
**STACK FLOW AND LOSS MEASUREMENTS
OF A COMMERCIAL TANK WATER HEATER**

Minneapolis Energy Office*

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October, 1989

Prepared under contract to
the Energy Resource Center

MEO/TR89-8-MF

*Now the Center for Energy and the Urban Environment

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I. Overview

The purpose of this study is to better understand the stack losses of a commercial tank water heater. The measurements will be used to help interpret an ongoing study of the heater energy use and domestic hot water (dhw) demand and estimates of standby losses.

The heater has an input of 365,000 Btu/h, a 70-gallon storage tank, and a recovery efficiency of 70%. It is equipped with intermittent ignition, an integral flue damper, and can be fitted with a thermal vent damper. The thermal damper is located after the draft diverter. The integral flue damper is installed vertically in the rectangular hood and is motor actuated. The damper does not seal air tight. When the damper is closed, the open duct area is reduced from 103.0 to 6.74 square inches for a 93.5% reduction in the open area.

II. Setup

The heater flue flow (i.e. air flow through the tank - before the diverter) was estimated using a constant injection tracer gas technique. An electronic mass flow controller was used to inject the tracer gas (sulphur hexafluoride) at the bottom of the heater, immediately before the combustion tubes (see Figure 1). The concentration was measured by pumping a sample of the flue gas from the top of the heater to an infrared analyzer. By applying the conservation of mass equation to the tracer gas flue flow, the total flue gas flow is found to be approximately equal to the tracer gas injection rate divided by the tracer gas flue concentration. More specifically:

$$F_f = (T_f/T_i)(F_i/C_f) \quad (1)$$

where:

- F_f = heater flue flow (cfm)
- F_i = tracer gas injection rate (cfm)
- T_f = flue temperature (R)
- T_i = tracer gas injection temperature (R)
- C_f = tracer gas flue concentration (ft^3/ft^3)

that can be manually opened. The boiler vent is connected into the same chimney as the heater vent. The chimney is approximately 50 feet high.

III. Procedure

Four sets of heater flow measurements were conducted: flow array comparison, fan-induced flue flow, flow under "natural" conditions, and long-term (5 hours). All of the measurements were made when the heater was not being fired. Before each set of tests the heater was fired until it satisfied the aquastat setting of 140°F.

A. Comparison

In order to verify proper operation of the equipment, a test was conducted to compare measurements by the tracer gas method and flow array device. The array uses a multiple point velocity pressure measurement to indicate the air flow rate. The flow equation for the calibrated flow array is given by:

$$F_a = 21.0(p_a)^{0.504} * (0.075/q_a)^{0.5} \quad (4)$$

where:

F_a = flow through the array (cfm)

p_a = array pressure (Pa)

q_a = density of air through array (lb/ft³)

The heater vent was disconnected before the second heater and connected to a variable speed fan and flow array (see Figure 1). The draft diverter was sealed so that the flow through the heater is equal to that flowing through the flow array. By varying the fan speed, measurements were taken at four different flow rates from 50 to 170 cfm.

B. Fan Induced

These tests were conducted in order to simulate the variety of vent pressures that may be encountered throughout the year. Each of the three damper modes (integral open, integral closed, and thermal installed with integral open) was studied over a variety of flow rates. The integral damper open and closed modes were typically performed at the same fan setting.

The setup was similar to that used for the comparison tests except the draft diverter was left open. The vent pressure was measured with an electronic transducer and the array pressure with a diaphragm/magnetic linkage type gauge. The mechanical gauge has an accuracy of 0.005 inches of water.

C. "Natural"

These tests were conducted in order to measure the heater flows and vent pressures that occur naturally. Measurements were

top of the tubes to the top of the tank. In order to achieve a more representative measurement, two sample manifolds were placed approximately one inch before the flue damper and about one inch from the top and bottom of the hood (see Figure 1). The use of a sample manifold, instead of a single point, should have achieved a representative sample. It was not possible to determine the level of accuracy of the sampling process with a secondary method. Consequently, it is difficult to estimate the absolute accuracy of the tracer gas method. Judging from the flow array measurements, it is probably between 10% and 20%. The precision of the method and its ability to measure relative differences between flows should be better than the estimated accuracy - probably between 5% and 15%.

