TESTING OF THE STOKERMASTER BOILER CONTROL SYSTEM

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INTRODUCTION

Over the last ten years the state and other public agencies have modified existing boilers or, in some some cases, have installed new boilers to burn wood. The goal was to substitute a cheap and abundant indigenous fuel for a more expensive fuel originating outside the state. Today, many of the installations have poor efficiency ratings and/or emissions problems. The state recognizes that it has a responsibility to help boiler owners improve efficiency and reduce emissions.

StokerMaster is the trademark for a series of boiler control devices designed by Engineered Energy Concepts (EEC) of Kingsport, Tennessee. EEC claims that *StokerMaster* devices simultaneously improve efficiency and reduce emissions. A test program to evaluate these devices was designed by the Department of Natural Resources and submitted to the Legislative Commission on Minnesota Resources (LCMR) for its consideration. The primary objective was to determine whether new microprocessor-based control systems could be used to reduce emission levels and increase the efficiency of wood-fired boilers. A secondary consideration was to determine whether the same control system would allow boiler operators to switch from relatively high priced wood pellets to lower cost wood chips without creating localized emissions problems.

The LCMR approved the *StokerMaster* project in December 1986 as a two phase test. Phase I was a test of a *StokerMaster II* at the Independent School District (ISD) 318 Elementary School in Cohasset, Minnesota. Phase II was a test of a *StokerMaster III* at the South Middle School in Grand Rapids, Minnesota.

Phase I was completed in April 1987 and an interim report was given to the LCMR in June of that year. The LCMR approved Phase II testing for the 1987-88 heating season.

This report summarizes the results of both Phases, details the results of Phase II, and presents recommendations based on the results of the entire program.

EXECUTIVE SUMMARY

Phase I.

Phase I consisted of testing a *StokerMaster II* [1] at the Cohasset Elementary School. The initial goals of the Phase I program were to determine whether a *StokerMaster II* control system fulfilled the claims of its inventor by simultaneously reducing particulate emissions and enhancing boiler performance. Before the testing began, these goals were supplemented to include continuous emissions monitoring (CEM) and the installation of an air preheater, which would allow for short tests of wood chips. Testing began on February 15 and concluded on March 27, 1987.

The major conclusions drawn from the Phase I tests were:

- The *StokerMaster II* reduced particulate emissions when compared to the old system which uses ON/OFF controls.
- Opacity levels were approximately equal in both systems when the stoker was operating 100 percent of the time. However, when the stoker was operating less than 100 percent of the time the *StokerMaster II* had lower opacity readings. This indicated that the *StokerMaster II* exhibited better overall control than the old system.
- The *StokerMaster II* generated a fuel savings of about 12 percent when compared to the old system.
- Use of the air preheater when high moisture wood chips were burned resulted in significantly lower emissions than when the preheater was not used.
- Boiler operability was improved with the *StokerMaster II,* as evidenced by reduced clinkering and less ash deposition in the boiler tubes and flues.
- The *StokerMaster II* consistently produced higher carbon monoxide levels (this may have resulted because the elimination of over fire air reduced the amount of turbulence in the furnace).

1 The *StokerMaster II* is a computer-controlled, electro-mechanical system designed for use with small commercial boilers in the 25 to 100 HP range having ON/OFF control systems.

Results of the Phase I testing were encouraging and indicated that the StokerMaster II was an improvement over the old control system used at the school. Furthermore, results indicated that low-cost wood chips might be burned more efficiently using a *StokerMaster* control system. The need to verify these indications provided the rationale to proceed to Phase II.

Phase II.

Phase II consisted of testing a *StokerMaster III*[2] at the Grand Rapids South Middle School in May 25 and 26, 1988. The goal of Phase II was to compare the performance of a *StokerMaster III* with the existing control system when using wood chips. In addition to the *StokerMaster III*, the following equipment was installed at the school: a ceramic grate, an air preheater, a draft control damper, an oxygen and combustibles meter, and a computer for data collection. Four conditions were tested each day:

1. *StokerMaster III with air preheater OFF*
2. *StokerMaster III with air preheater ON*
3. *Old control system with air preheater OFF*
4. *Old control system with air preheater ON*

Data collected included:

opacity,
combustibles,
fuel flow,
flue gas velocity,
flue gas temperature,
steam pressure, and
outside air temperature.

Each variable was sampled every five seconds, and averaged over three minute intervals. The averages were stored on disk for analysis.

Hardwood chips having an average moisture content of 27.5 percent were used throughout the test.

