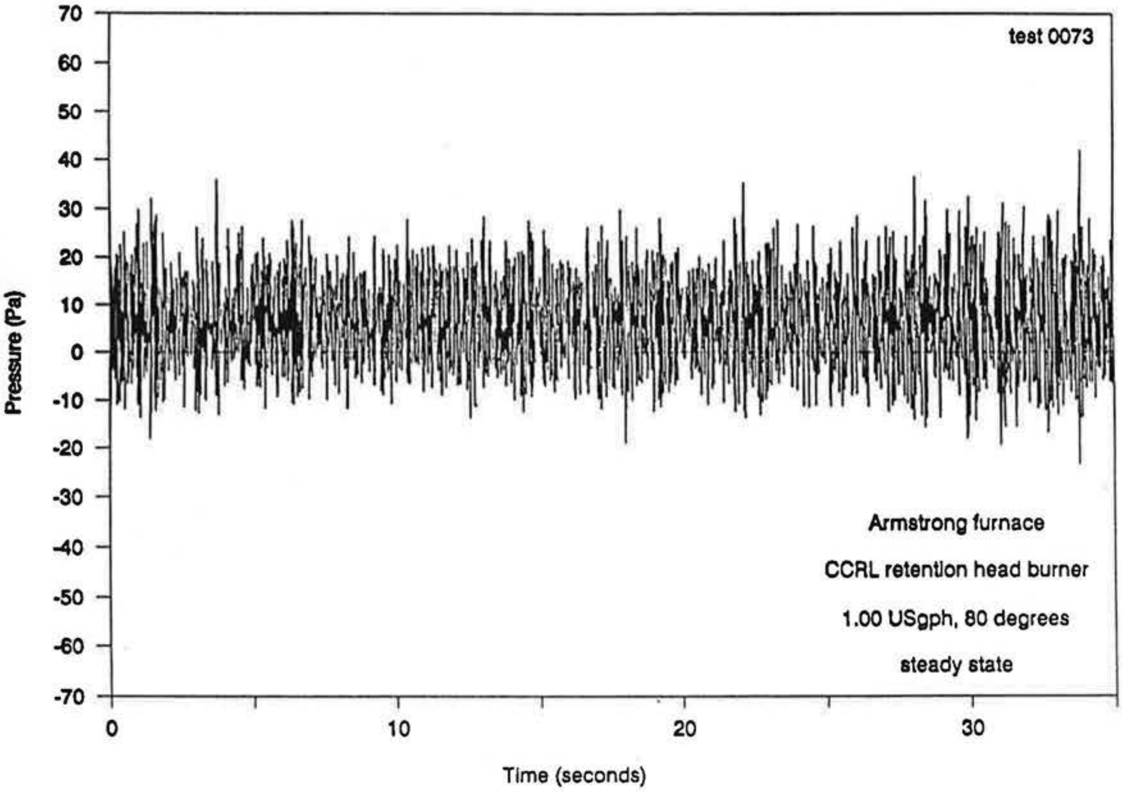
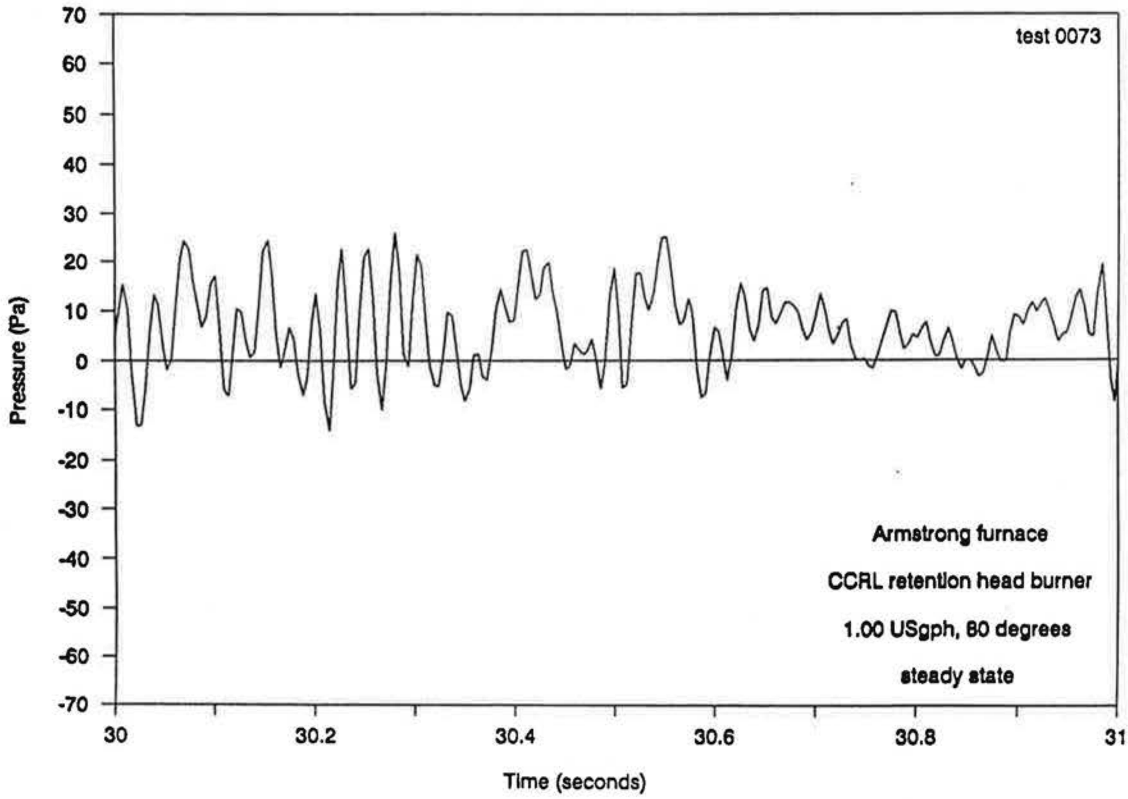
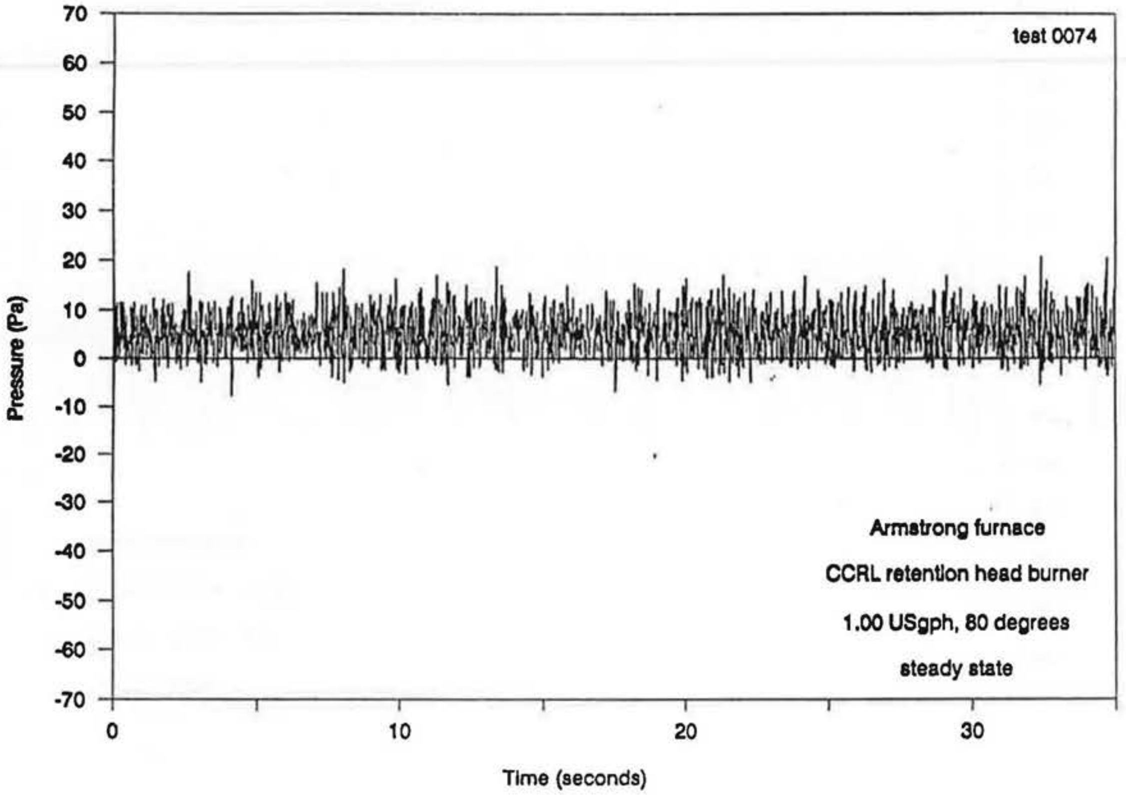
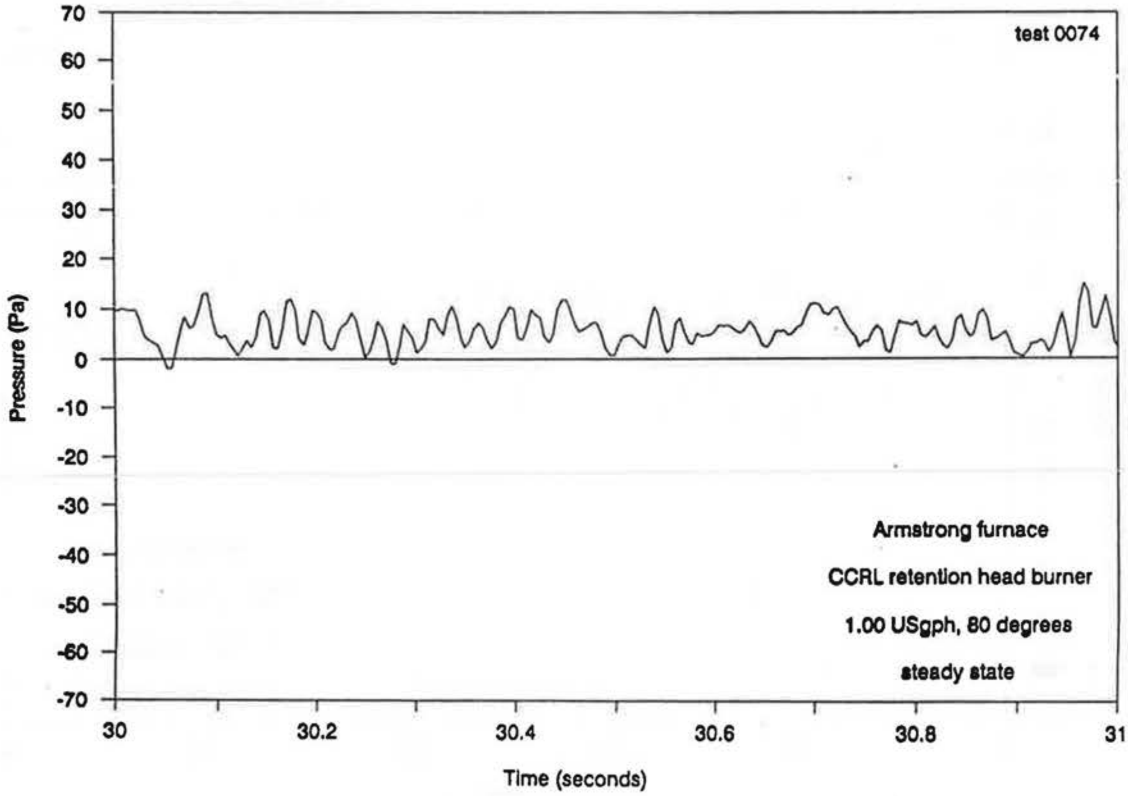




