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DATA FOR MODEL VALIDATION SUMMARY REPORT

A Summary of Data for Validation and Benchmarking of Recovery Boiler Models

T. Grace, S. Lien, W. Schmidl,
M. Salcudean, Z. Abdullah

July 1997

Work Performed Under Contract No. DE-FG07-90CE40936

For
U.S. Department of Energy
Assistant Secretary for
Energy Efficiency and Renewable Energy
Washington, DC

By
The Institute of Paper Science and Technology
Atlanta, GA
and
University of British Columbia
Vancouver, BC, Canada

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INTRODUCTION

One of the tasks in the project was to obtain data from operating recovery boilers for the purpose of model validation. Another task was to obtain water model data and computer output from University of British Columbia for purposes of benchmarking the UBC model against other codes. In the course of discussions on recovery boiler modeling over the course of this project, it became evident that there would be value in having some common cases for carrying out benchmarking exercises with different recovery boiler models. In order to facilitate such a benchmarking exercise, the data that was obtained on this project for validation and benchmarking purposes has been brought together in a single, separate report. The intent is to make this data available to anyone who may want to use it for model validation.

The report contains data from three different cases. Case 1 is an ABBCE recovery boiler which was used for model validation. The data are for a single set of operating conditions. Case 2 is a Bobcock & Wilcox recovery boiler that was modified by Tampella. In this data set, several different operating conditions were employed. The third case is water flow data supplied by UBC, along with computational output using the UBC code, for benchmarking purposes.

BRIEF DISCUSSION OF CASES

Case One

Introduction

Case One is a kraft pulp mill producing 1,000 metric tons per day of bleached softwood and hardwood product, of which 800 metric tons is market pulp, and 200 metric tons is various specialty papers. The mill has five batch digesters and one 566 tpd Kamyr single-vessel hydraulic continuous digester [1996 Lockwood-Post Directory].

The chemical recovery plant has one five-effect evaporator with an HPD concentrator, and one Combustion Engineering low-odor design recovery boiler built in 1982 and rated at 3.7 million lb. per day black liquor solids firing capacity. The boiler has a two level air system, 16 black liquor guns (four on each wall), and eight smelt spouts (four on the Left side and four on the Right side). It is typically run with a very low bed. Currently, it is operating at a firing rate of approximately 4.2 million lb. per day of black liquor solids, or about 112% of rated capacity.

The Case One recovery boiler was chosen for this validation test because it was possible to cooperate with an ongoing test program being carried out by the University of Toronto, and so greatly expand the amount of data that could be acquired.

Overall Test Strategy

The objective of this model validation test was to acquire all of the necessary data to (1), properly and completely set up a CFD simulation of the boiler using the UBC code, and (2), evaluate the validity of the model by comparing the predicted boiler performance from the simulation to the actual boiler performance as measured by acquired process and analytical data. Furthermore, the tests on this boiler were to be performed during a period of steady operation, and preferably at full firing load.

The overall test strategy focused on a collaborative effort among researchers from IPST, the mill's recovery personnel, Honghi Tran and his research group at the Pulp & Paper Centre at the University of Toronto, and Diamond Power Specialty Company (DPSC) which loaned IPST a "portable" infrared camera for viewing and videotaping the high temperature furnace interior. Unfortunately, the camera was shipped to the mill with a straight lens tube instead of the expected right angled one. This limited the usefulness of the camera for top down imaging of the liquor sprays and the char bed.

Specific data to be acquired included detailed information on the furnace geometry, locations and dimensions of ports, tube banks, etc., and operating information, such as air flow rates, steam side flow information, and liquor firing conditions which are required to set up the simulation; and actual boiler performance data to compare to simulation results, such as velocity fields, temperature fields, gas composition fields, and liquor behavior. In addition, videotape records of the liquor sprays, gas circulation patterns, and char bed behavior were desired.

Measurements Performed or Attempted

Furnace Geometry and Process Data Acquisition

Copies of engineering drawings were obtained from the mill. These included a side sectional view of the entire boiler, the black liquor spray equipment and gun port arrangement; superheater header and tube arrangements; secondary air port, damper, and windbox arrangement and geometry; and primary air port and damper arrangement. These drawings were used to determine critical furnace geometry information such as the overall dimensions, the locations and dimensions of all permanent ports (smelt spouts, air ports, black liquor gun ports, etc.), and the locations, dimensions, geometry, and arrangements of the screen and superheater tube banks.

Process and operating data from the mill were acquired for the 48 hour time period of 3/27/96 and 3/28/96. This data was used to help set up the computer simulation, and as performance data to compare to the simulation results. This data set included primary and secondary air flow rates, liquor solids, flow rate, and temperature, steam side flow rates, temperatures, and pressures, various other flows, and char bed surface temperatures from through-the-lens pyrometry measurements by one of the two DPSC fixed bed cameras.

Infrared Video Imaging

The DPSC portable camera was used to image the furnace interior on the third, fourth, and sixth floors. These represent the black liquor gun level, secondary air level, and the screen tube level, respectively. These activities were recorded on two separate VHS videotapes. In addition, a full length (two hour) videotape was recorded of one of the two DPSC char bed camera images.

On the third floor, the lens was inserted into three different gun ports on the West wall (Left side) of the boiler to image the liquor sprays. On the fourth floor, the lens was inserted into a Front wall port to image the NW secondary air port and liquor sprays. On the sixth floor, the lens was inserted in front of the screen tube banks. These video images were subsequently analyzed to estimate liquor spray angles, spray penetration into the furnace, and the qualitative behavior of the sprays and gas flow patterns.

The char bed videotape was later studied to qualitatively describe the bed's shape, and its changing behavior with time and the gas flow patterns.

Operating Information to Set Up a Simulation

In order to properly set up a simulation, data on the feed air conditions, liquor firing conditions, and liquor properties were collected.

In addition to the primary, secondary, and total air mass flow rates that were acquired in the set of mill process data, the lower primary air port velocities were measured with a pitot tube in 65 of the 114 total lower primary air ports covering all four sides of the boiler. Unfortunately, the pitot tube failed while measuring the last set of lower primary air ports, and therefore, the secondary air port velocities were not measured. Inlet air temperatures for nine lower primary air ports (two or three per wall) and all four secondary air ports, were measured with a type K thermocouple.

Under routine operating conditions, a total of six as-fired black liquor samples were collected by mill personnel every two hours from 08:00 to 18:00 on 3/27/96, and three smelt samples were collected every four hours from 08:00 to 16:00 on 3/27/96. These were subsequently analyzed for elemental composition. The black liquors were also tested for higher heating value and single drop combustion behavior. Miscellaneous data, such as liquor gun nozzle size and shape, tilt angle, and liquor pressure in the main feed line, were determined during the on-site testing and afterwards.

Combustion Side Gas Information

Upper furnace gas temperatures were measured at the bullnose, primary superheater, boiler bank inlet and exit, and the economizer exit using a suction thermocouple probe. Mill process data was acquired for the carbon monoxide and oxygen concentrations in the stack and the excess oxygen concentration at the precipitator inlet.

Upper Furnace Deposit Information

A sampling probe was used in the upper furnace to collect a variety of fume samples which were subsequently analyzed for composition. The sampling locations were on the sixth floor, before and after the screen tubes, on the eighth floor, between the primary and secondary superheaters, and at the generating bank inlet. A sample of the precipitator dust was also collected, and the total dust production rate was estimated to equal the internal dust recycle rate.

Char Bed Information

The University of Toronto researchers carried out an extensive and lengthy experimental study to profile the temperature distribution of the char bed. They used a temperature probe consisting of a type K thermocouple embedded in a 3.7 m long closed end stainless steel tube and inserted it into the char bed until it hit the frozen smelt layer. The probe was then slowly withdrawn from the frozen surface in 5 cm increments, and at each increment, the temperature was allowed to stabilize before readings were taken. Numerous profiles were recorded in this manner at several locations around the bed. The location and temperature of the bed surface was then back calculated from the complete depth profile data.

This experimental protocol proved to be far more successful at correlating char bed surface temperatures measured by thermocouples with those determined by the bed camera's infrared pyrometer than the simplistic and brief experiments attempted by the IPST researchers who relied on a visual estimation of the location of the bed surface to make single point temperature measurements. They used a similar type of probe assembly consisting of a type K thermocouple inside a 316 stainless steel tube. This probe was inserted into the furnace at one corner access port so that it was visible in the bed camera image.

Because the Case One boiler ran with a low char bed, it was expected that the mixing behavior of the smelt bed approximated that of an ideal stirred tank reactor. To investigate this, the smelt bed retention time distribution was determined by means of a zinc sulfate tracer compound that was introduced into the furnace with the black liquor feed. The smelt was then sampled from both the East and West sides at varying time intervals for a total of five hours, and both smelt samples, and firing liquor samples were collected before the tracer addition, and a black liquor sample was collected at the conclusion of the experiment in order to establish baseline values for the tracer compound. The decay with time of the zinc concentration relative to the sodium and potassium concentrations was then later analyzed.

Char bed sampling was attempted by inserting a hollow stainless steel tube into the bed from a corner access port and then withdrawing it. This was a very simplistic approach and was largely unsuccessful. Each time a sample was retrieved, it appeared to slide back out of the tube, and/or burn up. Because the sampling was not conducted under inert atmospheric conditions, sample oxidation was unavoidable.

Characterization of the Test

Overall, the Case One validation test was a success. Despite encountering some problems during the on-site testing, the collaborative efforts of the team yielded an adequate body of data to meet the objectives of this model validation test.

The DPSC infrared camera was not as valuable a tool as had been expected. The right angle lens, which one of the IPST researchers had used previously, would have been more useful for imaging the liquor sprays than the wide angle straight lens that was used. Because of the camera's low resolution, individual drops and carryover particles could not be seen. The camera also required significant time and effort by two people to move, assemble, and use.

The measured air flow velocities were very sensitive to the relative position of the pitot tube in the air port, the relative position of the port rodder, and the degree of char build up on the port. In order to achieve accurate and consistent air port velocity measurements, a constant penetration depth of the pitot tube in the air port was maintained. This placed the measuring end at the approximate port opening.

The char bed temperature profile experiments performed by the University of Toronto researchers were very successful and yielded significant data. By contrast, it was difficult for the IPST researchers to correlate char bed surface temperatures measured by the thermocouple probe with those determined from the fixed bed camera's infrared pyrometer. Determining the location of the bed surface was very difficult; the transition from the gas phase to the char bed and the smelt bed was essentially imperceptible, and only the transition to the frozen smelt layer was obvious. Although the thermocouple lasted for more than 15 minutes in the furnace, as the probe assembly heated up, it rapidly lost mechanical strength and deflected to a bent shape. This made positioning the probe much more difficult. A higher strength stainless steel alloy, such as 310, should be used in the future.

Case Two

During July of 1996 testing was performed at a small recovery boiler with a rated capacity of 1.5 x 10^6 lb/day of black liquor solids. This work was performed as part of a project on recovery boiler modelling. An effort was made to collect a large set of data, which would be useful in the development and testing of computational fluid dynamics based models. With the cooperation of mill personnel, we were able to systematically vary the operating conditions of the recovery boiler and measure the response. This experimental trial was a joint effort by IPST, Radian Corp., and mill personnel.

General Approach

Originally, this mill was selected for study and application of the recovery boiler model as a part of a project on recovery boiler modelling which was funded by the state of Georgia. After discussions with the mill personnel the plan was modified to increase the amount of time and effort which would be spent on boiler measurements. Because the mill was in the unique situation of having adequate recovery boiler capacity on other two units, they were willing to give us a large degree of control over the operating conditions on the smaller #4 Recovery Boiler.

Subsequently Radian Corporation indicated an interest in participating in the boiler testing. Radian was attracted to the potential for the application of neural net models for the control of recovery boilers, especially in regard to the control of air emissions. As part of the testing Radian provided a complete stack testing trailer to monitor O2, CO2, CO, NOX, SO2 and TRS on a continuous basis.

IPST's part of the study was focused on obtaining physical measurements from the boiler which are not normally available, to help in the development and verification of the recovery boiler models. Individual air port velocities were measured using a pitot tube. Char bed temperatures were measured and recorded using a thermocouple probe inserted through the primary air ports. The char bed retention time was measured through the use of a zinc tracer added to the black liquor and by samples collected at the smelt spouts on regular intervals. In the upper furnace, near the bull-nose, gas temperatures were measured using an aspirated thermocouple probe.

During the period for which physical testing was performed, data were collected from the mill's data retrieval system. These data are stored in a PI data archive system which is connected to the mills distributed control system (DCS). The system contains a total of 166 variables that refer directly to recovery boiler #4. Eighty-one of these were selected as being most useful and the data were available for seventy-nine of these variables (these 81 variables are listed in Appendix B).

The data were collected for the time period from 8:00am on Sunday, July 14, 1996, until 8:00am on Saturday, July 20, 1996. These data were automatically recorded in a spreadsheet at five minute intervals.

During the entire one week test period, stack testing was also performed by Radian Corporation at recovery boiler (#4). These data were recorded once a minute and then later converted to five minute averages, to put the data in the same format as the mill data. Eleven more variables are contained in this data set (also listed in Appendix B).

Primary Test Variables and Average Operating Conditions

To provide a large data base for the neural net model, Radian wanted to vary the operating parameters at regular intervals. In contrast the manual measurements made by IPST required relatively long time periods at steady-state. The final test plan was a compromise between these two competing objectives. During the five days of testing, the controlled variables were changed for various lengths of time to give the desired operating conditions.

An analysis of the complete set of test data shows that there were 18 periods of steady operating conditions. These eighteen tests are listed in Table 1 below, along with the start and stop time for the test. The test periods vary in length from 55 minutes to 24 hours. In addition, there were periods of time where the operating conditions were not steady or the variables were in transition.

The main test variables that were studied during these tests (also listed in Table 1) were:

1) the boiler load (black liquor flow rate)
2) the air distribution between primary, secondary and tertiary
3) the amount of excess air
4) black liquor firing temperature

Additional data on the test conditions are listed in Table 2. The total air flow into the boiler is broken down by the three air levels, primary, secondary, and tertiary. The physical testing which was performed during this time period is also listed in the last column of the table.

A statistical analysis of all of the measured variables, during each of the 18 test periods, is included in the Appendix B. *For each variable the mean, minimum, maximum, standard deviation, and* number of data points are calculated.

Table 1. Steady-State Operating Conditions - Case 2

				Black Liquor		Total	Outlet	
Run #	Date	Start	Stop	Flow	Temp	Air	O2	Operating
		Time	Time	GPM	C	KPPH	%	Conditions
0	7/14/96	8:00		120	126	243	4.4	Pre-test
	7/16/96		8:00					
1a	7/16/96	9:20	12:50	120	126	229	4.1	Normal
1b	7/16/96	12:55	15:05	121	126	261	4.7	High Tertiary
1c	7/16/96	15:10	17:15	122	126	247	4.2	Med. Tertiary
1d	7/16/96	17:25	8:45	119	126	222	3.5	Normal
2a	7/17/96	9:00	14:05	121	126	195	3.4	No Tertiary
2b	7/17/96	14:20	17:00	137	126	250	2.7	High BL Flow
2c	7/17/96	17:40	8:10	101	125	193	4.6	Low BL Flow
3a	7/18/96	8:45	14:30	119	122	209	2.9	Low BL Temp
3b	7/18/96	14:40	16:55	120	129	226	3.4	High BL Temp
3c	7/18/96	17:00	17:55	119	130	203	3.4	High BL Temp
3d	7/18/96	18:20	23:35	119	121	201	2.2	Low BL Temp
4a	7/18/96	23:45	1:45	120	121	220	2.5	Low Tertiary
4b	7/19/96	2:30	6:20	120	121	259	4.1	Med. Tertiary
4c	7/19/96	6:50	8:30	120	122	260	4.5	Med. Tertiary
4d	7/19/96	8:40	14:10	120	122	225	3.5	Low Tertiary
4e	7/19/96	14:15	15:40	120	121	212	2.6	Zero Tertiary
4f	7/19/96	16:20	8:00	119	121	224	3.0	Low Tertiary

Table 2. Measurements Made at Steady-State Conditions - Case 2

	Black Liquor		Inlet Air Flow				Outlet	
Run #	Flow	Temp	1°	2°	3°	Total	O2	Measurements
	GPM	C	KPPH	KPPH	KPPH	KPPH	%	
0	120	126	120	103	20	243	4.4	
1a	120	126	95	105	29	229	4.1	Port Velocity Bed Temp
1b	121	126	94	95	72	261	4.7	Stack Test
1c	122	126	101	94	52	247	4.2	Stack Test
1d	119	126	97	97	27	222	3.5	Stack Test
2a	121	126	101	94	0	195	3.4	Zn Tracer Test Gas Temp
2b	137	126	104	102	44	250	2.7	Port Velocity Gas Temp
2c	101	125	98	96	0	193	4.6	Stack Test
3a	119	122	102	106	0	209	2.9	Gas Temp
3b	120	129	101	103	22	226	3.4	Gas Temp
3c	119	130	99	104	0	203	3.4	Stack Test
3d	119	121	96	103	2	201	2.2	Stack Test
4a	120	121	101	105	15	220	2.5	Stack Test
4b	120	121	103	111	45	259	4.1	Stack Test
4c	120	122	109	109	42	260	4.5	Stack Test
4d	120	122	104	106	14	225	3.5	Stack Test
4e	120	121	104	109	0	212	2.6	Stack Test
4f	119	121	97	103	24	224	3.0	Stack Test

Measurements and Data Collection

This section contains a general description of the measurements that were made or attempted, along with a summary of results. The complete data set is included below in the section on Data for Case 2 and in the attached Appendices.

Air Port Velocities

Recovery Boiler #4 is constructed with a total of sixty primary air ports, fifteen on each wall. A thorough analysis of primary port velocity was made during Test 1a. Using a pitot tube the velocity was measured at nearly every other air port. For each of the primary ports two individual readings were made. These correspond to a low and a high position within the port.

The boiler has a total of ten secondary air ports - five on the right wall and five on the left wall. The velocity was measured at each of these ports during Test 1a. Four measurements were made at each port opening, one high one low, and two in the middle.

The air port arrangement at the tertiary level consists of four air ports on the rear wall and three air ports on the front wall. These ports are arranged in an interlaced configuration. In general, this mill uses low tertiary velocities. These air port velocities were also measured during Test 1a.

Using the measured velocity and the known air port dimensions the total primary air flow rate can be calculated and compared with the value from the control system.

Char Bed Temperatures

Char bed temperatures were measured and recorded using a thermocouple probe inserted through the primary air ports. These measurements were made on July 16, 1996, during Test 1a. The readings were obtained using a type K thermocouple supported by a probe fabricated from ½" SS(310) pipe, approximately 12 ft long. Readings were taken at four different port locations on the north and south walls. The probe was inserted into the boiler from 1 to 7 ft.

The temperatures measured at or above the char bed surface were hotter than those measured below the surface. The average temperature for the above surface measurements was 1170 C, the minimum was 940 C and the maximum was 1200 C. Below the char bed surface the average temperature was only 877, the minimum was 688 and the maximum was 1026 C.

Smelt Retention Time

The char bed retention time was measured through the use of a zinc tracer added to the black liquor. A zinc sulfate solution was added to the black liquor at the mix tank overflow box. The tracer was added over a relatively short time period (2.5 minutes). Samples were collected at the smelt spouts at regular intervals. These samples were analyzed for zinc and by comparing the zinc level to the baseline value, a retention time distribution was plotted. The tracer test was conducted on July 17, during Test 2a.

Analysis of the results showed that the retention time distribution was only a fair approximation to that of a continuously stirred tank reactor (CSTR) with a retention time of 160 minutes. This corresponds to a smelt volume which would be 13" deep over the floor of this furnace.

Upper Furnace Temperatures

In the upper furnace above the bull-nose, gas temperatures were measured using an aspirated thermocouple probe. Measurements were made on July 17 during test 2a and 2b and on July 18 during test 3a and 3b. The probe was inserted at three ports across the front of the boiler on the 5th floor. The probe was inserted from 2 to 8 ft into the boiler. These readings correspond to locations near the screen tubes and the first set of superheaters. The gas temperature ranged from 540 C to 840 C.

Black Liquor Samples

Nine black liquor samples were collected at various times throughout 7/16, 7/17, and 7/18/96 and consist of three "virgin" samples (concentrated liquor without the recycled saltcake added in), and six "as-fired" samples. An elemental analysis (along with the heating value) for the liquor was performed for several of these samples and the measured values are quite typical for black liquor.

Burning tests were performed on one black liquor sample in the IPST Single Particle Reactor. In this reactor a single drop of black liquor (approximately 10 mg) is suspended on a wire in a high temperature environment (700 C). The drop is also subjected to an upward flowing gas with a velocity of about 1.86 m/sec to simulate a recovery boiler environment. By analysis of the video the time for each of the burning stages is determined along with the amount of swelling.

Stack Gas Sampling

As mentioned above, stack testing was performed by Radian Corp. during the entire one week test period, at recovery boiler (#4). These data were recorded once a minute and then later converted to five minute averages, to put the data in the same format as the mill data. Eleven different measurements were recorded (O2, CO2, CO, NO, NO2, NOx, SO2, TRS, Temp, RH, BP).

Case Three

The third case presented in this report is for flow model benchmarking purposes for other CFD modeling studies. The case chosen is an isothermal flow experiment carried out at UBC in a scale model of a Babcock & Wilcox recovery boiler. The model boiler is a water model on a 1:28 scale of a recovery boiler located in a Weyerhaeuser mill in Kamloops, British Columbia. The model walls are transparent, to allow laser doppler velocimeter measurements at different elevations.

In addition to the descriptions of the model geometry and operating conditions, and the velocity measurements, computational output for a CFD simulation of this case with the UBC code is also included.

DATA FOR CASE ONE

Introduction

As was discussed previously, the overall objective of this model validation test was to acquire sufficient data to (1), properly, and completely set up a CFD simulation of the case one boiler using the UBC code, and (2), evaluate the validity of the model by comparing the predicted boiler performance from the simulation results to the actual performance as measured by the acquired process and analytical data.

The data set for case one's recovery boiler consists of furnace geometry and layout information, operating information relating to liquor side, air side, and steam side process data, and actual boiler performance data, such as velocity fields, temperature fields, gas composition fields, and liquor and char bed behavior. The bulk of this data is presented in the appendix in the form of drawings of the furnace geometry, and graphs and tables of measured physical properties and acquired process data. A review of the plots of the process data indicate that the boiler was operating under steady state conditions during the time of this validation test. In the next three sections, this data is summarized in tabular form and accompanied by a brief discussion.

Recovery Boiler Geometry and Layout Data

The recovery boiler is a Combustion Engineering low odor design built in 1982 and rated at 3.7 million lb per day black liquor solids firing capacity, although it is currently operating at approximately 112% of capacity. Drawings of the boiler, with selected features and dimensions identified, are provided in the Appendix. This information is also summarized in Tables 3 and 4 below.

The orientation of the furnace is such that the Front wall, Rear wall, Left Side wall, and Right Side wall correspond to the compass directions of South, North, West, and East, respectively. For the purposes of setting up the computer simulation of the boiler, the origin of the x, y, z coordinate system used here, i.e. (x, y, z) = (0, 0, 0) was arbitrarily set to be the corner where the Front wall, the Left side wall, and the Floor meet.

Table 3. Furnace Orientation and Layout

Furnace or Level	Process Feature	Comments
First (Ground) Floor	Smelt Dissolving Tanks	
Second Floor	Primary Air Ports, Smelt Spouts	Upper primaries closed
Third Floor	Black Liquor Gun Ports, Control Room	
Fourth Floor	Secondary Air Ports	
Sixth Floor	Bullnose, Screen Tubes	
Eighth Floor	Screen Tubes, Superheater Tube Banks	

The boiler has a two level air system with both lower and upper primary air ports on the second level, and secondary air ports on the fourth level. These ports are distributed as follows:

- Lower primary air ports (114 total): 26 on the Front and Rear walls, and 31 on the Left and Right side walls.
- Upper primary air ports (36 total): Nine ports on each wall.
- Secondary air ports (4 total): One port on each corner.

The lower primary air ports have automatic port rodders, and the dampers were set wide open. The upper primary air ports were not in use during this validation study. The dampers are kept closed, but they are not permanently sealed off. Since this testing was conducted towards the end of an operating cycle, it was assumed that the upper primary ports were completely slagged over.

The secondary ports are located on each corner of the boiler and are oriented to supply air in a concentric flow pattern. Each windbox consists of five separate ducts. Two of these ducts are for the gas guns and ignitors. During normal operation, these ducts are kept closed, but there is likely some leakage air coming through. The remaining three ducts are run wide open.

Black liquor is sprayed into the furnace through 16 straight pipe guns (four on each wall), and the smelt drains out through eight spouts (four on the Left side and four on the Right side). The steam generating section in the upper furnace is a two drum design, and the pendant tube banks consist of furnace screen tubes, and rear, center, and front superheater tube banks.

Table 4. Furnace Dimensions

Dimensions	Distance, in. (m)	Comments
Floor	z = 0 (0)	
Width	x = 395 (10.03)	
Depth	y = 359 (9.12)	
Height to Roof	z = 1,568 (39.83)	
Height to Nose Arch (start/bottom/top)	z = 977 / 1,025 / 1,064 (24.82 / 26.04 / 27.03)	
Nose Arch Protrusion into Furnace	y = 88 (2.24)	
Height to Mud Drum center	z = 1,260 (32.00)	
Height to Steam Drum center	z = 1,608 (40.84)	
Port Locations	Centerline Elevations above Floor, in. (m)	Dimensions (width x height), in.; Total Area, $in.^2$
Smelt Spouts	z = 15.63 (0.397)	8 x 12, elliptical; 603
Lower Primary Air Ports	z = 42 (1.067)	1.88 x 6.69; 1,434
Char Bed Cameras; Gas Burners	z = 66.4 (1.686)	Not measured
Upper Primary Air Ports	z = 72 (1.829)	1.88 x 6.0; 406; Not used
Black Liquor Gun Ports	z = 262 (6.655)	4.5 x 12; 864
Secondary Air Ports	z = 405 (10.29)	See Appendix A; 1,230

Note: the reference elevation for the floor is z = 0 in. (0 m) which is measured at the floor tube centerline. The boiler width and depth are measured from the appropriate waterwall tube centerlines.

Recovery Boiler Operating Data

Air Side

The complete set of process data downloaded from the mill's data acquisition/process control system is presented in Appendix A. Overall mean values for the primary, secondary, and total air flow rates have been included in the summary presented below. As mentioned previously, only the primary air port velocities were measured because the pitot tube failed before others could be measured.

Table 5. Air Side Operating Information

Parameter	Value	Comments
Primary air flow	366.0 klbm/hr	
Secondary air flow	304.1 klbm/hr	
Total air flow	670.2 klbm/hr	
Primary air velocities	53.42-64.70 m/sec	Complete data in Appendix A.
Secondary air velocities	Not measured	Calculated values given in Appendix A.
Primary & secondary port dampers	Set wide open	Upper primary dampers closed.
Static pressures in primary and secondary windboxes	Not measured	Calculated values given in Appendix A.
Primary air port temperatures	129-133 °C	Range for 9 ports tested (2 or 3 per wall).
Secondary air port temperatures	119-128 °C	Range for all four secondary ports.
Leakage air through burner ports	Not measured	Calculated value given in Appendix A.
Furnace draft	-0.1 in. water	Two taps located on Front/Right wall, one tap located on Front/Left wall.

Black Liquor Firing Conditions

Mean valves for the black liquor flow rate, solids, and temperature, for the 48 hour test period, are presented in Table 6. The complete process data is given in Appendix A. The on-line black liquor solids data from both refractometers reported Appendix A was considered to be inaccurate, and was replaced in Table 6 by off-line generated solids data from a Computrac solids analyzer. Liquor spray parameters--spray expansion angle, spray distance into furnace, and spread of spray into furnace, were estimated from the infrared video images obtained with the DPSC camera.

Table 6. Black Liquor Firing Conditions

Parameter	Value	Comments
Number, location, and type of liquor guns	16 guns (four per wall); 1.5" Sch. 40 pipe	Exact location of gun openings given in Appendix A.
Nozzle size	ID = 1.61 in.	
Gun tilt angle	15° down	
Flow rate to furnace	358.7 gpm	
Temperature	130.3 °C	
Pressure to nozzles	15 psig	Measured from main line before split to individual nozzles.
Solids content (as-fired)	71.3 %	Mean of Computrac solids data.
Initial Drop Velocity	4 m/sec	Guesstimate accounting for liquor flashing.
Mean drop diameter	3.25-4.5 mm	Estimated from spraying correlations for V-jet nozzles.
Spray expansion angle	10° total spray angle	Estimated from videos.
Spray distance into furnace	10-12 ft.	Estimated from videos.
Spread of spray into furnace	18-20 in. spray diam. after 6 ft. penetration	Estimated from videos; consistent with a 10° total spray angle.

Black Liquor Properties

A compositional analysis of the black liquors was performed using standard analytical techniques. The data is presented in Table 7 and represents mean values for the six samples collected. Single drop combustion tests were also performed on one liquor sample and this data is presented in Table 8.

Table 7. Black Liquor Elemental Analysis

Analyte	Concentration, Wt. %
Total Carbon	35.72
Organic Carbon	35.36
Inorganic Carbon	0.36
Hydrogen	4.15
Oxygen	34.59
Sulfur	4.86
Chloride	0.57
Sodium	17.70
Potassium	3.34
Total	100.92
Higher Heating Value	6,456 Btu/lbm

Table 8. Black Liquor Single Particle Combustion Tests

Combustion Phase	Time
Drying (Start to Ignition)	1.9 sec
Pyrolysis (Ignition to Max. Volume)	1.5 sec
Char Burning (Max. Vol. to Smelt Bead)	10.5 sec
Total Combustion	12.0 sec
Swelling Measurements	*Specific Volume, cc/g*
Swelling at Ignition	17.39
Maximum Swelling	34.38
	Drop Diameter Ratio
Diam. At Ignition/Initial Diam.	2.87
Diam. at Max. Volume/Initial Diam.	3.60

Recovery Boiler Performance (Output) Data

Steam Side Performance Data

Performance data is used to test the validity of the boiler simulation. Included in the set of process data downloaded from the mill's data acquisition/process control system, and presented in Appendix A, are a number of steam side flow rates, temperatures, and pressures. Overall mean values for these parameters are provided in Table 9. Several parameters were not measured or recorded: boiler drum pressure, attemporator flow rate, and attemporator temperature.

Table 9. Steam Side Performance Data

Parameter	Value	Comments
Final steam flow rate	535.0 klbm/hr	
Final steam temperature	422.2 °C	
Final steam pressure	899.1 psig	
Superheater #1 inlet pressure	956.2 psig	
Superheater #2 exit temperature	426.3 °C	
Superheater #2 outlet pressure	861.2 psig	
Superheater #3 inlet temperature	389.0 °C	
Sootblower steam flow rate	56.25 klbm/hr	Drawn from the final steam line.
Feedwater flow rate	594.3 klbm/hr	
Feedwater temperature	138.9 °C	
Boiler exit temperature	378.2 °C	
Economizer exit temperature	217.7 °C	
Heat absorption in furnace waterwalls	6,900 kBTU/min	Approximation

Combustion Side Gas Information

Gas temperatures and concentrations in the upper furnace are additional performance data that can be used to test the validity of the simulation. A suction thermocouple probe was used by the University of Toronto researchers to measure gas temperatures at various locations in the upper furnace. This data is presented in Table 10. Mill process data was acquired for the carbon monoxide and oxygen concentrations in the stack and the excess oxygen concentration at the precipitator inlet. This data is presented in Table 11. Complete data for the excess oxygen concentration is given in Appendix A.

Table 10. Upper Furnace Gas Temperatures

Location	Low Temp., °C	High Temp., °C	Ave. Temp., °C
Bullnose	970	992	985
Primary Superheater	703	740	714
Boiler Bank Inlet	575	623	595
Boiler Bank Exit	370	388	379
Economizer Exit	199	233	218

Table 11. Mill Data on Combustion Gas Analysis

Gas	Concentration	Comments
Carbon monoxide	600-650 ppm	Measured in the stack.
Oxygen	8.6%	Measured in the stack.
Excess Oxygen	2.69%	Mean value, measured at precipitator inlet.
Sulfur dioxide, Total Reduced Sulfur	Not provided	

The videotapes were studied to determine gas velocities and flow patterns based on paths taken by suspended particles. Due to the poor image resolution, and the nonlinearities inherent in the wide angle images, this was largely unsuccessful, and only rough qualitative observations were made. At the fourth floor, the gas circulation pattern was very variable, but appeared to be in a cyclonic pattern. At the third floor, there was significant gas turbulence.

Upper Furnace Deposit Information

Fouling and plugging of the upper furnace heat transfer surfaces due to the deposition of fume and carryover particles is an important operating condition that must kept in check. As part of an ongoing program to study this phenomenon, Honghi Tran and his research group collected fume samples at various locations in the upper furnace and subsequently analyzed them for composition. These data are presented in Table 12 and are mean values normalized to 100%. They cover an extended period of time, including March, 1996, but are weighted to prior time periods. From experience, the fume composition has remained relatively constant.

Table 12. Upper Furnace Fume Composition

Sampling Location	Na, wt. %	K, wt. %	Cl, wt. %	SO_4, wt. %	CO_3, wt. %
6th Floor—before Screen Tubes	29.6	4.8	1.8	60.1	3.7
6 th Floor—after Screen Tubes	28.3	6.4	4.8	57.7	2.8
8th Floor—between Primary & Sec. SH	29.3	6.8	2.2	54.3	7.4
8th Floor—at Generating Bank Inlet	29.3	6.8	2.2	54.3	7.4
Precipitator Dust	29.1	6.8	1.4	56.7	6.0

The rate of total dust production (fume generation), however, was not directly measured, but was estimated to equal the internal dust recycle rate of eight to ten weight percent of the black liquor solids firing rate. This corresponds to approximately 6,400 to 8,000 kg/hr. Carryover particle flows were not measured, and the mill also claims to not have a fouling problem.

Char Bed Information

The qualitative behavior of the char bed over a two hour time period was captured on videotape from the Northwest corner DPSC bed camera image. For modeling purposes, the bed remained essentially flat. The char bed actually displayed gently varying mounds, depressions, and ridges that gradually grew, shrank, and changed position. The surface constantly shifted between lighter and darker micro- and macrodomains, indicating regions of higher and lower temperature, respectively. Temporary localized dark (cold) spots on the bed surface were created by char particles from the liquor sprays and larger masses of char that sloughed off the walls and landed on the bed. Mounds also periodically broke apart and collapsed and thereby created additional temporary areas of colder bed surface.

Temperature mapping of the char bed surface was not possible, but overall surface temperatures were recorded from the DPSC char bed cameras' Fireside Advisory System (FAS): 1,086°C for the Front/Right (Southeast) camera, and 1,132°C for the Rear/Left (Northwest) camera. These are mean temperatures for the 48 hour time period of 3/27 through 3/28/96; plots of the complete data are in Appendix A. Although the through-the-lens pyrometer for each of the two fixed bed cameras provided approximate surface temperatures for four different areas of the bed, there was no correlation between these measurement areas and the physical dimensions of the bed. The measurement areas were defined during normal furnace operation, and there was no opportunity to match their visual locations with actual ones in the furnace during a shut down.

Temperature profiles of the char bed interior, showing the variation in temperature with approximate vertical depth, were generated from thermocouple probe measurements made at various times and are presented in Appendix A. Significant results extracted from these profiles are listed in Table 13 and represent average values for five profiles.

Table 13. Char Bed Temperature Profiles

Parameter	Value	Comments
Thickness of molten smelt layer	0.16 m	
Temperature of molten smelt layer	750°C	Std. dev. = 15°C. Variation for one profile: 7-32°C.
Thickness of char layer/combustion zone	0.46 m	Std. dev. = 0.05 m. Overall range = 0.38-0.51 m.
Surface height above frozen smelt	0.62 m	Std. dev. = 0.05 m. Overall range = 0.54-0.67 m.
Surface/gas phase temperature	1,083°C	Std. dev. = 36°C. Variation in gas phase temp. for one profile = 4-25°C

From the small standard deviations, it is evident that the bed temperature and height remained relatively constant, and the thickness of the molten smelt layer essentially did not change. The char layer/combustion zone displayed a rapid temperature increase.

Sampling the char bed by means of a hollow stainless steel tube proved to be unsuccessful as discussed previously. To properly sample the char bed and avoid sample oxidation would require a continuous purge of the entire sampling process with an inert gas such as nitrogen. Unfortunately, constructing a sampling probe capable of this, and using it properly, would be a difficult and cumbersome task.

This mill has eight smelt spouts (four on the East side and four on the West side), and the smelt appeared to run heavier from the West side than from the East side. The boiler floor is probably sloped slightly toward the West side. Smelt temperatures were not directly measured, but the smelt composition was determined by standard analytical techniques. This data is presented in Table 14, and represents mean values for the three samples collected.

Table 14. Smelt Composition

Analyte	Concentration, Wt. %
Total Carbon	7.97
Organic Carbon	0.16
Inorganic Carbon	7.81
Hydrogen	0.54
Oxygen	38.52
Sulfur	9.23
Sodium	36.98
Potassium	5.40
Total	98.65

The smelt bed residence time distribution (RTD) experiment, utilizing a zinc sulfate tracer compound, confirmed the expectation that the mixing behavior of the smelt bed approximated that of an ideal stirred tank reactor. Plots showing the time decay of the zinc concentration, for both the East and West sides, are given in Appendix A. Significant data extracted from these plots is presented in Table 15 below.

Table 15. Smelt Bed Residence Time Distribution

Parameter	Value	Comments
Time Constant: East Side / West Side / Mean Value	76 / 63 / 70 min.	Na reference
Composite Time Constant: East+West Sides	78 min.	Na reference
Smelt Bed Depth	8 in.	Na ref.; est. using mean time const.
Zinc Recovery	88% / 107%	Na reference / K reference

The smelt bed depth was estimated from the mean time constant, black liquor solids firing rate, boiler cross sectional area, an assumed smelt density of 120 lbm/ft^3, and an assumed 40 percent of the liquor solids ending up in the smelt.

DATA FOR CASE TWO

This section is intended to provide a detailed summary of the data collected Recovery Boiler #4. This data could be useful in the development and application of recovery boiler models and for others working this field.