B. Fan Induced

The results of the measurements are shown in Table 3. For the tests performed without the thermal damper, the total vent flow (heater plus draft diverter) varied from 75 to 205 cfm and the vent pressure from about 2 to 15 Pa. Over this wide range of vent pressures, the series of flows for the integral damper open or closed modes did not change significantly. For example, when the integral damper was open and the vent pressure increased from 1.97 to 13.88 Pa the heater flow only increased from 48.3 to 48.6 cfm. This indicates that the draft diverter does substantially de-couple the magnitude of the flow through the heater from that of the vent pressure. Data from the long-term tests will be used to examine the driving factors for the heater flow.

When the thermal damper was installed the vent pressure influenced the heater flow only at low pressures. For vent pressures from 19 to 100 Pa the heater flow was consistently between 45.2 and 46.3 cfm. As the pressure dropped to 9.7 Pa, the total vent flow and heater flow dropped to 41 cfm. A further decrease in the pressure to 2.9 Pa reduced the total vent flow to 23 cfm and the heater flow to 37 cfm. At these lower pressures, smoke investigations showed that some air was flowing out of, not into, the bottom of the draft diverter. This test indicates that until the total flow through the vent approaches that of the heater flow, the thermal damper does not effect the heater flow.

The data also show that closing the integral flue damper reduces the heater flow. The average heater flow for all the tests was 49.3, 25.5, and 43.5 cfm for the damper open, closed, and thermal damper. Thus, closing the integral damper reduced the heater flow by 48.3%. The average flue losses also were reduced by 51.6%. The reduction is not as significant as expected. However, 6.5% of the duct area was not closed off -- leaving a large flow path.

The thermal damper reduced the heater flow by only 11.8%. This reduction was most likely due to the lower supply water temperature and reduced flow at the lower pressures. The reduction in the total vent flow was much greater. At a vent pressure of about 8.5 Pa, the total vent flow for the integral

vent flow with the thermal damper also resulted in greater vent pressures. For example, when the draft diverter of the second heater was closed and the boiler was fired, the vent pressure was 6.5 Pa when the stack temperature was 142°F and the integral damper open with no thermal damper. Under similar conditions, with a chimney temperature of 139°F and the thermal damper installed, the vent pressure was 10.0 Pa.

The position of the steam boiler damper did not greatly affect the vent pressure. For example, when the integral damper and the draft diverter of the second heater were closed, closing the boiler damper decreased the vent pressure from 3.07 Pa to 3.02 Pa. At the same time, the chimney temperature decreased from 110°F to 102°F. Since the boiler was relatively warm, the decrease in the chimney temperature was probably due to a decrease in the warm air flow out of the boiler. Thus, closing the boiler damper closed a large flow path, which should have caused more flow through the heater vent. It also reduced the stack pressure by lowering the chimney temperature. The two effects appear to cancel each other.

D. Long-term

Figure 4 is a plot of the variation in the heater flue flow and loss rate with the thermal damper in place. Over the five hour test, both of the variables decreased as the tank temperature decreased. The results from the earlier tests indicate that the heater vent pressure has little effect on the heater flow. If this is true, the major driving force for the heater flow is the difference between the density of the heater flue gas and the boiler room air - i.e. the thermal stack effect (or pressure). Thus, the heater flow should be approximately related to the difference between the average temperature of the gas flowing up the heater and the boiler room temperature. For the following analysis the flue temperature before the draft diverter has been used in place of the average heater air temperature. There should be a strong relationship between the two temperatures. Using the flue temperature will result in a larger temperature difference.

Figure 5 is a plot of the relationship between the heater flow and the difference in the flue and boiler room temperatures and the vent pressure. There is a strong correlation between the heater flow and temperature difference. A least squares regression analysis of the heater flow to the temperature difference resulted in the following equation (standard errors are given in brackets):

$$F_f = 3.41 + 0.615(T_f - T_{br}) \quad (5)$$

[0.45] [0.025]

where:

T_{br} = boiler room temperature (F)

TABLE 1
Anemometer Measurements Of Heater Flue Flow

distance from the outside edge of the flue (")	flow velocity (ft/min)		
	mean	min	max
0.29	3	-5	15
0.92	5	-5	20
1.65	10	-5	35
2.54	32	10	45
3.85	50	45	55
7.41	51	45	55
8.71	49	45	55
9.61	45	30	53
10.33	35	10	50
10.96	12	3	35

outside diameter = 11.25" average - 29.2
integral damper open indicated flow rate - 20.2 (cfm)
no thermal damper