Pulsations at the furnace flue collar





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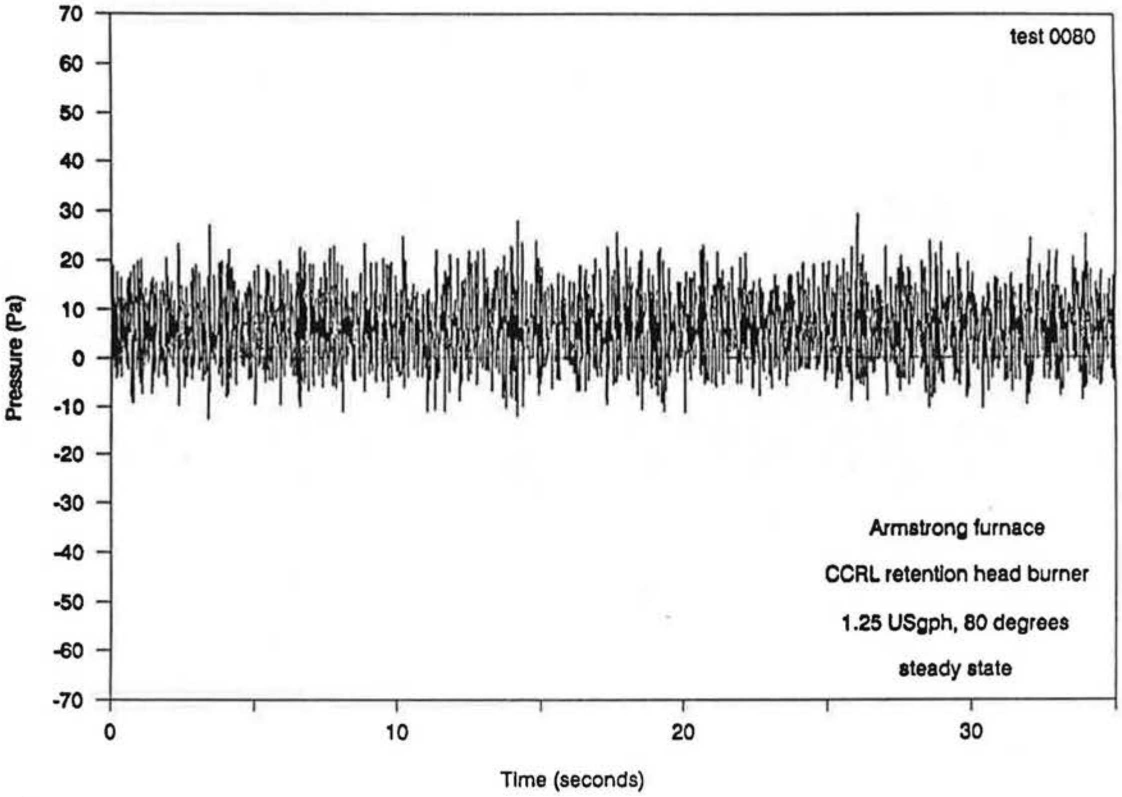