Recovery furnace geometry and layout data

Drawings depicting the furnace geometry, dimensions and locations of the tube banks, dimensions and locations of air ports, black liquor gun ports, and other burner openings are provided in this section. A summary of the overall furnace dimensions is listed below in Table 16. Figure 1 is a drawing of the entire boiler from the right side.

Table 16. Overall Furnace Dimensions

Overall Dimensions	Distance, in (m)	Comments
Width	266 (6.76)	Side to side
Depth	254 (6.45)	Front to rear
Height to Roof	1,104 (28.05)	
Height to Center of Nose Arch	679 (17.26)	
Nose Arch Protrusion into Furnace	77.1 (1.96)	
Furnace Orientation		Front = West, Rear = East, Left = North, and Right = South
Floor elevation	621' 6" (189.43)	

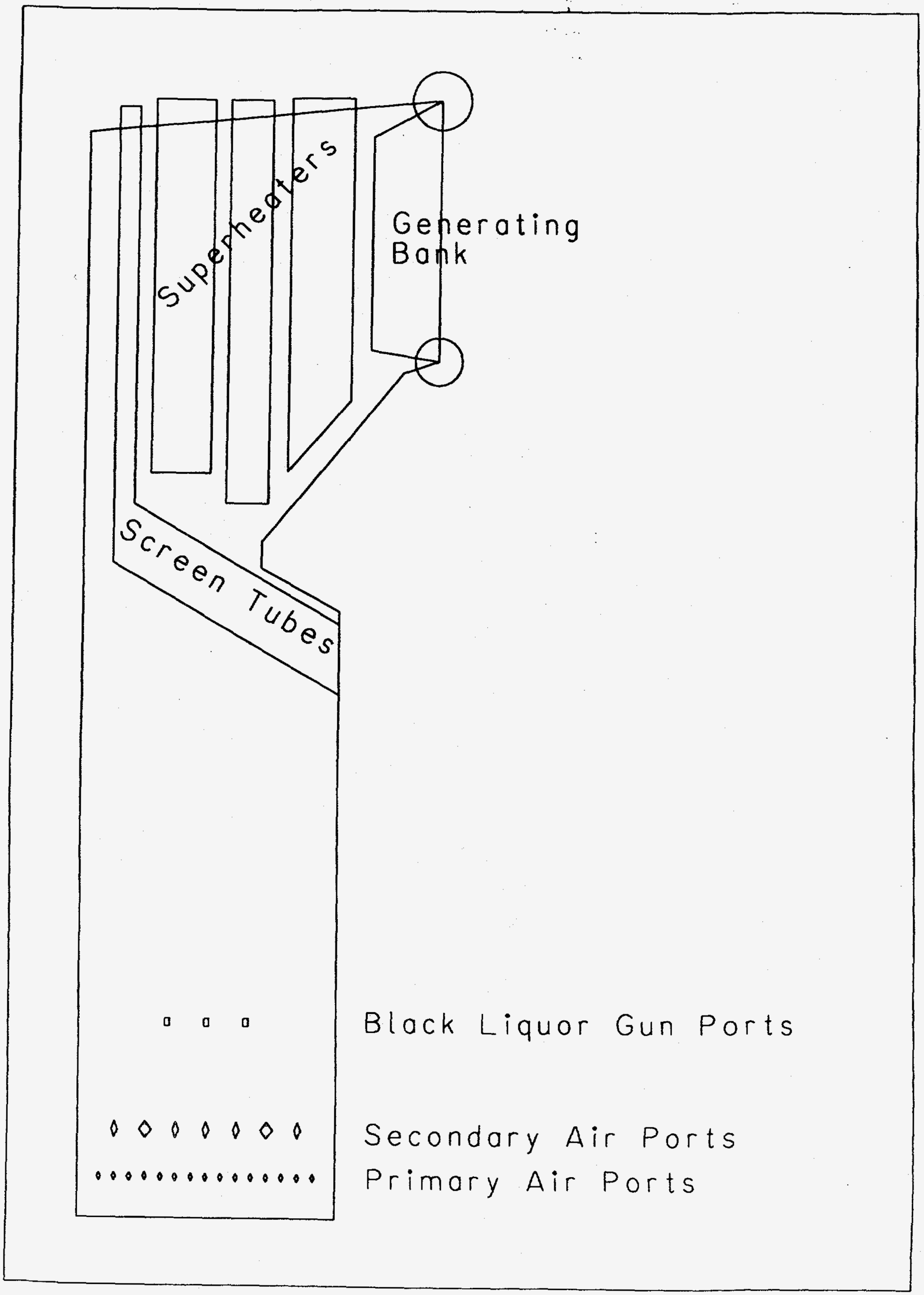


Figure 1. Overall Furnace Right Elevation

Air Port Size and Arrangement

The arrangement of the air ports and other openings to the boiler are described in this section. Table 17 contains the critical dimensions for all of these ports. In addition, the port arrangement is shown in Figures 2 and 3.

The primary ports are located at an elevation of 42 inches above the floor (to the centerline), with 15 on each wall for a total of 60 ports. Horizontally the ports are spaced 15 inches from centerline to centerline. Each port has an opening area of 18.1 in2. The air ports are roughly diamond shaped, so that the area corresponds to about one half of the width times the height.

The secondary ports are located at an elevation 91 inches above the floor, five on both the right and left walls. Both the primary and secondary ports are symmetric with those on the opposite wall. The tertiary ports are located at an elevation of 318 inches. There are three ports on the front wall and four ports on the rear wall in an interlaced configuration.

There are also 3 smelt spouts on the front wall of the furnace at an elevation of 12 inches. The black liquor gun ports are arranged at an elevation of 201 inches. There are three gun ports on both the right and left wall on a 39 inch centerline spacing. The current firing practice at the mill is to use only the two outside gun ports on each wall, so the center port on each wall is closed off.

Table 17. Air Port Arrangement

Air Level	Side	Elevation (in)	Number of Ports	Horizontal Spacing (in)	Port height (in)	Port width (in)	Individual Port area (in^2)	Total Port area (m^2)
<u>Smelt Spouts</u>								
	Front	12	3	48	6.5	4	18.1	54.4
<u>Primary Ports</u>								
	Left	42	15	15	9	4	18.6	279.0
	Right	42	15	15	9	4	18.6	279.0
	Front	42	15	15	9	4	18.6	279.0
	Rear	42	15	15	9	4	18.6	279.0
	All	42	60	15	9	4	18.6	1116.0
<u>Secondary Ports</u>								
	Left	91	5	30/60	17	6	55.8	279.0
	Right	91	5	30/60	17	6	55.8	279.0
	All	91	10	30/60	17	6	55.8	558.0
<u>Gun Ports</u>								
	Left	201	3	39	8	5	40.0	120.0
	Right	201	3	39	8	5	40.0	120.0
	All	201	6	39	8	5	40.0	240.0
<u>Tertiary Ports</u>								
	Front	318	3	39	13	6	43.4	130.2
	Rear	318	4	39	13	6	43.4	173.6
	All	318	7	39	13	6	43.4	303.8

resulting particulates to the melt body, akin to the operation of the baghouse roughing filter in the Pit 1 project. Both lead and zinc, although present at only normal background concentrations in Pit 1 soils, were found to be significantly volatile in the ISV process and a major portion of their inventory was contained in the filter particulates.

During the melt expulsion, a calculated volume of 230,000 standard L of off-gas was released in an uncontrolled mode as the pressurized hood was lifted from the ground surface. Off-gas sampling during this event revealed that the activity of ^{137}Cs in the off-gas was 0.93 dpm/L resulting in a total release of 9.6×10^{-8} Ci. Using worst-case meteorological assumptions of wind speed, direction, and dispersion, such a release could have delivered a hypothetical and insignificant dose of 0.015 μrem to the nearest resident over 2 km away. Were an ISV melt body, containing over 10,000 Ci of ^{137}Cs , to experience a similar melt expulsion, a correspondingly larger hypothetical dose of 55 μrem could be delivered to an individual at the same location. This is well below the DOE administrative limit of 10 mrem/yr for the general public. Although no preventable uncontrolled release is justified, this calculation puts into perspective the magnitude of the risks posed by ISV even under such a worst-case accident scenario.

Among the treatability study's original objectives, the demonstration of ISV product quality, depth capability, and off-gas handling capability, even considering the unplanned melt expulsion, have been well established by the results reported here. The objective to demonstrate site characterization techniques to establish ISV targets and to plan ISV operations is addressed in the site characterization report (see Volume 2). The objective to demonstrate melt setting overlap capability was not attained because the project was suspended after the melt expulsion and neither the second nor third melt settings were attempted. However, since the conception of this project in 1993, Geosafe Corp. has clearly established this capability for ISV by producing 37 overlapping large-scale melt bodies at the Wasatch Chemical site in Salt Lake City in 1995 and other large, overlapping melts in Michigan and Washington. The remaining objective, to establish public confidence in ISV technology, has clearly not been fulfilled due to the melt expulsion incident and its perceived results and implications. The implementation and selection of ISV technology for remediation of the WAG 7 seepage pits and trenches or other waste management units in Oak Ridge will require a considerable effort to involve the public in the decision process and, thereby, increase their appreciation of its benefits. The main findings of this Pit 1 treatability study are the excellence of the ISV waste form, compared to any other technology, and the inherent conservatism of the process with respect to off-gas release of radioactivity during normal and accident situations. Much remains to be understood as to the proper economic comparison of ISV with other technical options for Oak Ridge contaminated soils, particularly the inherently large costs associated with any technology requiring long-term monitoring. The ability to prevent, control, and endure melt expulsions during ISV operations needs to be factored into the expected operating cost, as well as programmatic and public expectations. Increased and continued experience with ISV operations in very humid regions with saturated soil near the ground surface, like Oak Ridge, will, by necessity, result in empirical procedures, practices, and strategies which will minimize the probability of future melt expulsions. These risks are small and manageable compared to the enormous benefits of essentially permanent and complete waste isolation of radioactive contaminants from virtually all future environmental transport.

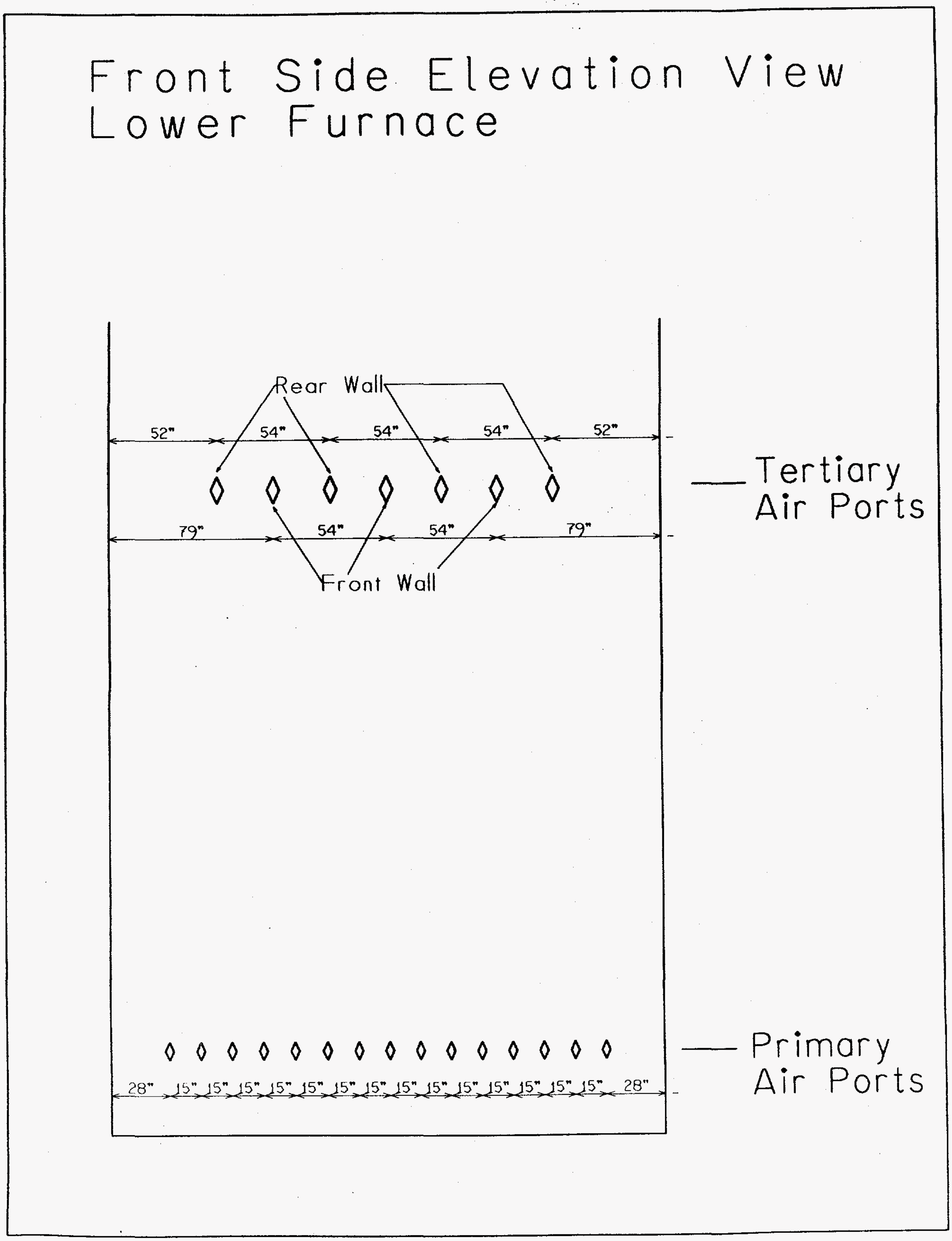


Figure 3. Air Port Arrangement - Front Elevation Lower Furnace

Upper Furnace

The arrangement of the heat transfer surfaces in the upper furnace are list in Table 18 below. In addition the arrangement is shown schematically in Figure 4. The bottom of the Primary I Superheater is slanted to match the slope of the bullnose. On the high side the bottom is at an elevation of 834" above the floor and the low side is at 762". The dimensions given for the screen tubes are for the vertical section only, but the tubes also continue down past the bullnose, at a slope of 30°.

Table 18. Arrangement of the Heat Transfer Surfaces in the Upper Furnace

	Z-Spacing		X-Spacing			Y-Spacing	
	Top	Bottom	No. of	Tube	Overall	No. of	Platen
Section	Elevation	Elevation	Tubes	Spacing	Size	Platens	Spacing
	(in)	(in)		(in)	(in)		(in)
Primary I Superheater	1140	762	20	3.1	61	17	15-3/8
Primary II Superheater	1138	730	20	2.1	42	33	7-11/16
Secondary Superheater	1138	760	15	4	59	17	15-3/8
Screen Tubes	1130	669	12	2.5	30	17	15-3/8

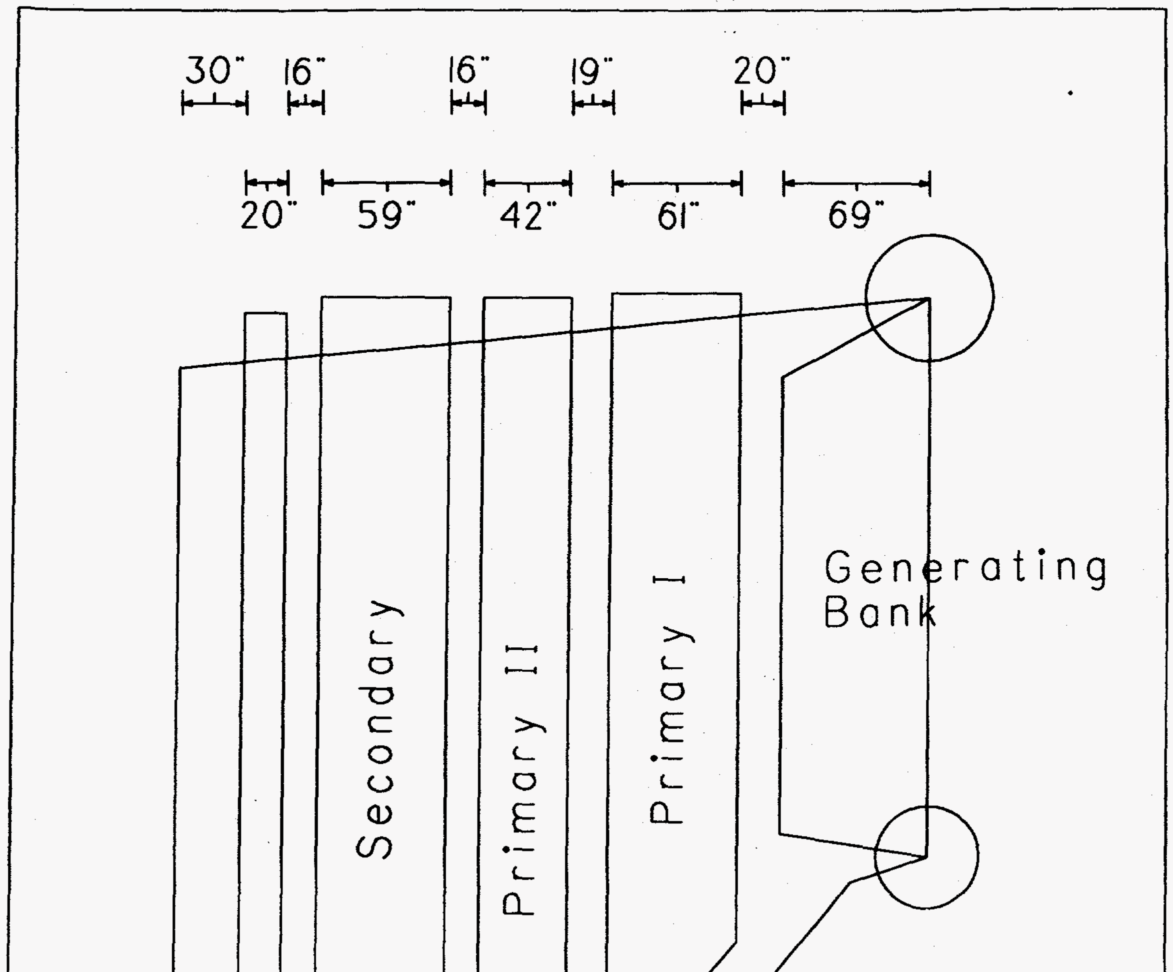


Figure 4. Upper Furnace Arrangement - Heat Transfer Sections

Recovey Boiler Operating Data

The operating conditions for the tests performed are described in the section below. This data represents the input data for the application of recovery boiler models. There were eighteen different steady-state test conditions during this mill trial. Data from the mill control system and gas sampling systems were collected on a continuous basis. A statistical summary of the data collected from the mill control system is attached in Appendix B. This includes the average, range, and standard deviation for each of these variables, for each of the 18 test conditions. Other more specific testing was performed only during limited time periods. This additional data is described in the following section on performance data.

Air Inlet Conditions

The air flow into the furnace is a critical parameter in the application of CFD models to a recovery boiler. In Table 19 below the air flow rate to each of the three air levels is given for all eighteen cases. The temperature of the inlet air is also contained in this table. The air to the primary and secondary levels is preheated and the temperature leaving the air heater is given below. The air to the tertiary level is unheated and that temperature is also given. The table also contains the air pressure in the ducts feeding the air ports.

Using this data and the information on the air port dimensions, from the previous section it is possible estimate the inlet gas jet velocities. For one case (1a) the velocities were measured to verify the calculated results.

Black Liquor Firing Conditions

Another crucial parameter in the application of recovery boiler simulations is the black liquor firing conditions. This mill uses four Tampella nozzles (24mm diameter), two on the left and two on the right wall. Information on the firing conditions is listed below in Table 20. The flow-rate is "as-fired", measured after the salt-cake mix tank. The solids content from the mill control system, the liquor temperature and the nozzle pressure are also listed.

Nine black liquor samples were collected at various times, from July 16 to 18, 1996, during the mill trial. They consist of three "virgin" samples (concentrated liquor without the recycled saltcake added in), and six "as-fired" samples. An elemental analysis (along with the heating value) was performed on five of the liquor samples (one virgin and four as-fired). The average values for the "as-fired" liquor samples are listed below in Table 21. There was little variation between the individual samples and the average results are expected to be representative of the liquor during the entire test period. The measured values are quite typical for black liquor.

Burning tests were performed on the same black liquor sample in the IPST Single Particle Reactor. In this reactor a single drop of black liquor (approximately 10 mg) is suspended on a wire in a high temperature environment (700°C). The drop is also subjected to an upward flowing gas with a velocity of about 1.86 m/sec to simulate a recovery boiler environment. By analysis of the video the time for each of the burning stages is determined along with the amount of swelling. The results of this test are listed in Table 22 below.

Table 19. Air Inlet Conditions

	Air Flow	--- Secondary ---					Gas Temperatures		Duct Pressures			
Run #	Primary	North	South	Total	Tertiary	Air-Total	Air Heater	Tertiary	Primary-Duct	Second-North	Second-South	Tertiary-Duct
	KPPH	KPPH	KPPH	KPPH	KPPH	KPPH	DEG F	DEG F	"H2O	"H2O	"H2O	"H2O
0	119.7	52.8	48.2	101.0	19.4	240.1	296.2	114.9	2.584	9.933	7.170	2.274
1a	95.0	56.3	48.0	104.3	28.5	227.8	298.4	109.6	1.693	9.241	5.484	2.793
1b	94.0	51.7	41.6	93.3	72.2	259.5	301.6	114.3	1.735	6.933	4.271	11.535
1c	100.7	51.2	41.3	92.5	52.3	245.5	301.9	117.9	1.897	6.343	4.066	6.496
1d	97.1	51.7	45.4	97.0	27.2	221.3	300.8	116.3	2.087	10.557	6.417	2.534
2a	101.0	48.0	46.0	94.1	0.0	195.0	300.5	121.4	2.047	7.800	5.274	1.035
2b	103.6	51.2	49.1	100.3	44.4	248.3	300.5	125.5	2.399	8.809	6.334	7.860
2c	97.8	49.7	46.9	96.6	0.0	194.3	299.0	127.2	2.713	10.180	7.055	0.200
3a	102.5	57.0	49.0	106.0	0.0	208.5	299.5	127.7	2.077	8.692	5.872	0.415
3b	101.1	56.2	48.0	104.1	21.8	227.0	300.5	129.2	2.099	8.707	5.997	4.070
3c	99.4	56.1	47.9	104.0	0.3	203.7	300.7	128.5	2.375	8.866	6.170	1.177
3d	96.4	54.6	46.9	101.5	2.2	200.2	301.0	126.8	2.789	9.329	6.361	0.830
4a	100.4	52.0	53.0	105.0	14.0	219.4	299.8	121.1	3.836	10.020	8.596	2.269
4b	103.0	56.6	54.2	110.8	44.7	258.6	297.3	111.9	3.201	8.823	8.432	9.073
4c	108.5	54.7	52.7	107.3	41.7	257.6	296.9	111.3	2.305	9.412	8.447	9.303
4d	104.4	53.3	52.2	105.4	14.0	223.8	299.3	126.1	1.951	9.783	6.933	2.583
4e	103.7	55.0	53.0	108.1	0.0	211.8	301.0	135.0	2.046	10.573	7.676	0.386
4f	97.5	49.3	53.7	103.0	24.0	224.5	300.4	118.9	2.542	11.954	8.073	2.634

Table 20. Black Liquor Firing Conditions

Run #	Nozzle Type	Nozzle Diameter (mm)	Nozzle Number	Liquor Solids %	Liquor Flow (gpm)	Heater Temp (C)	Nozzle Pressure (psig)
0	Tampella	24	4	68.64	120.41	125.80	16.55
1a	Tampella	24	4	68.78	119.72	125.73	16.45
1b	Tampella	24	4	68.90	121.16	125.72	16.86
1c	Tampella	24	4	68.93	121.99	126.48	17.12
1d	Tampella	24	4	68.82	118.98	125.91	17.30
2a	Tampella	24	4	68.83	120.58	126.36	17.29
2b	Tampella	24	4	68.89	137.48	125.95	18.81
2c	Tampella	24	4	68.67	100.64	125.05	15.27
3a	Tampella	24	4	68.59	119.49	121.62	15.62
3b	Tampella	24	4	68.69	119.87	129.11	18.67
3c	Tampella	24	4	69.04	119.15	129.84	18.82
3d	Tampella	24	4	69.42	119.43	121.06	15.05
4a	Tampella	24	4	69.43	119.87	121.05	14.95
4b	Tampella	24	4	69.24	119.85	120.78	14.50
4c	Tampella	24	4	69.07	119.66	122.15	14.17
4d	Tampella	24	4	68.97	119.78	122.11	14.57
4e	Tampella	24	4	69.04	120.21	120.94	14.95
4f	Tampella	24	4	69.31	119.38	121.24	15.23

Table 21. Black Liquor Elemental Analysis

Analysis	Concentration, Wt. %
Total Carbon	34.80
Organic Carbon	33.60
Inorganic Carbon	1.19
Hydrogen	3.54
Oxygen	34.30
Sulfur	5.01
Sodium	20.23
Potassium	1.96
Total	99.83
Higher Heating Value	6,079 BTU/lb

Table 22. Single Particle Combustion Tests

Combustion Phase	Time
Drying (Start to Ignition)	1.0 sec
Pyrolysis (Ignition to Max Volume)	2.6 sec
Char Burning (Max Vol. to Smelt Bead)	12.3 sec
Total Combustion	15.0 sec
Swelling Measurements	
Swelling at Ignition	4.78 cc/g
Maximum Swelling	26.02 cc/g
Drop Diameter Ratio	
Diam at Ignition/Initial Diam	1.86
Diam at Maximum/Initial Diam	3.28

Recovery boiler performance data

Stack Test Data

Radian performed stack sampling and analysis on a continuous basis from 7:00pm July 15, 1996, until 7:00am July 20, 1996. A summary of this data is shown below in Table 23, for each of the test periods. The mill also measured the oxygen levels at the outlet of the boiler and at the stack. These values are included in Table 23 in the far right columns. The oxygen levels measured in the stack by Radian and the mill show good agreement as illustrated in Figure 5 below. The two stack measurements are usually quite close, and as expected, the boiler O_2 levels are somewhat lower.

Radian Corp. also monitored the gas stream for many pollutants including CO, NOx, SO_2, and TRS. The level of carbon monoxide in the flue gas is strongly dependent on the amount of air fed to the boiler. Increasing the amount of air at the tertiary level, while holding the other variables steady, resulted in a decreasing CO concentration. This effect can be seen in Figure 6 below where CO is plotted as a function of the O_2 in the stack gas. As is common in combustion systems as the excess oxygen is increased the level of CO drops off sharply. The only other gas species which shows a correlation with O_2 is TRS. The correlation is similar to that for CO, as the excess oxygen increases the TRS drops off sharply.

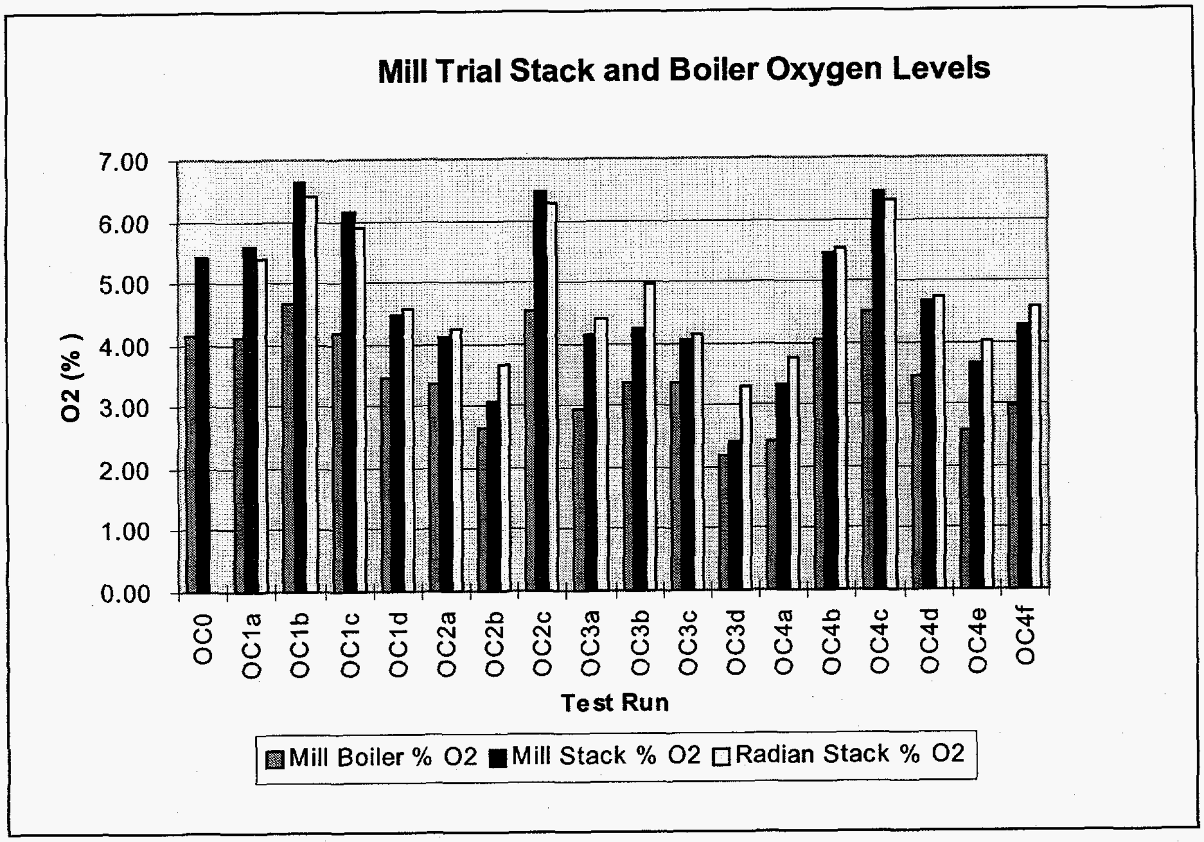


Figure 5. Oxygen Levels in Flue Gas

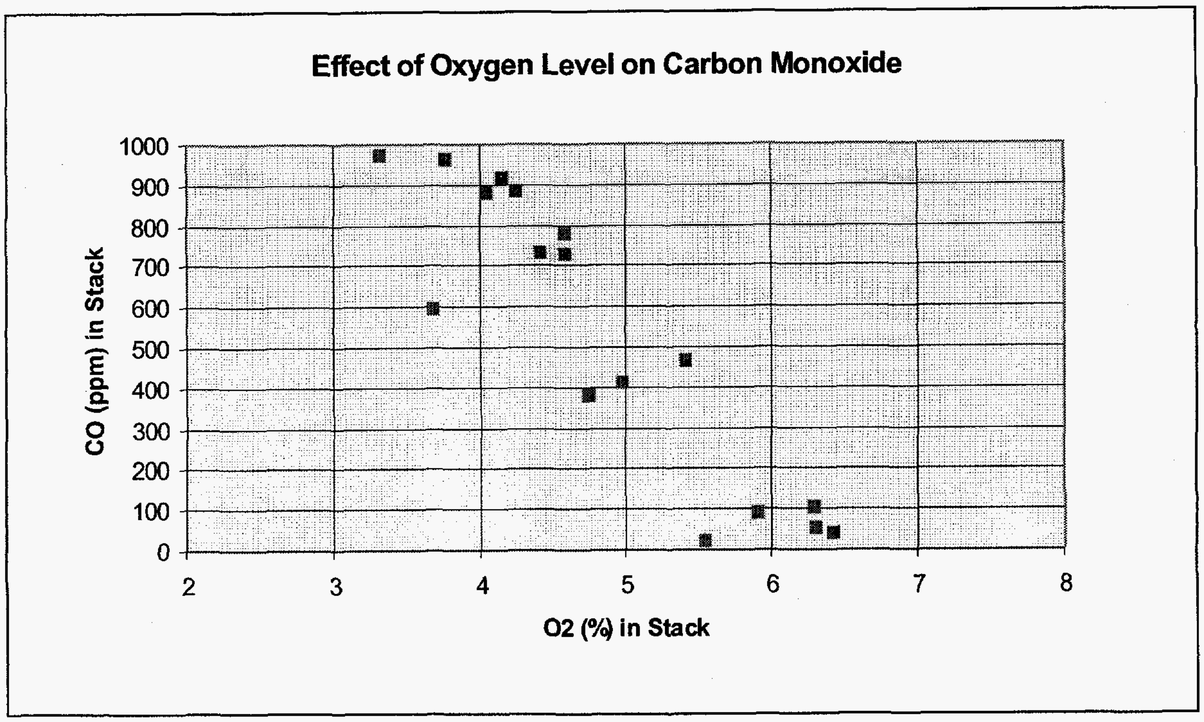


Figure 6. Increasing O2 Levels Result in Reduced CO Levels in Flue Gas

Table 23. Radian Stack Test Data (on a dry volume basis)

	------------------------ Radian Stack Test Measurements ------------------------										Mill Measurements	
Run #	**O_2**	**CO_2**	**CO**	**NO**	**NO_2**	**SO_2**	**TRS**	**Temp.**	**RH**	**BP**	**Boiler**	**Stack**
	%	**%**	**PPM**	**PPM**	**PPM**	**PPM**	**PPM**	**F**	**%**	**in Hg**	**% O2**	**% O2**
0	N/A	11.40	325.91	44.92	4.57	0.047	N/A	80.0	77.5	29.84	4.16	5.44
1a	5.40	13.95	467.62	63.78	5.51	0.237	7.181	79.8	75.6	29.95	4.14	5.58
1b	6.42	13.08	41.07	65.11	1.80	1.521	N/A	85.3	62.8	29.93	4.69	6.65
1c	5.90	13.38	89.52	74.42	2.27	1.240	N/A	89.5	54.2	29.92	4.18	6.14
1d	4.59	14.51	729.83	56.96	5.98	-0.193	N/A	83.5	70.5	29.95	3.46	4.50
2a	4.25	14.42	884.27	58.36	3.71	4.490	7.967	85.8	65.2	29.97	3.35	4.13
2b	3.67	14.84	594.93	62.73	3.03	4.920	11.462	92.9	46.6	29.90	2.66	3.06
2c	6.29	13.21	105.06	70.51	6.50	4.374	1.274	78.4	75.9	29.94	4.56	6.47
3a	4.42	14.18	733.50	63.76	6.54	4.135	4.987	85.0	64.5	29.97	2.94	4.16
3b	4.97	13.77	414.63	70.74	2.87	3.891	9.172	92.5	47.4	29.89	3.38	4.25
3c	4.15	14.15	915.92	59.68	2.50	4.768	6.122	92.5	46.0	29.87	3.36	4.05
3d	3.31	14.85	973.83	56.17	-0.31	5.086	19.332	88.5	56.7	29.86	2.18	2.42
4a	3.77	14.75	965.20	62.24	-0.78	5.873	23.413	82.4	69.6	29.86	2.42	3.34
4b	5.54	13.68	21.21	70.91	1.06	4.553	10.254	78.3	79.7	29.83	4.07	5.47
4c	6.30	13.20	53.74	67.54	2.07	4.369	11.741	76.7	83.4	29.86	4.50	6.46
4d	4.75	13.71	380.39	57.34	7.72	14.689	11.741	87.8	60.0	29.84	3.46	4.69
4e	4.04	13.91	882.15	59.36	3.47	5.370	13.771	93.4	44.2	29.79	2.57	3.66
4f	4.58	14.20	781.61	55.81	5.75	14.106	N/A	85.0	64.6	29.73	2.97	4.30

Case 1a

On the first day of testing, during test 1a, two different measurements were made. First the air port velocities were measured for the primary, secondary, and tertiary air ports.. Second char bed temperature readings were collected using a thermocouple probe. All testing this day was conducted under normal operating conditions. All of the individual velocity measurements are included in Tables 24 and 25.

Air Port Velocities

Primary Air Ports

The boiler is constructed with a total of sixty air ports, with fifteen on each of the four walls. A thorough analysis of primary port velocity was made during test IRC-1a. Using a pitot tube the velocity was measured at nearly every other air port. For each of the primary ports two individual readings were made. These correspond to a low and a high position within the port. The readings were taken inside the ports just before the opening to the furnace.

The average velocity for each port is plotted in Figure 7. The velocities are plotted as a scan around the entire boiler starting on the front part of the left wall and continuing around to the front wall. It is apparent that there is a significant variation in the air velocity from one port to another. The range of velocities measured at the individual ports is also plotted in Figure 7. The variation in the velocity at a single port appears to be due to the natural fluctuations in the turbulent gas flow and the normal error in the measurement technique. This error is less than the variation which is due to the change in port location or air flow-rate.

There is also a difference in the average velocity from one wall to another. The Left and right wall primary ports have lower velocities then the front and rear walls. Additional preliminary data, collected in November of 1995, confirms this difference in velocity from one wall to the next.

Secondary Ports

Recovery Boiler #4 has a total of ten secondary air ports - five on the right wall and five on the left wall. The velocity was measured at each of these ports during test IRC-1a. Four measurements were made at each port opening, one high, one low, and two in the middle. The velocity data is plotted in Figure 8. The velocities on the left side are quite consistent, but the velocities on the right wall show a large port to port variation. The velocity is lowest near the rear of the boiler, and increases in moving to the front of the boiler.

Data collected on 11/7/95 shows the same trend on the right wall of the boiler, but on the left wall, the velocity shows a trend of increasing velocity in going from the rear of the boiler towards the front.