TABLE 2
Comparison of Flue Flow Rate Via Tracer Gas and Flow Array

number of data points	Flue Temp (F)		Array Pres (Pa)		Flue Flow Rate (cfm)					Difference	
	mean	SD	mean	SD	Array		Tracer Gas			(cfm)	(%)
					mean	SE	mean	SD	SE		
6	102.4	0.2	56.12	1.24	167.2	7.3	143.5	2.2	7.2	23.7	14.2
6	102.5	0.1	32.90	0.92	127.8	5.6	104.8	1.2	5.2	23.0	18.0
6	102.9	0.1	20.67	0.32	101.1	4.6	82.9	1.3	4.1	18.2	18.0
7	104.1	0.1	8.03	0.11	62.8	3.6	55.5	0.6	2.8	7.4	11.7

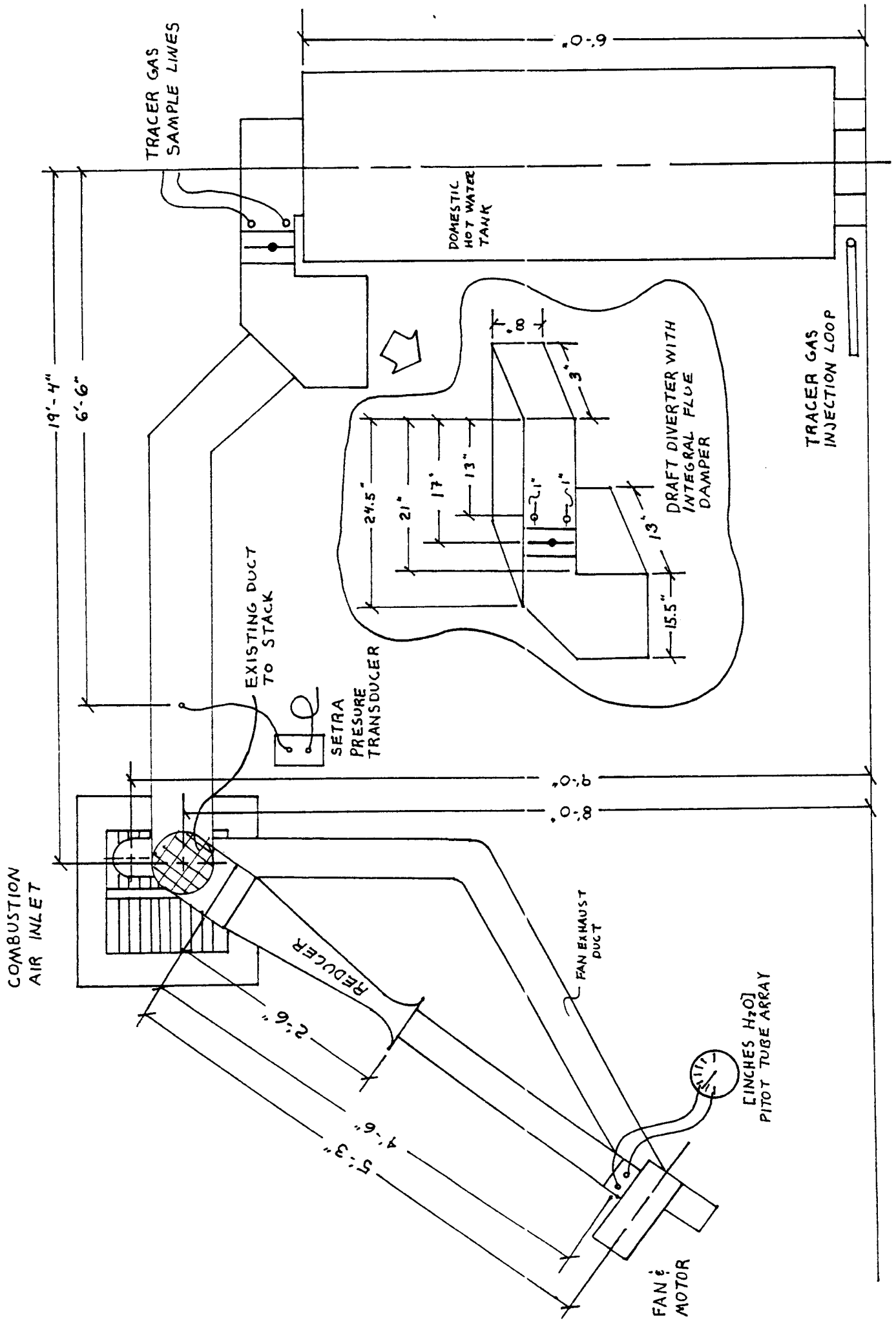
Note - each data point represents a one minute average.
There are approximately four measurements in each minute.
SD - standard deviation of the measured values
SE - standard error of the reported value