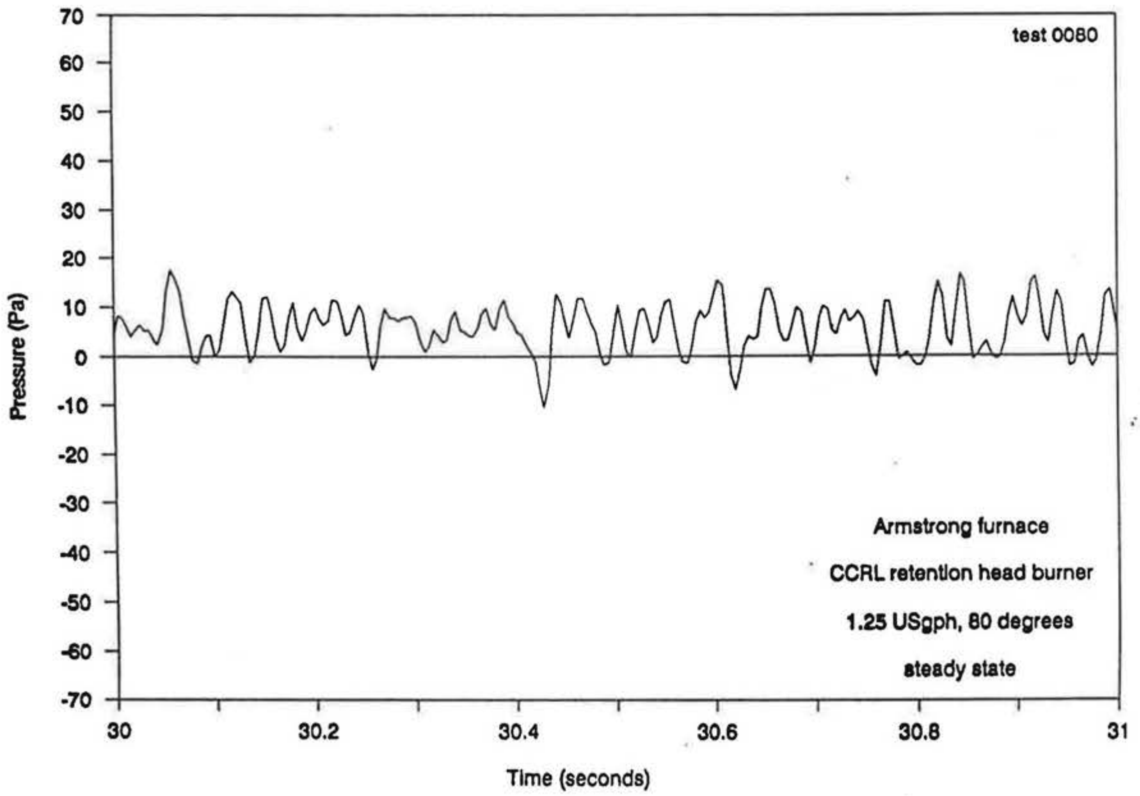

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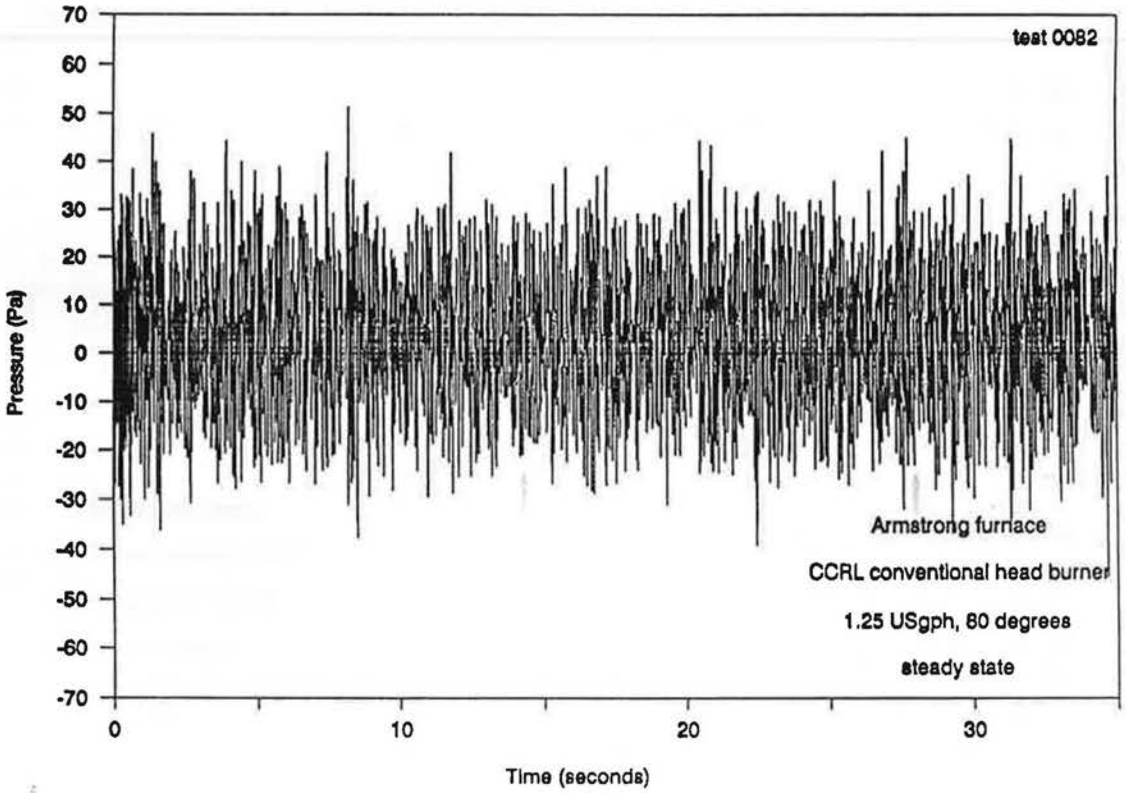

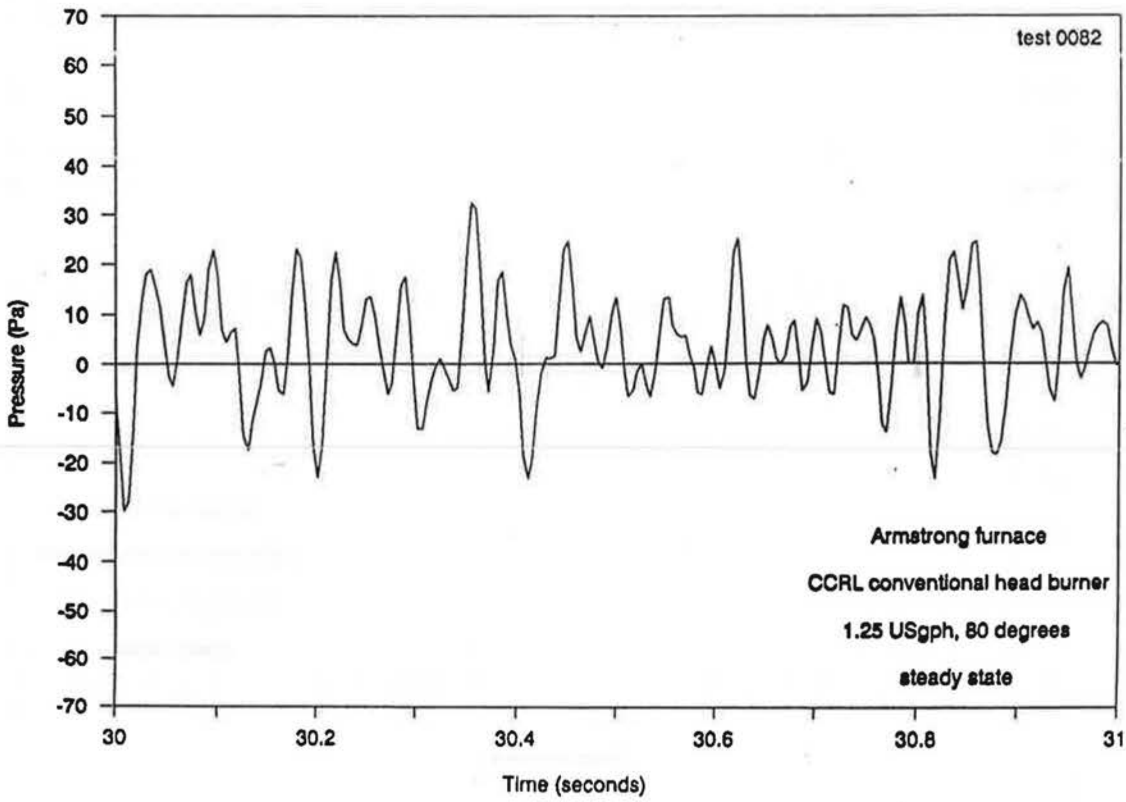

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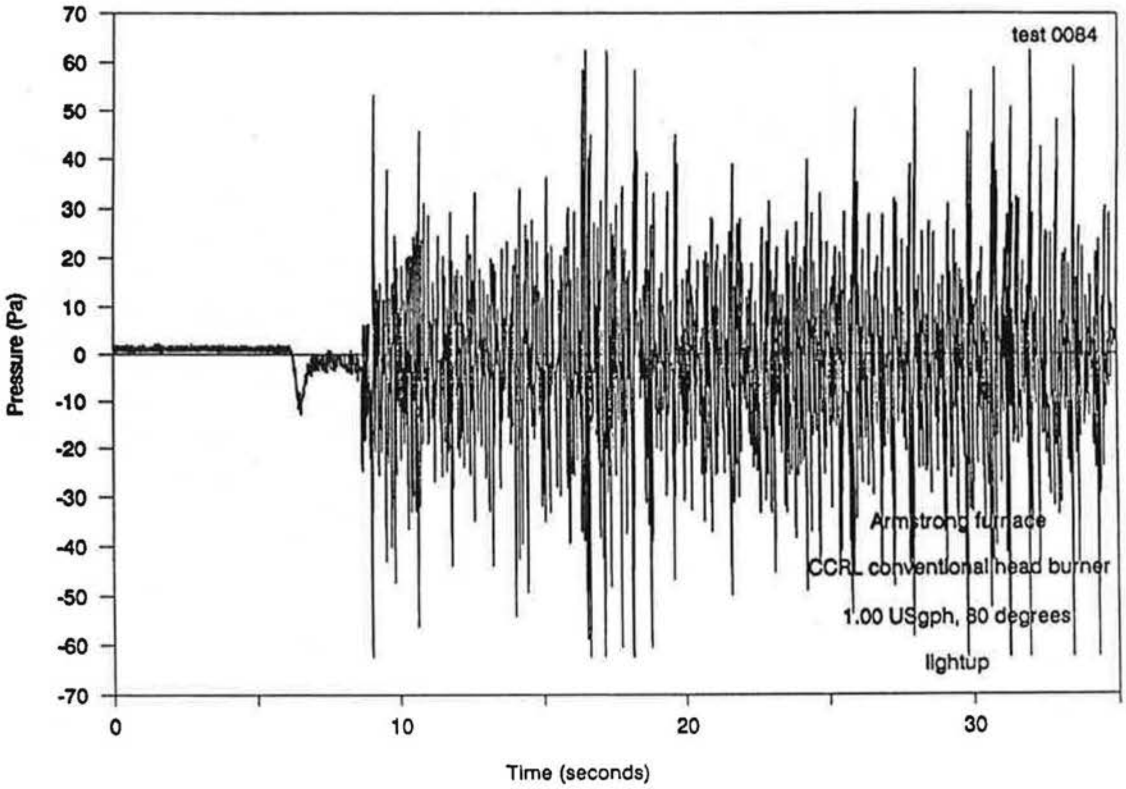