Tertiary Air Ports

The air port arrangement at this level consists of four air ports on the rear wall and three air ports on the front wall. These ports are arranged in an interlaced configuration. In general, this mill uses low tertiary velocities. The air port velocities measured during test IRC-1a is shown in Figure 9 below. However the lower velocities measured are due to partial plugging of the pitot tube with smelt A corrected profile would probably show uniform velocities at all ports, as was found during the earlier testing

Table 24. Primary Jet Velocities

Primary Jets			Velocity	
	Port	X or Z	high	low
	No.	(inch)	(m/s)	(m/s)
Left Wall				
	1	34.5	22.3	23.8
	3	64.5	17.9	15.8
	5	94.5	15.7	15.3
	7	124.5	8.1	13.4
	9	154.5	21.5	15.6
	11	184.5	17.2	17.8
	13	214.5	16.2	16.1
	15	244.5	11.9	14.0
Rear Wall				
	1	31.5	26.0	28.2
	3	61.5	28.5	27.2
	5	91.5	29.1	24.9
	7	121.5	29.8	24.5
	9	151.5	31.2	23.3
	11	181.5	22.8	18.4
	13	211.5	22.4	21.6
	15	241.5	26.7	22.1
Right Wall				
	14	229.5	21.2	25.3
	12	199.5	21.8	19.3
	9	154.5	22.1	22.0
	7	124.5	17.8	11.9
	5	94.5	22.2	23.5
	3	64.5	17.6	17.6
	1	34.5	23.1	17.7
Front Wall				
	14	226.5	23.5	19.0
	12	196.5	25.8	22.8
	9	151.5	26.4	25.1
	6	106.5	28.6	23.6
	3	61.5	27.9	21.3
	1	31.5	23.9	19.7

Table 25. Secondary and Tertiary Velocities

			Velocity		Velocity	
	Port	X or Z	mid	high	low	mid
	No.	(inch)	(m/s)	(m/s)	(m/s)	(m/s)
Secondary Jets						
Left Wall						
	1	49.5	54.9	49.9	54.7	55.9
	2	109.5	53.4	52.7	55.3	54.7
	3	139.5	54.7	51.5	54.7	54.8
	4	169.5	54.8	53.6	54.2	53.3
	5	229.5	55.3	53.0	54.1	53.4
Right Wall						
	1	49.5	42.6	32.8	48.4	43.2
	2	109.5	46.3	39.1	46.0	45.0
	3	139.5	45.0	45.3	50.1	47.9
	4	169.5	51.9	46.4	48.8	48.9
	5	229.5	49.8	47.3	49.0	50.5
	Tertiary Jets					
Rear Wall						
	1	55.5			24.3	
	2	109.5		22.3	19.1	
	3	163.5		24.6	24.6	
	4	217.5		12.3	12.0	
Front Wall						
	1	82.5		14.2	6.7	
	2	136.5		0.0	0.0	
	2	190.5		11.8	9.4	

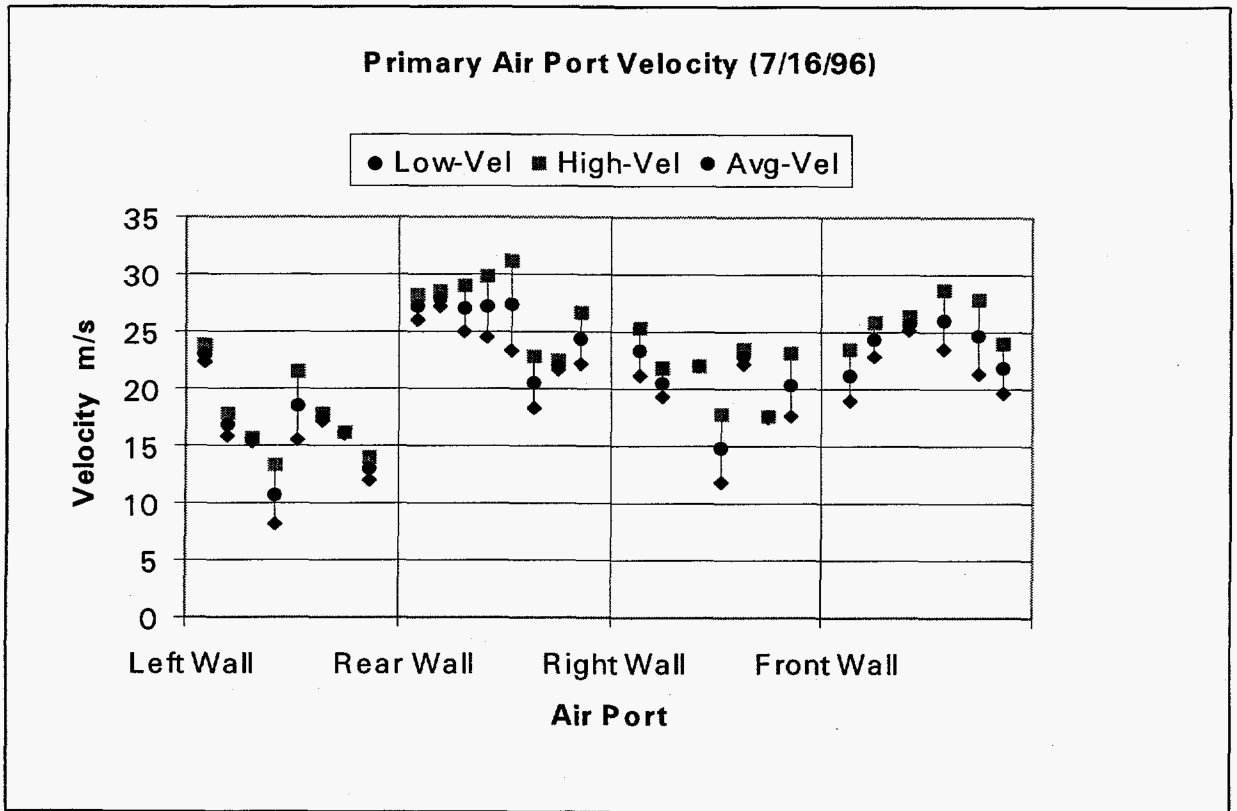


Figure 7. Primary Air Port Velocities

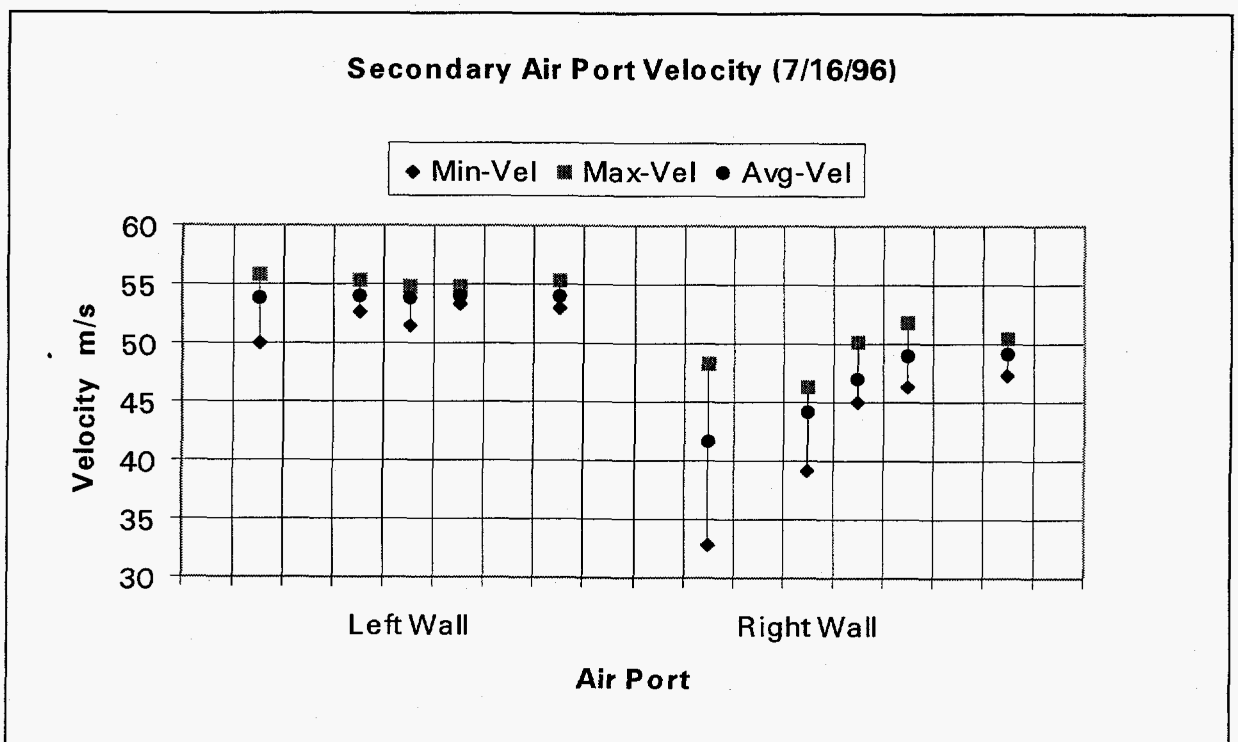


Figure 8. Secondary Air Port Velocities

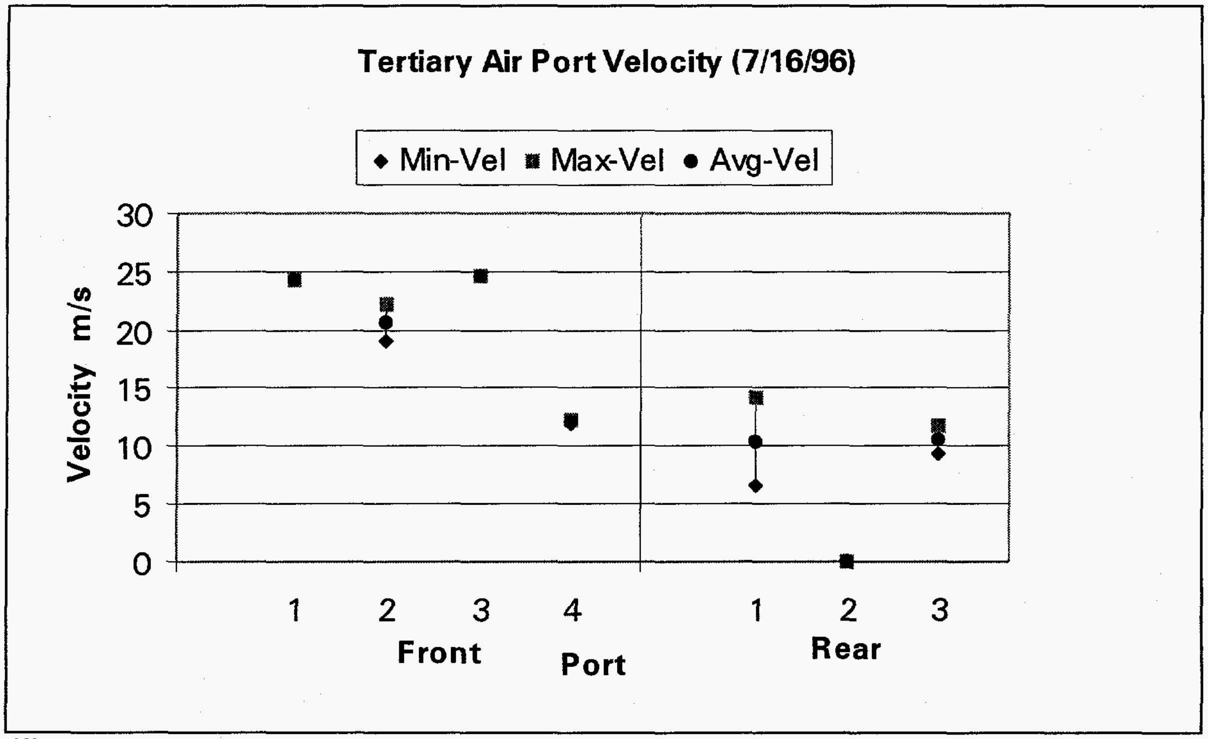


Figure 9. Tertiary Air Port Velocities

Integrated Air Flow

Using the measured air port velocities and the known area of the individual air ports, it is straightforward to calculate the total air flow into the boiler at each of the air levels. This calculation was performed and is listed below in Table 26, along with the air flow rate from the mill control system. Overall, the flow determined from the pitot tube measurements is about 10% higher than the mill's reading . The air flow at the primary air level is also slightly higher than the mill data - 12.9 versus 12.0 kg/sec. Similarly the calculated flow-rate at the secondary level is somewhat higher (15.1 versus 13.1 kg/sec). Only the calculated tertiary flow is lower than mill's value. However due to plugging of the pitot tube the actual flow rate may be somewhat higher.

Table 26. Integrated Mass Flow Calculated From Velocity Measurements

Air Level	Temp. (C)	Average Velocity (m/s)	Port area (m^2)	Integrated Flow (kg/s)	Percent of Total (%)	Mill Mass (kg/s)	Percent of Total (%)
Test 1a							
Primary	150	21.50	0.720	12.93	41.3%	11.97	41.7%
Secondary	150	50.08	0.361	15.06	48.0%	13.14	45.8%
Tertiary	30	15.48	0.252	3.36	10.7%	3.60	12.5%
Total				31.35	100.0%	28.70	100.0%
Test 2b							
Primary	150	22.08	0.720	13.28	34.4%	13.05	41.7%
Secondary	150	50.90	0.361	15.31	39.6%	12.64	40.4%
Tertiary	30	44.14	0.252	10.05	26.0%	5.59	17.9%
Total				38.64	100.0%	31.28	100.0%

Char Bed Temperatures

Thermocouple probe measurements were taken of the char bed surface and subsurface temperatures. The thermocouple probe consisted of an 11 ft long type K thermocouple encased in a 310 SS pipe. This probe was inserted into the char bed through the primary air ports identified in Table 27. This testing was performed under normal operating conditions (run #IRC-1a).

Probe was inserted into primary air rod ports 5 and 10 on the South side, 6 and 11 on the North side, and port 12 on the East side. In general, temperature readings rose slowly to an equilibrium value, and then slowly decreased. Possibly, heat conduction losses along the length of the pipe need to be taken into account. The 310 SS pipe held up very well and retained its mechanical strength throughout the experiment.

The temperatures measured above the char bed surface were hotter than those measured below the surface. The average temperature at or above the surface was 1170°C, the minimum was 940° C and the maximum was 1200°C. Below the char bed surface the average temperature was only 877, the minimum was 688 and the maximum was 1026°C.

The temperatures measured at the four different ports are plotted in Figure 10 below. The distance is the extent of the probe into the char bed. Because of the low angle of the probe (10-15°), this does not correspond to a vertical depth below the surface. The graph indicates that the temperature is more uniform below the surface of the char bed, and more variable near or above the surface of the bed.

Table 27. Char Bed Temperature Profile

Air Port	Probe Length inside Furnace, ft	Corresponding Temperature, °C	Probe Angle
South #5	1.3 (bed surface)*	940	10°
South #5	2.5	868	10°
South #5	3.5	844	10°
South #5	4.5	848	10°
South #5	5.5	877	10°
South #10	0.5	~1140	10°
South #10	1.0 (bed surface)*	~1100	10°
South #10	1.5	983	10°
South #10	2.5	816	10°
South #10	3.5	814	10°
South #10	4.5	863	10°
South #10	5.5	865	10°
South #10	6.5	867	10°
North #6	1.5	1040-1140	15°
North #6	2.5 (bed surface)*	1155-1190	15°
North #6	3.5	765-770	15°
North #6	4.5	967	15°
North #6	5.5	893	15°
North #11	1.5	1000-1200	15°
North #11	2.5 (bed surface)*	960-1020,	15°
North #11	3.5	1018-1026	15°
North #11	4.5	899-905,	15°
North #11	5.5	890-911	15°
North #11	6.5	885	15°

* Location of the bed surface is approximate.

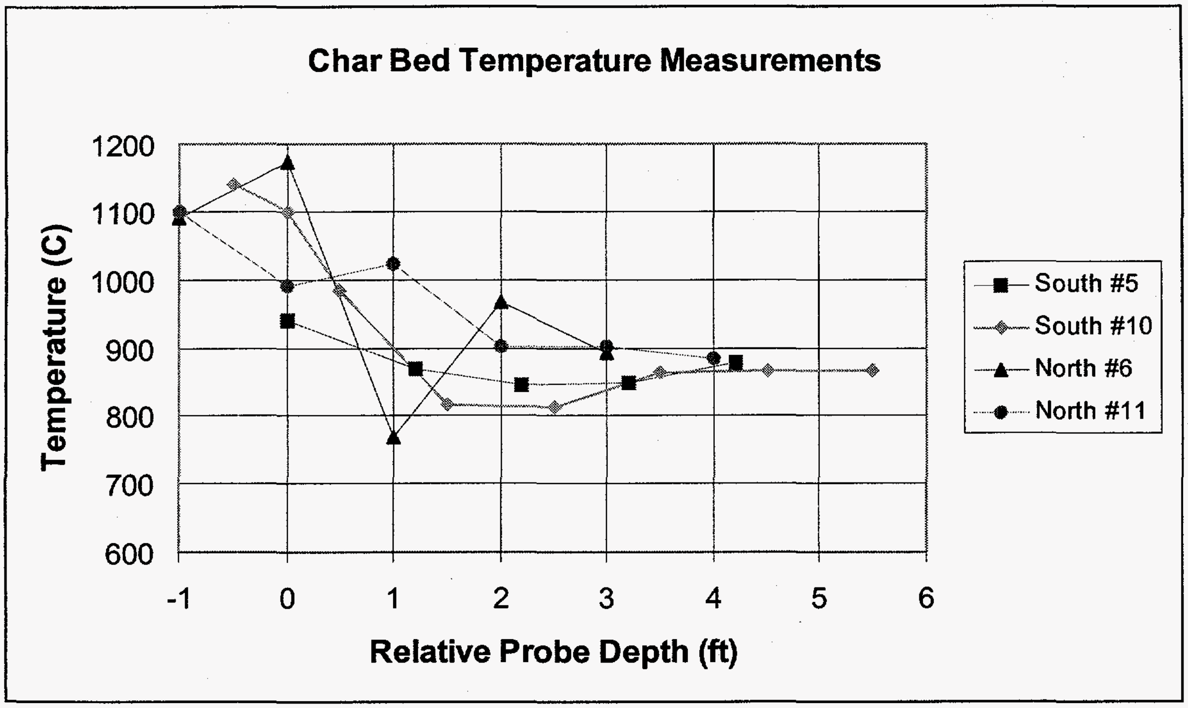


Figure 10. Char Bed Temperatures

Case 2a

Smelt Sampling and Char Bed Retention Time

Zinc was used as a tracer to determine the retention time distribution for smelt in the char bed. The tracer test was conducted during test period 2a, with typical black liquor firing conditions, but no tertiary air to the boiler. First, baseline smelt samples were collected from each of the three smelt spouts. Next, a zinc sulfate heptahydrate solution -12 kg (2.73 kg zinc) in approximately 30 L of water - was poured into the mix tank overflow box over a 2.5 minute time period. Smelt samples were then collected successively from the north, middle and south spouts every five minutes for the next 1:40 hours, and every 15 minutes for the remaining 1:45 hours of the test. Smelt sampling was carried out with a probe consisting of a black steel sampling cup (1-1/2" to 1/2" reducing coupling with a plug in the 1/2" end) welded to a seven foot piece of 1/2" Sch. 40 304 SS pipe to serve as a handle.

The smelt samples were analyzed for zinc, sodium, potassium, and other elements. By plotting the zinc concentration on a log scale it is possible to determine the retention time distribution of the zinc tracer (Figure 11). The relatively flat section of the curve indicates that the distribution can be approximated as a continuous stirred tank reactor (CSTR). Using the slope of this curve the retention time was calculated to be 160 minutes (Table 28). Based on the black liquor feed rate, the floor area of the boiler, and the density of smelt; the retention time corresponds to a smelt pool depth of 13 inches. The average smelt composition is given in Table 29.

Table 28. Smelt Bed Residence Time Distribution

Parameter	Value	Comments
Time Constant	160 min.	Na or K reference
Smelt Bed Depth	13 in	Na or K reference
Zinc Recovery	55% / 61%	Na reference / K reference

Table 29. Smelt Composition

Analysis	Concentration, Wt. %
Total Carbon	7.94
Organic Carbon	0.11
Inorganic Carbon	7.83
Hydrogen	0.13
Oxygen	35.07
Sulfur	8.60
Sodium	42.7
Potassium	3.48
Total	97.92

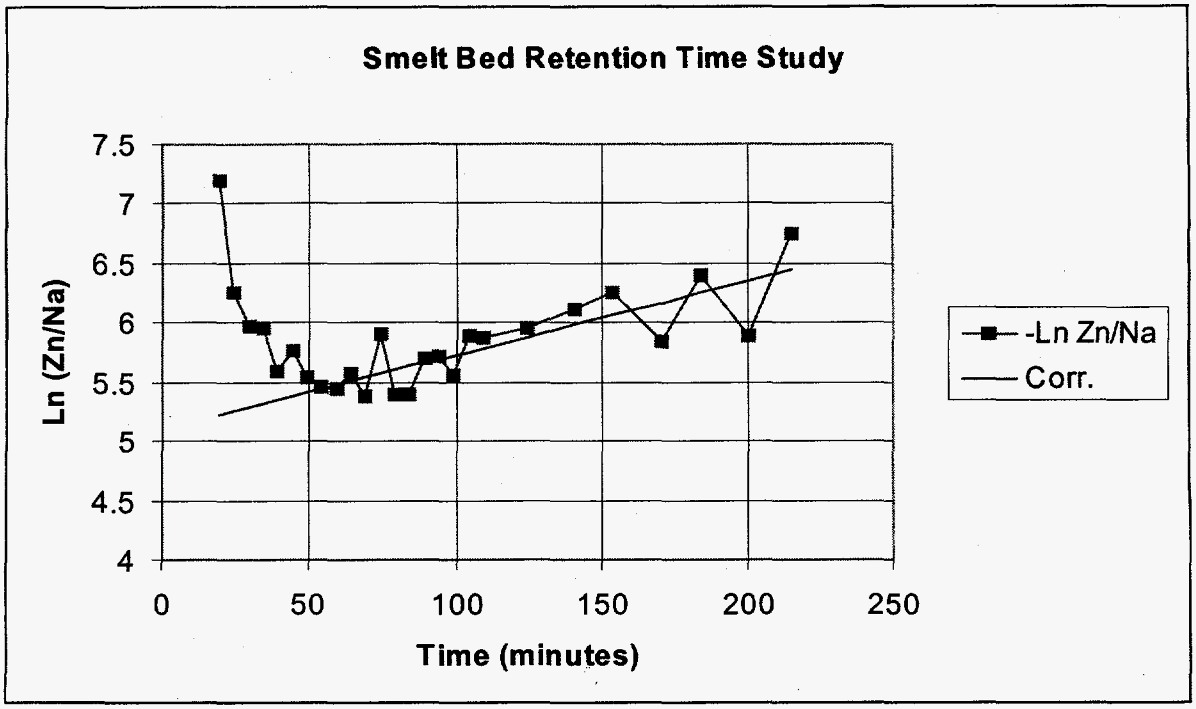


Figure 11. Smelt Bed Retention Time Study

Upper Furnace Gas Temperatures

Gas temperatures in the upper furnace were measured on the fifth floor under varying operating conditions. Access to the boiler was at three ports located on the front wall of the boiler at an elevation of 75ft above the floor of the boiler. This location is about 17 ft above the bullnose and in-line with the main part of the convective heat transfer sections, directly in front of the screen tubes. The center port is located on the centerline of the boiler and the other two ports are spaced 5 ft away. The left, center, and right ports correspond to Y-direction locations of 6, 11, and 16 ft, measured from the left wall of the boiler. The probe was inserted into the boiler in the X-direction, measured from the front wall. The probe was inserted straight into the furnace (perpendicular to wall) except for a few cases where a small angle was used to vary the Y location. The entire probe has a length of about 11 ft so that the probe can be inserted up to 8 ft into the boiler.

The measurements were performed using a commercial high velocity thermocouple (HVT) probe. In this type of probe the gas is drawn across the tip of the thermocouple to increase the convective heat transfer. As the velocity increases the measured temperature approaches the actual gas temperature. A radiation shield around the thermocouple is also used to reduce the error due to radiative heat transfer. The gas is drawn by a vacuum generated using an ejector driven with compressed air. The probe is constructed of stainless steel and the main section is water cooled.

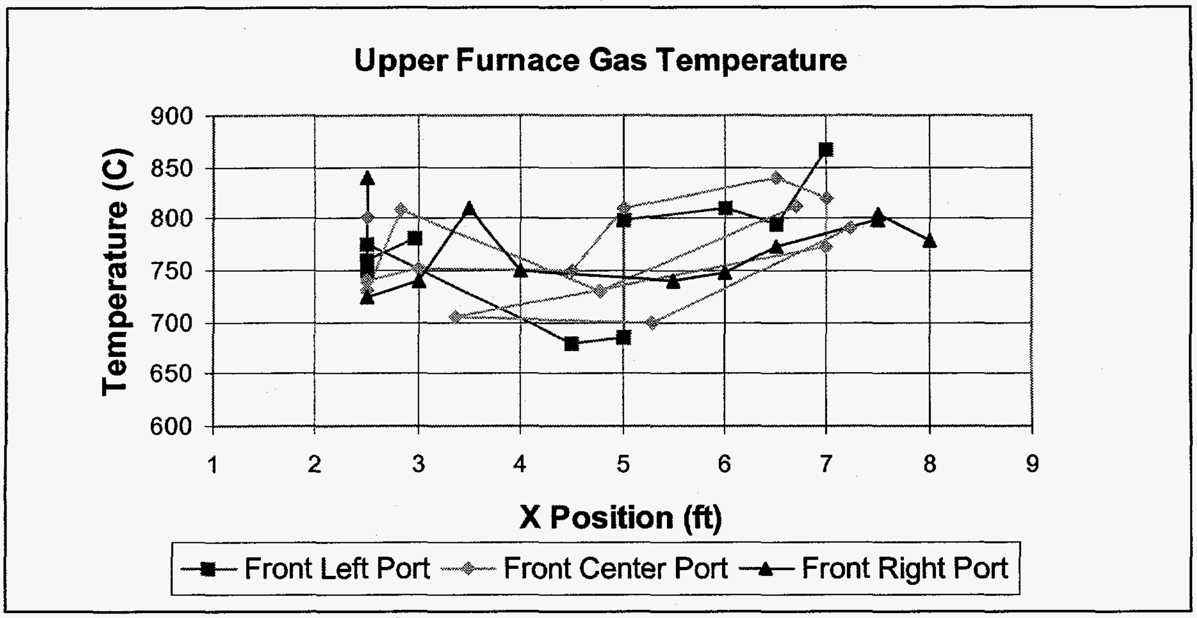


Figure 12. Upper Furnace Gas Temperatures

The measurements were performed during tests 2a and 2b on July 17, 1996, and tests 3a and 3b on July 18, 1996. The entire data set is summarized in Table 30. There does not appear to be any significant variation in the gas temperature due to the change in test conditions. Similarly, the variation in the Y-direction does not have a statistically significant effect on the temperature. The only variable which appeared to influence the temperature was the X position (or the extent the probe was inserted in the boiler.) As shown in Figure 12, the temperature seems to have a minimum in the range from 4 to 5 ft into the boiler. This corresponds approximately to the location of the screen tubes (from 3.5 to 5.5 ft) which certainly lowers the gas temperature near the tubes.

As viewed through from these front wall access ports, the gas flow appeared to go straight up with few indications of cross flow. The flow appeared slightly more turbulent in the left port. Very few sparklers or signs of carryover could be seen. None were seen in the right port and only a few were noted in the left port. Four additional readings were taken at a port on the right (south) wall of the boiler on the fifth floor. This port is located about 16 ft from the front wall of the boiler at an elevation of 72 ft above the floor of the furnace. As expected the temperature is lower at this point which is closer to the generating bank.

Table 30. Upper Furnace Gas Temperatures

	Port	X	Y	Gas			Port	X	Y	Gas
Test	Location	Depth	Posi-tion	Temp		Test	Location	Depth	Posi-tion	Temp
Run		(ft)	(ft)	(C)		Run		(ft)	(ft)	(C)
Run 2a	7/17/96					Run 3a	7/18/96			
2a	Front-Left	2.5	6	760		3a	Front-Center	2.8	10	808
2a	Front-Center	2.5	11	730		3a	Front-Left	3.0	5.5	781
2a	Front-Center	2.5	11	740		3a	Front-Center	3.0	11	751
2a	Front-Right	2.5	16	840		3a	Front-Right	3.0	16	741
2a	Front-Center	4.5	11	750		3a	Front-Center	4.8	9.5	731
2a	Front-Center	6.5	11	840		3a	Front-Left	5.0	6	686
						3a	Front-Right	5.5	16	741
Run 2b	7/17/96					3a	Front-Left	6.5	6	795
2b	Front-Left	2.5	6	750		3a	Front-Center	6.7	9	813
2b	Front-Center	2.5	11	800		3a	Front-Right	7.5	16	798
2b	Front-Center	2.5	11	740		3a	South wall	16.0	15.5	628.5
2b	Front-Right	2.5	16	725		3a	South wall	16.0	18	598
2b	Front-Right	4.0	16	750						
2b	Front-Left	4.5	6	680		Run 3b	7/18/96			
2b	Front-Center	5.0	11	810		3b	Front-Left	2.50	6	775
2b	Front-Left	6.0	6	810		3b	Front-Center	3.35	12	705
2b	Front-Right	6.5	16	773		3b	Front-Right	3.50	16	811
2b	Front-Center	7.0	11	820		3b	Front-Left	5.00	6	799
2b	Front-Center	7.0	11	773		3b	Front-Center	5.29	12.5	700
2b	Front-Right	8.0	16	780		3b	Front-Right	6.00	16	748
						3b	Front-Left	7.00	6	867
						3b	Front-Center	7.23	13	790
						3b	Front-Right	7.50	16	804
						3b	South wall	16.0	15.5	548
						3b	South wall	16.0	18	541

DATA FOR CASE THREE

The third case presented in this report is for flow model benchmarking purposes for other CFD modeling studies. The case chosen is an isothermal flow experiment carried out at UBC in a scale model of a Babcock & Wilcox recovery boiler. The model boiler is a water model on a 1:28 scale of a recovery boiler located in a Weyerhaeuser mill in Kamloops, British Columbia. The model walls are transparent, to allow laser doppler velocimeter measurements at different elevations.

In addition to the descriptions of the model geometry and operating conditions, and the velocity measurements, computational output for a CFD simulation of this case with the UBC code is also included.

An isothermal flow case - benchmarking exercise

The case chosen for this benchmarking exercise is the isothermal flow experiment carried out in a recovery boiler model of Babcock & Wilcox design. Details of the experimental setup can be found in Ajersch (1995).

The model is a 1:28 scale model of a recovery boiler located in a Weyerhaeuser mill in Kamloops, British Columbia. The model walls are constructed of 16 mm thick plexiglass, so that laser light can be transmitted freely through to the measurement locations. The three elevations of air injection are included in the model, as well as the sloped furnace floor. The upper sections of the furnace model includes the bullnose and the heat exchangers. A schematic diagram of the model is given in Figure 13. Detailed drawings of the boiler are presented next which are suitable for use in a CFD modeling exercise.

Detailed Geometry

Figure 14 displays a profile of the recovery boiler model showing the positions of different elevations of injection ports, the dimensions of the bullnose, and the locations of the three levels (#1, #2, #3) where laser doppler velocimetry (LDV) measurements were taken. The model boiler has a sloping floor and the primary injection ports are inclined from the front of the back of the model.

Figures 15, 16, and 17 show positions and dimensions of the primary, secondary, and tertiary injection ports, respectively. Due to the numerous primary ports that are present, their positions can only be schematically illustrated in Figure 15. Detailed locations of individual ports can be found in Figures 18(a) and (b), which are drawings of the aluminum templates used for crafting the orifices.

The 174 primary air ports are nearly evenly distributed around the perimeter of the furnace. At the secondary air elevation, four ports are located on the front and back walls, and five on the left and right. Also included in this elevation are two large starting burners on each of the front, left and right walls. The tertiary air is distributed in an interlaced fashion, with four ports on the front wall and five on the back.

Experimental conditions and flow measurements

The experiment considered was as follows: the total volume flow rate through the model was set to 570 L/min, and the flow was through primary and secondary ports only. Approximately 60% of the flow is diverted to the primary ports and the rest to the secondary ports; there was no tertiary injection.

The flow system for the model was designed such that at the secondary elevation, water is supplied to each port by its own line. At the primary elevation, however, flow to the 174 ports was supplied by only 24 lines, each of which fed a group of 7 or 8 ports. Figure 15 shows the volume flow rates and momentum fluxes at the primary and secondary levels.

From the flow rate figures and dimensions of each individual port, a velocity value can be calculated for the flow leaving each port.

Measurements were acquired in three horizontal planes. Each plane was divided into a 6x6 grid of rectangular cells with the measurement locations corresponding to the cell centers. The lower plane was located at the liquor gun elevation, or 175 mm above the secondary ports. The middle plane was located approximately the same distance (177 mm) above the tertiary ports. The upper plane was located 445 mm above the tertiary ports, so as to evenly space the three planes along the boiler's vertical axis. These three planes are referred to as levels 1, 2 and 3, respectively (shown earlier in Figure 14).

As a first order verification of the LDV measurements, the total flow through a horizontal section was calculated by summing the individual measured flows through each cell in the 6x6 grid. A volume flow rate was calculated for each of the measurement levels with the results summarized in Table 31.

Table 31. Measured vs. Set bulk volume flow

Location	Set bulk flow across the level [L/min]	Measured bulk flow [L/min]	Percent error in measurement
Level 1	570	754	+32%
Level 2	570	641	+12%
Level 3	570	656	+15%

The general disagreement may be attributed to the following factors:

1. The measurement grid is rather coarse and may not well represent some of the lower velocity regions.
2. Turbulence levels, in particular at level 1, are high, and may lead to significant errors in flow statistics.
3. Operation of the LDV data acquisition equipment with less than extreme care may have led to a systematic filtering of signals corresponding to low velocity measurements.

At higher elevations, the error is not as significant, and probably has little effect on the information retrieved from the data with respect to the observed trends and large scale patterns in the flow field.

Comparison between experimental and numerical results

Measurements made for the flow field reveal the following general flow feature: there is a strong upward flow core, mostly in the central region, but deflected somewhat towards the rear-left corner. A fairly strong downward flow region exists along the right wall. The downward flow is more pronounced in the front right corner. Weak downward flow was also measured in the front left corner.

Figure 20 shows the distribution of the upward velocity component at level 1, above the secondary elevation. There is upward flow close to the left side wall, and downward flow along the right wall, closer to the front wall. The small circles on the left image indicate the 6 by 6 measurement grid. The upward flow core closer to the left side can be seen. The computed and the measured flows are quite similar. Figure 21 shows the vertical velocity distribution at level 2. Similar features in the flow field can be seen; that is, upward flow in the rear left half of the model, and downward flow in the front right half. Figure 22 shows the velocity distribution at level 3, under the bullnose. Similar velocity fields are found for both cases, with upward flow in the rear left side and downward flow in the front right side.

resulting particulates to the melt body, akin to the operation of the baghouse roughing filter in the Pit 1 project. Both lead and zinc, although present at only normal background concentrations in Pit 1 soils, were found to be significantly volatile in the ISV process and a major portion of their inventory was contained in the filter particulates.

During the melt expulsion, a calculated volume of 230,000 standard L of off-gas was released in an uncontrolled mode as the pressurized hood was lifted from the ground surface. Off-gas sampling during this event revealed that the activity of ^{137}Cs in the off-gas was 0.93 dpm/L resulting in a total release of 9.6×10^{-8} Ci. Using worst-case meteorological assumptions of wind speed, direction, and dispersion, such a release could have delivered a hypothetical and insignificant dose of 0.015 µrem to the nearest resident over 2 km away. Were an ISV melt body, containing over 10,000 Ci of ^{137}Cs , to experience a similar melt expulsion, a correspondingly larger hypothetical dose of 55 µrem could be delivered to an individual at the same location. This is well below the DOE administrative limit of 10 mrem/yr for the general public. Although no preventable uncontrolled release is justified, this calculation puts into perspective the magnitude of the risks posed by ISV even under such a worst-case accident scenario.

Among the treatability study's original objectives, the demonstration of ISV product quality, depth capability, and off-gas handling capability, even considering the unplanned melt expulsion, have been well established by the results reported here. The objective to demonstrate site characterization techniques to establish ISV targets and to plan ISV operations is addressed in the site characterization report (see Volume 2). The objective to demonstrate melt setting overlap capability was not attained because the project was suspended after the melt expulsion and neither the second nor third melt settings were attempted. However, since the conception of this project in 1993, Geosafe Corp. has clearly established this capability for ISV by producing 37 overlapping large-scale melt bodies at the Wasatch Chemical site in Salt Lake City in 1995 and other large, overlapping melts in Michigan and Washington. The remaining objective, to establish public confidence in ISV technology, has clearly not been fulfilled due to the melt expulsion incident and its perceived results and implications. The implementation and selection of ISV technology for remediation of the WAG 7 seepage pits and trenches or other waste management units in Oak Ridge will require a considerable effort to involve the public in the decision process and, thereby, increase their appreciation of its benefits. The main findings of this Pit 1 treatability study are the excellence of the ISV waste form, compared to any other technology, and the inherent conservatism of the process with respect to off-gas release of radioactivity during normal and accident situations. Much remains to be understood as to the proper economic comparison of ISV with other technical options for Oak Ridge contaminated soils, particularly the inherently large costs associated with any technology requiring long-term monitoring. The ability to prevent, control, and endure melt expulsions during ISV operations needs to be factored into the expected operating cost, as well as programmatic and public expectations. Increased and continued experience with ISV operations in very humid regions with saturated soil near the ground surface, like Oak Ridge, will, by necessity, result in empirical procedures, practices, and strategies which will minimize the probability of future melt expulsions. These risks are small and manageable compared to the enormous benefits of essentially permanent and complete waste isolation of radioactive contaminants from virtually all future environmental transport.