average - 18.1 15.5

TABLE 3
Flue Air Flow and Heater Flue Loss Using a Fan on the Vent

data	Config pts	supply temp (F)	vent pres (Pa)	Flue temp (F)	Air Inlet temp (F)	Flue Flow (cfm)	Flue Loss (Btu/h)	Total Vent Array pres
IO	6	135.1	0.1	127.3	0.4	48.6	2275	26
IC	11	135.6	0.1	125.5	0.2	28.6	1269	108
IO	8	138.6	0.0	132.5	1.0	51.4	2685	93
IC	6	138.4	0.0	128.2	0.2	25.8	1221	41
IO	3	137.8	0.1	130.5	0.3	49.6	2478	49
IO	7	137.2	0.2	128.9	0.2	48.4	2343	20
IC	5	138.2	0.0	127.8	0.2	26.1	1213	61
IC	6	138.1	0.1	127.8	0.2	22.0	1026	23
IO	7	136.2	0.1	127.9	0.2	48.3	2293	24
IC	7	135.9	0.0	125.1	0.2	25.2	1122	62
Thm	5	134.8	0.1	126.3	0.1	46.3	2121	32
Thm	6	134.5	0.1	126.0	0.1	45.7	2073	24
Thm	6	134.0	0.2	125.6	0.1	45.5	2044	7
Thm	7	133.4	0.1	125.3	0.1	45.2	2018	13
Thm	6	133.3	0.1	125.1	0.1	41.7	1855	36
Thm	8	132.9	0.1	125.2	0.1	36.5	1651	88
----- average of all tests -----								
						49.3	2415	171
						25.5	1170	97
						43.5	1960	176

one minute average, four to five measurements per minute
The mean and standard deviation is reported for each variable except the array pressure.
standard error of the flue flow = +/- 5%, array pressure = +/- 0.005 "water
IO: Integral Damper Open (No Thermal)
IC: Integral Damper Closed (No Thermal)
Thm: Thermal Damper (Integral Open)