The major conclusions of the Phase II testing were:

- The *StokerMaster III* performed better than the old control system when the air preheater was off (conditions 1 and 3, above). There was less variation in fuel flow and opacity was lower using the *StokerMaster.*

2 The *StokerMaster III* is a computer-controlled, fully modulating control system capable of varying fuel and air rates independently. It uses proportion, integral, and derivative (PID) control devices to modulate all process variables.

- Adding load to the boiler eliminated opacity excursions with the *StokerMaster III.*

- The air preheater eliminated the opacity excursions in the old system and reduced average opacity by about 1 percent for both systems (conditions 2 and 4, above).

- The air preheater reduced the level of combustibles in the flue gas by about 25 percent for both systems.

- Both systems were able to maintain effective control over steam pressure.

- The *StokerMaster III* performed marginally better than the old system, but did not vastly improve efficency or emissions.

- Operation of both systems were improved when the air preheater was used.

- The ceramic grate, designed by EEC, enabled the boiler to maintain higher average temperatures than were possible using the steel grate.

The data gathered at the test sites show that the *StokerMaster* devices can improve the operation of wood-fired boilers with ON/OFF controls, and that the use of ceramic grates and air preheaters improve operation with wetter fuels. Ceramic grates and air preheaters are two low-cost modifications that are easily implemented and result in an immediate improvement in boiler performance.

Current prices for the *StokerMaster II,* (approximately $3,600 FOB Kingsport, Tennessee) indicate that these devices may prove to be quite cost-effective if installation charges can be minimized.

STOKERMASTER DEVICES

The *StokerMaster* series of boiler control systems consists of three devices:

- *StokerMaster I:* a residential version designed to work with very small systems having underfeed stokers and burning wood pellets. This device was not tested as part of the state's *StokerMaster* project.
- *StokerMaster II:* a computer-controlled, electro-mechanical system designed for use with small commercial boilers in the 25 to 100 horsepower range having on/off control systems.
- *StokerMaster III:* a computer-controlled, fully modulating control system capable of varying fuel and air rates independently. It uses proportion, integral, and derivative (PID) control devices to modulate all controlled process variables.

The state tested a *StokerMaster II* at the Cohasset Elementary School in February and March 1987. The *StokerMaster III* was tested at the South Middle School in Grand Rapids in May 1988.

StokerMaster II.

The target market for *StokerMaster II* is boilers with underfeed stokers and ON/OFF controls. Many of the schools which converted from oil to wood pellet firing during the past ten years use this type, as do many other facilities with new systems installed to burn pellets.

When on/off controls are used in wood-burning systems, clinkering and emission of wood volatiles often occur. When the high steam pressure limit is reached, the control system stops both fuel and air flow. At that point the firebox is at, or near, its maximum temperature and contains an inventory of unburned fuel. The boiler immediately starts to draft naturally -- the amount of air entering the firebox depends upon how "tightly" it is built. The volatiles in the unburned fuel cannot be burned adequately because of a lack of oxygen. Reducing conditions usually prevail, and the ash can form clinkers. The result of continued on/off cycling is lower operating efficiency and increased emissions. *StokerMaster* aims to correct both problems simultaneously.

The *StokerMaster II* system uses a programable controller to determine fuel auger on/off time and thereby simulate the effect of continuously modulating controls. It operates with manual damper settings on the underfire air fan and with manually set speeds on the fuel auger. With each *StokerMaster II*, EEC installs a new high pressure underfire air fan, removes the old fan that came with the stoker, and modifies the firebox such that all of the underfire air is directed into the retort. The new underfire air fan operates continuously. An air preheater can be added to the system to control emissions at low firing levels or as an aid to combustion of high moisture fuels.

The installed parts are standard and are readily available from various suppliers. The programable controller used is also commonly available. Equipment assembly and the algorithm used in the programmable controller are the unique elements supplied by EEC.

StokerMaster III.
The target market for the *StokerMaster III* is larger boilers with either ON/OFF or partially modulating controls. Several of these were installed in high schools and colleges in Minnesota during conversion to wood firing. The *StokerMaster III* is designed to:

control fuel flow by modulating fuel auger speed
control air flow by modulating damper settings
control boiler draft by modulating dampers in the breeching

Optional equipment such as an air preheater or instrumentation such as oxygen or steam flow meters may also be connected. The heart of the unit is a programmable PID controller which transmits set point signals to fuel and air flow controllers. Again, the unique aspects of this system are the programs written by EEC and the assembly of the components.