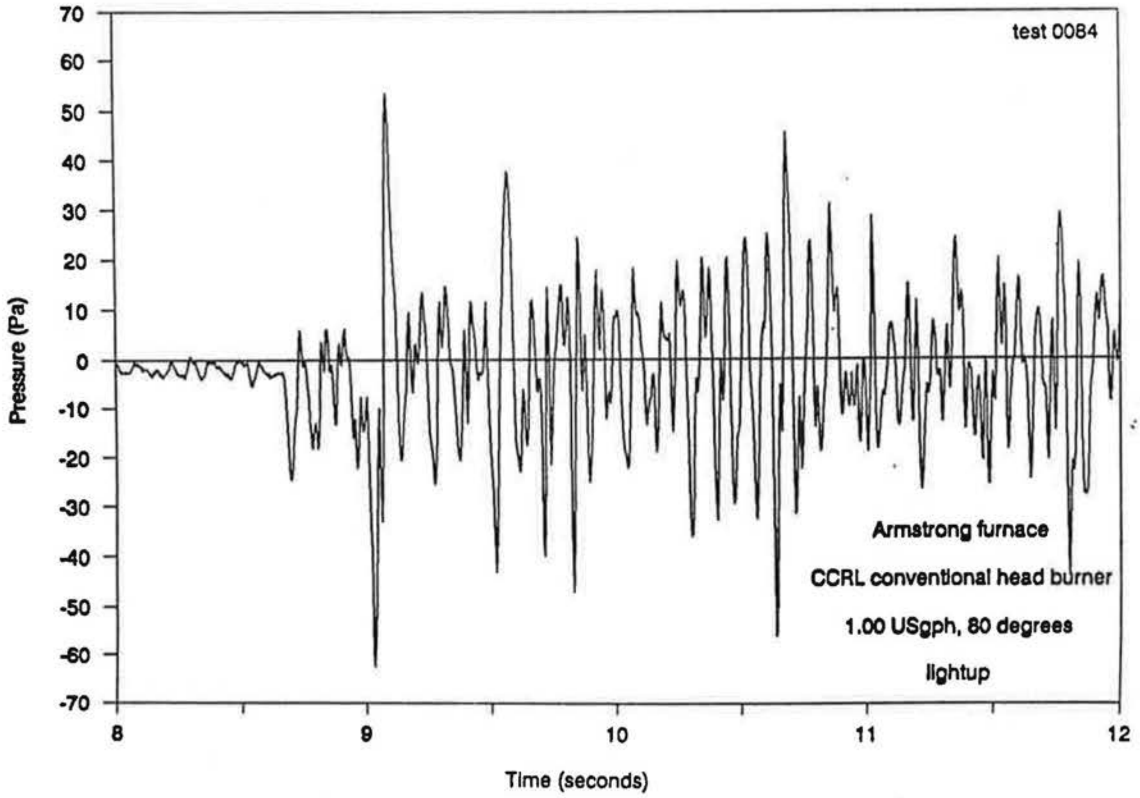

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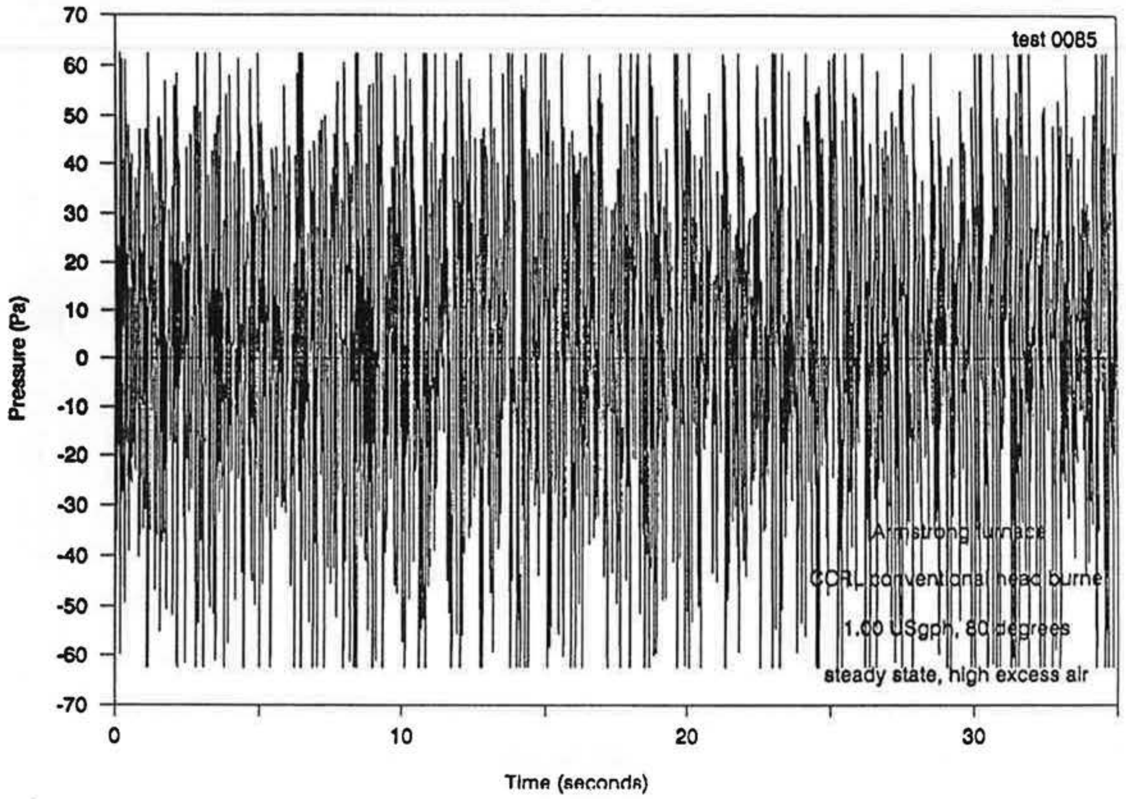