TEST EQUIPMENT LAYOUT:
 Fan connected for comparison and fan tests
 FIGURE 1

Flue Temperature Sensor Array Configuration

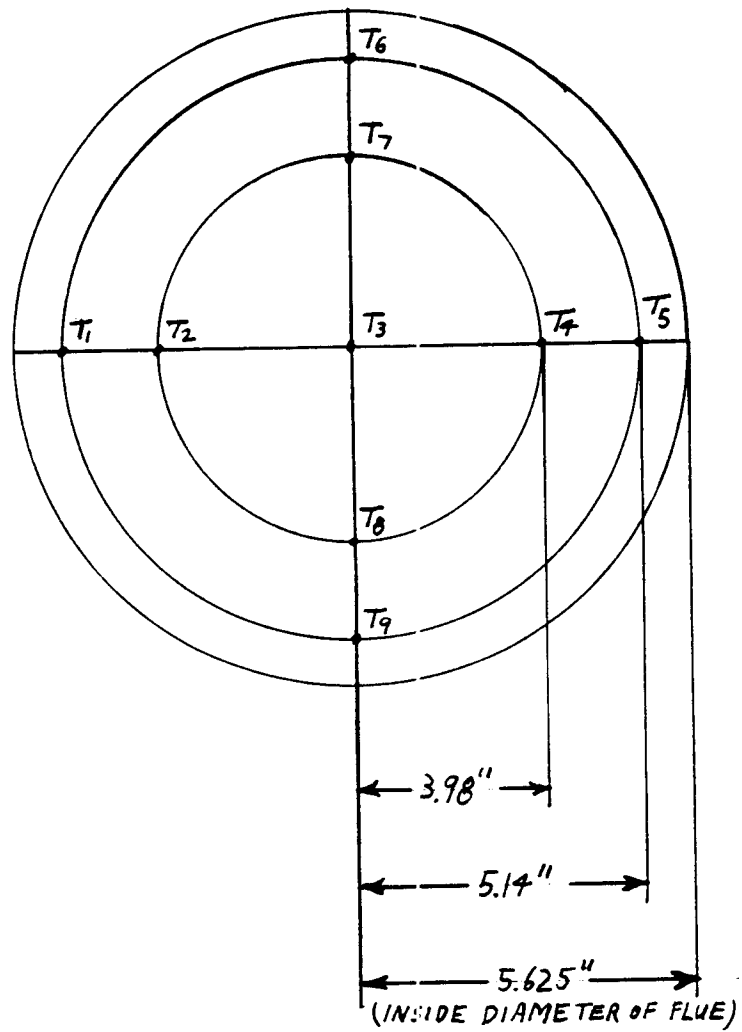


Figure 2

Vent Configuration at
636 Grand Ave (24 units)