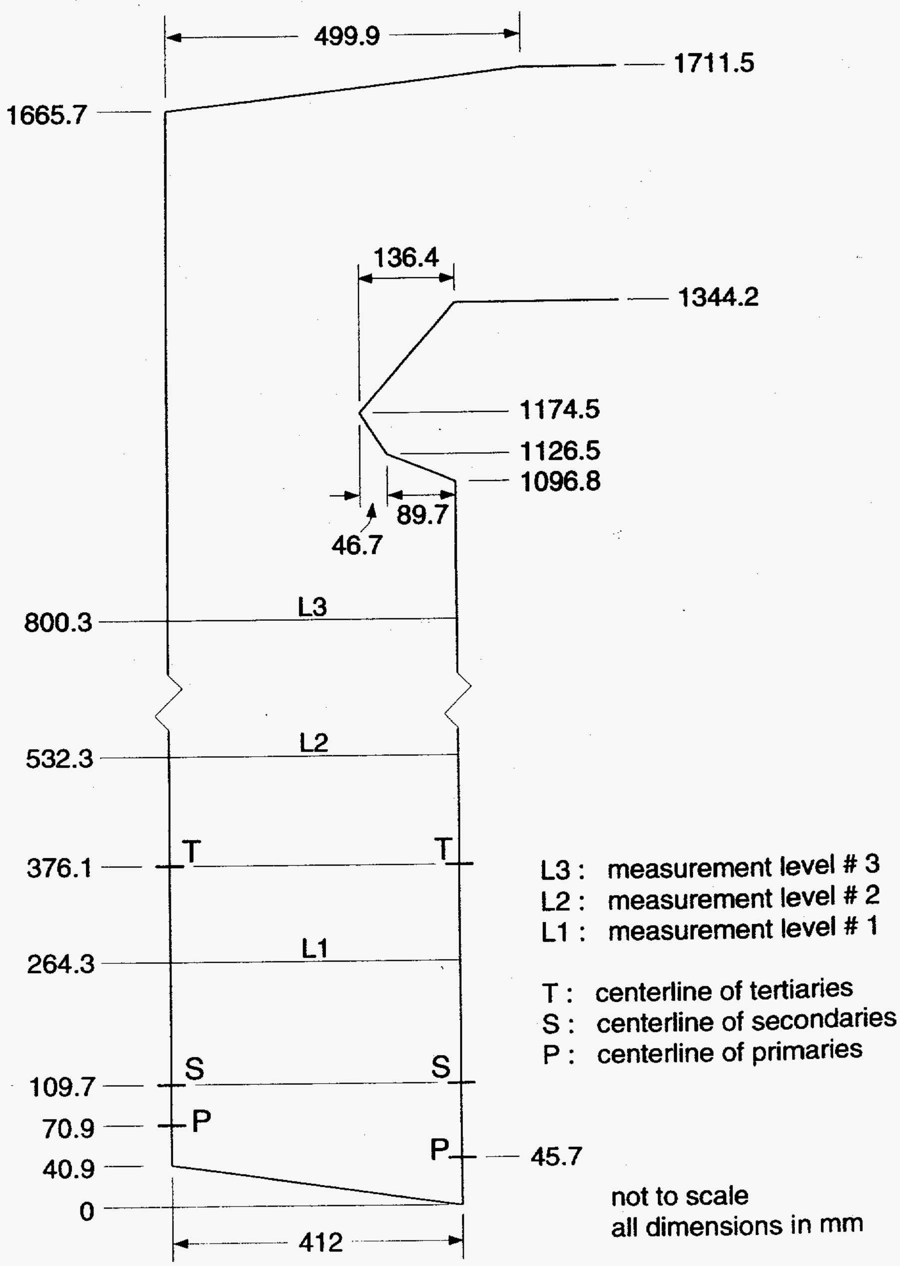


Figure 14: Kamloops boiler water model: vertical cross-sectional profile.

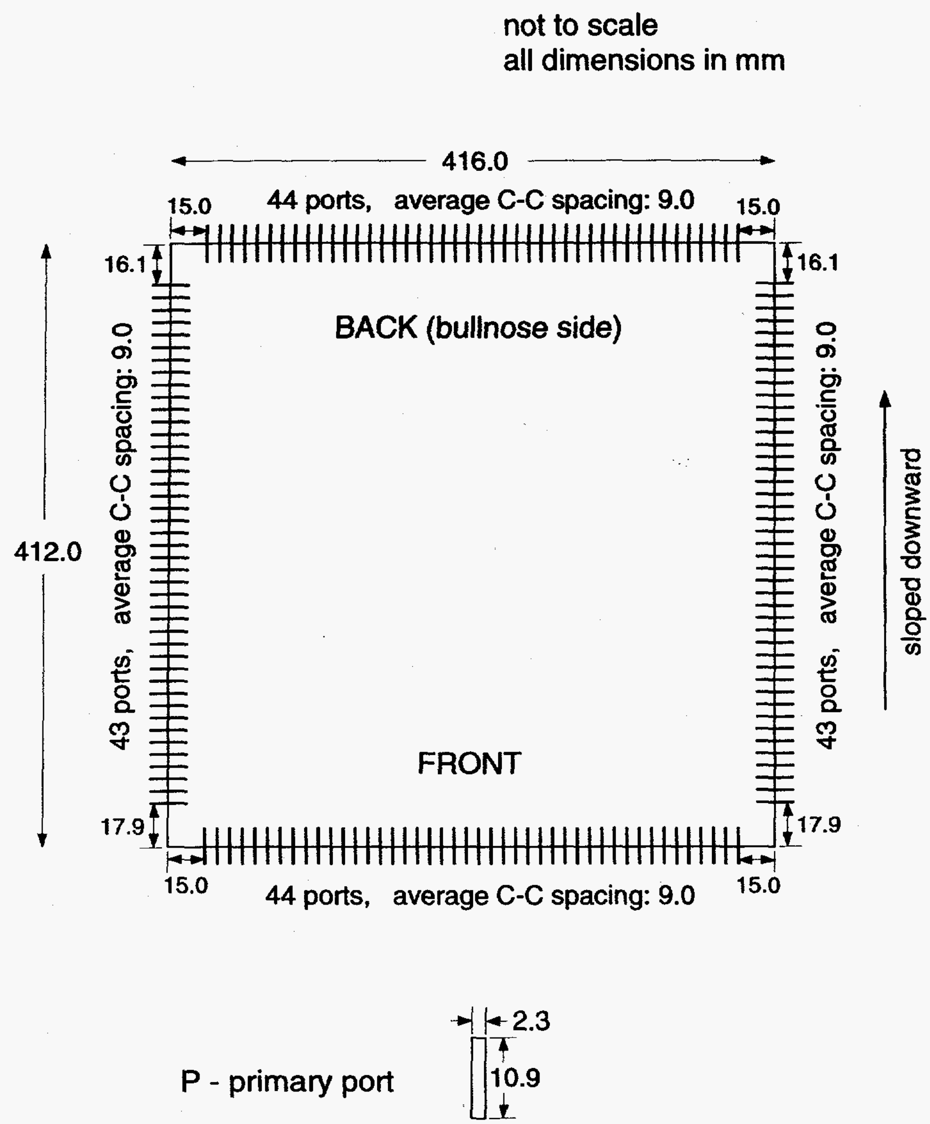


Figure 15: Kamloops boiler water model: locations of primary ports.

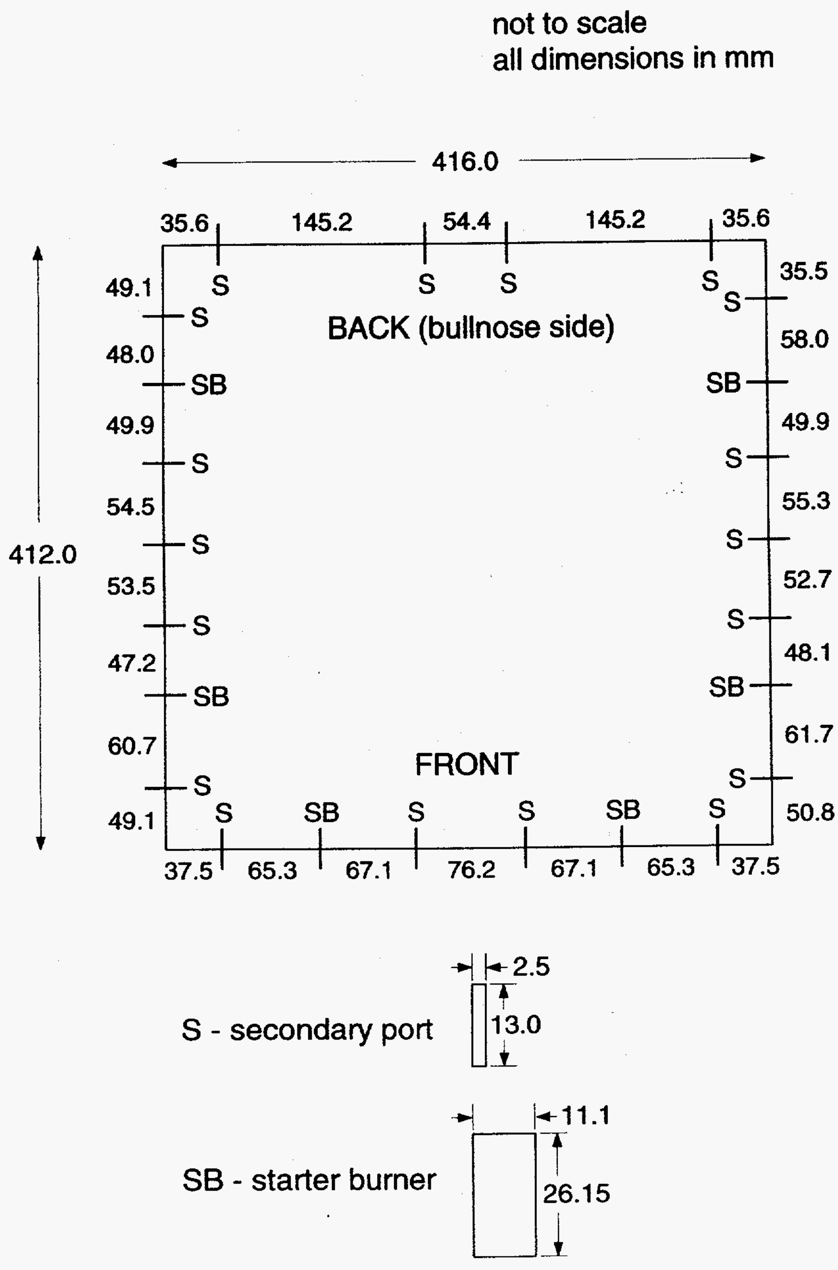


Figure 16: Kamloops boiler water model: locations of secondary ports.

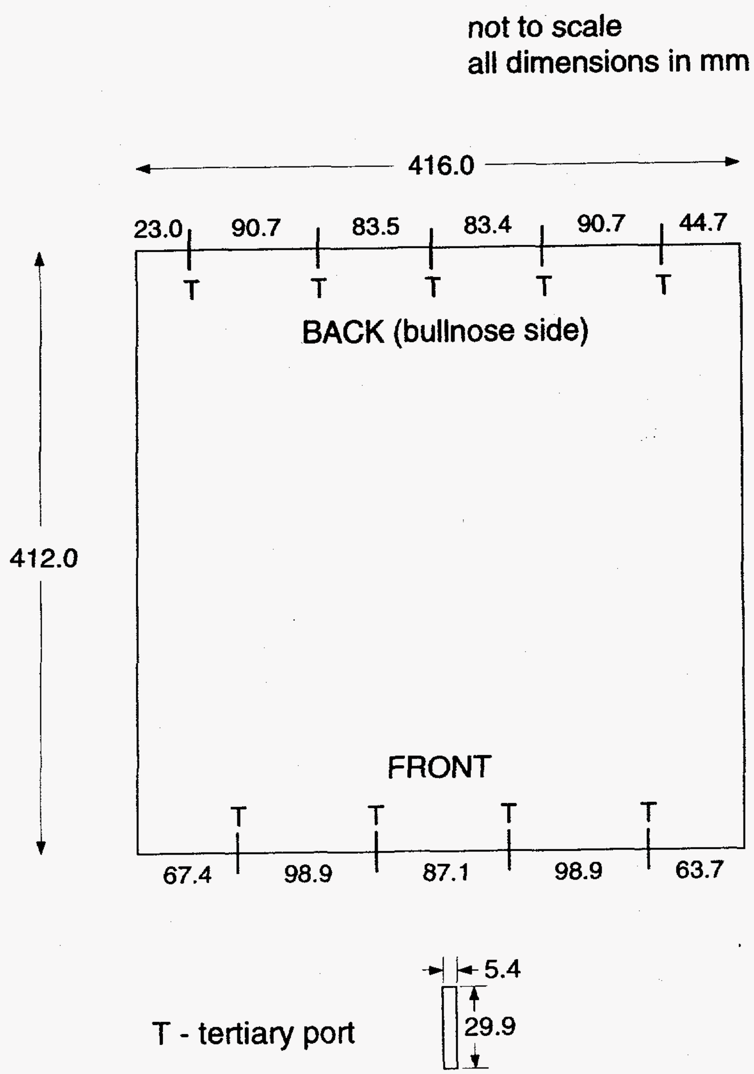


Figure 17: Kamloops boiler water model: locations of tertiary ports (closed in the benchmark experiment).

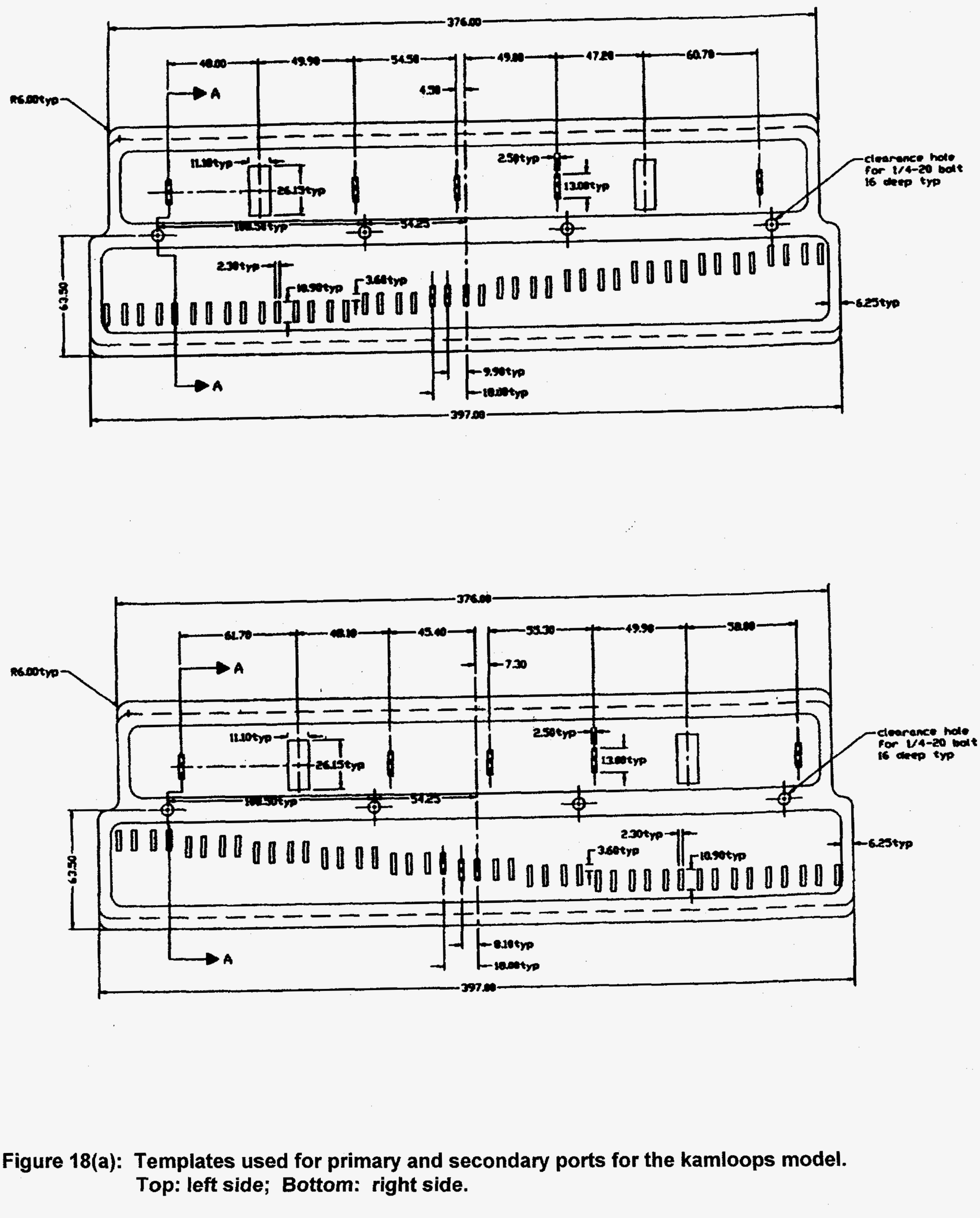


Figure 18(a): Templates used for primary and secondary ports for the kamloops model.
Top: left side; Bottom: right side.

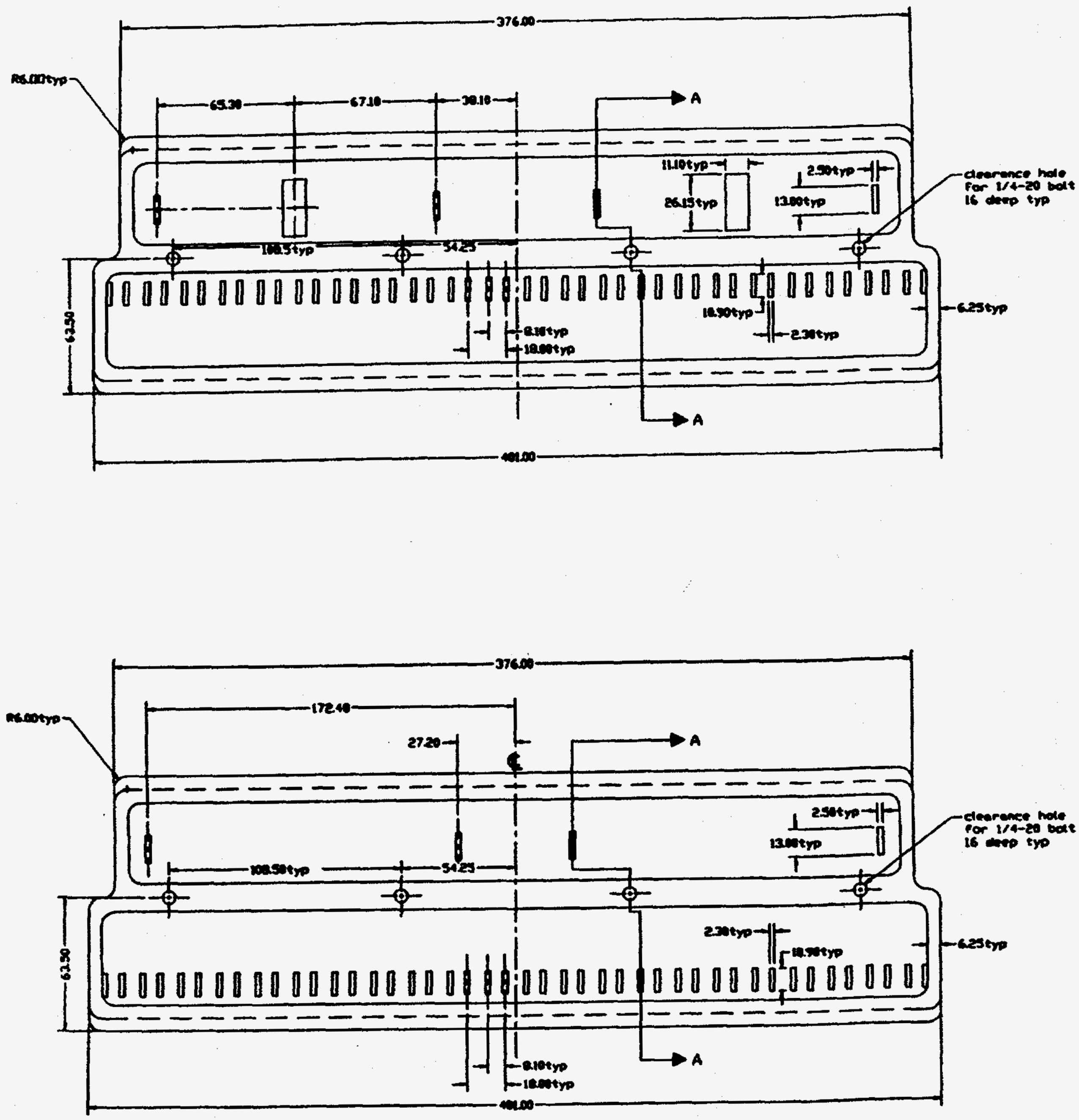


Figure 18(b): Templates used for primary and secondary ports for the kamloops model.
Top: front side; Bottom: back side.

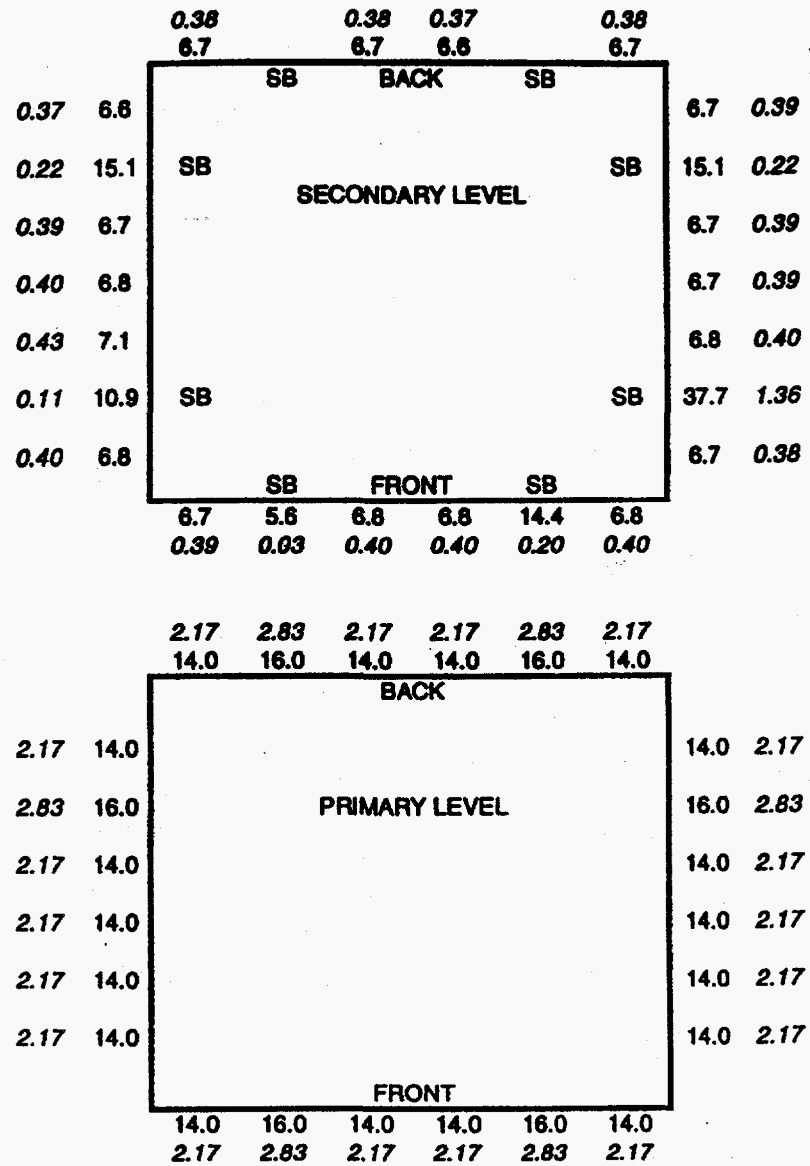


Figure 19: Experimental volume flow rates (normal text) and momentum fluxes (italic text) at the primary and secondary elevations. SB denotes 'starter burner'.

Kamloops Boiler Water Model

Measurements and Computational Results

Primary and Secondary, Average velocity=0.055m/s

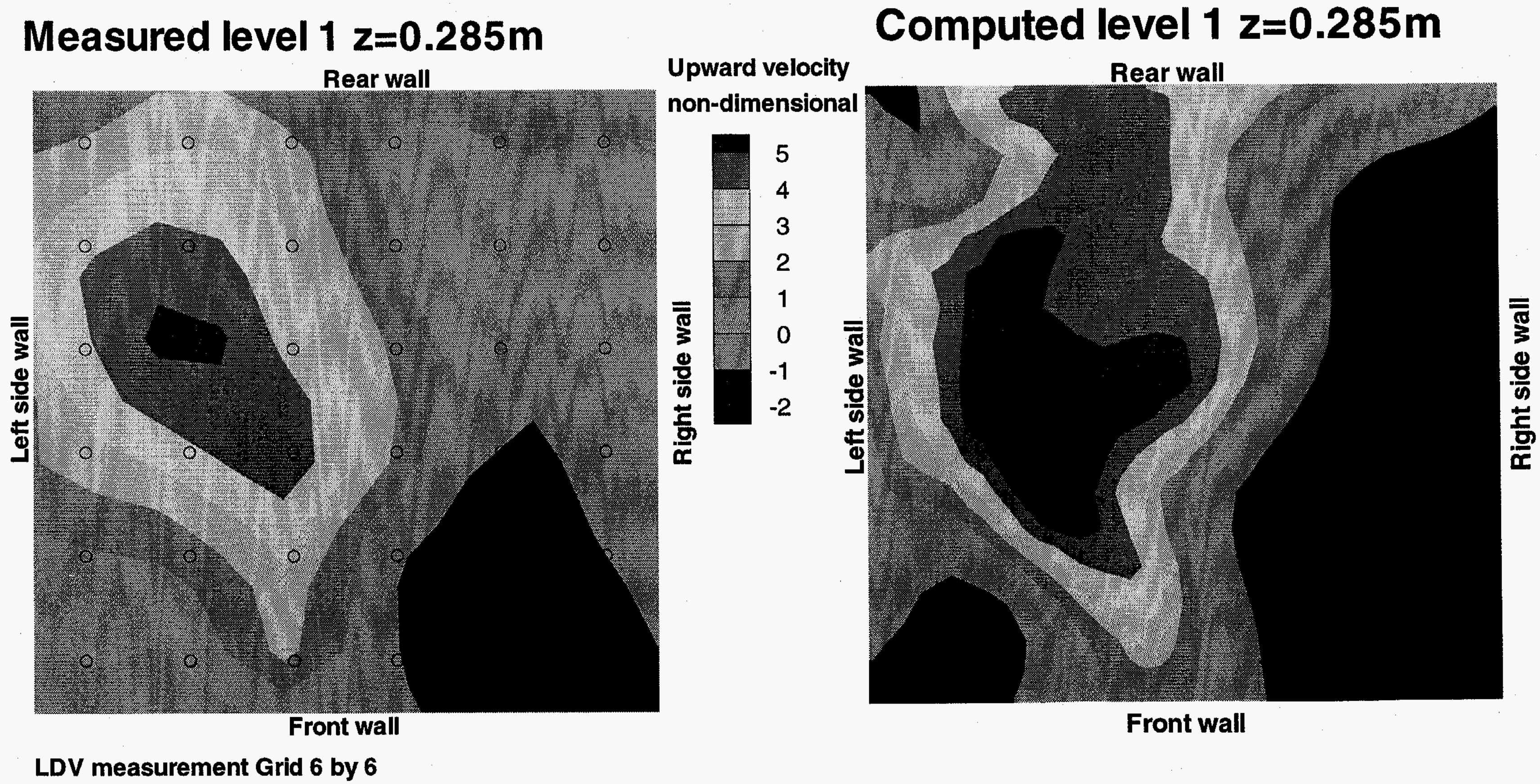
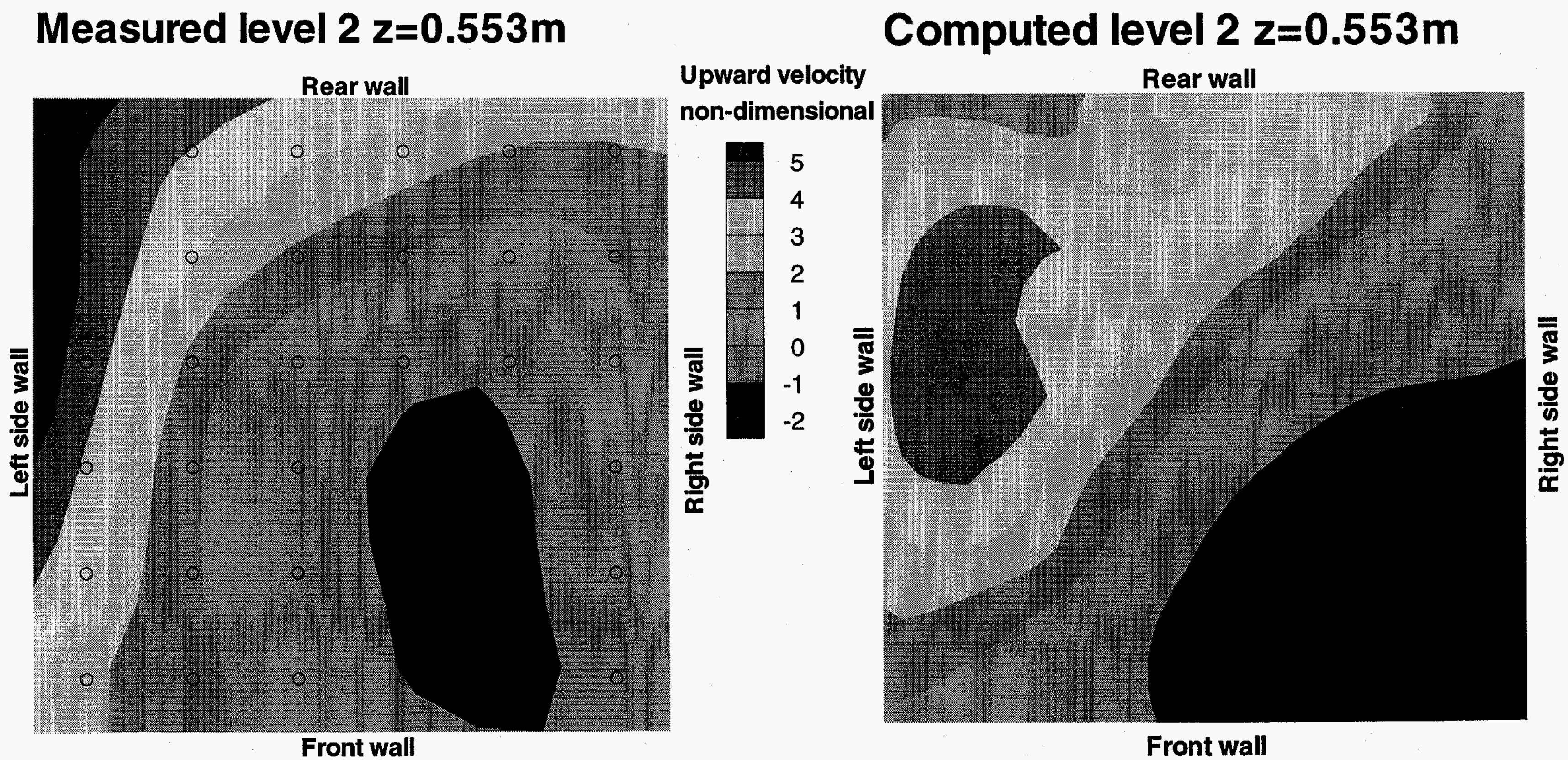


Figure 20. Measured and Computed Vertical Velocity Contours at Level 1.

Kamloops Boiler Water Model

Measurements and Computational Results

Primary and Secondary, Average velocity=0.055m/s



LDV Measurement Grid 6 by 6

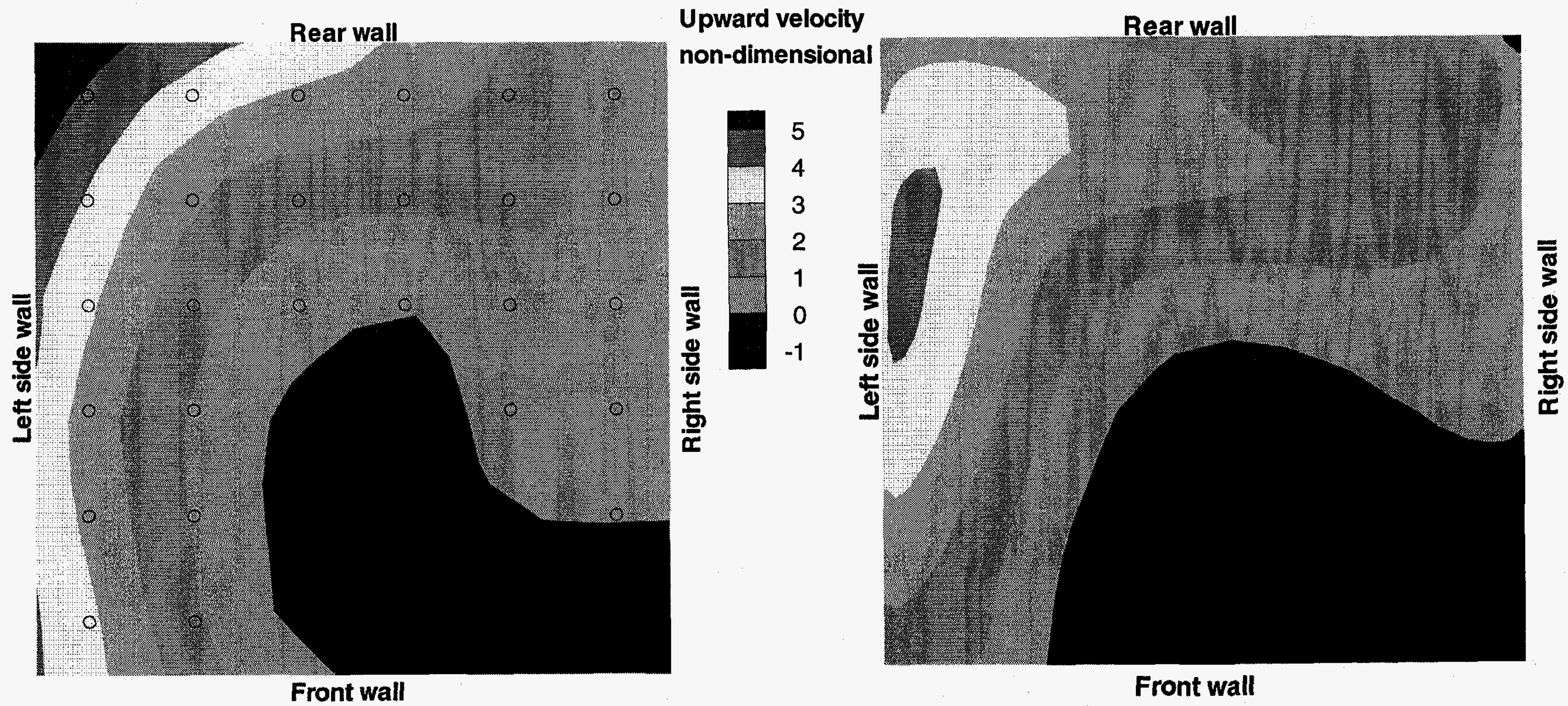
Figure 21. Measured and Computed Vertical Velocity Contours at Level 2.

Kamloops Boiler Water Model

Measurements and Computational Results

Primary and Secondary, Average velocity=0.055m/s

Measured level 3 z=0.82m **Computed level 3 z=0.82m**



LDV Measurement Grid 6 by 6

Figure 22. Measured and Computed Vertical Velocity Contours at Level 3.

APPENDIX A: DATA FOR CASE ONE

Overview

Appendix A contains drawings and tables that show the overall geometry and dimensions of the furnace including the locations and dimensions of various process systems, a complete set of process data for the 48 hour test period, and specific information on the behavior of the char bed. A list of the tables and figures included in this appendix is provided below:

Furnace Geometry

Process Data

Furnace Drawings

Table A1. Superheater and Furnace Screen Tube Arrangement

Tube Bank	Tube Geometry and Arrangement
Rear Superheater	2.0 in. OD tubes; 30 per row. Platen arrangement; 0.03 in. gap between tubes. 32 rows; 12 in. center-to-center spacing. 11.5 in. space: tube to side waterwall center-to-center.
Center Superheater	1.875 in. OD tubes; 22 per row. Platen arrangement; 0.03 in. gap between tubes. 32 rows; 12 in. center-to-center spacing. 11.5 in. space: tube to side waterwall center-to-center.
Front Superheater	1.875 in. OD tubes; 22 per row. Platen arrangement; 0.03 in. gap between tubes. 32 rows; 12 in. center-to-center spacing. 11.5 in. space: tube to side waterwall center-to-center.
Furnace Screen	2.25 in. OD tubes; 17 per row. Platen arrangement; tangent tube design. 17 rows; 24 in. center-to-center spacing. 5.5 in. space: tube to side waterwall center-to-center.