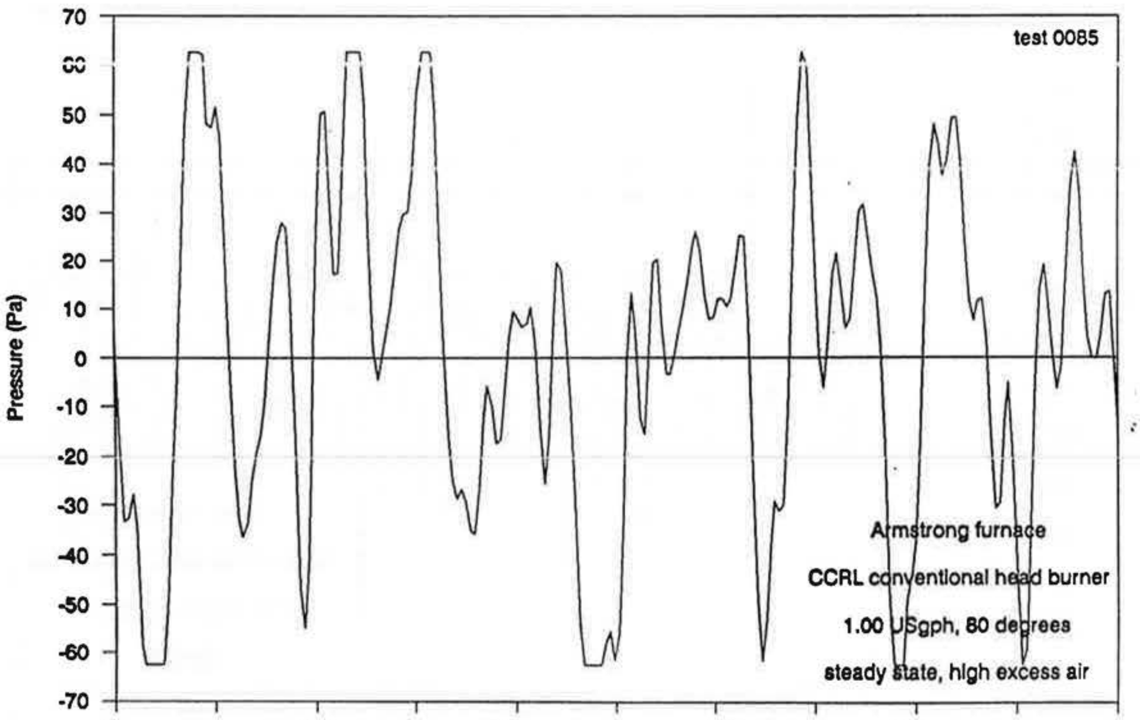

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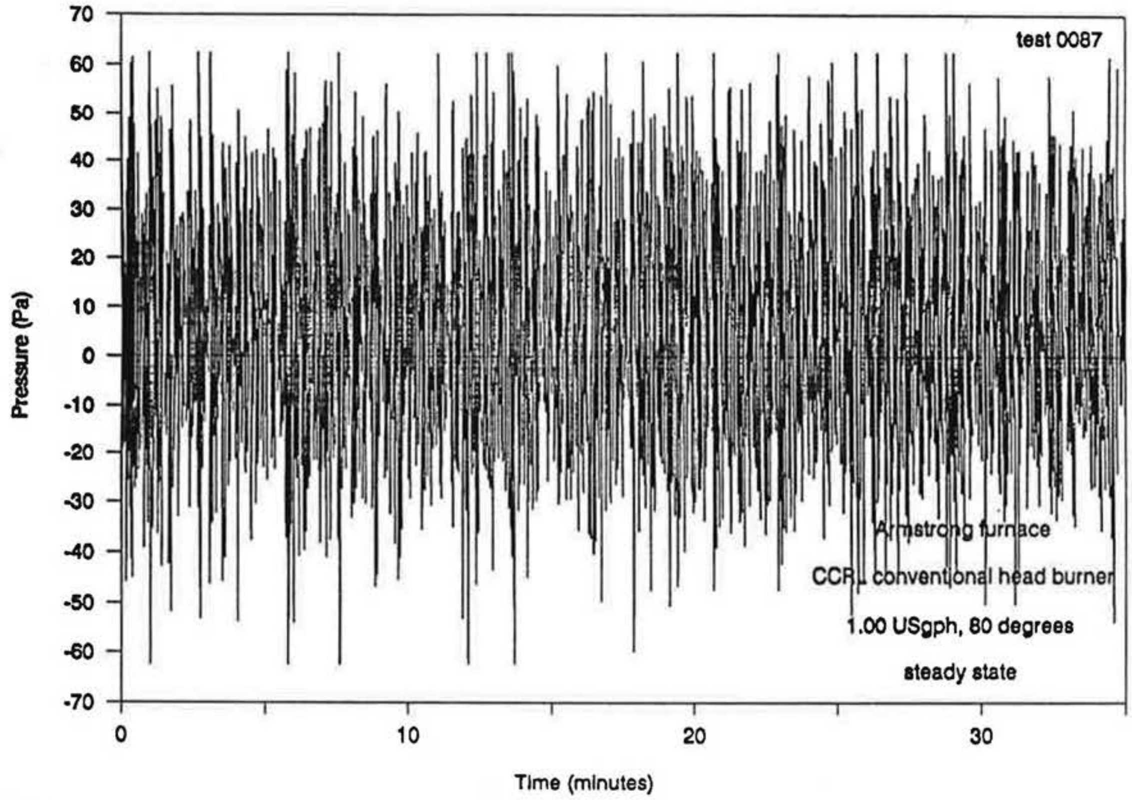
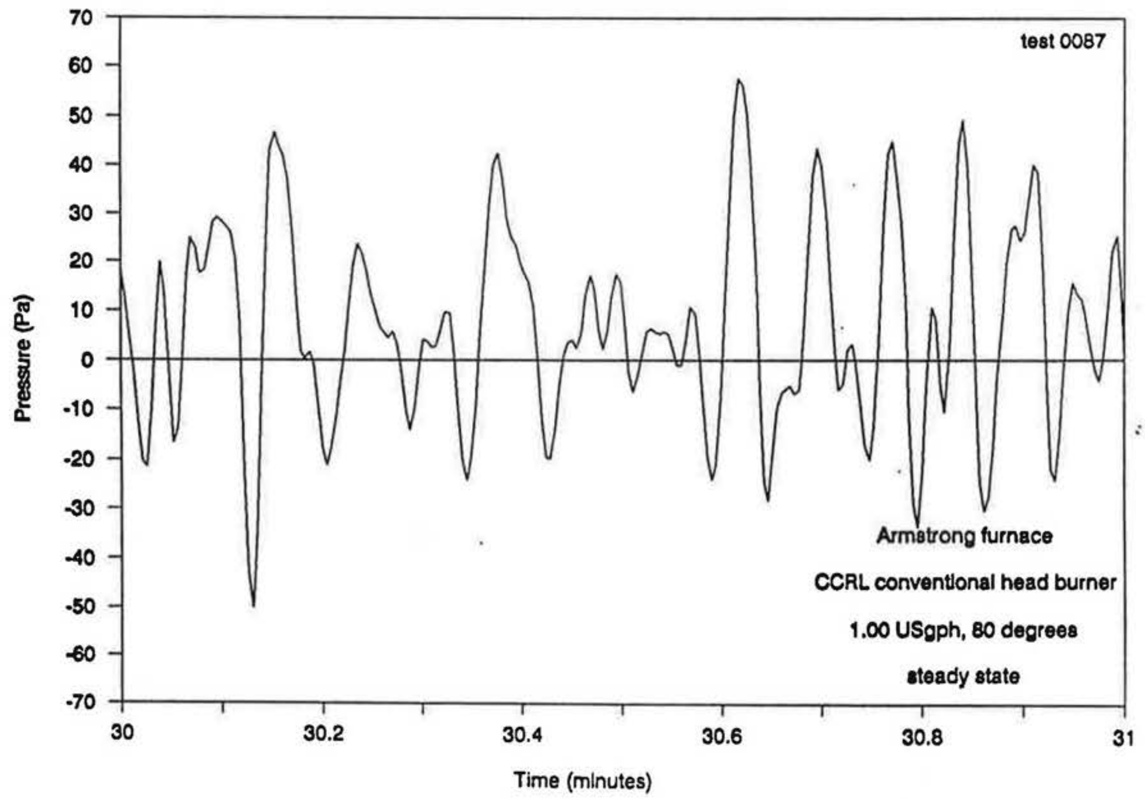
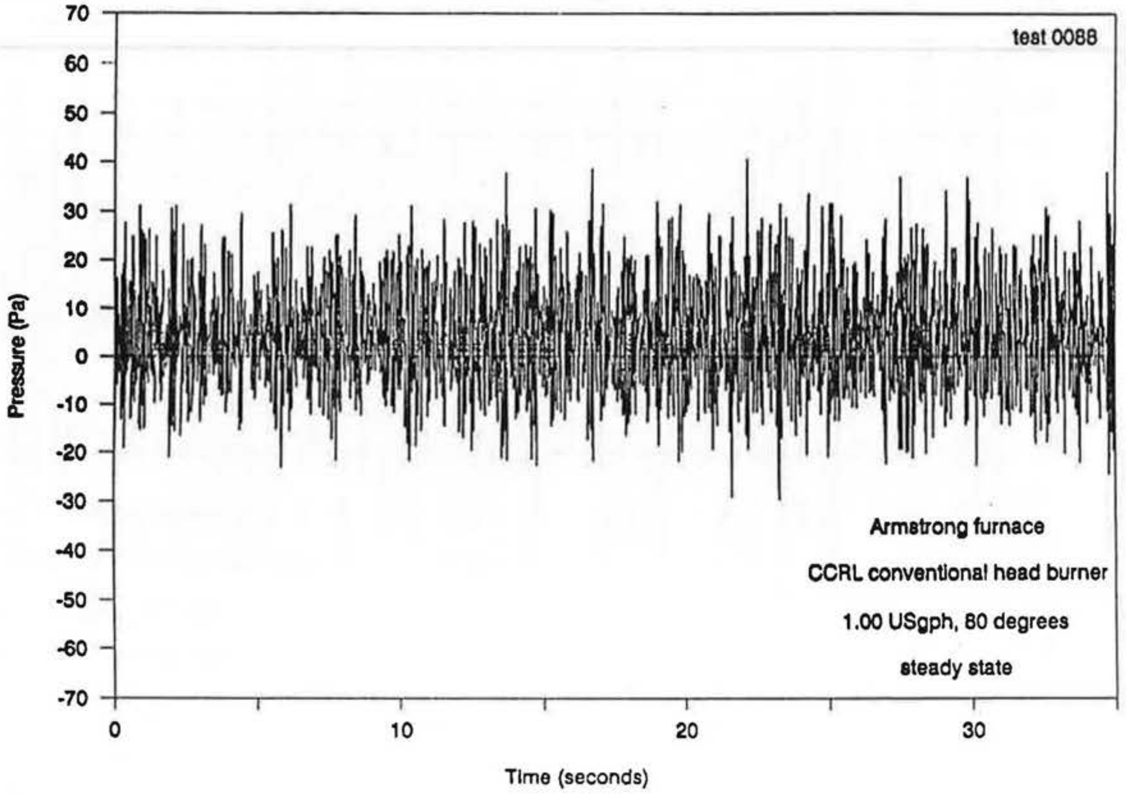
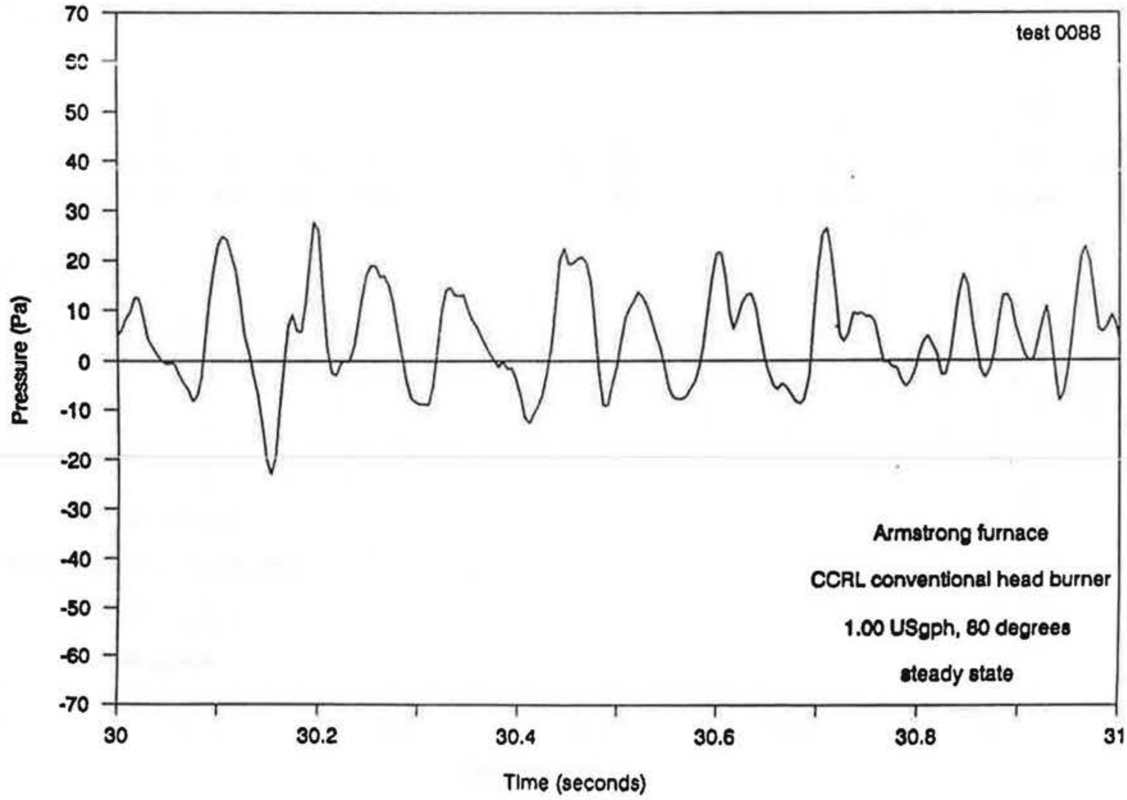