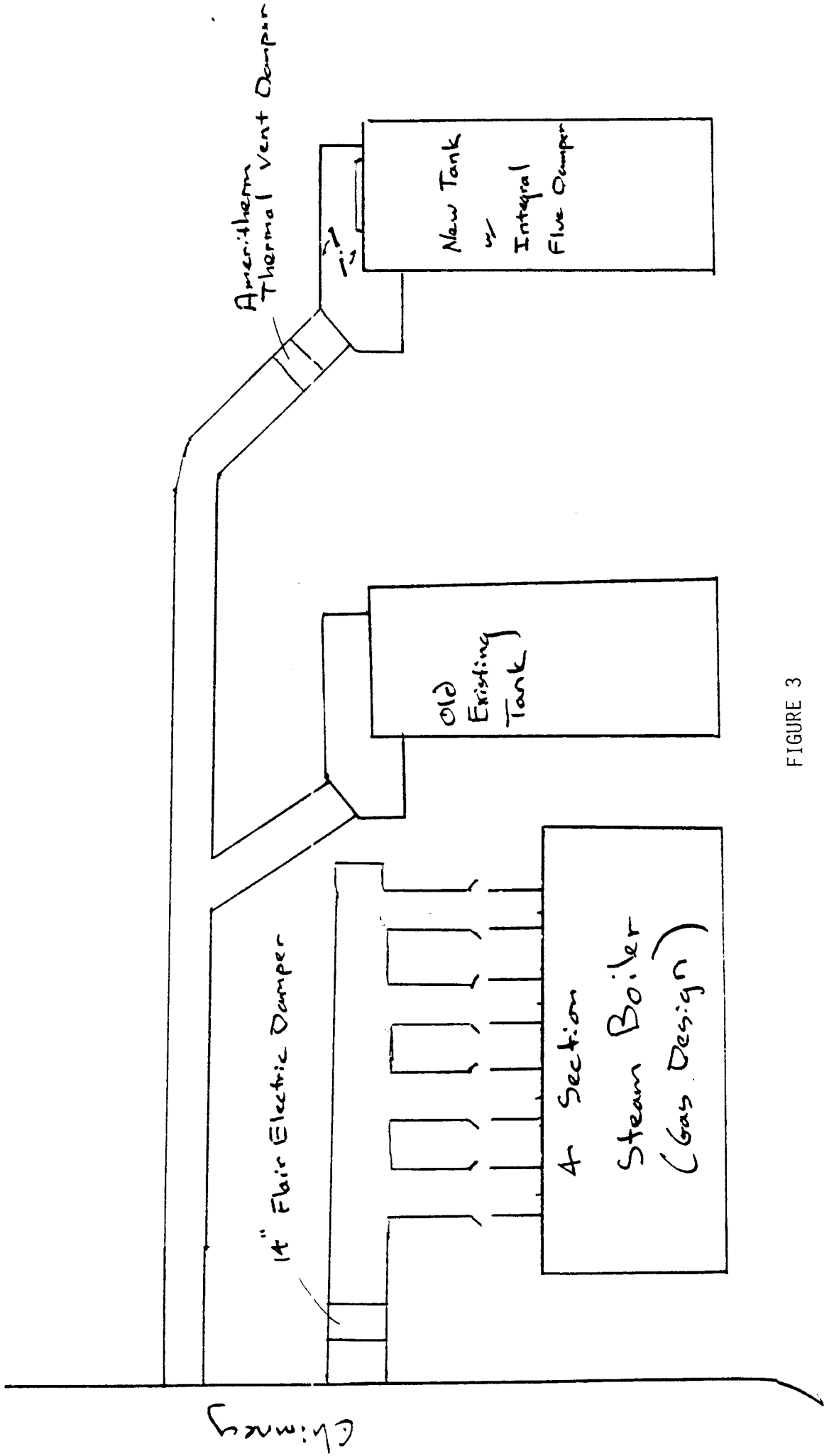


FIGURE 3

Heater Flue Flow and Energy Loss

Thermal Damper