Table A2. Lower Primary Air Port Spacing

Front & Rear Ports Port No.	Distance from West wall to port center, in.	East & West Ports Port No.	Distance from Front wall to port center, in.
West wall	x = 0	Front wall	y = 0
1	71	1	20.5
2	80	2	29.5
3	89	3	38.5
4	98	4	47.5
5	107	5	56.5
6	116	6	68
7	125	7	77
8	142.5	8	86
9	151.5	9	95
10	160.5	10	104
11	169.5	11	123.5
12	178.5	12	132.5
13	187.5	13	141.5
Centerline	197.5	14	150.5
14	205.5	15	159.5
15	214.5	16	168.5
16	223.5	Centerline	179.5
17	232.5	17	195
18	241.5	18	204
19	250.5	19	213
20	269	20	222
21	278	21	231
22	287	22	249
23	296	23	258
24	305	24	267
25	314	25	276
26	323	26	285
East wall	x = 395	27	297
		28	306
		29	315
		30	324
		31	333
		Rear wall	y = 359

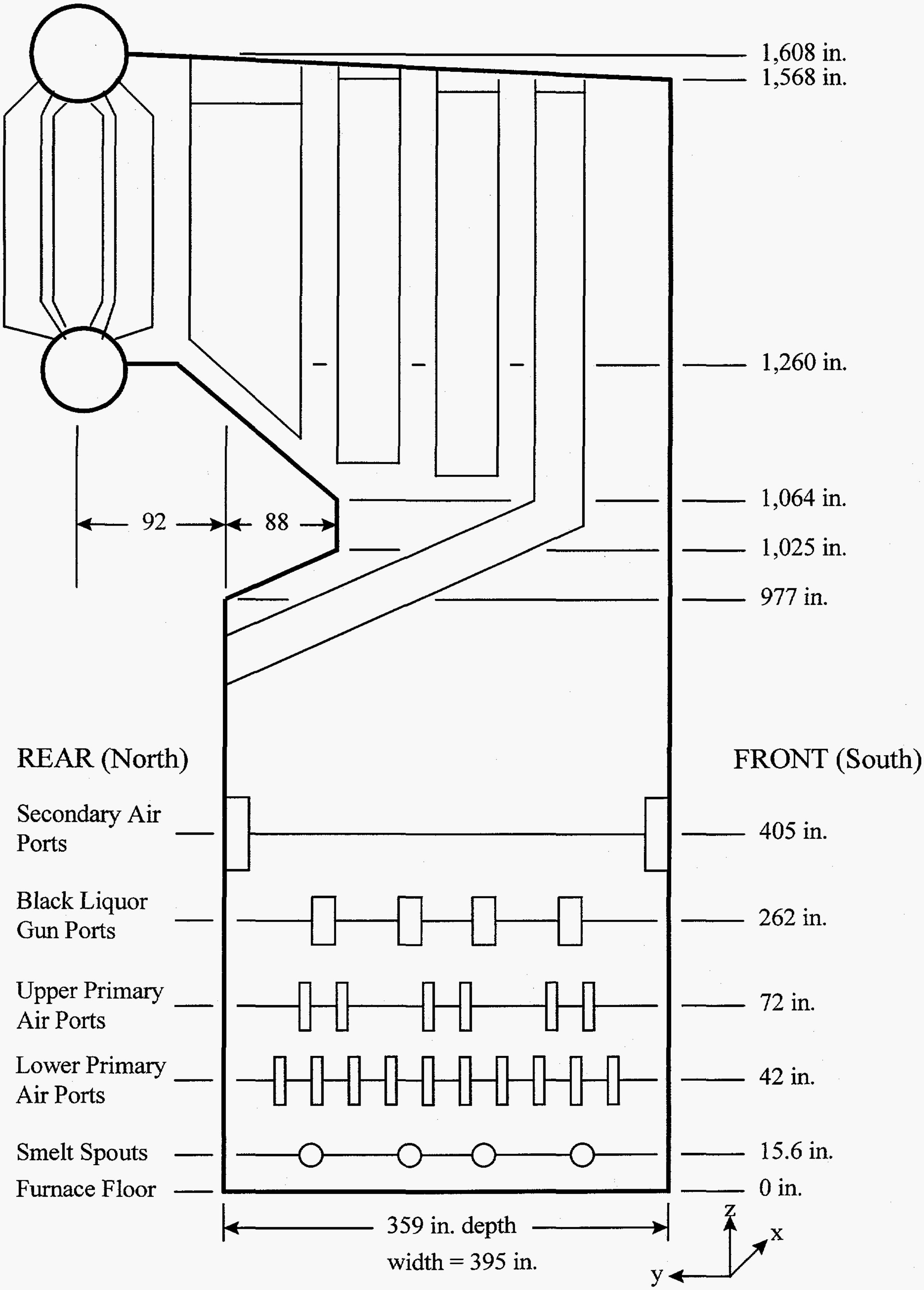


Figure A1. Overall Furnace Dimensions and Elevations (in inches).

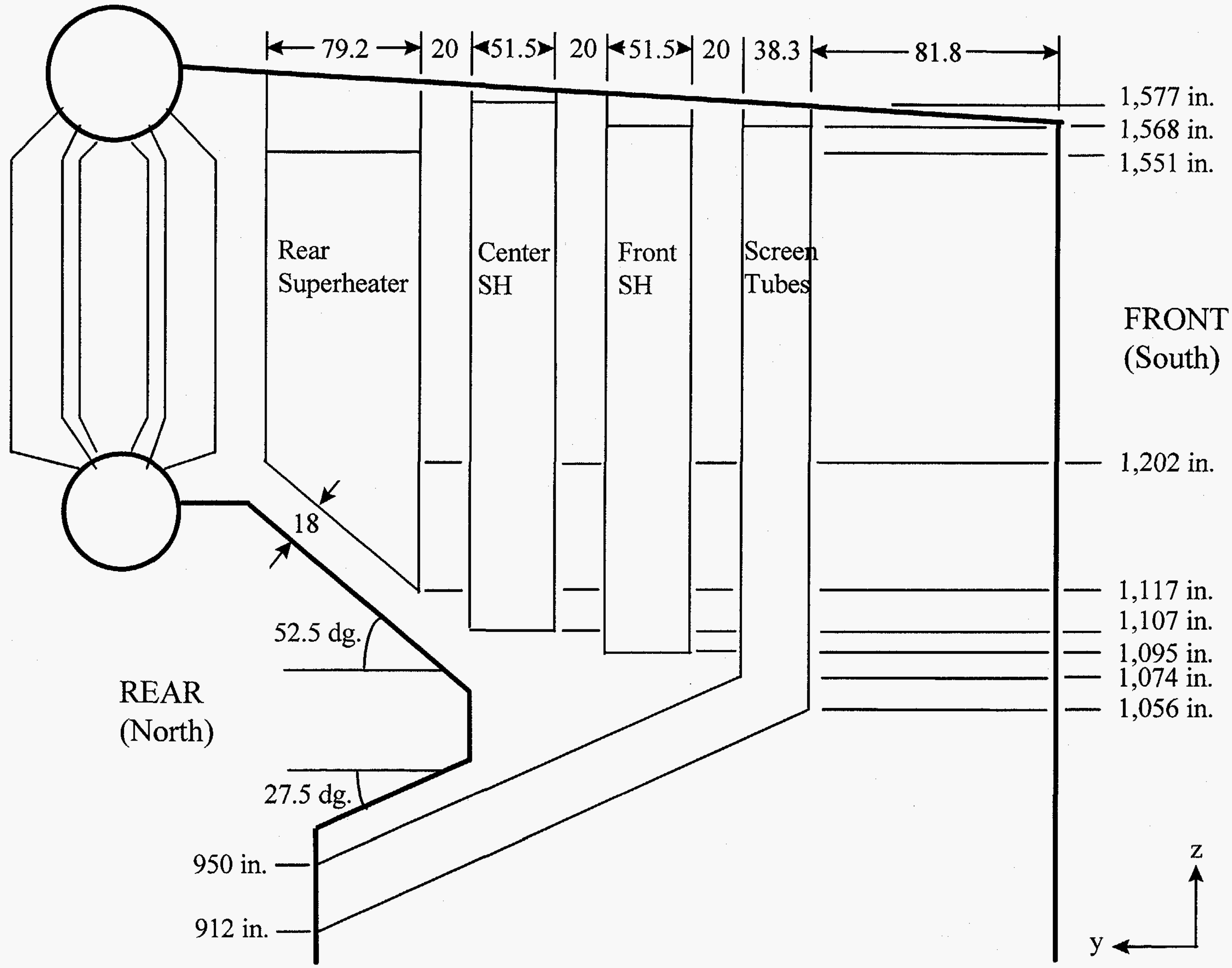


Figure A2. Upper Furnace Tube Banks: Arrangement, Dimensions, and Elevations (in inches).

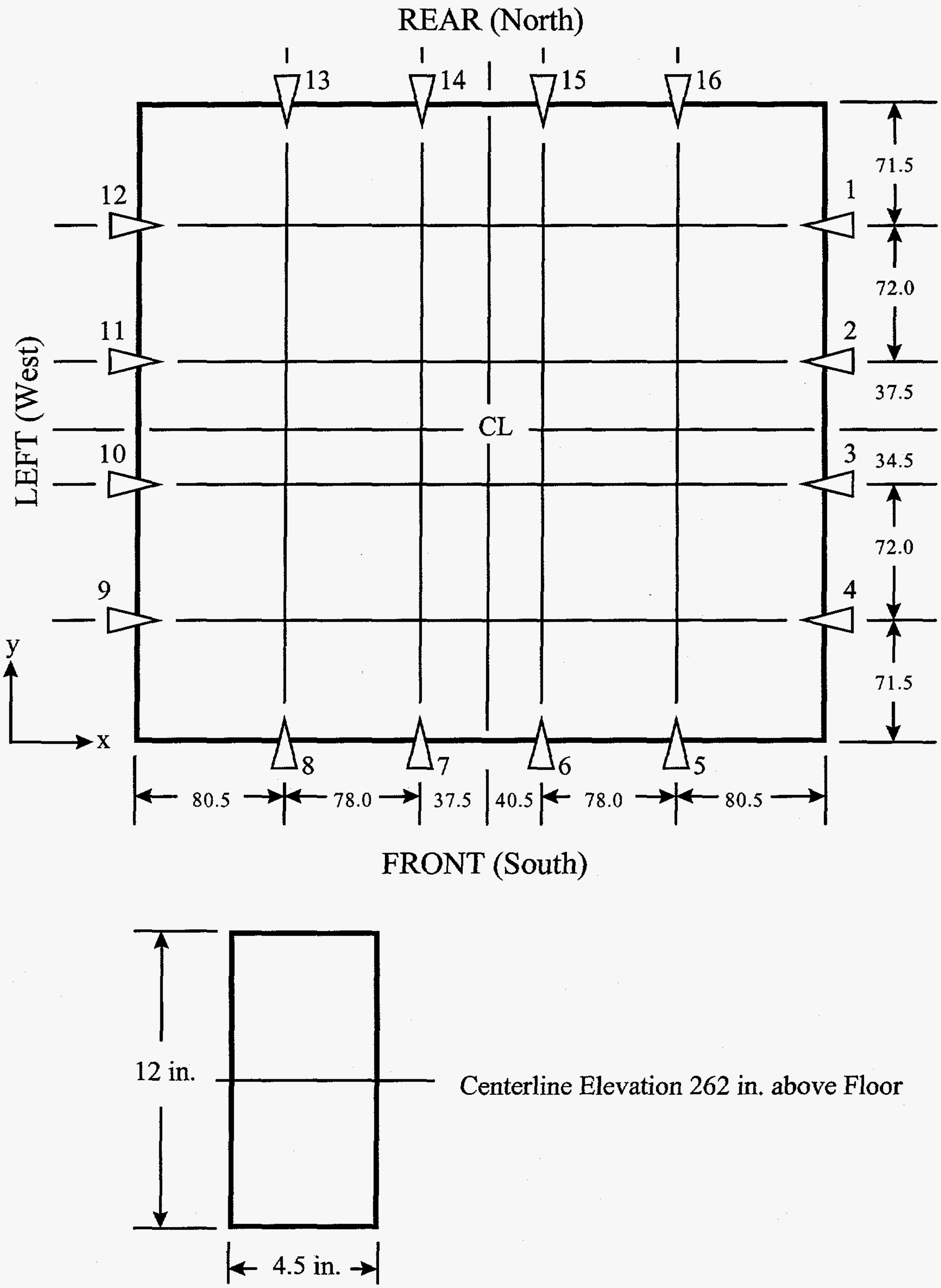
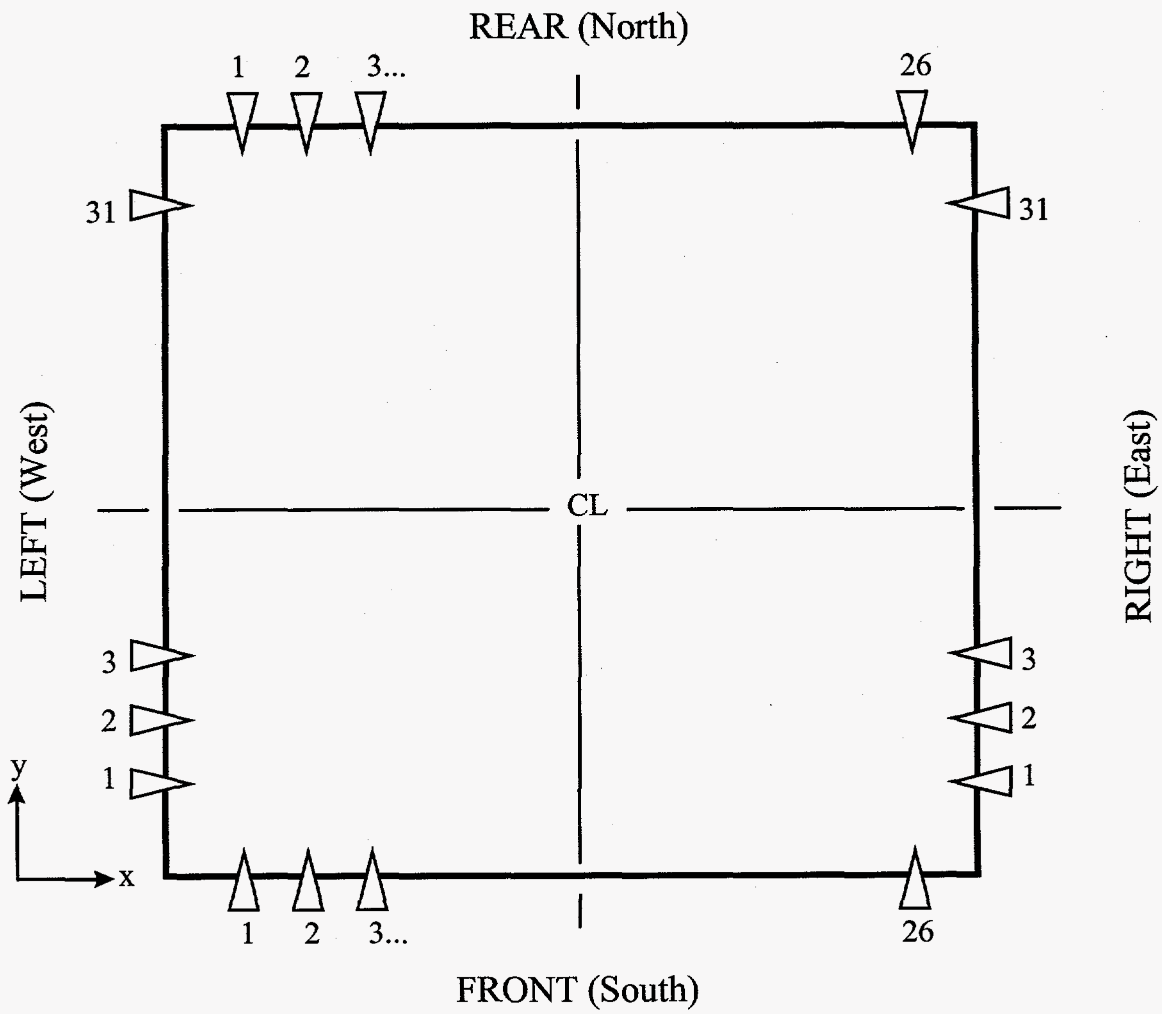


Figure A3. Black Liquor Gun Port Layout (top), and Dimensions (in inches; bottom).



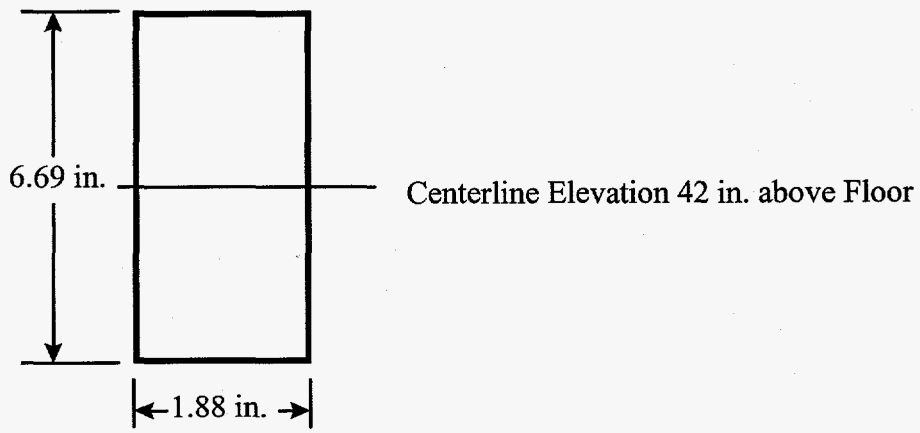


Figure A4. Lower Primary Air Port Layout (top), and Dimensions (in inches; bottom).

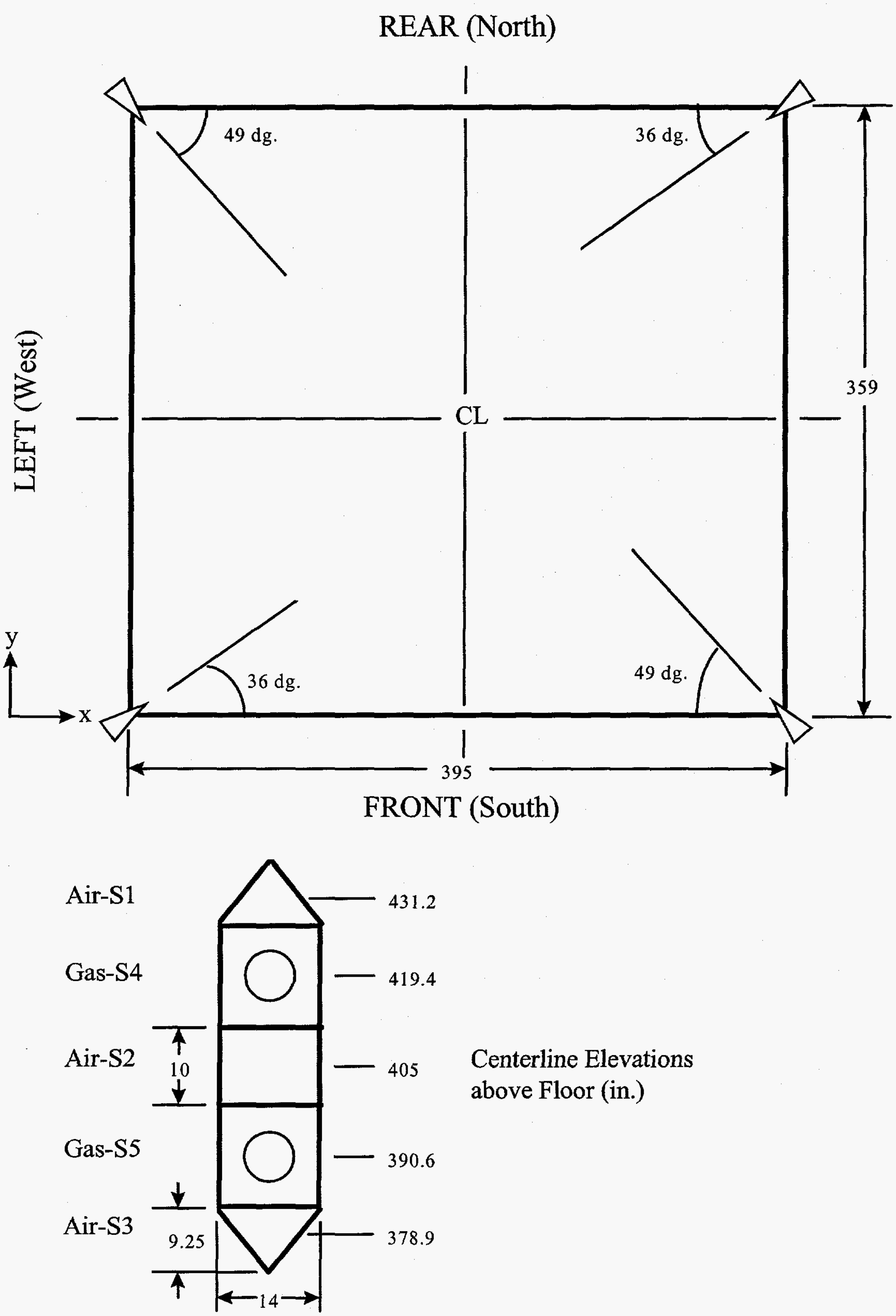


Figure A5. Secondary Air Port Layout (top), and Dimensions (in inches; bottom).

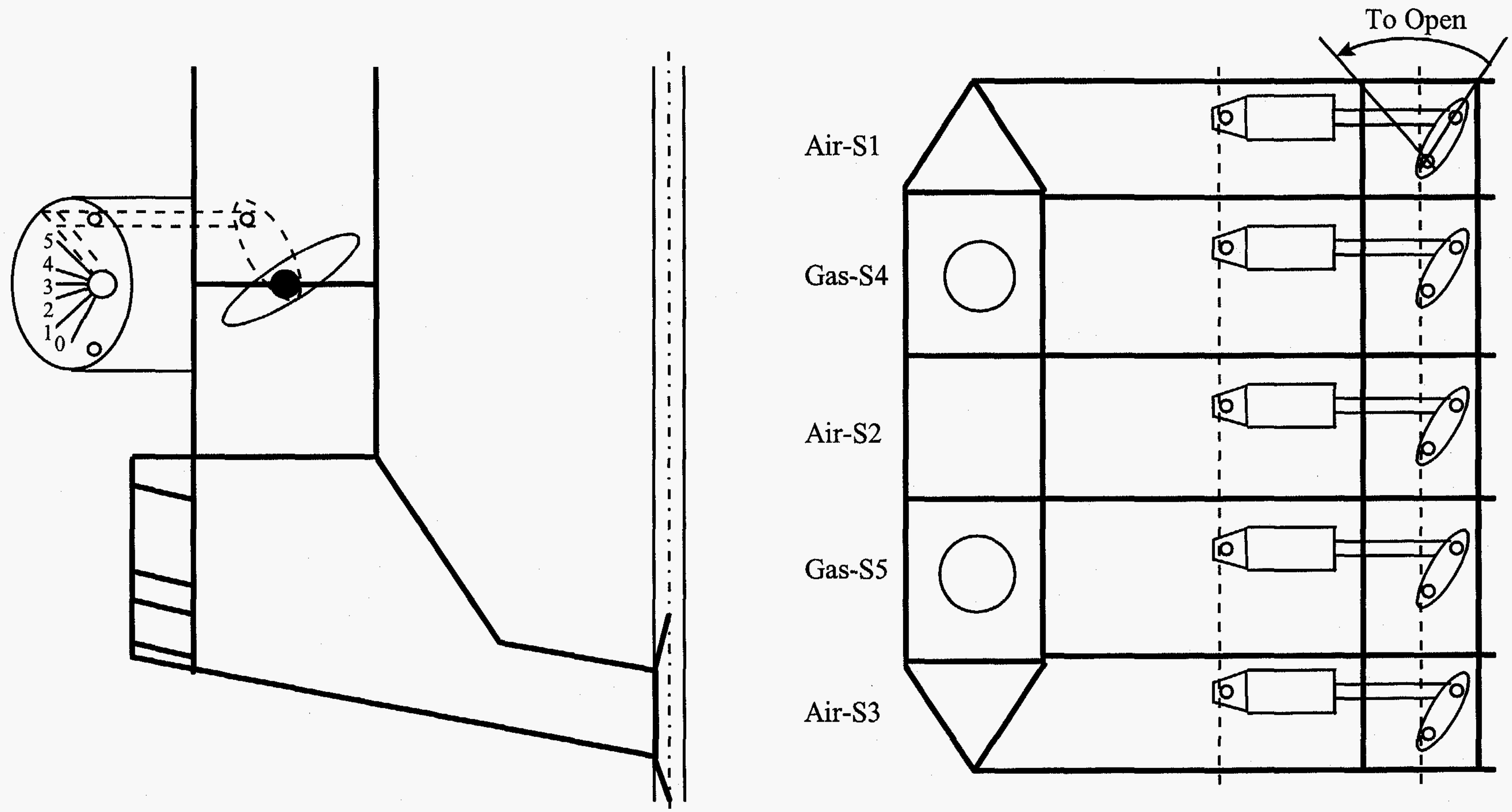
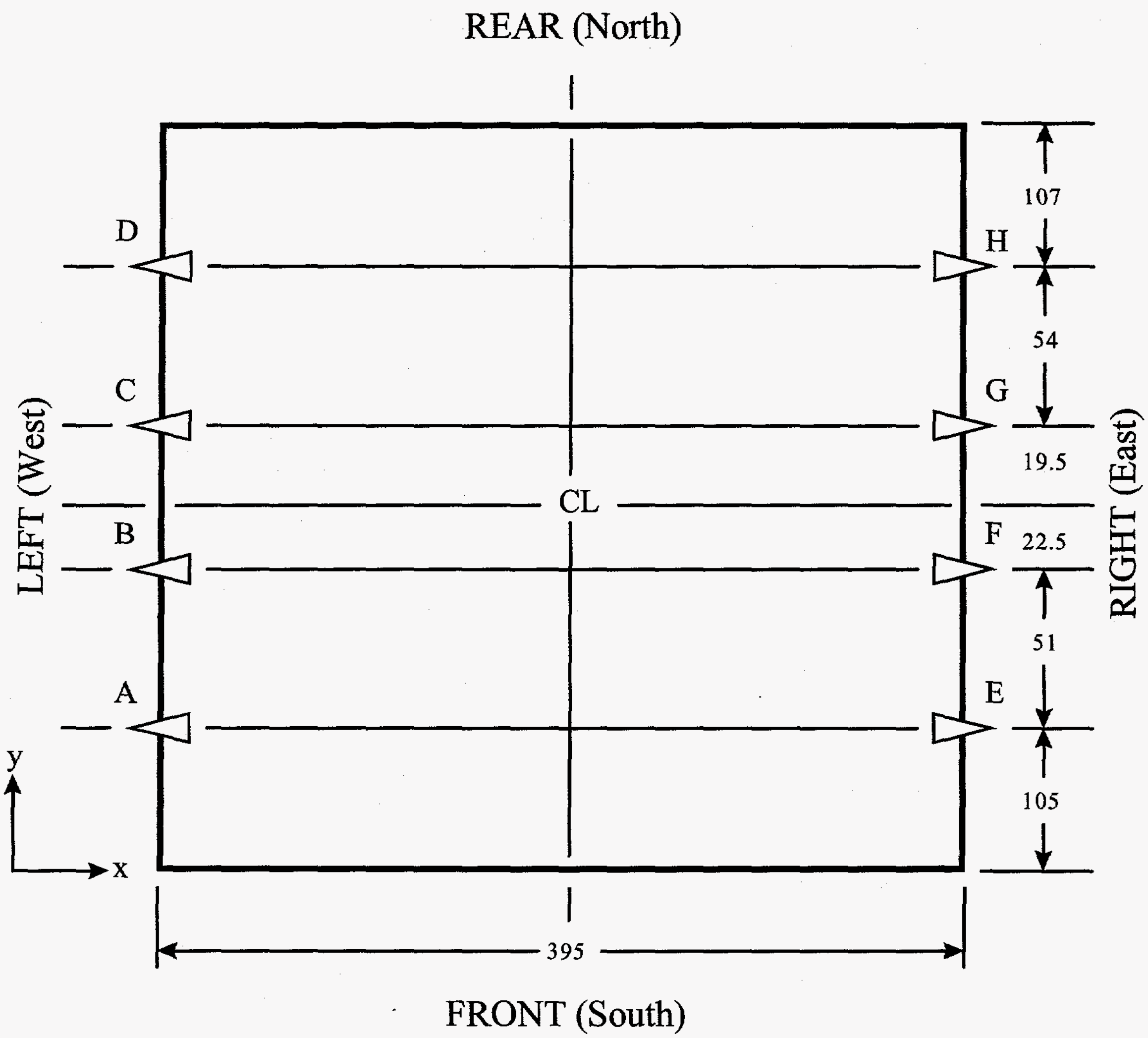


Figure A6. Air Port Dampers: Schematic of Lower Primary Windbox and Damper Assembly (left), and Secondary Windbox and Damper Assembly (right).



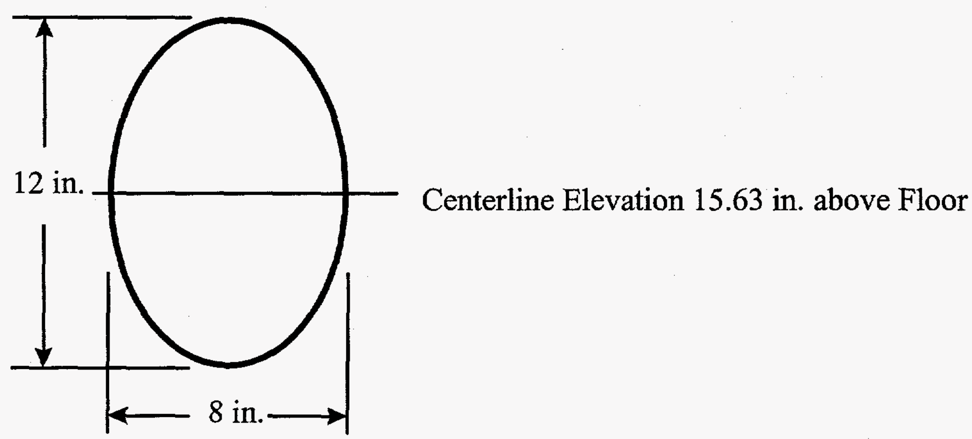


Figure A7. Smelt Spout Layout (top), and Dimensions (in inches; bottom).

Process Data

Table A3. Primary Air Port Velocities

Port No.	Lower Primary Air Port Velocities (Temperature corrected), m/sec			
	Front Wall	Rear Wall	Right Wall	Left Wall
Mean Vel., m/s	62.94	64.70	61.78	53.42
Std. Dev., m/s	4.06	5.20	6.03	11.20
1	63.53	68.28		
2	65.32	60.64	61.75	
3	57.70			
4	62.30		46.48	
5	58.32	66.14	56.93	
6	66.30	62.42		
7	62.40			
8	72.11		53.88	
9	59.12	60.90		
10	70.29	58.23	60.55	
11	60.94		56.22	
12	66.45	73.87	64.38	
13	63.16	55.50		
14	53.31	61.83		62.14
15	61.58	64.24	68.35	53.41
16	65.91		66.62	
17	66.96		66.11	33.54
18	65.85	60.44		39.66
19	64.47	68.56		
20	62.00	63.80	65.75	
21	63.69	67.25		
22	61.48			
23	62.43		66.50	
24	56.61	71.16		
25	61.59	72.02		66.24
26	62.70		65.45	56.51
27			65.20	
28				
29			62.51	
30				58.92
31				56.93

Table A4. Primary and Secondary Air Port Temperatures

Primary Air Port Temperatures, °C			
Front Wall	Rear Wall	Right Wall	Left Wall
133 (Port 1)	129 (Port 8)	129 (Port 1)	130 (Port 11)
132 (Port 14)	129 (Port 19)	129 (Port 16)	129 (Port 26)
133 (Port 26)			
Secondary Air Port Temperatures, °C			
Southwest	Southeast	Northwest	Northeast
125	128	119	124

Table A5. Measured and Calculated Air Port Inlet Conditions

Air Ports	Measured Conditions				
Location (No. of Ports)	Temp., K	Port Area, cm^2	Total Area, m^2	Velocity, m/s	Flow, kg/s
Primary (114)	403	73	0.8360	61.92	45.38
Front (26)	406	73	0.1907	62.94	10.45
Rear (26)	402	73	0.1907	64.70	10.84
Right (31)	402	73	0.2273	61.78	12.34
Left (31)	403	73	0.2273	53.42	10.66
Black Liquor Gun Leaks (16)		232	0.3716		
Secondary (20)	397.1	3555	1.3361		
Top Air (4)		429	0.1716		
Hi Gas (4)		897	0.3587		
Mid Air (4)		903	0.3613		
Low Gas (4)		897	0.3587		
Low Air (4)		429	0.0858		
Air Ports	Calculated Conditions				
Location (No. of Ports)	% of Total Design Load	Flow, kg/s	Temp., K	Velocity, m/s	Windbox Pressure, in. H_2O
Primary (114)	54.8%	46.12	403.2	62.94	6.98
Front (26)	12.5%	10.52	403.2	62.94	6.98
Rear (26)	12.5%	10.52	403.2	62.94	6.98
Right (31)	14.9%	12.54	403.2	62.94	6.98
Left (31)	14.9%	12.54	403.2	62.94	6.98
Black Liquor Gun Leaks (16)	4.8%	4.01	298	9.09	0.20
Secondary (20)	45.2%	38.04	397.1	31.99	1.83
Top Air (4)	12.5%	10.55	397.1	69.09	8.54
Hi Gas (4)	2.0%	1.68	397.1	5.27	0.05
Mid Air (4)	26.4%	22.22	397.1	69.09	8.54
Low Gas (4)	2.0%	1.68	397.1	5.27	0.05
Low Air (4)	6.3%	5.28	397.1	69.09	8.54

Table A6. Air Port Inlet Conditions: Isothermal Model Conditions

Air Port	Isothermal Model Conditions						
Location (No. of Ports)	Temp., K	Vol., m^3/kg	Area, m^2	Width, m	Height, m	Actual Area, m^2	Velocity m/s
Primary (114)	1273	3.602	2.640			4.216	39.40
Front (26)	1273	3.602	0.602	0.192	0.193	0.959	39.52
Rear (26)	1273	3.602	0.602	0.192	0.193	0.959	39.52
Right (31)	1273	3.602	0.718	0.193	0.193	1.149	39.30
Left (31)	1273	3.602	0.718	0.193	0.193	1.149	39.30
Black Liquor Gun Leaks (16)	1273	3.602	1.587	0.193	0.692	2.132	6.77
Secondary (20)	1273	3.602	4.283			0.740	185.19
Top Air (4)	1273	3.602	0.550	0.192	0.193	0.147	257.71
Hi Gas (4)	1273	3.602	1.150	0.192	0.193	0.147	41.11
Mid Air (4)	1273	3.602	1.158	0.193	0.193	0.148	539.49
Low Gas (4)	1273	3.602	1.150	0.193	0.193	0.148	40.88
Low Air (4)	1273	3.602	0.275	0.193	0.193	0.148	128.13

Table A7. Process Data: Mean Values for 3/27/96 through 3/28/96

Process Variable	Units	Mean Value	Pop. Std. Dev.	Rel. Std. Dev., %
Feedwater	klbm/hr	594.3	16.40	2.76
Sootblowers	klbm/hr	56.25	2.95	5.25
Final Steam	klbm/hr	535.0	10.83	2.02
SH #2 Exit Temp.	°C	426.3	3.01	0.71
SH #3 Inlet Temp.	°C	389.0	2.62	0.67
Final Steam	°C	422.2	3.11	0.74
SH #1 Inlet Pressure	psig	956.2	2.54	0.27
SH #2 Outlet Pressure	psig	861.2	5.96	0.69
Final Steam Pressure	psig	899.1	1.30	0.14
Black Liquor Flow	gpm	358.7	2.92	0.91
Liquor Solids, Refr. 1	%	73.46	1.00	1.36
Liquor Solids, Refr. 2	%	73.76	0.88	1.19
Liquor Temp.	°C	130.3	0.07	0.05
Primary Air Flow	klbm/hr	366.0	2.08	0.57
Secondary Air Flow	klbm/hr	304.1	1.39	0.46
Total Air Flow	klbm/hr	670.2	2.57	0.38
Air Temperature	°C	122.2	1.49	1.22
Excess Oxygen	%	2.69	0.64	23.9
Boiler Exit Temp.	°C	378.2	4.76	1.26
Econ. Exit Temp.	°C	217.7	6.26	2.87
ID Fan Speed	RPM	561.6	10.41	1.85
Feedwater Temp.	°C	138.9	0.21	0.15
Flow to Mix Tank	gpm	348.6	3.34	0.96
Spray Water Temp.	°F	239.1	3.81	1.60

APPENDIX B: DATA FOR CASE TWO

Appendix B summarizes operating conditions during the Case 2 tests. Table B1 provides a list and description of the variables in the mill data archive system. It also includes a list of variables from Radian stock testing.

Table B2 provides statistical data on operating variables during different test periods. The data sets repeat every three pages in Table B2. The first page is for tests OC0-OC2a, the second page is for tests OC2b - OC3d, and the third page is for tests OC4a-OC4f. Each repetition is with a different set of operating variables.