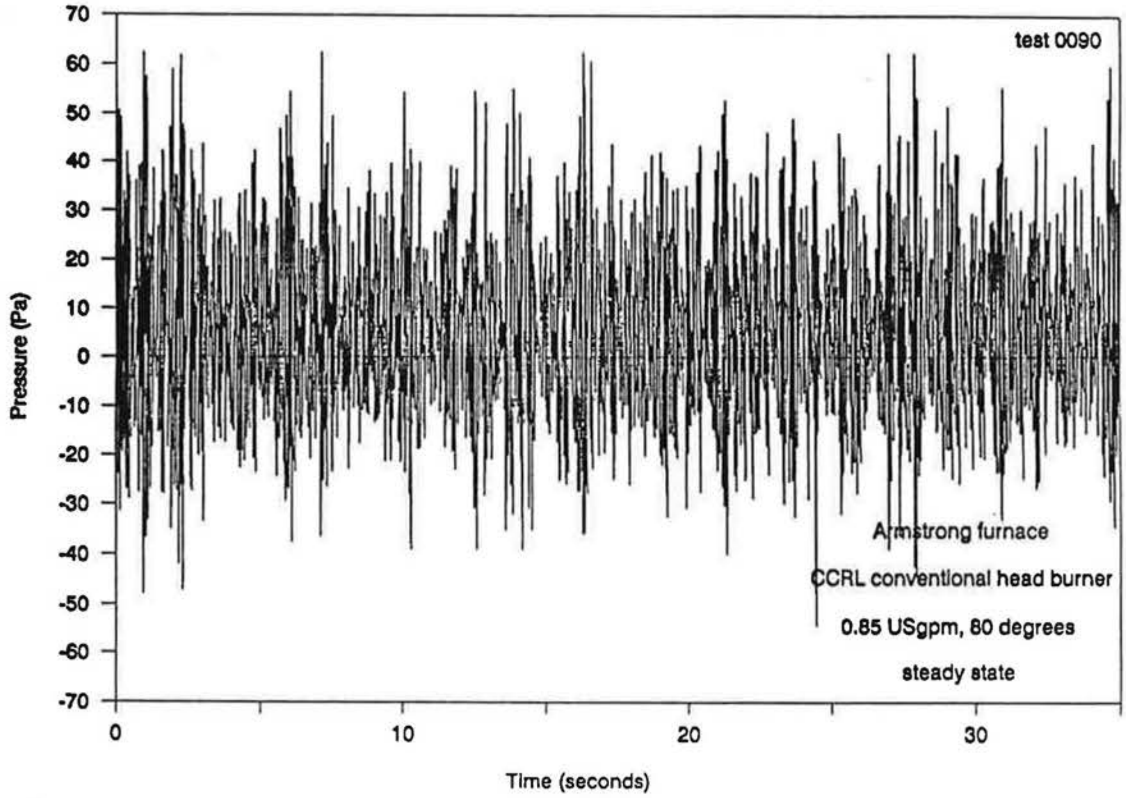


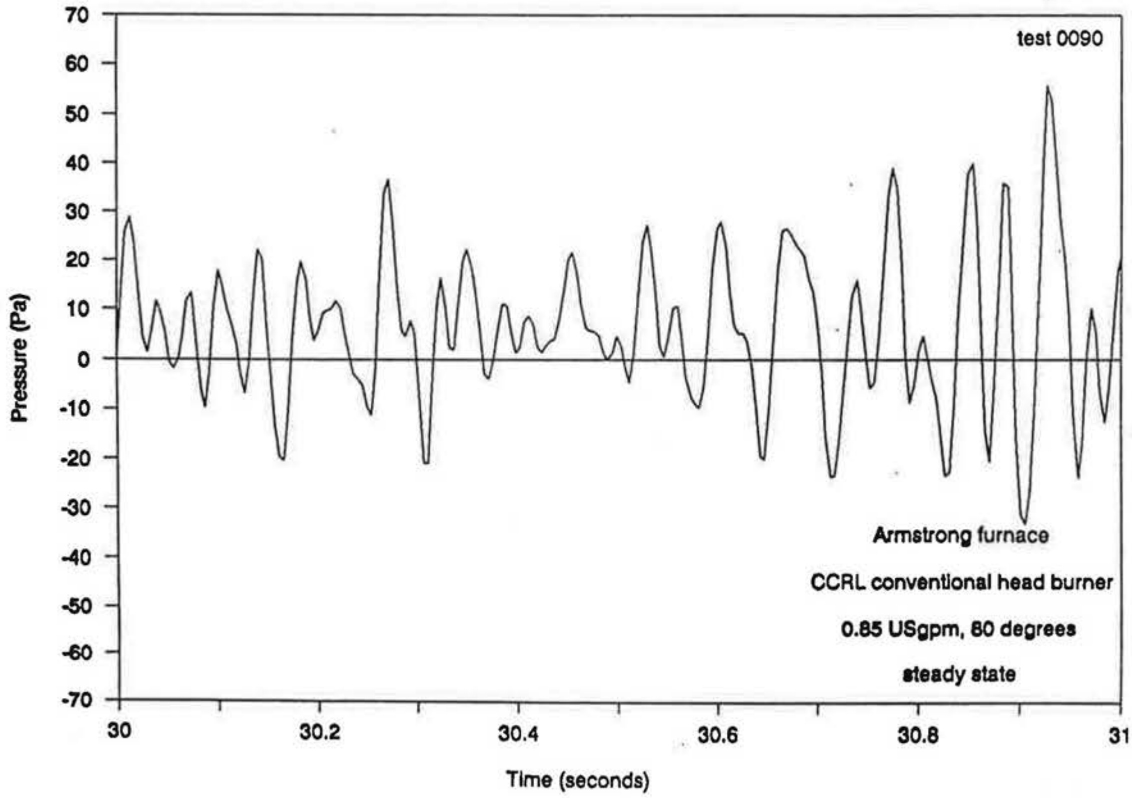
Pulsations at furnace flue collar





Combustion chamber pulsation





APPENDIX H - MEASURING PRESSURE OSCILLATIONS IN THE ARMSTRONG OIL FURNACE

TABLE OF CONTENTS

1.0 PROBLEM

During the course of the CMHC chimney study at the Armstrong house in Ottawa, IRTA identified chimney static pressures as changing very rapidly, probably in response to pulsations generated by the furnace burner.

Static pressures recorded at 12-second intervals showed up as erratic pulsations. IRTA recordings were not rapid enough to capture the true frequency of the pressure oscillating curves.

2.0 OBJECTIVES OF STUDY

The objectives of this investigation were

- to identify the frequency and amplitude of the pressure oscillations in the Armstrong oil furnace
- to give some indication as to the cause of the pulsations.
- to evaluate effects on house air quality

Because of the limited scope of this work IRTA was only trying to identify the cause of the pulsation problem and not solve it.

3.0 NATURE OF PRESSURE OSCILLATIONS (PULSATIONS)

3.1 Background

Combustion oscillations have been identified in oil and gas burners for a long time. While their nature is fairly complex the combustion oscillations were well understood and all but eliminated by designs which recognized how these were generated.

The combustion oscillation problem re-surfaced again on many occasions when new designs evolved without giving adequate consideration to the causes of the pressure oscillations.

3.2 Cause

Combustion oscillations in oil furnaces seem to be self-excited and generated by certain operating conditions. The two main causes for the oscillations are[3]:

- the pulsing manner in which the fuel is burnt by the oil burner (in spurts). This gives us an OSCILLATION OF THE FLAME.

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[3]taken from Symposium on Combustion-Driven Oscillations Design criteria and Models for Preventing Combustion Driven Oscillations, P.K.Blade (ASHRAE Publication)

- the variations in pressure in the combustion chamber caused by the different rates of volume expansion (of the heated air) of the oscillating flame. This gives us PRESSURE OSCILLATIONS in the combustion chamber.

IRONICALLY ONE IS CAUSED BY THE OTHER AND IS THE SOURCE OF THE OTHER OSCILLATIONS. While the flame oscillations cause the pressure oscillations in the combustion chamber these same flame oscillations (where fuel is burnt in spurts) are in turn caused by the pressure variations in the combustion chamber.

The oscillations are largest when both the flame and the pressure oscillations are in phase. The geometry of the furnace's combustion chamber, heat exchanger and pipes can also be responsible for changing the frequency and magnitude of the vibrations.

Changes in the air-fuel ratio have also shown to influence combustion oscillations in existing systems.

4.0 APPROACH TO TESTING

Being less familiar with this pulsation phenomenon, IRTA approached Mr. Skip Hayden at the Canadian Combustion Research Labs (CCRL) for an insight into the problem. This helped us develop the following approach to the study.

- the investigation was to include three different types of burners ... the Armstrong house burner, a second conventional type burner and a flame retention head burner. Because it was thought that the nozzle firing rate might be responsible for the oscillations, each burner would be tested with 3 different nozzle sizes. This gave us a total of 9 basic tests. IRTA added a few additional tests to verify combustion chamber pressures during furnace lightup and whether lean or rich fuel mixtures influenced the oscillations. Table 1 lists the different tests.