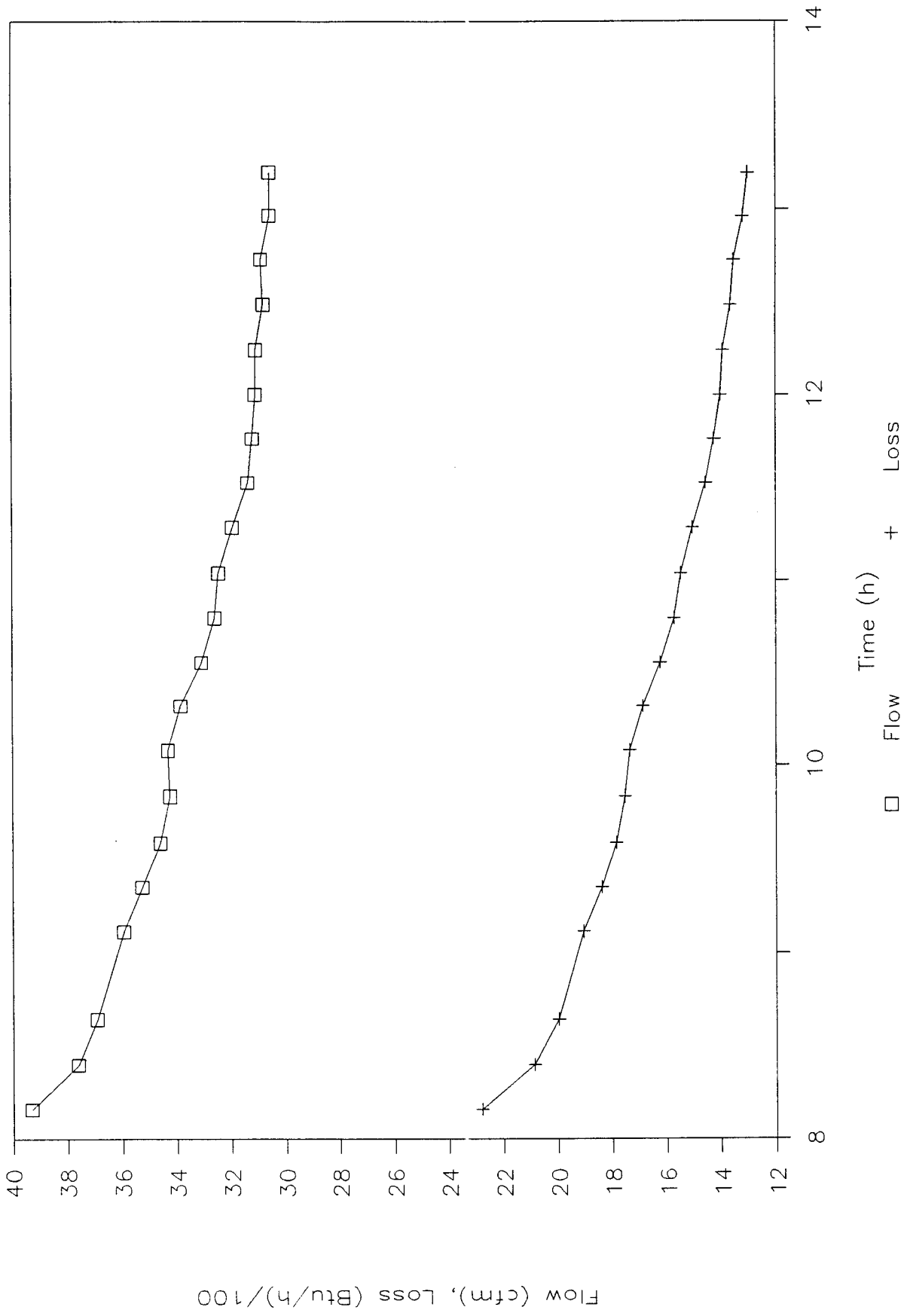


FIGURE 4

Response of Heater Flue Flow

to delta temp. and vent pres.