Table B1. Operating Variables

No.	Tag	Descriptor	Other	Location	Unit
	Variables from Mill Data Archive System				
1	25:4D624A.	RB4 BLK LIQ DENSTY A-NORTH		BL North	Solids %
2	25:4D624B.	RB4 BLK LIQ DENSTY B-SOUTH		BL South	Solids %
3	25:4F110A.PV	RB4 PRIMARY AIR FLOW CTRL		Prim	KPPH
4	25:4FC403.PV	RB4 FEEDWATER FLOW CNTRL		Feed-H2O	KPPH
5	25:4F110B.PV	RB4 TERT FANDAMPR CTRL		Tert	KPPH
6	25:4F110B.SP	RB4 TERT FANDAMPR CTRL	SP	Tert	KPPH
7	25:4F130A.	RB4 SEC AIR FLW LT NER DWN		Sec-NW	KPPH
8	25:4F130A.PV	RB4 SECONDARY AIR FLW LEFT		Sec-North	KPPH
9	25:4F130B.	RB4 SEC AIR FLW LT FAR DWN		Sec-NE	KPPH
10	25:4F130B.PV	RB4 SECONDARY AIR FLW RGHT		Sec-South	KPPH
11	25:4F130C.	RB4 SEC AIR FLW RT NER DWN		Sec-SW	KPPH
12	25:4F130D.	RB4 SEC AIR FLW RT FAR DWN		Sec-SE	KPPH
13	25:4F618A.PV	RB4 BLQ LIQ SLDS FLOW CTRL		BLS	KPPH
14	25:4F618A.SP	RB4 BLQ LIQ SLDS FLOW CTRL	SP	BLS	KPPH
15	25:4F618B.PV	RB4 BLQ LIQ GPM FLOW CTRL		BL Flow	GPM
16	25:4F618B.SP	RB4 BLQ LIQ GPM FLOW CTRL	SP	BL Flow	GPM
17	25:4FI101.	RB4 TOTAL PRI&SEC AIR FLOW		Prim + Sec	KPPH
18	25:4FI130.PE	RB4 SECONDARY AIR FLOW SUM		Sec-Total	KPPH
19	25:4FI408.	RB4 SOOTBLOWER STEAM FLOW		Sootblow	KPPH
20	25:4FI410.	RB4 MAIN STEAM FLOW		Main-steam	KPPH
21	25:4FQ101.	RB4 TOTAL AIR(PRI,SEC,TET)		Air-Total	KPPH
22	25:4FQ130.	RB4 SEC AIR TOTAL FLOW		Sec-Total	KPPH
23	25:4II233.	RB4 ID FAN AMPS		ID Fan	AMPS
24	25:4P104A.PV	RB4 FD FAN DAMPER CONTROL		FD Damper	"H2O
25	25:4P104A.SP	RB4 FD FAN DAMPER CONTRO	SP	FD Damper	"H2O
26	25:4P113A.	RB4 SEC AIR DUCT PRES LT		Sec-North	"H2O
27	25:4P113B.	RB4 SEC AIR DUCT PRES RT		Sec-South	"H2O
28	25:4P201T.	RB4 H2O UNFILTERED FURN PR		Furn	"H2O
29	25:4PC201.PV	RB4 ID FAN FURN PRES CNTRL		Furn	"H2O
30	25:4PC201.SP	RB4 ID FAN FURN PRES CNTRL	SP	Furn	"H2O
31	25:4PC407.PV	RB4 SOOTBLOWING STM PRESS		Sootblow	PSIG
32	25:4PI112.	RB4 PRIMARY AIR DUCT PRESS		Prim-Duct	"H2O
33	25:4PI115.	RB4 TERTIARY AIR DUCT PRES		Tert-Duct	"H2O
34	25:4PI404.	RB4 FEEDWATER PRESSURE		Feed-H2O	PSIG
35	25:4PI411.	RB4 MAIN STEAM PRESSURE		Main-steam	PSIG
36	25:4PI619.	RB4 BLK LIQ AT NOZZLE PRES		BL Noz	PSIG
37	25:4SI232.	RB4 ID FAN SPEED		ID Fan	RPM
38	25:4T105A.	RB4 AIR HTR AIR OUTLET TMP		Air Htr	DEG F
39	25:4T105B.	RB4 TERTIARY AIR OUT TEMP		Tert	DEG F
40	25:4TC412.PV	RB4 MAIN STEAM TEMP CNTRL		Main-steam	DEG F
41	25:4TC412.SP	RB4 MAIN STEAM TEMP CNTR	SP	Main-steam	DEG F
42	25:4TC608.PV	RB4 PRI LIQ HTR TEMP CTRL		BL Htr-1	DEG F
43	25:4TC608.SP	RB4 PRI LIQ HTR TEMP CTRL	SP	BL Htr-1	DEG F
44	25:4TC610.PV	RB4 SEC LIQ HTR TEMP CTRL		BL Htr-2	DEG F
45	25:4TC610.SP	RB4 SEC LIQ HTR TEMP CTRL	SP	BL Htr-2	DEG F
46	25:4TI704.	RB4 BLACK LIQ S.RING HEADR		BL Head	DEG F
47	25:4TI705.	RB4 BLACK LIQ N.RING HEADR		BL Head	DEG F
48	25:4L405A.PV	RB4 DRUM LEVEL CNTRL		Drum	Inches

Table B1. Operating Variables

No.	Tag	Descriptor	Other	Location	Unit
	Variables from Mill Data Archive System				
49	25:4PD224.	RB4 RT SID BLR TO ECO 1 DF		Econ1-Sou	"H2O
50	25:4PD225.	RB4 LT SID BLR TO ECO 1 DF		Econ1-Nort	"H2O
51	25:4PD226.	RB4 RT SID BLR TO ECO 2 DF		Econ2	"H2O
52	25:4PI102.	RB4 FD FAN OUTLET PRESSURE		FD Fan	"H2O
53	25:4PI114.	RB4 BOILER INLET DRAFT PRS		Furn-1	"H2O
54	25:4PI210.	RB4 BOILR INTRMEDT DRFT PR		Furn-2	"H2O
55	25:4PI217.	RB4 ECONO #2 OUTLET DRAFT		Econ3	DEG F
56	25:4PI406.	RB4 DRUM PRESSURE		Drum	PSIG
57	25:4PI628.	RB4 PRECIP N. INLET GAS PR		Precip-Nort	"H2O
58	25:4PI629.	RB4 PRECIP S. INLET GAS PR		Precip-Sout	"H2O
59	25:4T211A.	RB4 ECONO S.INLET GAS TEMP		Econ1-Sou	DEG F
60	25:4T212A.	RB4 ECONO S.BLIND PASS TMP		Econ2-Sou	DEG F
61	25:4T212B.	RB4 ECONO N.BLIND PASS TMP		Econ2-Nort	DEG F
62	25:4T213A.	RB4 ECONO S.OUTLET GAS TMP		Econ3	DEG F
63	25:4TI401.	RB4 FEEDWATER TEMPERATURE		Feed-H2O	DEG F
64	25:4TI422.	RB4 SEC SUPRHTRINLET HEADR		Super1	DEG F
65	25:4TI424.	RB4 PRI SUPRHTRINLET HEADR		Super2	DEG F
66	25:4TI426.	RB4 ECON #1 FW INLET TEMP		Econ1	DEG F
67	25:4TI427.	RB4 ECON #1 TO #2 FW TEMP		Econ2	DEG F
68	25:4TI428.	RB4 ECON #2 FW OUTLET TEMP		Econ3	DEG F
69	25:4TI627.	RB4 PRECIP OUTLET GAS TEMP		Precip-out	DEG F
70	25:4TI630.	RB4 PRECIP N.INLET GAS TMP		Precip-Nort	DEG F
71	25:4TI632.	RB4 PRECIP N.SHELL AIR TMP		Precip-Sout	DEG F
72	25:4DC650.PV	RB4 GRN LIQ DENSITY CNTRL		GL	S.G.
73	25:4AC205.PV	RB4 BOILER O2 OXYGEN CNTRL		O2	% O2
74	25:4AC206.PV	RB4 BOILER PPM: CARBN MONX		CO	PPM
75	25:4AI220.	RB4 STACK OUTLET % SO2		SO2	% SO2
76	25:4AI221.	RB4 STACK OUTLET % OXYGEN		O2	% O2
77	25:4DC650.CO	RB4 GREEN LIQUOR DENSITY		GL	%
78	25:4F403A.	RB4 FW TO STM FLW RATIO		FW/STM	%
79	25:4F618B.	RB4 STEAM TO FUEL RATIO		STM/Fuel	%
80	25:4FI313.	RB4 TOT FUEL OIL TO RECS		Fuel Oil	L PER HC
81	25:4TI648.	RB4 DISSOLV TNK GRN LIQ TP		GL	DEG F
	Variables from Radian Stack Testing				
82		**date time**	5 min avg		
83		**O2**	5 min avg		%VD
84		**CO2**	5 min avg		%VD
85		**CO**	5 min avg		**PPMVD**
86		**NO**	5 min avg		**PPMVD**
87		**NO2**	5 min avg		**PPMVD**
88		**NOx**	5 min avg		**PPMVD**
89		**SO2**	5 min avg		**PPMVD**
90		**TRS**	5 min avg		**PPMVD**
91		**Temp**	5 min avg		**degF**
92		**RH**	5 min avg		%
93		**BP**	5 min avg		**inHg**

Table B2. Operating Conditions Statistical Data

	TIME	BL Solids	BLS	BL Flow	BL Htr-2	BL Noz	
		%	KPPH	GPM	DEG C	PSIG	
		Black Liquor					
OC0							
Minimum	7/15/96 8:00	68.34	40.42	115.90	122.32	15.70	
Maximum	7/16/96 8:00	68.95	42.54	124.31	128.78	17.68	
Average	7/15/96 20:00	68.64	41.53	120.41	125.80	16.55	
Std Dev	0.290	0.183	0.446	1.817	0.921	0.359	
Norm SD	0.00%	0.27%	1.07%	1.51%	0.73%	2.17%	
Count	289	289	289	289	289	289	
OC1a							
Minimum	7/16/96 9:20	68.70	40.48	118.85	124.19	16.14	
Maximum	7/16/96 12:50	68.86	40.86	120.58	127.37	16.80	
Average	7/16/96 11:05	68.78	40.74	119.72	125.73	16.45	
Std Dev	0.044	0.047	0.122	0.517	0.527	0.191	
Norm SD	0.00%	0.07%	0.30%	0.43%	0.42%	1.16%	
Count	43	43	43	43	43	43	
OC1b							
Minimum	7/16/96 12:55	68.86	40.79	120.62	125.68	16.69	
Maximum	7/16/96 15:05	68.92	40.83	121.69	125.76	17.04	
Average	7/16/96 14:00	68.90	40.81	121.16	125.72	16.86	
Std Dev	0.028	0.020	0.011	0.327	0.024	0.105	
Norm SD	0.00%	0.03%	0.03%	0.27%	0.02%	0.63%	
Count	27	27	27	27	27	27	
OC1c							
Minimum	7/16/96 15:10	68.92	40.75	121.40	124.86	16.78	
Maximum	7/16/96 17:15	68.93	40.79	122.39	127.87	17.32	
Average	7/16/96 16:12	68.93	40.77	121.99	126.48	17.12	
Std Dev	0.027	0.003	0.011	0.263	0.862	0.147	
Norm SD	0.00%	0.00%	0.03%	0.22%	0.68%	0.86%	
Count	26	26	26	26	26	26	
OC1d							
Minimum	7/16/96 17:25	68.67	40.72	116.73	124.36	16.48	
Maximum	7/17/96 8:45	68.95	41.77	121.17	128.18	17.71	
Average	7/17/96 1:07	68.82	41.31	118.98	125.91	17.30	
Std Dev	0.187	0.106	0.259	1.183	0.539	0.239	
Norm SD	0.00%	0.15%	0.63%	0.99%	0.43%	1.38%	
Count	186	186	186	186	186	186	
OC2a							
Minimum	7/17/96 9:00	68.76	41.46	120.15	124.46	17.06	
Maximum	7/17/96 14:05	68.89	42.34	122.62	127.66	17.42	
Average	7/17/96 11:32	68.83	41.90	120.58	126.36	17.29	
Std Dev	0.063	0.040	0.258	0.691	0.982	0.088	
Norm SD	0.00%	0.06%	0.62%	0.57%	0.78%	0.51%	
Count	62	62	62	62	62	62	

Table B2. Operating Conditions Statistical Data

	TIME	BL Solids	BLS	BL Flow	BL Htr-2	BL Noz	
		%	KPPH	GPM	DEG C	PSIG	
		Black Liquor					
OC2b							
Minimum	7/17/96 14:20	68.89	47.55	135.38	124.80	18.03	
Maximum	7/17/96 17:00	68.89	48.31	139.58	127.07	19.45	
Average	7/17/96 15:40	68.89	47.84	137.48	125.95	18.81	
Std Dev	0.034	0.001	0.197	1.266	0.605	0.369	
Norm SD	0.00%	0.00%	0.41%	0.92%	0.48%	1.96%	
Count	33	33	33	33	33	33	
OC2c							
Minimum	7/17/96 17:40	68.24	33.43	95.27	123.56	14.09	
Maximum	7/18/96 8:10	68.90	36.86	105.88	127.65	16.45	
Average	7/18/96 0:57	68.67	34.20	100.64	125.05	15.27	
Std Dev	0.177	0.231	0.473	2.476	0.711	0.568	
Norm SD	0.00%	0.34%	1.38%	2.46%	0.57%	3.72%	
Count	176	176	176	176	176	176	
OC3a							
Minimum	7/18/96 8:45	68.53	39.47	119.12	120.11	15.32	
Maximum	7/18/96 14:30	68.61	41.12	119.85	123.37	18.27	
Average	7/18/96 11:37	68.59	40.88	119.49	121.62	15.62	
Std Dev	0.071	0.016	0.432	0.214	0.959	0.677	
Norm SD	0.00%	0.02%	1.06%	0.18%	0.79%	4.34%	
Count	70	70	70	70	70	70	
OC3b							
Minimum	7/18/96 14:40	68.46	39.99	119.30	127.90	18.14	
Maximum	7/18/96 16:55	68.93	42.46	121.49	130.55	19.85	
Average	7/18/96 15:47	68.69	41.06	119.87	129.11	18.67	
Std Dev	0.029	0.145	0.659	0.622	0.651	0.378	
Norm SD	0.00%	0.21%	1.61%	0.52%	0.50%	2.02%	
Count	28	28	28	28	28	28	
OC3c							
Minimum	7/18/96 17:00	68.94	40.57	119.06	128.01	17.71	
Maximum	7/18/96 17:55	69.14	42.80	119.27	131.52	19.32	
Average	7/18/96 17:27	69.04	41.89	119.15	129.84	18.82	
Std Dev	0.013	0.065	0.733	0.075	1.101	0.556	
Norm SD	0.00%	0.09%	1.75%	0.06%	0.85%	2.95%	
Count	12	12	12	12	12	12	
OC3d							
Minimum	7/18/96 18:20	69.20	41.56	119.12	120.79	14.98	
Maximum	7/18/96 23:35	69.53	41.77	119.74	121.08	15.12	
Average	7/18/96 20:57	69.42	41.67	119.43	121.06	15.05	
Std Dev	0.065	0.100	0.061	0.183	0.035	0.042	
Norm SD	0.00%	0.14%	0.15%	0.15%	0.03%	0.28%	
Count	64	64	64	64	64	64	

Table B2. Operating Conditions Statistical Data

	TIME	BL Solids	BLS	BL Flow	BL Htr-2	BL Noz	
		%	KPPH	GPM	DEG C	PSIG	
		Black Liquor					
OC4a							
Minimum	7/18/96 23:35	69.40	41.48	119.74	121.05	14.92	
Maximum	7/19/96 1:45	69.46	41.56	119.99	121.06	14.98	
Average	7/19/96 0:40	69.43	41.52	119.87	121.05	14.95	
Std Dev	0.028	0.019	0.026	0.078	0.003	0.018	
Norm SD	0.00%	0.03%	0.06%	0.06%	0.00%	0.12%	
Count	27	27	27	27	27	27	
OC4b							
Minimum	7/19/96 2:30	69.13	41.26	119.74	120.47	14.13	
Maximum	7/19/96 6:20	69.36	41.44	119.95	121.19	14.86	
Average	7/19/96 4:25	69.24	41.35	119.85	120.78	14.50	
Std Dev	0.048	0.071	0.055	0.064	0.189	0.217	
Norm SD	0.00%	0.10%	0.13%	0.05%	0.16%	1.50%	
Count	47	47	47	47	47	47	
OC4c							
Minimum	7/19/96 6:50	69.03	41.16	119.62	122.07	14.08	
Maximum	7/19/96 8:30	69.11	41.24	119.71	122.23	14.25	
Average	7/19/96 7:40	69.07	41.20	119.66	122.15	14.17	
Std Dev	0.021	0.023	0.024	0.029	0.048	0.052	
Norm SD	0.00%	0.03%	0.06%	0.02%	0.04%	0.36%	
Count	22	22	22	22	22	22	
OC4d							
Minimum	7/19/96 8:40	68.96	41.09	119.55	120.88	14.27	
Maximum	7/19/96 14:10	69.02	41.29	120.11	122.56	14.86	
Average	7/19/96 11:25	68.97	41.17	119.78	122.11	14.57	
Std Dev	0.068	0.017	0.062	0.179	0.491	0.175	
Norm SD	0.00%	0.02%	0.15%	0.15%	0.40%	1.20%	
Count	67	67	67	67	67	67	
OC4e							
Minimum	7/19/96 14:15	69.01	41.30	120.12	120.89	14.87	
Maximum	7/19/96 15:40	69.07	41.37	120.30	120.99	15.02	
Average	7/19/96 14:57	69.04	41.33	120.21	120.94	14.95	
Std Dev	0.019	0.019	0.022	0.057	0.031	0.048	
Norm SD	0.00%	0.03%	0.05%	0.05%	0.03%	0.32%	
Count	18	18	18	18	18	18	
OC4f							
Minimum	7/19/96 16:20	69.09	40.96	117.76	121.03	15.01	
Maximum	7/20/96 8:00	69.40	41.70	120.56	121.43	15.42	
Average	7/20/96 0:10	69.31	41.47	119.38	121.24	15.23	
Std Dev	0.190	0.083	0.189	0.845	0.107	0.111	
Norm SD	0.00%	0.12%	0.46%	0.71%	0.09%	0.73%	
Count	189	189	189	189	189	189	

Table B2. Operating Conditions Statistical Data

	Prim KPPH Air Flow	Sec-North KPPH	Sec-South KPPH	Sec-Total KPPH	Tert KPPH	Air-Total KPPH	Air-Total KPPH	
OC0								
Minimum	116.7	45.6	43.5	91.8	18.2	233.0	232.3	
Maximum	124.1	58.9	54.5	111.2	23.0	250.5	253.5	
Average	119.7	52.8	48.2	101.0	19.4	240.1	241.6	
Std Dev	2.00	2.57	3.05	5.15	1.00	4.78	5.46	
Norm SD	1.67%	4.86%	6.33%	5.10%	5.15%	1.99%	2.26%	
Count	289	289	289	289	289	289	289	
OC1a								
Minimum	94.4	54.0	46.5	101.7	26.7	223.9	227.4	
Maximum	99.4	58.9	49.3	106.5	30.4	233.5	238.8	
Average	95.0	56.3	48.0	104.3	28.5	227.8	230.9	
Std Dev	0.92	1.39	0.82	1.29	1.12	2.20	2.10	
Norm SD	0.97%	2.47%	1.70%	1.24%	3.93%	0.97%	0.91%	
Count	43	43	43	43	43	43	43	
OC1b								
Minimum	93.4	49.8	41.5	91.4	69.5	256.9	254.9	
Maximum	95.2	52.7	41.7	94.3	74.9	263.4	262.5	
Average	94.0	51.7	41.6	93.3	72.2	259.5	259.0	
Std Dev	0.38	0.89	0.08	0.85	1.66	2.02	2.26	
Norm SD	0.40%	1.73%	0.20%	0.91%	2.29%	0.78%	0.87%	
Count	27	27	27	27	27	27	27	
OC1c								
Minimum	97.5	50.5	41.2	91.7	50.9	240.1	245.5	
Maximum	104.0	51.8	41.4	93.3	53.7	251.0	255.3	
Average	100.7	51.2	41.3	92.5	52.3	245.5	250.4	
Std Dev	1.99	0.39	0.08	0.47	0.86	3.32	2.99	
Norm SD	1.98%	0.76%	0.20%	0.51%	1.64%	1.35%	1.19%	
Count	26	26	26	26	26	26	26	
OC1d								
Minimum	96.5	45.6	43.1	89.4	26.6	213.5	210.1	
Maximum	98.7	59.0	52.1	106.8	28.5	231.9	234.1	
Average	97.1	51.7	45.4	97.0	27.2	221.3	221.8	
Std Dev	0.53	3.83	1.82	5.11	0.60	5.51	5.83	
Norm SD	0.55%	7.41%	4.00%	5.26%	2.20%	2.49%	2.63%	
Count	186	186	186	186	186	186	186	
OC2a								
Minimum	98.9	46.0	45.0	91.9	0.0	192.5	197.5	
Maximum	103.0	50.5	46.3	96.6	0.0	198.2	203.3	
Average	101.0	48.0	46.0	94.1	0.0	195.0	199.4	
Std Dev	1.21	1.24	0.23	1.25	0.00	1.53	1.61	
Norm SD	1.20%	2.58%	0.49%	1.33%	#DIV/0!	0.78%	0.81%	
Count	62	62	62	62	62	62	62	

Appendix B -Data For Case Two

Mill Trial 7/15 to 7/20/96

Table B2. Operating Conditions Statistical Data

	Prim	Sec-North	Sec-South	Sec-Total	Tert	Air-Total	Air-Total	
	KPPH	KPPH	KPPH	KPPH	KPPH	KPPH	KPPH	
	Air Flow							
OC2b								
Minimum	101.4	49.4	47.6	97.0	43.9	243.1	250.1	
Maximum	104.6	53.0	50.3	102.6	44.8	250.4	252.5	
Average	103.6	51.2	49.1	100.3	44.4	248.3	251.3	
Std Dev	0.84	1.09	0.83	1.88	0.26	2.17	0.72	
Norm SD	0.81%	2.13%	1.69%	1.88%	0.58%	0.87%	0.29%	
Count	33	33	33	33	33	33	33	
OC2c								
Minimum	96.0	44.7	45.8	91.3	0.0	189.5	191.0	
Maximum	100.4	55.2	49.0	103.4	0.0	203.8	204.4	
Average	97.8	49.7	46.9	96.6	0.0	194.3	195.0	
Std Dev	1.16	2.56	0.87	3.23	0.00	4.17	3.11	
Norm SD	1.19%	5.15%	1.85%	3.35%	#DIV/0!	2.15%	1.60%	
Count	176	176	176	176	176	176	176	
OC3a								
Minimum	98.8	55.1	47.5	102.6	0.0	204.9	206.5	
Maximum	104.0	58.5	53.9	110.9	0.0	211.7	212.9	
Average	102.5	57.0	49.0	106.0	0.0	208.5	211.4	
Std Dev	1.49	1.05	0.88	1.78	0.00	1.81	1.79	
Norm SD	1.45%	1.84%	1.81%	1.68%	#DIV/0!	0.87%	0.85%	
Count	70	70	70	70	70	70	70	
OC3b								
Minimum	99.9	54.5	46.9	101.4	21.7	224.9	219.4	
Maximum	102.2	57.3	48.5	105.7	21.9	228.9	228.7	
Average	101.1	56.2	48.0	104.1	21.8	227.0	224.6	
Std Dev	0.70	1.01	0.58	1.59	0.07	1.22	2.05	
Norm SD	0.69%	1.80%	1.21%	1.53%	0.33%	0.54%	0.91%	
Count	28	28	28	28	28	28	28	
OC3c								
Minimum	98.9	55.8	47.8	103.6	0.0	203.1	201.5	
Maximum	99.8	56.4	48.1	104.4	0.5	204.3	202.1	
Average	99.4	56.1	47.9	104.0	0.3	203.7	201.8	
Std Dev	0.31	0.17	0.09	0.26	0.17	0.40	0.21	
Norm SD	0.31%	0.31%	0.19%	0.25%	61.11%	0.20%	0.11%	
Count	12	12	12	12	12	12	12	
OC3d								
Minimum	94.1	51.8	45.7	97.6	0.8	196.5	198.1	
Maximum	99.7	56.9	49.6	104.5	3.7	204.8	204.9	
Average	96.4	54.6	46.9	101.5	2.2	200.2	199.6	
Std Dev	1.41	1.44	0.72	2.03	0.87	2.17	1.12	
Norm SD	1.47%	2.64%	1.54%	2.00%	38.87%	1.08%	0.56%	
Count	64	64	64	64	64	64	64	

Table B2. Operating Conditions Statistical Data

	Prim	Sec-North	Sec-South	Sec-Total	Tert	Air-Total	Air-Total	
	KPPH	KPPH	KPPH	KPPH	KPPH	KPPH	KPPH	
	Air Flow							
OC4a								
Minimum	99.7	51.2	49.6	101.3	3.7	204.8	204.9	
Maximum	101.2	53.3	53.4	106.1	15.8	223.1	221.3	
Average	100.4	52.0	53.0	105.0	14.0	219.4	219.5	
Std Dev	0.46	0.67	0.71	0.87	2.31	3.46	3.01	
Norm SD	0.45%	1.29%	1.34%	0.83%	16.46%	1.57%	1.37%	
Count	27	27	27	27	27	27	27	
OC4b								
Minimum	101.7	53.3	52.5	107.1	43.0	254.5	259.2	
Maximum	104.4	58.9	55.1	113.0	46.4	260.5	268.7	
Average	103.0	56.6	54.2	110.8	44.7	258.6	262.6	
Std Dev	0.79	1.17	0.69	1.08	1.03	1.11	1.63	
Norm SD	0.77%	2.07%	1.27%	0.97%	2.31%	0.43%	0.62%	
Count	47	47	47	47	47	47	47	
OC4c								
Minimum	106.0	53.2	52.1	105.3	41.0	252.4	264.2	
Maximum	110.9	56.4	53.0	109.3	42.5	262.1	268.1	
Average	108.5	54.7	52.7	107.3	41.7	257.6	266.1	
Std Dev	1.49	1.11	0.25	1.30	0.46	3.22	1.18	
Norm SD	1.37%	2.02%	0.48%	1.21%	1.10%	1.25%	0.44%	
Count	22	22	22	22	22	22	22	
OC4d								
Minimum	92.6	47.6	49.2	97.0	10.4	211.2	211.6	
Maximum	113.6	62.3	57.8	120.1	17.5	237.8	231.3	
Average	104.4	53.3	52.2	105.4	14.0	223.8	221.9	
Std Dev	6.47	3.82	2.60	5.70	2.12	6.94	4.90	
Norm SD	6.20%	7.16%	4.99%	5.40%	15.15%	3.10%	2.21%	
Count	67	67	67	67	67	67	67	
OC4e								
Minimum	102.6	52.9	52.7	106.1	0.0	208.7	214.6	
Maximum	105.4	58.9	53.8	112.7	0.0	218.1	215.1	
Average	103.7	55.0	53.0	108.1	0.0	211.8	214.9	
Std Dev	0.89	1.95	0.26	2.02	0.00	2.90	0.16	
Norm SD	0.86%	3.54%	0.50%	1.87%	#DIV/0!	1.37%	0.08%	
Count	18	18	18	18	18	18	18	
OC4f								
Minimum	94.1	38.8	51.1	92.5	22.8	214.3	214.9	
Maximum	101.8	60.6	59.1	119.1	27.0	242.7	241.9	
Average	97.5	49.3	53.7	103.0	24.0	224.5	225.0	
Std Dev	2.01	6.50	2.01	8.07	0.81	9.08	8.41	
Norm SD	2.06%	13.19%	3.74%	7.84%	3.39%	4.04%	3.74%	
Count	189	189	189	189	189	189	189	

Table B2. Operating Conditions Statistical Data

	Feed-H2O	Sootblow	Main-steal	Sootblow	Feed-H2O	Main-steal	Drum	Main-steam	
	KPPH	KPPH	KPPH	PSIG	PSIG	PSIG	PSIG	DEG F	DEG F
	Steam								
OC0									
Minimum	187.0	0.0	179.8	596.6	899.2	855.4	860.0	782.1	790.0
Maximum	242.7	5.8	213.7	858.8	943.7	892.9	901.7	798.4	790.0
Average	211.7	3.7	196.4	668.0	922.5	872.7	881.7	790.7	790.0
Std Dev	8.98	2.15	5.96	30.51	10.47	6.03	9.33	5.04	0.00
Norm SD	4.24%	58.59%	3.04%	4.57%	1.14%	0.69%	1.06%	0.64%	0.00%
Count	289	289	289	289	289	289	289	289	289
OC1a									
Minimum	193.3	0.0	181.6	593.7	916.5	863.8	871.8	791.8	790.0
Maximum	243.3	2.4	208.0	849.4	941.8	883.7	893.6	793.8	790.0
Average	212.2	1.8	194.9	678.5	933.3	878.5	888.4	792.9	790.0
Std Dev	10.16	0.94	5.16	47.53	6.23	5.25	5.58	0.62	0.00
Norm SD	4.79%	52.78%	2.65%	7.00%	0.67%	0.60%	0.63%	0.08%	0.00%
Count	43	43	43	43	43	43	43	43	43
OC1b									
Minimum	191.6	0.0	183.6	643.6	906.2	857.5	862.0	790.7	790.0
Maximum	221.0	4.0	203.2	755.4	921.0	866.2	879.9	793.1	790.0
Average	206.8	0.6	193.0	666.2	914.1	861.7	871.1	791.9	790.0
Std Dev	7.67	1.12	4.98	21.22	4.94	2.65	5.97	0.74	0.00
Norm SD	3.71%	191.03%	2.58%	3.19%	0.54%	0.31%	0.69%	0.09%	0.00%
Count	27	27	27	27	27	27	27	27	27
OC1c									
Minimum	198.8	0.0	186.7	647.0	917.3	866.6	880.3	790.9	790.0
Maximum	244.4	5.6	203.9	717.2	921.8	870.2	884.3	795.5	790.0
Average	213.2	3.0	194.9	663.8	919.8	868.6	882.6	793.2	790.0
Std Dev	11.05	2.19	4.54	18.88	1.44	1.01	1.10	1.40	0.00
Norm SD	5.18%	73.59%	2.33%	2.84%	0.16%	0.12%	0.12%	0.18%	0.00%
Count	26	26	26	26	26	26	26	26	26
OC1d									
Minimum	185.1	0.0	172.0	597.1	898.4	835.4	849.6	783.2	790.0
Maximum	312.0	4.9	212.4	781.8	957.0	877.7	890.7	802.7	790.0
Average	208.5	2.3	195.7	666.2	913.3	869.3	881.4	790.8	790.0
Std Dev	12.08	2.15	6.83	25.99	8.43	6.87	6.56	5.94	0.00
Norm SD	5.80%	94.02%	3.49%	3.90%	0.92%	0.79%	0.74%	0.75%	0.00%
Count	186	186	186	186	186	186	186	186	186
OC2a									
Minimum	184.5	0.0	174.3	620.2	879.4	834.4	844.8	783.0	790.0
Maximum	238.5	5.8	210.9	745.8	919.2	869.7	871.4	785.4	790.0
Average	206.0	4.0	193.1	663.4	905.2	854.1	860.1	784.2	790.0
Std Dev	9.11	1.94	6.50	23.04	8.57	8.77	4.99	0.66	0.00
Norm SD	4.42%	49.07%	3.36%	3.47%	0.95%	1.03%	0.58%	0.08%	0.00%
Count	62	62	62	62	62	62	62	62	62

Table B2. Operating Conditions Statistical Data

	Feed-H2O	Sootblow	Main-stea	Sootblow	Feed-H2O	Main-stea	Drum	Main-steam	
	KPPH	KPPH	KPPH	PSIG	PSIG	PSIG	PSIG	DEG F	DEG F
	Steam								
OC2b									
Minimum	196.9	0.0	203.8	599.0	920.7	849.6	869.3	785.7	790.0
Maximum	261.7	5.2	236.5	749.0	922.5	862.7	885.2	787.7	790.0
Average	242.4	2.2	227.1	662.9	921.7	856.3	877.4	787.1	790.0
Std Dev	12.91	1.80	6.05	27.94	0.46	4.05	4.82	0.63	0.00
Norm SD	5.33%	81.83%	2.66%	4.21%	0.05%	0.47%	0.55%	0.08%	0.00%
Count	33	33	33	33	33	33	33	33	33
OC2c									
Minimum	151.5	0.0	146.4	586.1	878.3	836.6	843.9	781.8	790.0
Maximum	216.3	5.7	179.1	764.7	918.4	874.0	878.1	797.7	790.0
Average	177.7	2.3	163.4	661.0	905.8	862.4	866.1	786.7	790.0
Std Dev	8.83	2.07	6.26	23.65	9.81	7.98	7.87	2.80	0.00
Norm SD	4.97%	88.47%	3.83%	3.58%	1.08%	0.93%	0.91%	0.36%	0.00%
Count	176	176	176	176	176	176	176	176	176
OC3a									
Minimum	180.9	0.0	160.8	555.8	888.8	836.3	844.4	783.3	790.0
Maximum	236.4	4.7	220.4	702.6	935.2	877.0	893.6	803.2	790.0
Average	211.1	1.3	196.2	659.9	919.8	854.8	868.2	791.9	790.0
Std Dev	11.16	1.67	8.93	18.96	14.28	11.22	14.17	6.17	0.00
Norm SD	5.29%	131.53%	4.55%	2.87%	1.55%	1.31%	1.63%	0.78%	0.00%
Count	70	70	70	70	70	70	70	70	70
OC3b									
Minimum	196.2	3.0	188.8	604.0	890.8	837.3	848.7	782.0	790.0
Maximum	223.6	5.3	213.5	758.4	911.2	854.7	864.5	785.0	790.0
Average	210.6	4.3	201.9	661.0	903.8	848.3	858.0	783.3	790.0
Std Dev	7.06	0.76	5.77	25.52	7.72	6.96	4.70	0.95	0.00
Norm SD	3.35%	17.54%	2.86%	3.86%	0.85%	0.82%	0.55%	0.12%	0.00%
Count	28	28	28	28	28	28	28	28	28
OC3c									
Minimum	202.0	4.6	189.9	585.5	906.3	852.1	864.9	785.2	790.0
Maximum	230.2	5.2	199.2	681.3	908.5	853.2	868.6	786.7	790.0
Average	218.7	4.9	194.8	656.3	907.4	852.6	867.0	785.9	790.0
Std Dev	7.55	0.19	3.00	24.30	0.73	0.38	1.30	0.50	0.00
Norm SD	3.45%	3.80%	1.54%	3.70%	0.08%	0.04%	0.15%	0.06%	0.00%
Count	12	12	12	12	12	12	12	12	12
OC3d									
Minimum	193.5	0.0	177.5	534.2	898.1	837.6	848.7	783.6	790.0
Maximum	235.5	1.8	213.4	762.9	929.4	872.4	880.0	786.6	790.0
Average	212.6	0.2	199.4	658.0	910.2	856.9	867.3	784.7	790.0
Std Dev	9.83	0.29	6.88	30.68	10.97	11.83	10.19	0.98	0.00
Norm SD	4.62%	126.75%	3.45%	4.66%	1.21%	1.38%	1.18%	0.13%	0.00%
Count	64	64	64	64	64	64	64	64	64

Table B2. Operating Conditions Statistical Data

	Feed-H2O	Sootblow	Main-stea	Sootblow	Feed-H2O	Main-stea	Drum	Main-steam	
	KPPH	KPPH	KPPH	PSIG	PSIG	PSIG	PSIG	DEG F	DEG F
	Steam								
OC4a									
Minimum	200.5	0.0	185.0	644.5	929.1	872.4	880.0	783.8	790.0
Maximum	239.7	0.9	206.7	715.6	935.6	874.3	886.1	793.9	790.0
Average	218.6	0.2	200.8	667.5	932.3	873.8	882.4	789.8	790.0
Std Dev	9.66	0.24	5.43	18.22	1.95	0.63	1.92	4.25	0.00
Norm SD	4.42%	133.50%	2.71%	2.73%	0.21%	0.07%	0.22%	0.54%	0.00%
Count	27	27	27	27	27	27	27	27	27
OC4b									
Minimum	198.4	0.0	182.6	595.6	917.0	874.4	873.7	794.5	790.0
Maximum	241.9	5.3	214.7	694.6	925.7	877.4	887.1	797.5	790.0
Average	216.6	4.3	202.2	658.5	921.4	875.9	880.4	796.0	790.0
Std Dev	10.11	1.62	6.58	22.36	2.59	0.89	3.99	0.92	0.00
Norm SD	4.67%	37.53%	3.25%	3.40%	0.28%	0.10%	0.45%	0.12%	0.00%
Count	47	47	47	47	47	47	47	47	47
OC4c									
Minimum	196.7	0.0	183.0	615.6	912.1	877.8	866.1	788.2	790.0
Maximum	225.3	4.6	211.3	680.1	915.9	879.1	871.9	797.6	790.0
Average	210.5	4.3	198.1	656.5	914.0	878.4	869.0	792.8	790.0
Std Dev	9.02	0.96	6.65	16.86	1.15	0.40	1.78	2.89	0.00
Norm SD	4.28%	22.42%	3.36%	2.57%	0.13%	0.05%	0.20%	0.36%	0.00%
Count	22	22	22	22	22	22	22	22	22
OC4d									
Minimum	187.2	0.0	180.2	598.0	910.8	862.6	864.1	780.6	790.0
Maximum	242.6	5.6	225.1	711.0	927.8	879.4	888.4	787.2	790.0
Average	211.3	1.1	196.5	655.6	920.6	869.2	878.8	783.7	790.0
Std Dev	12.87	1.76	6.54	21.97	5.20	3.76	7.66	1.40	0.00
Norm SD	6.09%	158.72%	3.33%	3.35%	0.57%	0.43%	0.87%	0.18%	0.00%
Count	67	67	67	67	67	67	67	67	67
OC4e									
Minimum	187.1	0.0	178.9	537.6	920.2	868.6	887.4	764.0	790.0
Maximum	225.9	5.1	206.5	679.4	926.4	869.3	888.0	787.3	790.0
Average	207.5	1.8	196.3	649.8	923.3	868.9	887.7	773.2	790.0
Std Dev	11.06	2.09	7.06	30.67	1.94	0.21	0.20	6.69	0.00
Norm SD	5.33%	116.51%	3.60%	4.72%	0.21%	0.02%	0.02%	0.87%	0.00%
Count	18	18	18	18	18	18	18	18	18
OC4f									
Minimum	179.0	0.0	175.5	516.3	894.4	846.8	860.5	758.8	790.0
Maximum	235.5	5.7	217.6	729.2	933.3	875.3	894.2	780.7	790.0
Average	202.8	2.0	197.2	658.0	914.9	863.4	875.7	768.7	790.0
Std Dev	9.78	2.29	7.76	24.24	8.93	6.19	6.57	5.17	0.00
Norm SD	4.82%	114.26%	3.93%	3.68%	0.98%	0.72%	0.75%	0.67%	0.00%
Count	189	189	189	189	189	189	189	189	189

Table B2. Operating Conditions Statistical Data

		FD Dampe	FD Dampe	Prim-Duct	Sec-North	Sec-South	Tert-Duct	
		"H2O	"H2O	"H2O	"H2O	"H2O	"H2O	
		Air Pressures						
OC0								
Minimum		6.002	0.000	1.872	8.486	5.943	1.349	
Maximum		6.480	0.000	3.620	12.137	8.294	3.242	
Average		6.194	0.000	2.584	9.933	7.170	2.274	
Std Dev		0.1361	0.0000	0.3948	0.7749	0.5513	0.4927	
Norm SD		2.20%	-4.68%	15.28%	7.80%	7.69%	21.67%	
Count		289	289	289	289	289	289	
OC1a								
Minimum		6.413	0.000	1.444	8.245	5.067	2.521	
Maximum		6.690	0.000	2.018	10.151	5.934	3.097	
Average		6.547	0.000	1.693	9.241	5.484	2.793	
Std Dev		0.0776	0.0000	0.1375	0.4732	0.1953	0.1413	
Norm SD		1.19%	0.00%	8.12%	5.12%	3.56%	5.06%	
Count		43	43	43	43	43	43	
OC1b								
Minimum		6.546	0.000	1.525	6.240	3.748	6.311	
Maximum		6.898	0.000	1.967	7.649	4.627	13.439	
Average		6.721	0.000	1.735	6.933	4.271	11.535	
Std Dev		0.1058	0.0000	0.1324	0.4730	0.2582	1.3359	
Norm SD		1.57%	0.00%	7.63%	6.82%	6.05%	11.58%	
Count		27	27	27	27	27	27	
OC1c								
Minimum		6.165	0.000	1.674	5.710	3.761	6.179	
Maximum		6.467	0.000	2.205	6.947	4.342	6.936	
Average		6.219	0.000	1.897	6.343	4.066	6.496	
Std Dev		0.0685	0.0000	0.1517	0.4231	0.2050	0.2397	
Norm SD		1.10%	0.00%	8.00%	6.67%	5.04%	3.69%	
Count		26	26	26	26	26	26	
OC1d								
Minimum		6.032	0.000	1.460	7.620	4.920	1.906	
Maximum		6.851	0.000	3.250	13.213	7.263	3.234	
Average		6.451	0.000	2.087	10.557	6.417	2.534	
Std Dev		0.2157	0.0000	0.3771	1.4117	0.6591	0.2888	
Norm SD		3.34%	-6.53%	18.07%	13.37%	10.27%	11.39%	
Count		186	186	186	186	186	186	
OC2a								
Minimum		6.120	0.000	1.649	6.665	4.597	0.729	
Maximum		6.596	0.000	2.529	8.674	5.537	1.423	
Average		6.424	0.000	2.047	7.800	5.274	1.035	
Std Dev		0.1071	0.0000	0.1820	0.5670	0.2505	0.1616	
Norm SD		1.67%	0.00%	8.89%	7.27%	4.75%	15.62%	
Count		62	62	62	62	62	62	