- pressures would be recorded in the combustion chamber. This would give us the nature of the pressures pulsations at their source before they become transformed by the combustion chamber and heat exchanger. Furnace flue collar pressures would also be recorded for comparison to those at the burner.

- pressures would be recorded at a rate that is 10 times faster than the frequency of the pulsations. The faster recording would provide adequate data points for an accurate tracing of the curves. We were unaware at the time that recording high frequency pressures would require an entirely new approach.

- carbon monoxide would be monitored in the combustion chamber in an attempt to determine whether the combustion process is also affected by the furnace pulsations. We questioned the ability of our instrumentation to detect changes in CO to accompany the oscillatory nature of the burning rate of the flame.

- for uniformity each burner was adjusted so that its combustion air was less than .01 % CO in the combustion chamber.

- some ignition tests were done with the combustion chamber still hot from the previous test. Low and high combustion air settings were set with the help of a CO meter.

5.0 INSTRUMENTATION

Previously a Sciemetric datalogger recorded pressures at the rate of 12 readings per second. A Taurus datalogging system was used for the testing with a program written in BASIC. It was utilized with a 286 computer in order to obtain faster readings. The recording speed was increased to 228 data points per second . Recorded data was stored in Lotus files for analysis.

The 8000 lines available in the Lotus files limited recording time on each test to 35 seconds (i.e. 228 readings/sec X 35 sec). Pressure measurements were taken with differential pressure transducers.

6.0 TEST RESULTS

6.1 Limits of pressure transducers

We performed an entire series of tests to obtain what we thought was reliable test data. The pressure oscillation curves are shown at the back of this Appendix H. We questioned our data when its measured frequencies were lower than those mentioned in the reference materials of our bibliographical search.

We checked the response time of our pressure transducers only to discover that they were limited to 16 msec which would limit us to a maximum of 62 data points per second. This slow response time of the pressure transducers would prevent the detection of frequencies above 20 to 30 Hertz. Higher frequencies would be shown as averaged out to 20 to 30 Hertz.

While data recorded with the pressure transducers could not determine the frequency of the oscillations it gave accurate readings of their amplitude.

6.2 Changes to test methodology

To measure the high frequency of the pressure oscillations which were more in the form of dynamic pressures, we used a dynamic pressure transducer or microphone. The response time of the microphone is much faster than the static pressure transducers as it can pick up very high frequencies.

Measuring pressure oscillations with a microphone meant inserting it as close as possible to the pressure source, which was the burner in the combustion chamber. To protect it from the intense heat it was inserted into the flame inspection port for only a few seconds. The microphone would be cooled and tests repeated. The electrical signal from the microphone was amplified and viewed with an oscilloscope. The pressure oscillating curves on the oscilloscope screen were photographed for a hard copy which would be used to determine the curve frequencies.

6.3 Test results

NOTE: In the initial test series pressures were measured with the static pressure transducers and the Taurus datalogging system. On the additional series where pressure measurements were taken with a microphone only the Armstrong conventional burner was used, as the two other burner types were returned to their owners.

a) Frequency of pressure oscillations (Photo 1)

The frequency of the pressure oscillations on the Armstrong conventional head burner was measured in the range of 125 to 330 Hertz. Superimposed on top of these waves are much smaller oscillations with a much higher frequency in the range of 4000 Hertz.

Photo 1 shows the pressure oscillating curve on the oscilloscope screen. The screen's actual width is 10 cm. The oscilloscope sweep speed was set at 1 ms/cm of travel. The curve's wavelength was estimated as anywhere between 3 to 8 cm which would give a 3 to 8 ms period. Therefore the frequency would be estimated as being in the range of 1000 ms/(3 to 8 ms) or 125 to 330 Hertz.

b) Amplitude of pressure oscillations

The microphone and oscilloscope method of measuring frequency provided no vertical screen reference for measuring the amplitude of the dynamic pressures. Luckily the previous work with the static pressure transducers and the Taurus datalogger did. Graphs showing the results from this study may be found at the end of Appendix H. THESE CURVES ARE USED ONLY FOR IDENTIFYING THE AMPLITUDE OF THE OSCILLATIONS AS THEY ARE NOT REPRESENTATIVE OF ITS FREQUENCY.

Each curve is identified by the type of burner and nozzle which was used and whether the test was performed at steady state or at lightup. The amplitude of the static pressures are plotted on the y-axis and time plotted on the x-axis. The response time of the pressure transducers were too slow and hence averaged the amplitudes off the pressures over a 16 m/s period. This averaging of the amplitudes over this very short period does not remove any accuracy from the amplitude measurements.

i) Conventional head burners

Both the conventional head burners had the largest amplitudes. They ranged from 25 to 40 Pascals with spikes at times reaching 70 Pascals.

ii) Flame retention head burner

The flame retention head burner had smaller amplitudes ranging from 8 to 20 Pascals. We assume that because the flame retention head burner mixes the air and the oil spray more efficiently we get less violent pulsing from the mixed fuel and air packages. The flame oscillations would be smaller and hence so would the pressure oscillations. Pressures were also more uniform and did not show the large pressure spikes of the conventional head burners.

iii) Pressure oscillations on burner start up

Tests done during burner start up did not reveal any noticeable differences in amplitude with either of the burners.

iv) Pressure oscillations at the furnace flue collar

Pressure oscillations at the furnace flue collar were measured to be 5 to 10 Pascals lower than those in the combustion chamber. They were probably dampened by their travel through the heat exchanger.

6.4 Measuring CO in the combustion chamber

Unfortunately our CO measuring apparatus was unable to detect any changes in the level of CO in the combustion chamber. Its response time was probably much too slow.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Large-amplitude high-frequency combustion oscillations in the Armstrong oil furnace <u>do not</u> cause a severe spillage problems.

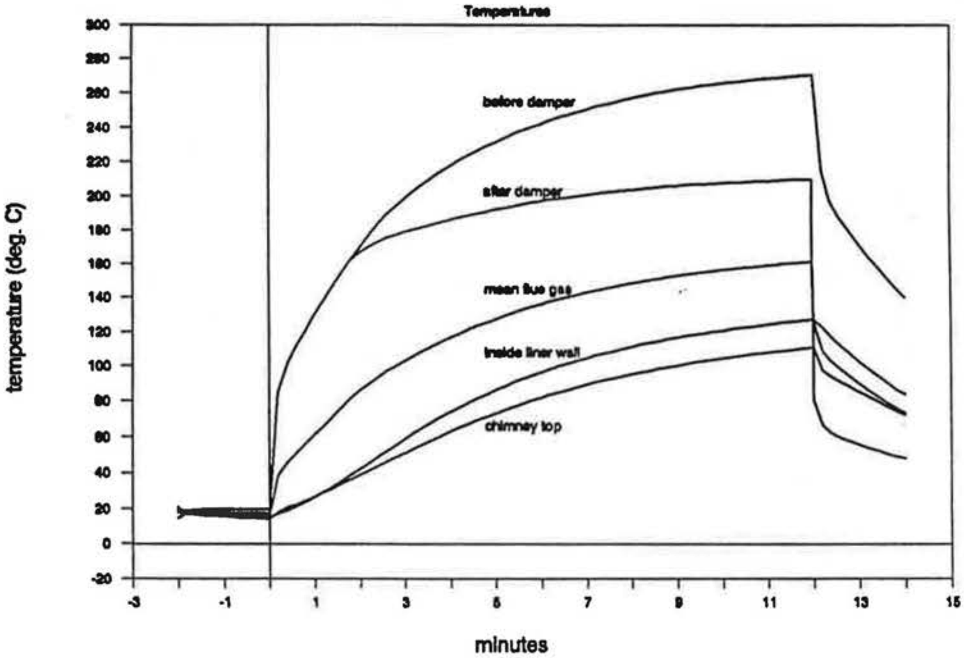
Large-amplitudes low-frequency combustion oscillations <u>can</u> cause spillage of combustion gases through the barometric damper.

While the nature of the pressure oscillations is complex and has been researched to a great extent we would recommend that any future work investigate the relationship of the combustion generated oscillations to the spillage of combustion gas products.