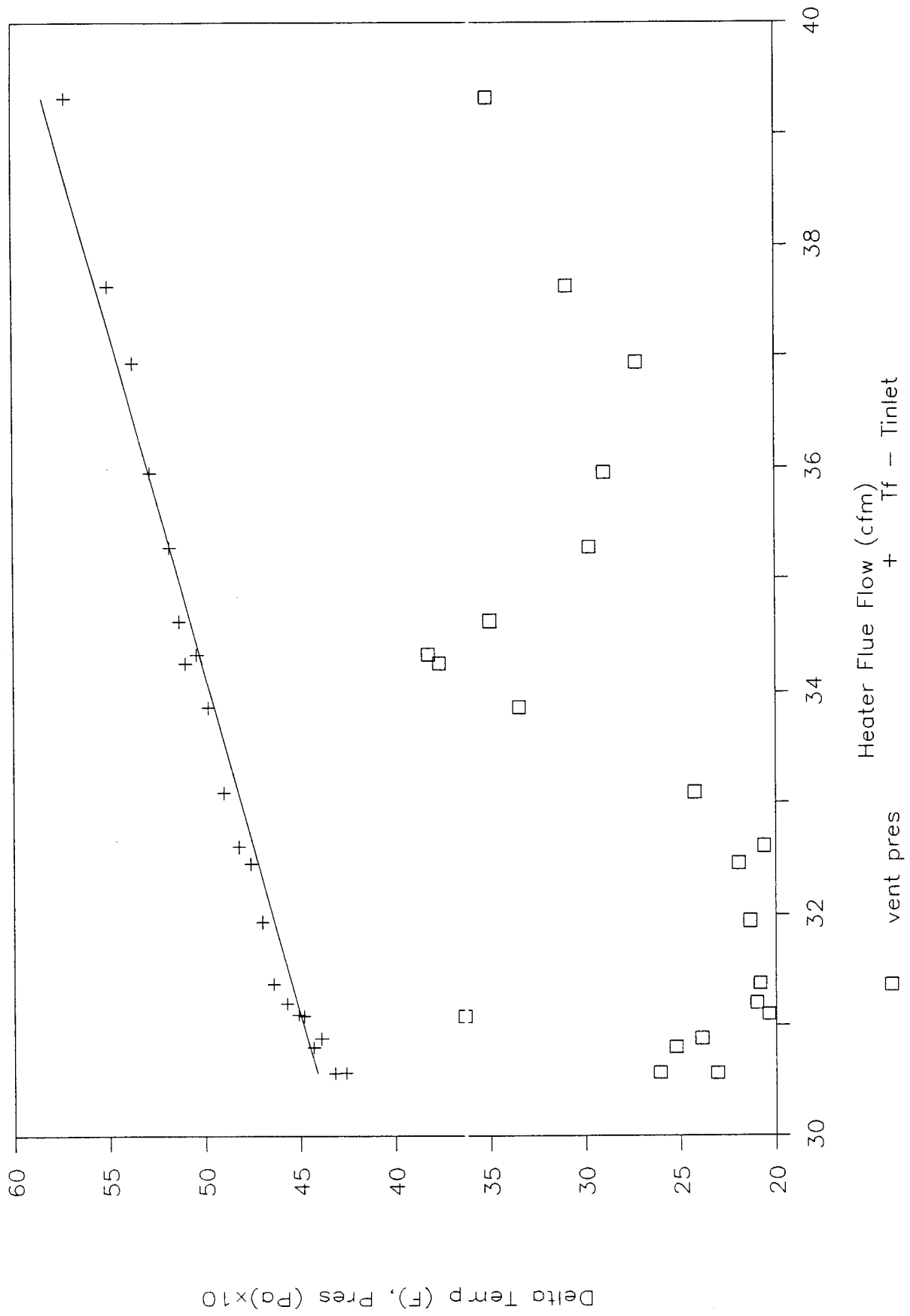


FIGURE 5

Relationship of Residuals From

Temp Diff Model to Vent Pres

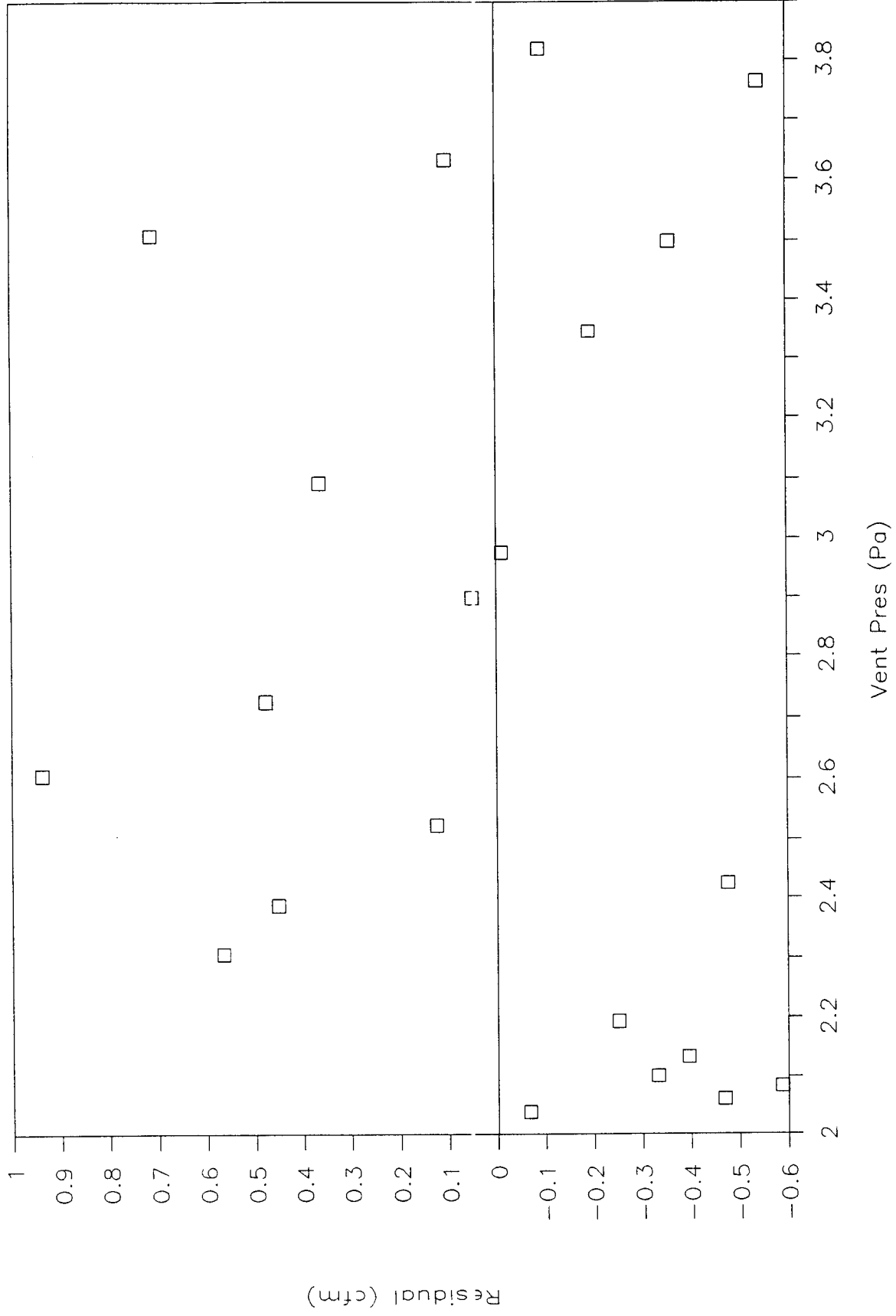


FIGURE 6