Table B2. Operating Conditions Statistical Data

		FD Dampe	FD Dampe	Prim-Duct	Sec-North	Sec-South	Tert-Duct	
		"H2O	"H2O	"H2O	"H2O	"H2O	"H2O	
		Air Pressures						
OC2b								
Minimum		5.904	0.000	1.917	8.074	5.852	7.638	
Maximum		6.016	0.000	2.850	9.388	6.862	8.121	
Average		5.960	0.000	2.399	8.809	6.334	7.860	
Std Dev		0.0338	0.0000	0.2436	0.3969	0.2984	0.1513	
Norm SD		0.57%	0.00%	10.15%	4.51%	4.71%	1.93%	
Count		33	33	33	33	33	33	
OC2c								
Minimum		6.096	0.000	1.635	7.916	5.795	-0.109	
Maximum		6.987	0.000	4.074	12.219	7.663	0.562	
Average		6.706	0.000	2.713	10.180	7.055	0.200	
Std Dev		0.2257	0.0000	0.6346	1.0482	0.4610	0.1478	
Norm SD		3.37%	-5.91%	23.39%	10.30%	6.54%	73.97%	
Count		176	176	176	176	176	176	
OC3a								
Minimum		5.920	0.000	1.608	7.959	5.432	0.026	
Maximum		6.447	0.000	3.009	9.593	6.446	0.807	
Average		6.071	0.000	2.077	8.692	5.872	0.415	
Std Dev		0.1557	0.0000	0.3160	0.3569	0.2055	0.1916	
Norm SD		2.56%	0.00%	15.22%	4.11%	3.50%	46.12%	
Count		70	70	70	70	70	70	
OC3b								
Minimum		5.938	0.000	1.641	8.014	5.510	3.923	
Maximum		6.074	0.000	2.780	9.682	6.434	4.375	
Average		5.991	0.000	2.099	8.707	5.997	4.070	
Std Dev		0.0452	0.0000	0.3434	0.5590	0.2782	0.1353	
Norm SD		0.75%	0.00%	16.36%	6.42%	4.64%	3.32%	
Count		28	28	28	28	28	28	
OC3c								
Minimum		5.914	0.000	2.193	8.701	6.052	0.391	
Maximum		5.936	0.000	2.538	9.124	6.287	1.707	
Average		5.925	0.000	2.375	8.866	6.170	1.177	
Std Dev		0.0071	0.0000	0.1093	0.1120	0.0892	0.4289	
Norm SD		0.12%	0.00%	4.60%	1.26%	1.44%	36.45%	
Count		12	12	12	12	12	12	
OC3d								
Minimum		5.894	0.000	1.737	7.779	5.548	0.370	
Maximum		6.345	0.000	4.133	10.476	8.578	1.644	
Average		6.101	0.000	2.789	9.329	6.361	0.830	
Std Dev		0.1424	0.0000	0.4883	0.6802	0.4279	0.2023	
Norm SD		2.33%	0.00%	17.51%	7.29%	6.73%	24.36%	
Count		64	64	64	64	64	64	

Table B2. Operating Conditions Statistical Data

		FD Dampe	FD Dampe	Prim-Duct	Sec-North	Sec-South	Tert-Duct	
		"H2O	"H2O	"H2O	"H2O	"H2O	"H2O	
		Air Pressures						
OC4a								
Minimum		6.298	0.000	3.594	9.594	8.578	1.644	
Maximum		6.345	0.000	4.133	10.721	8.613	2.502	
Average		6.321	0.000	3.836	10.020	8.596	2.269	
Std Dev		0.0143	0.0000	0.1260	0.3584	0.0109	0.1849	
Norm SD		0.23%	0.00%	3.29%	3.58%	0.13%	8.15%	
Count		27	27	27	27	27	27	
OC4b								
Minimum		6.197	0.000	2.219	7.975	8.170	8.793	
Maximum		6.281	0.000	3.703	9.742	8.662	9.299	
Average		6.239	0.000	3.201	8.823	8.432	9.073	
Std Dev		0.0252	0.0000	0.3836	0.4446	0.1458	0.1554	
Norm SD		0.40%	0.00%	11.98%	5.04%	1.73%	1.71%	
Count		47	47	47	47	47	47	
OC4c								
Minimum		6.256	0.000	1.928	8.902	8.439	9.171	
Maximum		6.317	0.000	2.903	10.243	8.458	9.487	
Average		6.301	0.000	2.305	9.412	8.447	9.303	
Std Dev		0.0183	0.0000	0.2829	0.3475	0.0051	0.1009	
Norm SD		0.29%	0.00%	12.27%	3.69%	0.06%	1.08%	
Count		22	22	22	22	22	22	
OC4d								
Minimum		5.864	0.000	1.209	8.014	5.730	2.412	
Maximum		6.414	0.000	2.326	11.980	8.742	2.794	
Average		6.140	0.000	1.951	9.783	6.933	2.583	
Std Dev		0.1990	0.0000	0.2060	1.2029	0.9662	0.0913	
Norm SD		3.24%	0.00%	10.56%	12.30%	13.94%	3.53%	
Count		67	67	67	67	67	67	
OC4e								
Minimum		5.904	0.000	1.770	9.585	7.646	0.140	
Maximum		5.928	0.000	2.512	11.126	7.999	0.623	
Average		5.916	0.000	2.046	10.573	7.676	0.386	
Std Dev		0.0075	0.0000	0.2087	0.4731	0.0809	0.1472	
Norm SD		0.13%	0.00%	10.20%	4.47%	1.05%	38.19%	
Count		18	18	18	18	18	18	
OC4f								
Minimum		5.850	0.000	1.634	9.174	7.155	1.774	
Maximum		6.670	0.000	3.928	14.933	9.011	4.719	
Average		6.284	0.000	2.542	11.954	8.073	2.634	
Std Dev		0.3089	0.0000	0.5414	1.7719	0.5338	0.5697	
Norm SD		4.92%	0.00%	21.30%	14.82%	6.61%	21.62%	
Count		189	189	189	173	189	189	

Appendix B -Data For Case Two Mill Trial 7/15 to 7/20/96

Table B2. Operating Conditions Statistical Data

	Furn	Furn	Furn	Econ1-South	Econ1-North	Econ2	FD Fan	Furn-1
	"H2O	"H2O	"H2O	"H2O	"H2O	"H2O	"H2O	"H2O
	Furnace Vacuum							
OC0								
Minimum	-1.122	-0.507	-0.260	1.841	1.724	1.259	8.447	-0.976
Maximum	0.390	-0.151	-0.260	2.662	2.712	1.919	9.048	-0.127
Average	-0.264	-0.309	-0.260	2.234	2.173	1.542	8.813	-0.472
Std Dev	0.2059	0.0643	0.0000	0.1528	0.1583	0.1115	0.1428	0.1279
Norm SD	-78.12%	-20.82%	0.00%	6.84%	7.28%	7.23%	1.62%	-27.09%
Count	289	289	289	289	289	289	289	289
OC1a								
Minimum	-1.026	-0.468	-0.260	1.880	1.816	1.445	8.858	-0.735
Maximum	0.220	-0.182	-0.260	2.328	2.253	1.713	9.029	-0.246
Average	-0.278	-0.303	-0.260	2.132	2.066	1.544	8.937	-0.531
Std Dev	0.2372	0.0678	0.0000	0.1001	0.1134	0.0607	0.0526	0.1036
Norm SD	-85.48%	-22.40%	0.00%	4.69%	5.49%	3.93%	0.59%	-19.51%
Count	43	43	43	43	43	43	43	43
OC1b								
Minimum	-0.400	-0.380	-0.260	2.133	2.131	1.586	8.898	-0.696
Maximum	0.072	-0.164	-0.260	2.772	2.784	1.828	9.031	-0.384
Average	-0.187	-0.310	-0.260	2.422	2.369	1.682	8.965	-0.537
Std Dev	0.1319	0.0505	0.0000	0.1436	0.1170	0.0618	0.0406	0.0832
Norm SD	-70.72%	-16.31%	0.00%	5.93%	4.94%	3.67%	0.45%	-15.50%
Count	26	27	27	27	27	27	27	27
OC1c								
Minimum	-0.922	-0.398	-0.260	1.929	1.891	1.506	8.765	-0.713
Maximum	0.054	-0.171	-0.260	2.667	2.585	1.760	8.893	-0.394
Average	-0.262	-0.263	-0.260	2.331	2.227	1.595	8.829	-0.537
Std Dev	0.2168	0.0564	0.0000	0.1527	0.1551	0.0586	0.0391	0.0813
Norm SD	-82.67%	-21.40%	0.00%	6.55%	6.96%	3.67%	0.44%	-15.13%
Count	26	26	26	26	26	26	26	26
OC1d								
Minimum	-1.019	-0.472	-0.260	1.729	1.133	1.208	8.587	-0.810
Maximum	0.112	-0.162	-0.260	2.450	2.328	1.700	8.832	-0.291
Average	-0.262	-0.303	-0.260	2.099	1.991	1.407	8.738	-0.574
Std Dev	0.1806	0.0633	0.0000	0.1269	0.1491	0.0871	0.0697	0.0926
Norm SD	-69.06%	-20.94%	0.00%	6.04%	7.49%	6.19%	0.80%	-16.14%
Count	185	186	186	186	186	186	186	186
OC2a								
Minimum	-0.859	-0.433	-0.260	1.747	1.656	1.264	8.530	-0.738
Maximum	0.059	-0.157	-0.260	2.146	2.103	1.557	8.744	-0.268
Average	-0.279	-0.285	-0.260	1.963	1.880	1.388	8.637	-0.539
Std Dev	0.2040	0.0636	0.0000	0.0819	0.1047	0.0696	0.0633	0.1080
Norm SD	-73.23%	-22.30%	0.00%	4.17%	5.57%	5.02%	0.73%	-20.04%
Count	62	62	62	62	62	62	62	62

Appendix B -Data For Case Two	Mill Trial 7/15 to 7/20/96

Table B2. Operating Conditions Statistical Data

	Furn	Furn	Furn	Econ1-South	Econ1-North	Econ2	FD Fan	Furn-1
	"H2O	"H2O	"H2O	"H2O	"H2O	"H2O	"H2O	"H2O
	Furnace Vacuum							
OC2b								
Minimum	-0.765	-0.413	-0.260	2.280	2.212	1.604	8.530	-0.734
Maximum	0.145	-0.194	-0.260	2.711	2.697	1.879	8.719	-0.299
Average	-0.265	-0.283	-0.260	2.489	2.435	1.696	8.625	-0.577
Std Dev	0.1743	0.0558	0.0000	0.1152	0.1019	0.0635	0.0570	0.0948
Norm SD	-65.84%	-19.71%	0.00%	4.63%	4.18%	3.75%	0.66%	-16.44%
Count	33	33	33	33	33	33	33	33
OC2c								
Minimum	-0.992	-0.438	-0.260	1.470	1.390	1.034	8.766	-0.794
Maximum	0.096	-0.126	-0.260	2.445	2.273	1.383	9.044	-0.069
Average	-0.256	-0.303	-0.260	1.811	1.721	1.179	8.932	-0.491
Std Dev	0.1884	0.0631	0.0000	0.1432	0.1426	0.0684	0.0725	0.1214
Norm SD	-73.65%	-20.83%	0.00%	7.91%	8.29%	5.80%	0.81%	-24.75%
Count	176	176	176	176	176	176	176	176
OC3a								
Minimum	-0.779	-0.398	-0.260	1.825	1.679	1.293	8.604	-0.739
Maximum	0.093	-0.177	-0.260	2.250	2.323	1.655	8.859	-0.233
Average	-0.270	-0.297	-0.260	2.024	1.969	1.426	8.697	-0.516
Std Dev	0.1738	0.0563	0.0000	0.0985	0.1239	0.0745	0.0836	0.1060
Norm SD	-64.28%	-18.98%	0.00%	4.86%	6.29%	5.23%	0.96%	-20.52%
Count	70	70	70	70	70	70	70	70
OC3b								
Minimum	-0.483	-0.414	-0.260	1.786	1.736	1.411	8.624	-0.749
Maximum	-0.007	-0.186	-0.260	2.386	2.415	1.678	8.646	-0.355
Average	-0.251	-0.326	-0.260	2.122	2.028	1.471	8.635	-0.536
Std Dev	0.1113	0.0576	0.0000	0.1462	0.1579	0.0534	0.0067	0.1012
Norm SD	-44.31%	-17.65%	0.00%	6.89%	7.78%	3.63%	0.08%	-18.88%
Count	28	28	28	28	28	28	28	28
OC3c								
Minimum	-0.824	-0.435	-0.260	1.734	1.750	1.304	8.647	-0.655
Maximum	-0.021	-0.206	-0.260	2.138	2.031	1.430	8.655	-0.307
Average	-0.288	-0.303	-0.260	1.974	1.889	1.375	8.651	-0.514
Std Dev	0.1985	0.0601	0.0000	0.1238	0.0872	0.0386	0.0029	0.0975
Norm SD	-68.84%	-19.79%	0.00%	6.27%	4.62%	2.81%	0.03%	-18.97%
Count	12	12	12	12	12	12	12	12
OC3d								
Minimum	-1.025	-0.467	-0.260	1.736	1.659	1.231	8.660	-0.845
Maximum	0.201	-0.132	-0.260	2.383	2.280	1.598	8.709	-0.261
Average	-0.262	-0.289	-0.260	1.988	1.901	1.343	8.684	-0.575
Std Dev	0.2202	0.0657	0.0000	0.1254	0.1185	0.0712	0.0145	0.1035
Norm SD	-84.12%	-22.68%	0.00%	6.31%	6.24%	5.30%	0.17%	-18.00%
Count	64	64	64	64	64	64	64	64

Table B2. Operating Conditions Statistical Data

	Furn	Furn	Furn	Econ1-South	Econ1-North	Econ2	FD Fan	Furn-1
	"H2O	"H2O	"H2O	"H2O	"H2O	"H2O	"H2O	"H2O
	Furnace Vacuum							
OC4a								
Minimum	-0.846	-0.391	-0.260	1.827	1.637	1.304	8.709	-0.885
Maximum	0.032	-0.185	-0.260	2.485	2.438	1.478	8.728	-0.351
Average	-0.284	-0.284	-0.260	2.069	1.977	1.368	8.718	-0.576
Std Dev	0.1697	0.0549	0.0000	0.1180	0.1480	0.0372	0.0060	0.1164
Norm SD	-59.70%	-19.30%	0.00%	5.70%	7.49%	2.72%	0.07%	-20.20%
Count	26	27	27	27	27	27	27	27
OC4b								
Minimum	-0.924	-0.447	-0.260	2.109	2.071	1.416	8.633	-0.679
Maximum	0.086	-0.095	-0.260	2.625	2.624	1.833	8.754	-0.201
Average	-0.226	-0.290	-0.260	2.385	2.329	1.561	8.722	-0.482
Std Dev	0.1992	0.0691	0.0000	0.1332	0.1247	0.0836	0.0355	0.1155
Norm SD	-88.10%	-23.84%	0.00%	5.59%	5.35%	5.36%	0.41%	-23.93%
Count	47	47	47	47	47	47	47	47
OC4c								
Minimum	-0.808	-0.415	-0.260	2.320	2.223	1.600	8.748	-0.786
Maximum	0.082	-0.215	-0.260	2.825	2.650	1.722	8.920	-0.331
Average	-0.226	-0.331	-0.260	2.598	2.502	1.671	8.860	-0.520
Std Dev	0.1879	0.0544	0.0000	0.1090	0.1027	0.0304	0.0348	0.1212
Norm SD	-83.24%	-16.46%	0.00%	4.20%	4.10%	1.82%	0.39%	-23.34%
Count	21	22	22	22	22	22	22	22
OC4d								
Minimum	-1.065	-0.419	-0.260	1.916	1.774	1.329	8.511	-0.864
Maximum	0.015	-0.197	-0.260	2.475	2.395	1.803	8.834	-0.215
Average	-0.274	-0.292	-0.260	2.086	2.043	1.524	8.718	-0.497
Std Dev	0.2170	0.0586	0.0000	0.1083	0.1258	0.0857	0.0914	0.1177
Norm SD	-79.12%	-20.04%	0.00%	5.19%	6.16%	5.62%	1.05%	-23.71%
Count	67	67	67	67	67	67	67	67
OC4e								
Minimum	-0.909	-0.433	-0.260	1.881	1.846	1.337	8.400	-0.769
Maximum	0.021	-0.253	-0.260	2.219	2.091	1.558	8.519	-0.502
Average	-0.241	-0.331	-0.260	2.067	1.956	1.417	8.438	-0.625
Std Dev	0.1899	0.0566	0.0000	0.0818	0.0770	0.0549	0.0335	0.0751
Norm SD	-78.68%	-17.09%	0.00%	3.96%	3.93%	3.88%	0.40%	-12.03%
Count	18	18	18	18	18	18	18	18
OC4f								
Minimum	-0.943	-0.483	-0.260	1.861	1.701	1.311	8.483	-0.824
Maximum	0.124	-0.155	-0.260	2.630	2.523	1.774	8.912	-0.294
Average	-0.246	-0.296	-0.260	2.129	2.077	1.490	8.735	-0.546
Std Dev	0.1616	0.0646	0.0000	0.1666	0.1556	0.0860	0.1176	0.0985
Norm SD	-65.59%	-21.86%	0.00%	7.82%	7.49%	5.77%	1.35%	-18.05%
Count	188	189	189	189	189	189	189	189

Table B2. Operating Conditions Statistical Data

	Furn-2	Econ3	Precip-No	Precip-South		Drum	ID Fan	ID Fan
	"H2O	"H2O	"H2O	"H2O		Inches	AMPS	RPM
	Furnace Vacuum					Miscellaneous		
OC0								
Minimum	-0.967	-4.183	0.142	0.246		-2.378	257	418
Maximum	-0.087	-2.765	0.167	0.284		0.575	345	536
Average	-0.473	-3.405	0.151	0.268		-1.063	289	431
Std Dev	0.1402	0.2144	0.0056	0.0097		0.4855	14.6	20.2
Norm SD	-29.64%	-6.30%	3.71%	3.61%		-45.67%	5.06%	4.70%
Count	289	289	289	289		289	289	289
OC1a								
Minimum	-0.827	-3.671	0.155	0.268		-2.364	277	422
Maximum	-0.272	-3.053	0.168	0.272		0.028	296	431
Average	-0.541	-3.370	0.162	0.270		-1.073	286	429
Std Dev	0.1146	0.1458	0.0039	0.0014		0.4735	4.1	1.3
Norm SD	-21.18%	-4.33%	2.43%	0.50%		-44.13%	1.44%	0.29%
Count	43	43	43	43		43	43	43
OC1b								
Minimum	-0.744	-4.075	0.168	0.271		-1.466	300	420
Maximum	-0.401	-3.493	0.174	0.273		0.021	338	527
Average	-0.569	-3.782	0.172	0.272		-0.932	318	486
Std Dev	0.0886	0.1499	0.0019	0.0004		0.3588	10.1	42.8
Norm SD	-15.58%	-3.96%	1.11%	0.15%		-38.50%	3.18%	8.80%
Count	27	27	27	27		27	27	27
OC1c								
Minimum	-0.656	-3.847	0.174	0.270		-2.264	290	420
Maximum	-0.382	-3.227	0.174	0.271		0.011	353	529
Average	-0.555	-3.561	0.174	0.271		-1.020	304	439
Std Dev	0.0836	0.1305	0.0001	0.0004		0.6063	12.3	29.7
Norm SD	-15.05%	-3.66%	0.06%	0.15%		-59.44%	4.04%	6.77%
Count	26	26	26	26		26	26	26
OC1d								
Minimum	-0.805	-3.678	0.174	0.267		-2.212	244	414
Maximum	-0.249	-2.675	0.184	0.282		0.466	307	425
Average	-0.543	-3.130	0.178	0.275		-1.025	269	421
Std Dev	0.1077	0.1661	0.0029	0.0053		0.4841	11.9	3.2
Norm SD	-19.82%	-5.31%	1.65%	1.93%		-47.25%	4.41%	0.76%
Count	186	186	186	186		186	186	186
OC2a								
Minimum	-0.722	-3.338	0.184	0.266		-2.240	248	421
Maximum	-0.253	-2.729	0.189	0.279		-0.041	294	429
Average	-0.515	-2.945	0.187	0.276		-1.000	259	423
Std Dev	0.1056	0.1221	0.0012	0.0031		0.4643	8.0	1.5
Norm SD	-20.50%	-4.15%	0.65%	1.14%		-46.42%	3.08%	0.36%
Count	62	62	62	62		62	62	62

Table B2. Operating Conditions Statistical Data

	Furn-2	Econ3	Precip-No	Precip-South		Drum	ID Fan	ID Fan
	"H2O	"H2O	"H2O	"H2O		Inches	AMPS	RPM
	Furnace Vacuum					Miscellaneous		
OC2b								
Minimum	-0.810	-4.147	0.183	0.240		-2.212	311	429
Maximum	-0.305	-3.458	0.189	0.264		-0.117	359	538
Average	-0.581	-3.830	0.186	0.252		-1.148	323	509
Std Dev	0.1238	0.1413	0.0019	0.0073		0.5295	10.2	28.8
Norm SD	-21.31%	-3.69%	1.01%	2.90%		-46.10%	3.18%	5.66%
Count	33	33	33	33		33	33	33
OC2c								
Minimum	-0.849	-3.043	0.155	0.232		-2.520	218	392
Maximum	-0.128	-2.283	0.181	0.272		0.455	275	421
Average	-0.431	-2.610	0.166	0.260		-1.021	237	404
Std Dev	0.1229	0.1443	0.0079	0.0128		0.4822	10.5	6.9
Norm SD	-28.49%	-5.53%	4.78%	4.90%		-47.24%	4.42%	1.70%
Count	176	176	176	176		176	176	176
OC3a								
Minimum	-0.709	-3.357	0.162	0.268		-2.385	257	417
Maximum	-0.257	-2.847	0.177	0.291		0.503	315	424
Average	-0.509	-3.072	0.170	0.277		-1.086	268	423
Std Dev	0.1065	0.1113	0.0048	0.0077		0.5674	10.5	1.0
Norm SD	-20.91%	-3.62%	2.80%	2.78%		-52.26%	3.90%	0.23%
Count	70	70	70	70		70	70	70
OC3b								
Minimum	-0.777	-3.530	0.175	0.292		-1.609	268	422
Maximum	-0.244	-2.972	0.177	0.303		0.124	312	423
Average	-0.521	-3.211	0.176	0.298		-0.895	277	422
Std Dev	0.1183	0.1280	0.0005	0.0034		0.4831	8.5	0.2
Norm SD	-22.72%	-3.99%	0.30%	1.15%		-53.95%	3.07%	0.05%
Count	28	28	28	28		28	28	28
OC3c								
Minimum	-0.661	-3.195	0.175	0.304		-2.069	258	422
Maximum	-0.260	-2.858	0.175	0.307		-0.267	266	422
Average	-0.501	-2.961	0.175	0.306		-1.214	262	422
Std Dev	0.1169	0.0908	0.0002	0.0013		0.5911	2.0	0.1
Norm SD	-23.33%	-3.07%	0.13%	0.41%		-48.71%	0.76%	0.02%
Count	12	12	12	12		12	12	12
OC3d								
Minimum	-0.763	-3.264	0.168	0.265		-1.943	243	416
Maximum	-0.340	-2.612	0.174	0.303		0.635	315	422
Average	-0.544	-2.920	0.172	0.284		-1.048	259	420
Std Dev	0.0965	0.1419	0.0017	0.0114		0.4350	13.4	1.8
Norm SD	-17.75%	-4.86%	0.99%	4.02%		-41.50%	5.18%	0.43%
Count	64	64	64	64		64	64	64

Table B2. Operating Conditions Statistical Data

	Furn-2	Econ3	Precip-No	Precip-South		Drum	ID Fan	ID Fan
	"H2O	"H2O	"H2O	"H2O		Inches	AMPS	RPM
	Furnace Vacuum					Miscellaneous		
OC4a								
Minimum	-0.730	-3.243	0.162	0.249		-2.753	250	422
Maximum	-0.282	-2.746	0.168	0.265		0.087	308	428
Average	-0.556	-3.051	0.165	0.257		-1.130	266	425
Std Dev	0.1152	0.1208	0.0017	0.0049		0.5986	11.4	1.8
Norm SD	-20.72%	-3.96%	1.05%	1.90%		-52.97%	4.29%	0.43%
Count	27	27	27	27		27	27	27
OC4b								
Minimum	-0.784	-3.975	0.150	0.249		-1.813	288	421
Maximum	-0.212	-3.305	0.160	0.252		0.103	372	531
Average	-0.506	-3.633	0.155	0.251		-0.957	308	461
Std Dev	0.1204	0.1707	0.0030	0.0009		0.4265	15.9	40.1
Norm SD	-23.79%	-4.70%	1.93%	0.37%		-44.57%	5.18%	8.70%
Count	47	47	47	47		47	47	47
OC4c								
Minimum	-0.822	-4.274	0.152	0.253		-2.387	308	522
Maximum	-0.401	-3.702	0.157	0.254		-0.108	373	534
Average	-0.562	-3.941	0.154	0.253		-1.143	331	527
Std Dev	0.1026	0.1388	0.0015	0.0004		0.5851	13.5	3.3
Norm SD	-18.25%	-3.52%	0.97%	0.16%		-51.21%	4.08%	0.62%
Count	22	22	22	22		22	22	22
OC4d								
Minimum	-0.758	-3.653	0.157	0.254		-2.339	263	416
Maximum	-0.111	-2.865	0.174	0.285		0.739	357	431
Average	-0.496	-3.226	0.165	0.267		-0.993	279	423
Std Dev	0.1355	0.1654	0.0048	0.0101		0.5784	15.7	3.9
Norm SD	-27.29%	-5.13%	2.89%	3.78%		-58.25%	5.63%	0.93%
Count	67	67	67	67		67	67	67
OC4e								
Minimum	-0.744	-3.453	0.173	0.286		-1.746	262	423
Maximum	-0.338	-2.804	0.174	0.295		0.338	305	426
Average	-0.568	-3.048	0.173	0.290		-0.865	270	425
Std Dev	0.1026	0.1486	0.0002	0.0030		0.6182	11.0	0.8
Norm SD	-18.06%	-4.88%	0.12%	1.04%		-71.45%	4.06%	0.19%
Count	18	18	18	18		18	18	18
OC4f								
Minimum	-0.737	-3.807	0.145	0.273		-2.407	252	415
Maximum	-0.250	-2.770	0.173	0.370		1.123	343	527
Average	-0.529	-3.205	0.162	0.290		-1.020	280	426
Std Dev	0.1090	0.2222	0.0098	0.0170		0.5464	17.5	14.4
Norm SD	-20.60%	-6.93%	6.04%	5.87%		-53.57%	6.26%	3.39%
Count	189	189	189	189		189	189	189

Table B2. Operating Conditions Statistical Data

		Air Htr	Tert	Econ1-South	Econ2-South	Econ2-North	Econ3	Feed-H2O
		DEG F	DEG F	DEG F	DEG F	DEG F	DEG F	DEG F
		Flue Gas Temperatures						
OC0								
Minimum		293.0	108.5	762.3	525.7	531.0	409.2	-35.6
Maximum		298.1	125.4	821.7	555.2	553.3	414.7	-35.1
Average		296.2	114.9	789.0	544.1	540.3	411.4	-35.4
Std Dev		1.51	5.35	14.67	6.73	6.81	1.68	0.14
Norm SD		0.51%	4.66%	1.86%	1.24%	1.26%	0.41%	-0.39%
Count		289	289	289	289	289	289	289
OC1a								
Minimum		296.3	107.7	781.3	539.2	540.3	413.0	-35.4
Maximum		300.4	112.3	786.2	543.3	551.3	414.1	-35.3
Average		298.4	109.6	783.7	541.8	543.6	413.5	-35.3
Std Dev		1.21	1.51	1.61	1.15	3.74	0.33	0.04
Norm SD		0.40%	1.38%	0.21%	0.21%	0.69%	0.08%	-0.12%
Count		43	43	43	43	43	43	43
OC1b								
Minimum		300.5	112.5	771.4	536.3	540.4	412.3	-35.5
Maximum		302.2	116.0	782.7	541.5	540.7	412.9	-35.4
Average		301.6	114.3	777.9	540.0	540.6	412.6	-35.4
Std Dev		0.58	1.09	3.58	1.49	0.08	0.21	0.02
Norm SD		0.19%	0.95%	0.46%	0.28%	0.01%	0.05%	-0.06%
Count		27	27	27	27	27	27	27
OC1c								
Minimum		301.8	116.2	754.7	528.3	540.7	411.5	-35.5
Maximum		302.1	119.6	770.8	535.8	541.3	412.2	-35.5
Average		301.9	117.9	759.2	531.1	541.0	411.9	-35.5
Std Dev		0.09	1.05	5.77	2.24	0.21	0.24	0.01
Norm SD		0.03%	0.89%	0.76%	0.42%	0.04%	0.06%	-0.03%
Count		26	26	26	26	26	26	26
OC1d								
Minimum		299.7	112.1	754.6	519.5	530.5	405.6	-35.6
Maximum		301.8	120.8	784.5	540.5	542.2	411.4	-35.4
Average		300.8	116.3	768.5	531.8	536.6	408.4	-35.5
Std Dev		0.53	2.47	7.46	6.21	3.66	1.73	0.04
Norm SD		0.18%	2.13%	0.97%	1.17%	0.68%	0.42%	-0.12%
Count		186	186	186	186	186	186	186
OC2a								
Minimum		300.3	119.7	766.9	514.2	534.8	408.3	-35.6
Maximum		300.7	122.7	787.7	540.9	537.7	416.8	-35.5
Average		300.5	121.4	774.5	523.4	536.3	412.6	-35.6
Std Dev		0.09	0.82	5.86	6.37	0.85	2.51	0.03
Norm SD		0.03%	0.68%	0.76%	1.22%	0.16%	0.61%	-0.08%
Count		62	62	62	62	62	62	62

Table B2. Operating Conditions Statistical Data

		Air Htr	Tert	Econ1-South	Econ2-South	Econ2-North	Econ3	Feed-H2O
		DEG F	DEG F	DEG F	DEG F	DEG F	DEG F	DEG F
		Flue Gas Temperatures						
OC2b								
Minimum		300.3	122.9	771.2	545.8	541.2	405.6	-35.6
Maximum		300.7	128.1	779.6	561.3	564.8	417.3	-35.6
Average		300.5	125.5	775.9	553.5	557.8	411.6	-35.6
Std Dev		0.10	1.60	2.48	4.58	5.11	3.61	0.02
Norm SD		0.03%	1.27%	0.32%	0.83%	0.92%	0.88%	-0.04%
Count		33	33	33	33	33	33	33
OC2c								
Minimum		297.8	126.3	722.2	493.5	504.3	392.5	-35.5
Maximum		300.3	129.5	753.3	528.6	532.5	407.0	-35.3
Average		299.0	127.2	736.4	511.6	514.7	398.8	-35.4
Std Dev		0.81	1.06	7.35	8.49	6.44	3.85	0.07
Norm SD		0.27%	0.84%	1.00%	1.66%	1.25%	0.96%	-0.21%
Count		176	176	176	176	176	176	176
OC3a								
Minimum		298.6	126.3	746.4	528.2	524.6	407.6	-35.6
Maximum		300.3	129.7	779.0	539.8	528.8	409.6	-35.4
Average		299.5	127.7	768.1	536.8	526.6	408.6	-35.5
Std Dev		0.53	1.12	10.02	3.14	1.28	0.59	0.06
Norm SD		0.18%	0.88%	1.30%	0.59%	0.24%	0.15%	-0.17%
Count		70	70	70	70	70	70	70
OC3b								
Minimum		300.3	128.7	762.6	523.8	525.2	406.6	-35.6
Maximum		300.6	129.7	775.7	526.6	531.4	407.5	-35.6
Average		300.5	129.2	765.5	524.5	528.3	407.1	-35.6
Std Dev		0.09	0.30	3.39	0.64	1.88	0.28	0.01
Norm SD		0.03%	0.23%	0.44%	0.12%	0.36%	0.07%	-0.04%
Count		28	28	28	28	28	28	28
OC3c								
Minimum		300.6	128.3	761.2	525.5	531.5	406.4	-35.7
Maximum		300.7	128.7	762.4	531.1	531.7	406.6	-35.6
Average		300.7	128.5	761.8	528.3	531.6	406.5	-35.6
Std Dev		0.04	0.13	0.41	1.85	0.06	0.05	0.01
Norm SD		0.01%	0.10%	0.05%	0.35%	0.01%	0.01%	-0.02%
Count		12	12	12	12	12	12	12
OC3d								
Minimum		300.5	123.8	752.5	529.6	530.3	406.5	-35.7
Maximum		301.3	128.1	777.0	537.3	531.5	406.8	-35.7
Average		301.0	126.8	760.4	532.9	530.9	406.6	-35.7
Std Dev		0.19	1.08	8.17	2.30	0.34	0.10	0.02
Norm SD		0.06%	0.85%	1.07%	0.43%	0.06%	0.02%	-0.06%
Count		64	64	64	64	64	64	64

Table B2. Operating Conditions Statistical Data

		Air Htr	Tert	Econ1-South	Econ2-South	Econ2-North	Econ3	Feed-H2O
		DEG F	DEG F	DEG F	DEG F	DEG F	DEG F	DEG F
		Flue Gas Temperatures						
OC4a								
Minimum		299.0	118.4	757.1	532.8	530.0	406.8	-35.7
Maximum		300.5	123.8	762.8	538.1	533.7	407.1	-35.6
Average		299.8	121.1	760.5	535.4	530.8	406.9	-35.7
Std Dev		0.43	1.62	1.53	1.64	1.12	0.06	0.02
Norm SD		0.14%	1.34%	0.20%	0.31%	0.21%	0.02%	-0.07%
Count		27	27	27	27	27	27	27
OC4b								
Minimum		296.1	107.2	751.3	538.7	537.6	407.4	-35.6
Maximum		298.6	116.6	762.9	551.7	560.8	408.9	-35.4
Average		297.3	111.9	757.6	543.1	548.7	408.1	-35.5
Std Dev		0.75	2.80	3.65	4.91	7.46	0.46	0.04
Norm SD		0.25%	2.50%	0.48%	0.90%	1.36%	0.11%	-0.12%
Count		47	47	47	47	47	47	47
OC4c								
Minimum		296.4	107.9	744.5	542.5	550.7	409.1	-35.5
Maximum		297.4	114.5	757.2	548.6	557.4	409.8	-35.5
Average		296.9	111.3	750.7	545.5	554.0	409.4	-35.5
Std Dev		0.32	2.02	3.88	1.87	2.05	0.21	0.02
Norm SD		0.11%	1.82%	0.52%	0.34%	0.37%	0.05%	-0.05%
Count		22	22	22	22	22	22	22
OC4d								
Minimum		297.5	115.2	737.5	527.2	549.8	409.8	-35.7
Maximum		301.0	137.0	766.6	545.3	551.3	411.9	-35.5
Average		299.3	126.1	750.9	538.6	550.5	410.9	-35.6
Std Dev		1.01	6.44	8.38	4.89	0.42	0.61	0.06
Norm SD		0.34%	5.11%	1.12%	0.91%	0.08%	0.15%	-0.17%
Count		67	67	67	67	67	67	67
OC4e								
Minimum		301.0	132.1	754.0	528.3	549.2	412.0	-35.7
Maximum		301.0	137.7	766.2	536.9	549.9	412.5	-35.7
Average		301.0	135.0	761.5	530.6	549.5	412.2	-35.7
Std Dev		0.00	1.80	3.64	2.45	0.21	0.17	0.00
Norm SD		0.00%	1.33%	0.48%	0.46%	0.04%	0.04%	0.00%
Count		18	18	18	18	18	18	18
OC4f								
Minimum		299.3	111.0	744.9	522.6	543.1	403.4	-35.7
Maximum		301.0	130.6	771.9	553.0	558.7	416.1	-35.4
Average		300.4	118.9	756.5	538.1	550.6	409.0	-35.6
Std Dev		0.63	5.82	7.39	9.29	4.16	3.35	0.11
Norm SD		0.21%	4.90%	0.98%	1.73%	0.76%	0.82%	-0.30%
Count		189	189	189	189	189	189	189