EXISTING BOILER CONTROL SYSTEM AT THE SOUTH MIDDLE SCHOOL

The South Middle School installed a wood-pellet fired boiler in 1982. The boiler control system installed at the school uses the difference between the steam pressure set point and the actual steam pressure to increase or decrease fuel and air flows. This difference generates a fuel auger RPM value and an underfire air damper setting which attempts to hold boiler pressure steady at any given boiler load.

The actual operating ranges can be set manually by adjusting the length of lever arms which control damper positions. The upper limit of an operating range can be reduced by using a rheostat, which limits maximum voltage, thereby limiting maximum auger RPM and maximum underfire air damper opening. Several manual adjustments are needed if gross changes in boiler load occur. There is no mechanism to trim air/fuel ratios in order to improve boiler efficiency.

This type of control system has a tendency to "hunt" as it attempts to find the proper control settings. Operation without a fixed set point for fuel and air flow usually is not critical since the building heat demand also changes over time. Also, a system which is sized properly for maximum boiler output will likely operate with large volumes of excess air at lower outputs unless dampers and augers are set manually to maintain better air/fuel ratios.

TEST PROCEDURE

The Phase II tests performed at the South Middle School on May 25 and 26, 1988 were designed to determine whether a *Stokermaster III* control system improved boiler performance and produced less emissions than the old control system. Phase I tests of the *StokerMaster II* at Cohasset indicated that use of the school's ON/OFF control system resulted in the dual problems of poor boiler performance and high emissions. These problems grew as higher moisture fuels were used (a full description of the tests conducted using the *StokerMaster II* are contained in Appendix A). Since the existing boiler controls at the South Middle School are capable of modulating fuel and air flows, problems caused by on/off controls were not expected. Also, it was expected that both control systems would perform well with wood pellets, therefore, the tests were designed to determine whether any differences between control systems could be detected when a higher moisture fuel, like wood chips, was burned.

The equipment installed for the test at the South Middle School included a *StokerMaster III* boiler control system, a ceramic grate, an air preheater, a draft control damper, an oxygen and combustibles meter, and an IBM PC-compatible computer with an analog-to-digital conversion board for data collection. Four conditions were tested each day:

1. *StokerMaster III controls with the air preheater OFF*
2. *StokerMaster III controls with the air preheater ON*
3. *Old control system with the air preheater OFF*
4. *Old control system with the air preheater ON*

Data collected during the tests included:

opacity,
combustibles,
oxygen,
fuel flow,
steam flow,
flue gas velocity,
flue gas temperature,
steam pressure, and
outside air temperature.

Continuous emissions monitoring consisted of measuring:

opacity using a Fireye smoke detector, and

oxygen and combustibles content of the flue gas using a Thermox meter.

The analog-to-digital converter sampled each variable every five seconds. These values were averaged over three-minute intervals, and the averages were stored on a disk file for analysis.

Description of Fuel Used.

The fuel normally used at the school are extruded wood pellets having an average moisture content of 5 to 12 percent. For this test, it was decided to use a fuel having a higher moisture content.

Hardwood chips screened to a one inch maximum size were used in the tests on both days. The fuel was produced by Rajala Timber Co. of Deer River, MN from logs harvested in January, 1988. These logs were stored until just prior to the test when they were processed into chips. The average moisture content of the fuel was 27.5 percent. The relatively low moisture content of the fuel is attributable to the length of time the logs were stored prior to chipping. A normal moisture content for green chips is closer to 45 percent.

The costs of wood fuel may vary, but the range is generally as shown in Table 1.

Table 1. Price Characteristics of Various Wood Fuels

Fuel	Cost/ton	% Moisture	$/mm Btu	$/mm Btu*
Wood pellets	. . . . $55	10	$3.90	$3.96
Screened chips	. . . $30	30	$2.20	$2.78
Green chips	. . . . . $17	45	$1.90	$2.13

* at the Lower Heating Value

The data in Table 1. show that the school's fuel costs might be substantially reduced if wetter fuels could be burned. On the other hand, use of wetter fuels generally increases capital and labor costs and may result in increased emissions. This study sought to determine whether new controls and other associated boiler modifications could be used to reduce the overall operating costs of wood-burning boilers.

TEST RESULTS

The tests were originally scheduled for December 1987, but problems with equipment installation created significant delays. During the initial installation, a bad connection in the electrical wiring sent high voltage AC signals through the control rectifier in the control panel and the analog-to-digital conversion board located in the PC. The burnout of these devices resulted in a two month delay. The second try at operation was aborted when the device measuring fuel flow did not generate the proper output signal. It appears that this problem was caused by an inappropriate selection of instrumentation.