PRESSURE OSCILLATION CURVES

(PART OF APPENDIX H)

CHIMNEY: 4" A-vent PIPE: 4" Insulated NO DEPRESSURIZATION



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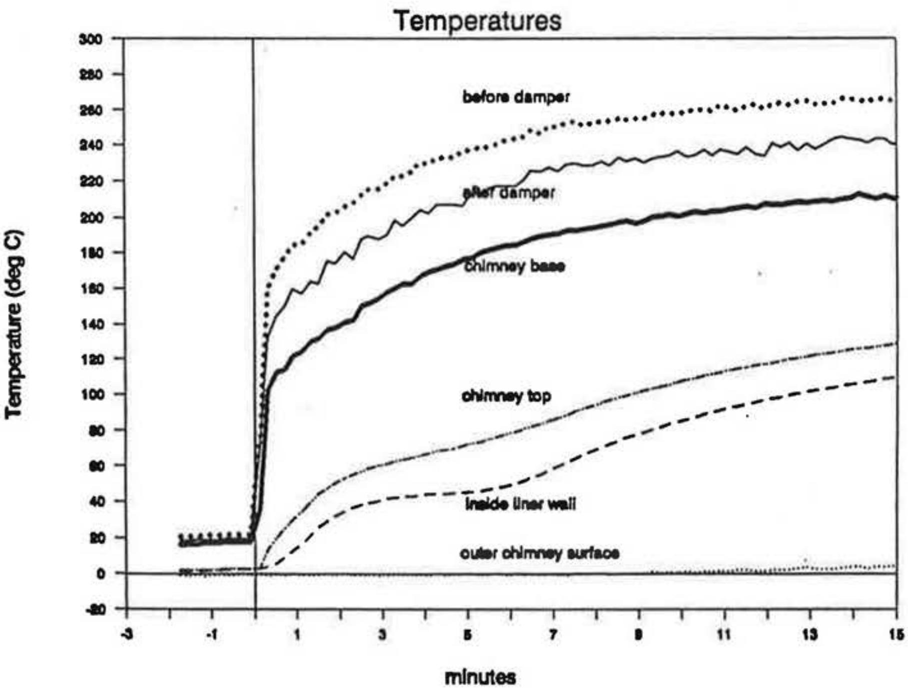

TEST 3420

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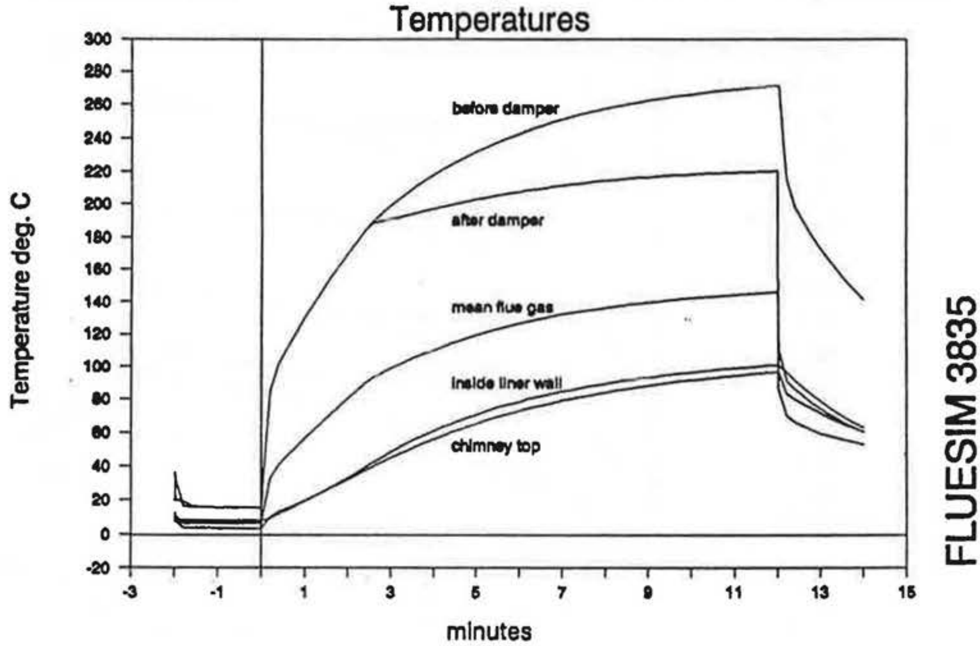
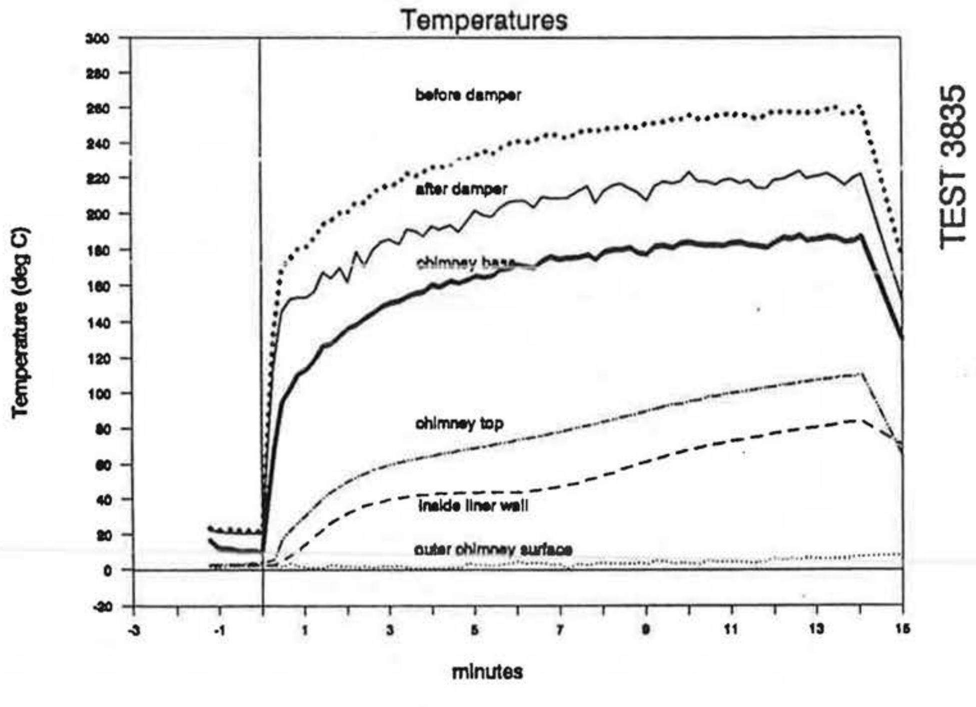
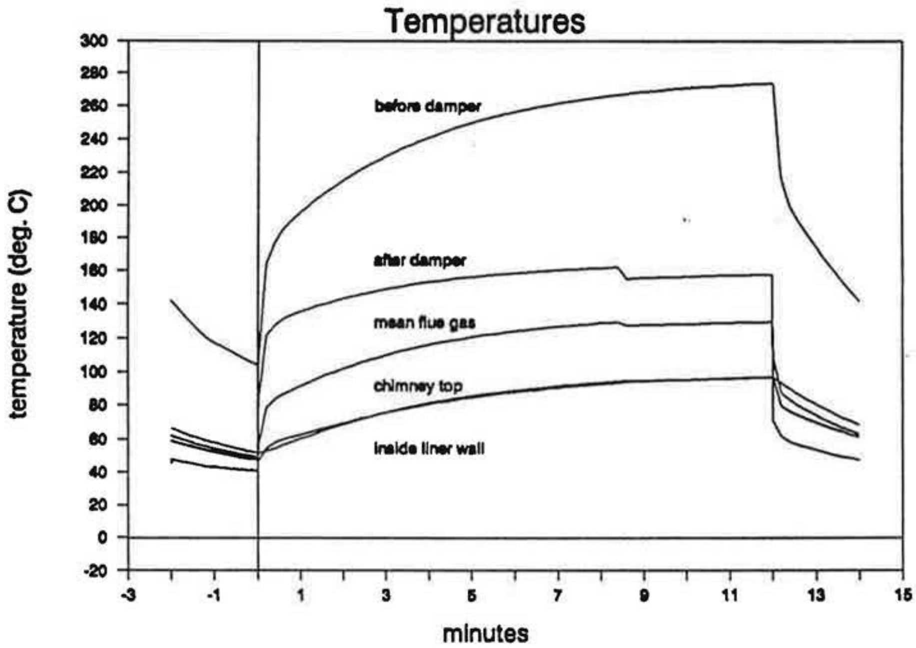




CHIMNEY: 7" A-vent PIPE: 4" Insulated NO DEPRESSURIZATION



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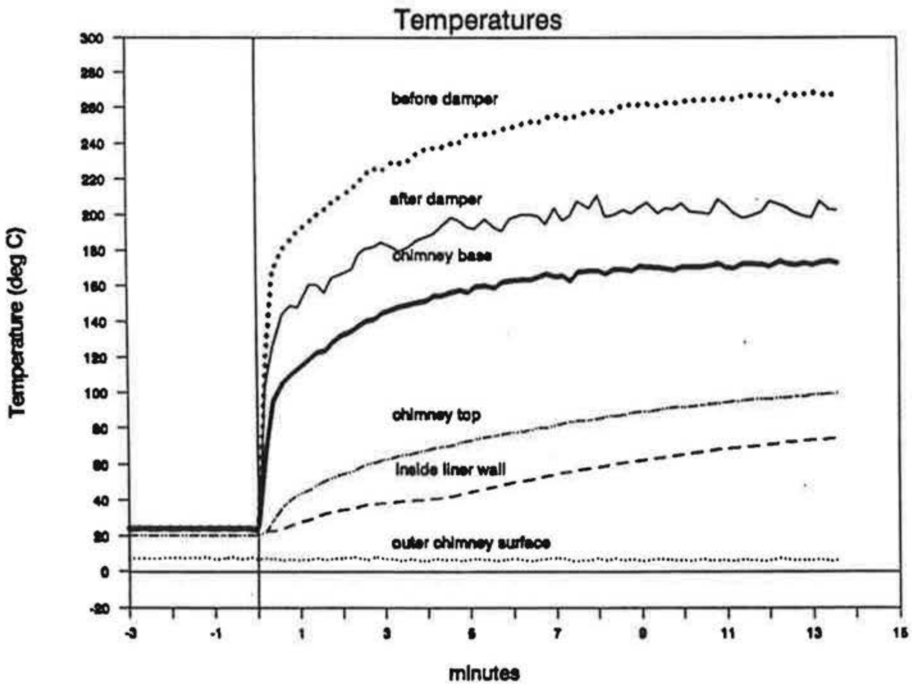

TEST 5429