Table B2. Operating Conditions Statistical Data

	Super1	Super2	Econ1	Econ2	Econ3	Precip-out	Precip-North	Precip-South
	DEG F	DEG F	DEG F	DEG F	DEG F	DEG F	DEG F	DEG F
	Flue Gas Temperatures							
OC0								
Minimum	598.1	697.5	305.9	366.3	468.0	387.0	366.7	302.6
Maximum	621.6	723.8	308.1	375.2	492.9	391.8	378.5	307.8
Average	612.1	711.0	306.5	370.2	477.4	388.0	373.4	305.1
Std Dev	4.86	6.12	0.60	2.59	6.46	1.16	3.01	1.32
Norm SD	0.79%	0.86%	0.19%	0.70%	1.35%	0.30%	0.81%	0.43%
Count	289	289	289	289	289	289	289	289
OC1a								
Minimum	614.8	691.1	308.7	373.3	474.4	390.0	378.8	305.6
Maximum	617.0	697.0	309.5	377.8	485.2	391.8	383.8	306.6
Average	615.6	694.4	309.2	375.5	479.9	390.9	381.5	306.1
Std Dev	0.73	1.67	0.21	1.39	3.29	0.55	1.42	0.30
Norm SD	0.12%	0.24%	0.07%	0.37%	0.69%	0.14%	0.37%	0.10%
Count	43	43	43	43	43	43	43	43
OC1b								
Minimum	617.3	694.1	308.3	372.5	482.4	391.3	382.8	306.6
Maximum	628.6	699.1	308.9	378.6	492.0	392.2	384.5	307.3
Average	622.9	696.5	308.6	376.2	488.3	391.8	383.7	307.0
Std Dev	3.46	1.46	0.21	2.01	2.83	0.28	0.52	0.21
Norm SD	0.56%	0.21%	0.07%	0.53%	0.58%	0.07%	0.14%	0.07%
Count	27	27	27	27	27	27	27	27
OC1c								
Minimum	623.9	692.2	307.6	368.3	477.2	389.9	380.7	307.4
Maximum	629.9	702.6	308.2	372.2	483.7.	391.2	382.7	308.0
Average	627.1	698.2	307.9	369.9	479.0	390.5	381.7	307.7
Std Dev	1.92	3.26	0.20	1.07	1.61	0.41	0.62	0.21
Norm SD	0.31%	0.47%	0.06%	0.29%	0.34%	0.10%	0.16%	0.07%
Count	26	26	26	26	26	26	26	26
OC1d								
Minimum	604.3	676.6	307.0	363.5	461.6	380.0	369.6	305.2
Maximum	623.3	703.5	308.6	370.8	485.8	389.8	380.5	308.6
Average	611.4	693.8	308.0	366.9	472.9	384.4	374.4	306.8
Std Dev	4.37	6.72	0.55	2.21	5.55	3.16	3.02	1.09
Norm SD	0.71%	0.97%	0.18%	0.60%	1.17%	0.82%	0.81%	0.36%
Count	186	186	186	186	186	186	186	186
OC2a								
Minimum	604.9	687.6	308.1	366.4	468.1	379.3	374.9	304.9
Maximum	611.7	706.5	308.6	373.0	480.7	383.5	376.2	306.0
Average	609.4	698.6	308.5	369.6	473.7	380.1	375.4	305.3
Std Dev	1.63	5.34	0.17	2.02	3.31	1.02	0.33	0.32
Norm SD	0.27%	0.76%	0.06%	0.55%	0.70%	0.27%	0.09%	0.11%
Count	62	62	62	62	62	62	62	62

Table B2. Operating Conditions Statistical Data

	Super1	Super2	Econ1	Econ2	Econ3	Precip-out	Precip-North	Precip-South
	DEG F	DEG F	DEG F	DEG F	DEG F	DEG F	DEG F	DEG F
	Flue Gas Temperatures							
OC2b								
Minimum	612.4	689.8	307.6	373.4	472.3	384.3	376.4	306.1
Maximum	624.5	706.7	308.1	373.9	487.3	393.5	387.3	307.0
Average	617.5	698.5	307.8	373.8	477.3	388.9	383.4	306.5
Std Dev	3.80	4.81	0.14	0.10	4.73	2.75	3.16	0.27
Norm SD	0.62%	0.69%	0.04%	0.03%	0.99%	0.71%	0.82%	0.09%
Count	33	33	33	33	33	33	33	33
OC2c								
Minimum	625.4	667.1	305.6	359.7	462.2	370.6	360.0	299.8
Maximum	647.0	702.7	308.2	375.8	478.0	393.2	380.7	307.6
Average	638.9	680.0	306.7	367.3	469.3	375.5	365.8	302.9
Std Dev	5.84	8.57	0.65	4.47	3.90	5.69	4.89	2.56
Norm SD	0.91%	1.26%	0.21%	1.22%	0.83%	1.52%	1.34%	0.85%
Count	176	176	176	176	176	176	176	176
OC3a								
Minimum	617.3	691.3	308.5	371.7	469.6	376.3	367.5	301.9
Maximum	636.4	712.0	309.6	375.7	483.9	384.0	375.8	305.1
Average	627.9	699.4	309.2	373.1	473.2	380.9	371.6	303.3
Std Dev	4.45	4.77	0.29	1.26	4.66	2.47	2.44	0.96
Norm SD	0.71%	0.68%	0.10%	0.34%	0.98%	0.65%	0.66%	0.32%
Count	70	70	70	70	70	70	70	70
OC3b								
Minimum	619.6	691.0	308.3	371.6	471.2	382.3	376.0	305.2
Maximum	632.7	694.4	308.8	372.3	471.7	383.3	378.4	306.6
Average	629.6	692.2	308.6	372.0	471.5	382.8	377.5	305.9
Std Dev	4.26	1.04	0.15	0.22	0.17	0.32	0.79	0.45
Norm SD	0.68%	0.15%	0.05%	0.06%	0.04%	0.08%	0.21%	0.15%
Count	28	28	28	28	28	28	28	28
OC3c								
Minimum	631.9	687.1	308.1	372.3	471.2	381.8	377.6	306.7
Maximum	632.2	693.3	308.3	372.6	476.4	382.3	378.1	307.3
Average	632.1	690.2	308.2	372.5	473.5	382.0	377.8	307.0
Std Dev	0.11	2.02	0.07	0.10	1.84	0.14	0.16	0.20
Norm SD	0.02%	0.29%	0.02%	0.03%	0.39%	0.04%	0.04%	0.06%
Count	12	12	12	12	12	12	12	12
OC3d								
Minimum	611.0	679.5	307.5	365.8	464.1	380.3	374.5	306.9
Maximum	631.8	710.1	308.0	373.0	483.5	382.7	377.3	307.9
Average	618.8	697.3	307.7	369.8	471.5	381.2	375.9	307.4
Std Dev	7.83	7.80	0.13	2.33	7.06	0.63	0.85	0.30
Norm SD	1.27%	1.12%	0.04%	0.63%	1.50%	0.17%	0.23%	0.10%
Count	64	64	64	64	64	64	64	64

Table B2. Operating Conditions Statistical Data

	Super1	Super2	Econ1	Econ2	Econ3	Precip-out	Precip-North	Precip-South
	DEG F	DEG F	DEG F	DEG F	DEG F	DEG F	DEG F	DEG F
	Flue Gas Temperatures							
OC4a								
Minimum	613.5	688.6	307.4	365.5	463.5	382.7	374.1	306.4
Maximum	619.6	705.1	307.5	374.2	472.6	385.0	379.7	306.9
Average	616.4	698.8	307.4	369.5	466.3	383.9	376.0	306.6
Std Dev	1.88	4.37	0.05	2.79	3.02	0.70	1.90	0.14
Norm SD	0.30%	0.63%	0.02%	0.75%	0.65%	0.18%	0.51%	0.05%
Count	27	27	27	27	27	27	27	27
OC4b								
Minimum	622.0	690.8	307.3	375.5	471.6	385.8	379.9	306.2
Maximum	634.2	696.6	307.9	375.8	487.0	390.4	384.5	307.2
Average	628.1	695.0	307.5	375.7	480.3	387.9	381.3	306.7
Std Dev	3.62	1.81	0.20	0.05	4.47	1.33	1.15	0.32
Norm SD	0.58%	0.26%	0.06%	0.01%	0.93%	0.34%	0.30%	0.10%
Count	47	47	47	47	47	47	47	47
OC4c								
Minimum	635.8	696.7	308.0	374.4	485.5	391.2	386.2	307.3
Maximum	640.5	697.2	308.3	375.2	486.8	393.8	392.2	307.8
Average	638.4	697.0	308.1	374.8	486.5	392.5	389.3	307.6
Std Dev	1.56	0.14	0.10	0.26	0.27	0.79	1.82	0.15
Norm SD	0.24%	0.02%	0.03%	0.07%	0.06%	0.20%	0.47%	0.05%
Count	22	22	22	22	22	22	22	22
OC4d								
Minimum	619.2	680.9	308.0	369.3	474.2	391.6	378.6	307.9
Maximum	640.8	704.7	308.7	379.3	484.4	394.3	391.5	309.1
Average	634.6	695.3	308.4	374.5	477.2	393.0	382.9	308.6
Std Dev	7.19	6.50	0.20	3.64	2.45	0.83	3.27	0.36
Norm SD	1.13%	0.94%	0.06%	0.97%	0.51%	0.21%	0.85%	0.12%
Count	67	67	67	67	67	67	67	67
OC4e								
Minimum	598.1	683.0	307.7	369.0	474.6	390.8	377.8	309.1
Maximum	618.6	704.2	308.0	369.7	481.9	391.6	378.5	309.4
Average	606.8	694.3	307.8	369.3	478.3	391.2	378.1	309.3
Std Dev	7.18	8.46	0.10	0.21	2.55	0.23	0.20	0.08
Norm SD	1.18%	1.22%	0.03%	0.06%	0.53%	0.06%	0.05%	0.03%
Count	18	18	18	18	18	18	18	18
OC4f								
Minimum	564.9	681.9	306.9	370.1	470.2	385.1	373.4	307.5
Maximum	609.0	707.1	308.7	378.8	495.2	393.0	382.8	310.0
Average	579.4	693.4	307.9	374.7	482.5	388.4	379.2	308.6
Std Dev	16.33	6.18	0.59	2.27	5.69	2.06	2.34	0.83
Norm SD	2.82%	0.89%	0.19%	0.61%	1.18%	0.53%	0.62%	0.27%
Count	189	189	189	189	189	189	189	189

Table B2. Operating Conditions Statistical Data

		GL	GL	GL		FW/STM	STM/Fuel	Fuel Oil
		%	DEG F	S.G.		%	%	GAL/HR
		Green Liquor				Miscellaneous		
OC0								
Minimum		28.34	177.5	1.000		1.007	3.554	468.2
Maximum		55.00	189.4	1.015		1.197	3.924	974.1
Average		46.49	180.7	1.002		1.080	3.703	847.2
Std Dev		11.162	2.51	0.0040		0.0287	0.0869	108.93
Norm SD		24.01%	1.39%	0.40%		2.65%	2.35%	12.86%
Count		289	289	289		289	289	289
OC1a								
Minimum		35.00	177.8	1.000		1.001	3.707	174.0
Maximum		35.00	179.1	1.000		1.142	3.709	780.9
Average		35.00	178.5	1.000		1.063	3.708	348.8
Std Dev		0.000	0.39	0.0000		0.0445	0.0004	135.66
Norm SD		0.00%	0.22%	0.00%		4.19%	0.01%	38.89%
Count		43	43	43		43	43	43
OC1b								
Minimum		35.00	177.9	1.000		1.015	3.709	188.5
Maximum		35.00	184.5	1.000		1.115	3.710	616.3
Average		35.00	181.2	1.000		1.080	3.709	306.7
Std Dev		0.000	2.00	0.0000		0.0321	0.0003	92.08
Norm SD		0.00%	1.10%	0.00%		2.97%	0.01%	30.02%
Count		27	27	27		27	27	27
OC1c								
Minimum		35.00	184.7	1.000		1.008	3.709	114.3
Maximum		35.00	185.3	1.000		1.129	3.710	204.9
Average		35.00	185.0	1.000		1.087	3.710	153.7
Std Dev		0.000	0.19	0.0000		0.0340	0.0004	26.89
Norm SD		0.00%	0.10%	0.00%		3.13%	0.01%	17.49%
Count		26	26	26		26	26	26
OC1d								
Minimum		25.00	182.7	1.000		0.996	3.698	69.8
Maximum		35.00	184.8	1.000		1.239	3.781	187.7
Average		30.37	183.8	1.000		1.082	3.725	90.4
Std Dev		3.778	0.62	0.0000		0.0483	0.0265	27.32
Norm SD		12.44%	0.34%	0.00%		4.46%	0.71%	30.24%
Count		186	186	186		186	186	186
OC2a								
Minimum		33.00	182.3	1.000		1.032	3.479	71.1
Maximum		33.00	184.2	1.000		1.159	3.744	71.7
Average		33.00	183.3	1.000		1.068	3.612	71.6
Std Dev		0.000	0.56	0.0000		0.0302	0.0783	0.17
Norm SD		0.00%	0.31%	0.00%		2.83%	2.17%	0.24%
Count		62	62	62		62	62	62

Table B2. Operating Conditions Statistical Data

		GL	GL	GL		FW/STM	STM/Fuel	Fuel Oil
		%	DEG F	S.G.		%	%	GAL/HR
		Green Liquor				Miscellaneous		
OC2b								
Minimum		33.00	178.8	1.000		0.932	3.499	71.5
Maximum		38.00	188.9	1.000		1.090	4.006	71.6
Average		36.28	184.4	1.000		1.056	3.752	71.6
Std Dev		2.374	2.81	0.0000		0.0495	0.1535	0.03
Norm SD		6.54%	1.52%	0.00%		4.69%	4.09%	0.04%
Count		33	33	33		33	33	33
OC2c								
Minimum		17.00	170.6	1.000		1.007	3.613	71.0
Maximum		38.00	186.3	1.000		1.292	4.077	74.9
Average		24.16	179.9	1.000		1.103	3.763	71.9
Std Dev		6.827	2.87	0.0000		0.0430	0.1108	1.09
Norm SD		28.26%	1.59%	0.00%		3.90%	2.94%	1.51%
Count		176	176	176		176	176	176
OC3a								
Minimum		17.00	184.2	1.000		0.926	3.700	66.4
Maximum		40.00	187.5	1.000		1.194	3.975	76.4
Average		33.19	185.9	1.000		1.074	3.825	71.6
Std Dev		8.496	0.98	0.0000		0.0597	0.0853	3.34
Norm SD		25.60%	0.53%	0.00%		5.56%	2.23%	4.66%
Count		70	70	70		70	70	70
OC3b								
Minimum		40.00	182.7	1.000		0.977	3.737	61.6
Maximum		40.00	184.1	1.000		1.108	3.998	70.9
Average		40.00	183.4	1.000		1.060	3.810	67.3
Std Dev		0.000	0.43	0.0000		0.0349	0.0988	2.73
Norm SD		0.00%	0.23%	0.00%		3.29%	2.59%	4.05%
Count		28	28	28		28	28	28
OC3c								
Minimum		40.00	181.9	1.000		1.106	3.725	61.9
Maximum		40.00	182.6	1.000		1.120	3.736	64.2
Average		40.00	182.2	1.000		1.114	3.730	63.2
Std Dev		0.000	0.24	0.0000		0.0048	0.0036	0.61
Norm SD		0.00%	0.13%	0.00%		0.43%	0.10%	0.97%
Count		12	12	12		12	12	12
OC3d								
Minimum		40.00	180.7	1.000		1.026	3.659	59.9
Maximum		40.00	183.3	1.000		1.186	3.720	72.4
Average		40.00	181.8	1.000		1.091	3.688	68.3
Std Dev		0.000	0.77	0.0000		0.0369	0.0185	3.59
Norm SD		0.00%	0.42%	0.00%		3.38%	0.50%	5.26%
Count		64	64	64		64	64	64

Table B2. Operating Conditions Statistical Data

		GL	GL	GL		FW/STM	STM/Fuel	Fuel Oil
		%	DEG F	S.G.		%	%	GAL/HR
		Green Liquor				Miscellaneous		
OC4a								
Minimum		40.00	183.3	1.000		1.098	3.661	68.5
Maximum		40.00	184.6	1.000		1.156	3.715	73.4
Average		40.00	183.9	1.000		1.115	3.688	71.8
Std Dev		0.000	0.42	0.0000		0.0175	0.0167	1.17
Norm SD		0.00%	0.23%	0.00%		1.57%	0.45%	1.63%
Count		27	27	27		27	27	27
OC4b								
Minimum		39.51	185.1	1.000		1.026	3.734	66.7
Maximum		40.00	185.7	1.000		1.097	3.831	72.0
Average		39.87	185.5	1.000		1.061	3.783	70.2
Std Dev		0.163	0.13	0.0000		0.0202	0.0289	1.35
Norm SD		0.41%	0.07%	0.00%		1.90%	0.76%	1.93%
Count		47	47	47		47	47	47
OC4c								
Minimum		38.97	185.2	1.001		1.008	3.840	58.4
Maximum		39.39	185.4	1.009		1.119	3.859	71.8
Average		39.17	185.3	1.005		1.039	3.850	65.2
Std Dev		0.127	0.04	0.0025		0.0371	0.0056	3.68
Norm SD		0.33%	0.02%	0.25%		3.57%	0.15%	5.65%
Count		22	22	22		22	22	22
OC4d								
Minimum		38.00	185.0	1.010		0.937	3.732	62.2
Maximum		38.93	186.1	1.138		1.142	3.837	73.1
Average		38.32	185.3	1.122		1.074	3.784	69.6
Std Dev		0.315	0.32	0.0204		0.0363	0.0312	3.12
Norm SD		0.82%	0.17%	1.82%		3.38%	0.82%	4.48%
Count		67	67	67		67	67	67
OC4e								
Minimum		38.00	186.1	1.104		1.045	3.706	62.7
Maximum		38.00	186.7	1.111		1.151	3.730	69.2
Average		38.00	186.4	1.108		1.105	3.717	65.9
Std Dev		0.000	0.18	0.0022		0.0315	0.0080	2.06
Norm SD		0.00%	0.10%	0.20%		2.85%	0.22%	3.12%
Count		18	18	18		18	18	18
OC4f								
Minimum		32.00	184.6	1.015		0.949	3.683	57.9
Maximum		38.00	188.2	1.101		1.198	3.871	74.2
Average		37.60	187.1	1.044		1.029	3.742	66.8
Std Dev		1.479	1.04	0.0225		0.0492	0.0611	3.47
Norm SD		3.93%	0.56%	2.16%		4.79%	1.63%	5.19%
Count		189	189	189		189	189	189

Table B2. Operating Conditions Statistical Data

	Boiler	Boiler	Stack	Stack		date time	O2	CO2	CO
	% O2	CO PPM	% SO2	% O2			%VD	%VD	PPMVD
	Mill Flue Gas Compostion					Stack Test Data			
OC0									
Minimum	2.96	40.41	0.25	2.48		18:43	7.64	10.13	25.84
Maximum	4.94	43.89	14.15	7.72		7:39	10.49	12.28	952.08
Average	4.16	42.79	1.45	5.44		1:13	9.00	11.40	325.91
Std Dev	0.432	1.130	0.995	0.780		3:46:32	0.764	0.589	209.593
Norm SD	10.39%	2.64%	68.64%	14.34%		0.00%	8.48%	5.16%	64.31%
Count	289	289	289	289		154	154	154	154
OC1a									
Minimum	3.62	41.55	0.32	3.59		9:31	4.92	13.11	163.60
Maximum	4.68	42.92	0.33	6.55		12:51	6.30	14.34	917.80
Average	4.14	42.24	0.32	5.58		11:11	5.40	13.95	467.62
Std Dev	0.230	0.407	0.003	0.547		0:59:54	0.230	0.194	147.734
Norm SD	5.56%	0.96%	0.89%	9.81%		0.00%	4.26%	1.39%	31.59%
Count	43	43	43	43		41	41	41	41
OC1b									
Minimum	4.49	42.95	0.31	5.77		12:56	6.05	12.81	6.15
Maximum	4.95	43.62	0.32	7.07		15:06	6.75	13.37	92.89
Average	4.69	43.34	0.32	6.65		13:53	6.42	13.08	41.07
Std Dev	0.135	0.219	0.002	0.382		0:44:59	0.231	0.187	25.613
Norm SD	2.88%	0.51%	0.58%	5.74%		0.00%	3.59%	1.43%	62.36%
Count	27	27	27	27		19	19	19	19
OC1c									
Minimum	3.90	43.63	0.30	5.08		15:11	5.41	13.12	9.00
Maximum	4.61	43.94	0.31	6.69		17:16	6.25	13.72	268.73
Average	4.18	43.78	0.31	6.14		16:13	5.90	13.38	89.52
Std Dev	0.209	0.093	0.002	0.356		0:38:15	0.229	0.157	69.281
Norm SD	4.99%	0.21%	0.73%	5.80%		0.00%	3.89%	1.17%	77.39%
Count	26	26	26	26		26	26	26	26
OC1d									
Minimum	2.65	43.16	0.21	1.99		17:26	3.52	13.45	48.88
Maximum	4.76	44.67	14.17	6.24		8:45	5.68	15.65	1008.42
Average	3.46	43.96	0.36	4.50		0:38	4.59	14.51	729.83
Std Dev	0.399	0.468	1.056	0.836		4:12:01	0.410	0.439	221.793
Norm SD	11.55%	1.06%	291.59%	18.60%		0.00%	8.94%	3.03%	30.39%
Count	186	186	186	186		174	174	174	174
OC2a									
Minimum	2.65	44.06	0.09	1.68		9:00	3.51	13.94	526.57
Maximum	3.92	45.81	12.11	5.61		14:05	4.71	14.90	1008.39
Average	3.35	44.94	2.33	4.13		11:32	4.25	14.42	884.27
Std Dev	0.310	0.517	2.625	0.708		1:30:12	0.295	0.224	142.414
Norm SD	9.23%	1.15%	112.66%	17.15%		0.00%	6.95%	1.55%	16.11%
Count	62	62	62	62		62	62	62	62

Table B2. Operating Conditions Statistical Data

	Boiler	Boiler	Stack	Stack		date time	O2	CO2	CO
	% O2	CO PPM	% SO2	% O2			%VD	%VD	PPMVD
	Mill Flue Gas Compostion					**Stack Test Data**			
OC2b									
Minimum	1.52	44.97	1.68	1.17		14:20	3.05	14.45	179.01
Maximum	3.15	45.90	26.31	4.40		17:02	4.11	15.21	827.84
Average	2.66	45.44	4.15	3.06		15:47	3.67	14.84	594.93
Std Dev	0.479	0.280	6.913	0.819		0:53:18	0.308	0.217	171.240
Norm SD	17.99%	0.62%	166.50%	26.75%		0.00%	8.38%	1.46%	28.78%
Count	33	33	33	33		26	26	26	26
OC2c									
Minimum	4.13	41.17	0.21	3.99		17:42	5.37	12.24	15.06
Maximum	5.23	44.74	2.06	8.53		7:16	7.29	14.05	300.20
Average	4.56	42.65	0.69	6.47		0:28	6.29	13.21	105.06
Std Dev	0.254	1.043	0.597	0.686		3:57:00	0.406	0.395	63.354
Norm SD	5.57%	2.45%	86.42%	10.60%		0.00%	6.46%	2.99%	60.30%
Count	176	176	176	176		164	164	164	164
OC3a									
Minimum	2.27	42.53	1.87	1.97		9:16	3.78	13.88	101.04
Maximum	3.42	45.65	10.93	5.98		14:31	4.93	14.50	1004.51
Average	2.94	44.14	2.32	4.16		11:53	4.42	14.18	733.50
Std Dev	0.266	0.948	1.225	0.933		1:33:05	0.244	0.130	239.053
Norm SD	9.06%	2.15%	52.72%	22.44%		0.00%	5.53%	0.92%	32.59%
Count	70	70	70	70		64	64	64	64
OC3b									
Minimum	2.85	45.26	0.39	2.32		15:24	4.63	13.41	259.01
Maximum	3.90	45.60	1.78	5.44		16:54	5.52	13.99	688.92
Average	3.38	45.43	1.26	4.25		16:09	4.97	13.77	414.63
Std Dev	0.279	0.105	0.365	0.840		0:28:07	0.222	0.147	129.888
Norm SD	8.26%	0.23%	28.99%	19.77%		0.00%	4.48%	1.06%	31.33%
Count	28	28	28	28		19	19	19	19
OC3c									
Minimum	3.25	45.11	1.80	2.97		16:59	3.69	13.95	877.60
Maximum	3.58	45.25	2.22	4.60		17:54	4.45	14.48	958.16
Average	3.36	45.18	2.01	4.05		17:26	4.15	14.15	915.92
Std Dev	0.098	0.046	0.136	0.472		0:18:01	0.219	0.157	21.725
Norm SD	2.91%	0.10%	6.79%	11.64%		0.00%	5.27%	1.11%	2.37%
Count	12	12	12	12		12	12	12	12
OC3d									
Minimum	0.68	44.00	0.93	-0.12		18:19	2.24	13.98	682.40
Maximum	3.91	45.04	28.06	4.58		23:34	4.49	15.47	1008.38
Average	2.18	44.61	12.41	2.42		20:56	3.31	14.85	973.83
Std Dev	0.834	0.285	10.030	1.200		1:33:06	0.571	0.414	44.778
Norm SD	38.28%	0.64%	80.85%	49.54%		0.00%	17.26%	2.79%	4.60%
Count	64	64	64	64		64	64	64	64

Table B2. Operating Conditions Statistical Data

	Boiler	Boiler	Stack	Stack		date time	O2	CO2	CO
	% O2	CO PPM	% SO2	% O2			%VD	%VD	PPMVD
	Mill Flue Gas Compostion					Stack Test Data			
OC4a									
Minimum	1.11	43.27	0.22	0.75		23:34	3.00	14.06	559.13
Maximum	3.31	44.00	27.65	5.69		1:43	4.65	15.24	1008.40
Average	2.42	43.64	5.99	3.34		0:38	3.77	14.75	965.20
Std Dev	0.546	0.225	8.458	1.297		0:39:23	0.429	0.314	99.844
Norm SD	22.51%	0.52%	141.16%	38.79%		0.00%	11.38%	2.13%	10.34%
Count	27	27	27	27		27	27	27	27
OC4b									
Minimum	3.66	41.73	0.75	3.34		2:28	4.85	12.97	1.42
Maximum	4.85	43.01	1.63	6.75		6:18	6.47	14.16	113.74
Average	4.07	42.36	1.19	5.47		4:23	5.54	13.68	21.21
Std Dev	0.323	0.388	0.262	0.717		1:08:33	0.375	0.276	24.249
Norm SD	7.94%	0.92%	22.12%	13.11%		0.00%	6.77%	2.02%	114.32%
Count	47	47	47	47		47	47	47	47
OC4c									
Minimum	4.20	41.97	0.09	4.24		6:48	5.36	12.90	7.06
Maximum	4.61	42.77	27.67	6.81		8:27	6.69	13.68	438.74
Average	4.50	42.38	1.67	6.46		7:27	6.30	13.20	53.74
Std Dev	0.108	0.244	5.808	0.513		0:26:53	0.287	0.171	104.314
Norm SD	2.40%	0.57%	346.85%	7.95%		0.00%	4.56%	1.29%	194.11%
Count	22	22	22	22		16	16	16	16
OC4d									
Minimum	2.51	42.85	0.16	2.11		8:48	4.06	12.98	48.65
Maximum	4.40	45.48	1.85	5.97		14:12	5.54	14.27	970.14
Average	3.46	44.16	1.17	4.69		11:35	4.75	13.71	380.39
Std Dev	0.369	0.776	0.486	0.696		1:33:41	0.376	0.322	211.345
Norm SD	10.66%	1.76%	41.42%	14.85%		0.00%	7.92%	2.35%	55.56%
Count	67	67	67	67		63	63	63	63
OC4e									
Minimum	1.68	45.12	1.87	2.13		14:17	3.63	13.61	798.47
Maximum	3.63	45.52	6.20	4.55		15:42	4.54	14.17	932.66
Average	2.57	45.33	2.61	3.66		14:59	4.04	13.91	882.15
Std Dev	0.504	0.130	1.386	0.795		0:26:42	0.255	0.139	40.116
Norm SD	19.58%	0.29%	53.01%	21.73%		0.00%	6.33%	1.00%	4.55%
Count	18	18	18	18		18	18	18	18
OC4f									
Minimum	0.72	41.42	0.06	1.46		16:22	3.32	13.09	235.31
Maximum	4.30	44.92	28.65	6.09		7:50	5.83	15.36	1008.41
Average	2.97	42.91	2.67	4.30		0:21	4.58	14.20	781.61
Std Dev	0.693	1.024	5.518	1.060		4:23:03	0.618	0.565	209.629
Norm SD	23.35%	2.39%	206.49%	24.66%		0.00%	13.49%	3.98%	26.82%
Count	189	189	189	189		180	180	180	180

Table B2. Operating Conditions Statistical Data

	NO	NO2	NOx	SO2	TRS	Temp	RH	BP
	PPMVD	PPMVD	PPMVD	PPMVD	PPMVD	degF	%	inHg
	Stack Test Data							
OC0								
Minimum	32.95	1.97	39.51	-3.466	-1.462	76.2	52.0	29.78
Maximum	50.45	10.25	54.79	21.116	3.180	88.6	86.1	29.91
Average	44.92	4.57	49.71	0.047	-0.319	80.0	77.5	29.84
Std Dev	3.634	1.590	3.202	4.2064	0.8213	3.82	9.76	0.035
Norm SD	8.09%	34.83%	6.44%	8864.06%	-257.66%	4.77%	12.59%	0.12%
Count	154	154	154	154	154	154	154	154
OC1a								
Minimum	58.12	3.29	64.55	-1.116	-1.710	77.5	68.0	29.95
Maximum	67.64	7.81	72.88	1.338	31.590	83.2	80.6	29.96
Average	63.78	5.51	69.36	0.237	7.181	79.8	75.6	29.95
Std Dev	2.337	0.807	2.133	0.8005	5.1565	1.57	3.50	0.002
Norm SD	3.66%	14.65%	3.08%	337.23%	71.81%	1.96%	4.63%	0.01%
Count	41	41	41	41	41	41	41	41
OC1b								
Minimum	59.81	1.44	62.13	0.736	#DIV/0!	83.2	57.5	29.92
Maximum	78.32	2.46	81.26	2.660	#DIV/0!	88.2	69.1	29.95
Average	65.11	1.80	67.67	1.521	#DIV/0!	85.3	62.8	29.93
Std Dev	4.461	0.282	4.524	0.5533	#DIV/0!	1.54	3.34	0.011
Norm SD	6.85%	15.67%	6.69%	36.38%	#DIV/0!	1.80%	5.31%	0.04%
Count	19	19	19	19	13	19	19	19
OC1c								
Minimum	68.69	1.38	72.22	1.034	#DIV/0!	88.1	51.5	29.92
Maximum	80.38	3.32	82.63	1.500	#DIV/0!	91.0	57.4	29.92
Average	74.42	2.27	77.38	1.240	#DIV/0!	89.5	54.2	29.92
Std Dev	3.197	0.485	2.861	0.1410	#DIV/0!	0.84	1.63	0.000
Norm SD	4.30%	21.37%	3.70%	11.37%	#DIV/0!	0.94%	3.01%	0.00%
Count	26	26	26	26	0	26	26	26
OC1d								
Minimum	43.54	3.56	50.49	-2.258	#DIV/0!	76.1	49.6	29.92
Maximum	71.16	9.78	75.82	3.640	#DIV/0!	90.9	88.8	29.98
Average	56.96	5.98	62.92	-0.193	#DIV/0!	83.5	70.5	29.95
Std Dev	5.925	1.411	5.120	1.1620	#DIV/0!	4.52	11.48	0.030
Norm SD	10.40%	23.58%	8.14%	-603.48%	#DIV/0!	5.41%	16.28%	0.10%
Count	174	174	174	174	1	174	174	174
OC2a								
Minimum	51.80	-0.56	55.45	2.800	0.960	80.1	51.3	29.94
Maximum	65.19	6.39	69.53	5.898	26.924	91.5	77.0	29.99
Average	58.36	3.71	62.51	4.490	7.967	85.8	65.2	29.97
Std Dev	3.387	1.792	3.683	0.8669	6.6678	3.45	7.70	0.012
Norm SD	5.80%	48.32%	5.89%	19.31%	83.70%	4.03%	11.81%	0.04%
Count	62	62	62	62	62	62	62	62

Table B2. Operating Conditions Statistical Data

	NO	NO2	NOx	SO2	TRS	Temp	RH	BP
	PPMVD	PPMVD	PPMVD	PPMVD	PPMVD	degF	%	inHg
	Stack Test Data							
OC2b								
Minimum	57.11	-0.78	61.69	3.030	-1.328	91.4	43.7	29.88
Maximum	69.77	6.68	72.19	13.448	53.616	94.4	51.8	29.93
Average	62.73	3.03	66.35	4.920	11.462	92.9	46.6	29.90
Std Dev	3.672	2.218	2.739	2.5823	15.2807	0.84	2.70	0.014
Norm SD	5.85%	73.16%	4.13%	52.49%	133.32%	0.90%	5.80%	0.05%
Count	26	26	26	26	26	26	26	26
OC2c								
Minimum	56.40	2.04	68.78	1.982	-0.614	74.1	53.5	29.89
Maximum	80.01	13.88	83.43	16.510	5.536	88.6	85.2	29.96
Average	70.51	6.50	76.91	4.374	1.274	78.4	75.9	29.94
Std Dev	4.205	1.900	3.007	2.4525	1.4237	3.17	7.64	0.017
Norm SD	5.96%	29.21%	3.91%	56.07%	111.73%	4.05%	10.08%	0.06%
Count	164	164	164	164	164	164	164	164
OC3a								
Minimum	56.52	-1.54	59.27	1.112	0.728	76.9	52.0	29.92
Maximum	70.49	13.34	74.84	16.784	22.010	91.3	79.9	30.00
Average	63.76	6.54	70.18	4.135	4.987	85.0	64.5	29.97
Std Dev	3.072	3.425	2.764	3.0823	4.3870	4.59	9.03	0.023
Norm SD	4.82%	52.38%	3.94%	74.54%	87.97%	5.40%	14.00%	0.08%
Count	64	64	64	64	64	64	64	64
OC3b								
Minimum	63.36	2.09	67.31	3.422	5.826	91.8	44.2	29.88
Maximum	74.69	3.59	77.73	4.396	15.020	93.6	52.9	29.91
Average	70.74	2.87	74.22	3.891	9.172	92.5	47.4	29.89
Std Dev	2.844	0.401	2.615	0.2860	2.9416	0.48	2.10	0.011
Norm SD	4.02%	14.00%	3.52%	7.35%	32.07%	0.52%	4.43%	0.04%
Count	19	19	19	19	19	19	19	19
OC3c								
Minimum	54.37	0.28	57.31	4.466	4.736	91.6	43.5	29.86
Maximum	62.14	4.00	65.47	5.076	8.112	93.7	48.8	29.88
Average	59.68	2.50	62.84	4.768	6.122	92.5	46.0	29.87
Std Dev	2.570	1.011	2.594	0.1479	1.1013	0.61	1.52	0.004
Norm SD	4.31%	40.43%	4.13%	3.10%	17.99%	0.66%	3.32%	0.01%
Count	12	12	12	12	12	12	12	12
OC3d								
Minimum	49.34	-2.16	49.67	4.394	1.926	84.0	46.4	29.86
Maximum	64.18	4.76	63.75	6.328	65.274	93.3	67.0	29.87
Average	56.17	-0.31	57.04	5.086	19.332	88.5	56.7	29.86
Std Dev	2.902	1.939	3.240	0.4719	15.7151	2.94	6.18	0.005
Norm SD	5.17%	-618.86%	5.68%	9.28%	81.29%	3.32%	10.90%	0.02%
Count	64	64	64	64	64	64	64	64

Table B2. Operating Conditions Statistical Data

	NO	NO2	NOx	SO2	TRS	Temp	RH	BP
	PPMVD	PPMVD	PPMVD	PPMVD	PPMVD	degF	%	inHg
	Stack Test Data							
OC4a								
Minimum	54.66	-1.91	55.40	5.238	0.420	81.0	64.7	29.85
Maximum	68.84	0.97	69.03	6.880	65.274	84.2	73.8	29.87
Average	62.24	-0.78	62.69	5.873	23.413	82.4	69.6	29.86
Std Dev	3.826	0.783	3.897	0.4179	15.1769	1.08	2.69	0.008
Norm SD	6.15%	-100.86%	6.22%	7.12%	64.82%	1.32%	3.86%	0.03%
Count	27	27	27	27	27	27	27	27
OC4b								
Minimum	62.46	0.12	66.36	2.984	7.220	76.9	75.0	29.83
Maximum	76.20	3.63	77.94	14.088	17.142	80.1	83.0	29.84
Average	70.91	1.06	72.82	4.553	10.254	78.3	79.7	29.83
Std Dev	2.430	0.640	2.060	2.1379	2.7219	0.96	2.29	0.005
Norm SD	3.43%	60.11%	2.83%	46.95%	26.54%	1.23%	2.88%	0.02%
Count	47	47	47	47	47	47	47	47
OC4c								
Minimum	60.01	1.15	65.58	3.644	4.810	75.9	82.3	29.84
Maximum	72.72	5.64	74.95	6.012	13.444	78.2	84.0	29.87
Average	67.54	2.07	70.27	4.369	11.741	76.7	83.4	29.86
Std Dev	3.302	1.186	2.544	0.7859	2.0485	0.55	0.48	0.010
Norm SD	4.89%	57.26%	3.62%	17.99%	17.45%	0.71%	0.57%	0.03%
Count	16	16	16	16	16	16	16	16
OC4d								
Minimum	34.99	4.12	52.16	5.008	-0.992	78.7	43.5	29.81
Maximum	68.22	20.83	73.00	56.204	19.012	93.8	82.3	29.87
Average	57.34	7.72	64.78	14.689	11.741	87.8	60.0	29.84
Std Dev	7.693	2.812	5.834	9.8500	4.6449	4.46	11.62	0.020
Norm SD	13.42%	36.45%	9.01%	67.06%	39.56%	5.08%	19.38%	0.07%
Count	63	63	63	63	63	63	63	63
OC4e								
Minimum	53.48	-1.01	58.49	4.334	9.884	92.5	41.5	29.78
Maximum	64.83	7.08	67.49	7.198	22.630	94.4	46.5	29.81
Average	59.36	3.47	63.33	5.370	13.771	93.4	44.2	29.79
Std Dev	3.299	3.176	2.980	0.7587	4.8072	0.64	1.46	0.008
Norm SD	5.56%	91.45%	4.71%	14.13%	34.91%	0.69%	3.31%	0.03%
Count	18	18	18	18	18	18	18	18
OC4f								
Minimum	42.93	-1.47	51.12	4.166	#DIV/0!	78.4	41.2	29.69
Maximum	68.94	12.91	74.46	110.730	#DIV/0!	95.1	81.0	29.76
Average	55.81	5.75	61.63	14.106	#DIV/0!	85.0	64.6	29.73
Std Dev	5.204	2.918	4.425	14.6600	#DIV/0!	5.23	13.37	0.018
Norm SD	9.32%	50.78%	7.18%	103.93%	#DIV/0!	6.15%	20.70%	0.06%
Count	180	180	180	180	173	180	180	180