Once these problems were corrected, steam vents were installed so that modest boiler loads could be maintained and the resulting steam vented outside of the building. Fuel and steam flow data indicates that the boiler was tested at about 15 percent of full load on May 25th and approximately 35 percent of full load on May 26th. These two runs generated a reasonable test of both control systems, since modulation at low output levels was necessary. However, emissions tests were insuffient because the full range of operating conditions could not be checked. It was possible to compare one control system against the other, but it was not possible to compare each against MPCA standards for either opacity or particulates.

All measuring systems appeared to operate properly except for the oxygen and steam flow systems. The oxygen meter on the control panel seemed to give accurate readings, but the linear output to the computer seemed to be out of calibration. The method used to measure steam flow, likewise, did not yield reliable results. The problem was isolated to the probe inserted in the steam line. It appeared that the probe was installed properly, but that it was collecting a tarry substance which destroyed the differential pressure measurements. It's likely that the material which interferred with the proper operation of the probe was a residue of the chemicals used for water treatment.

The lack of steam flow data eliminated the possibility of measuring fuel efficiency or estimating the fuel savings which may accrue to the school district based on use of the *StokerMaster* controls. However, as will be seen later, this was more of a theoretical constraint. Since the heat loads were relatively constant, it was possible to obtain a rough comparison of efficiency using only fuel flow data.

The data collected during the tests were entered into Supercalc 4.0 for analysis. The plots generated include:

Fuel Flow vs.Steam Pressure
Opacity vs. Fuel Flow
Combustibles vs. Fuel flow
Opacity vs. Time
Combustibles vs. Time
Steam Pressure vs. Time

Spreadsheet analysis and graphic output were used to quickly identify major trends in the data. It was found that this level of analysis was sufficient, because both systems generated similar results. The major test results are:

- Use of the air preheater reduced the level of combustibles in the flue gas for both the old system and *StokerMaster III.*

- The *StokerMaster III* with the preheater turned off showed excursions in opacity at output levels near 15 percent capacity while the old system with the preheater off showed excursions at 25 percent of capacity. However, average opacity for both systems was under 20 percent.

- Use of the air preheater eliminated opacity excursions on the old system.

- Adding load to the system eliminated excursions in opacity for both control systems.

- Both control systems exhibited adequate control over pressure in the output range tested (15 to 25 percent of full load).

- No strong correlation exists between opacity or combustibles and fuel flow in the range tested.

- In all cases opacity and combustibles levels were low.

- The control of fuel flow as a function of steam pressure is more precise when the *StokerMaster III* is used, i.e. *StokerMaster* produced less variation in steam pressure and fuel flow than the old system.

- The fuel requirements under both systems were nearly the same.

Testing was stopped on May 26, 1988, because higher boiler outputs could not be easily maintained due to warm weather conditions.

Fuel Flow vs. Steam Pressure
PreHeater Off

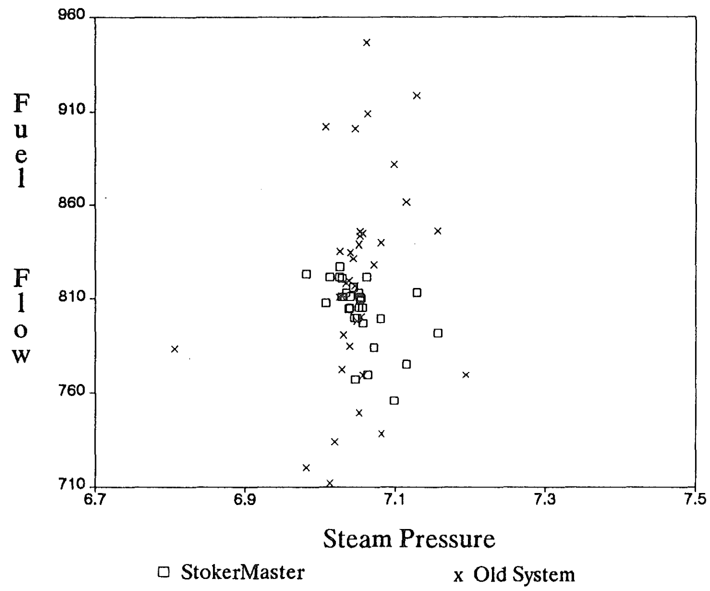


Figure 1.
This figure shows that the StokerMaster III control system produces less variation in fuel flow than the old system. The average fuel flow in both cases is about the same because the boiler loads are approximately constant.

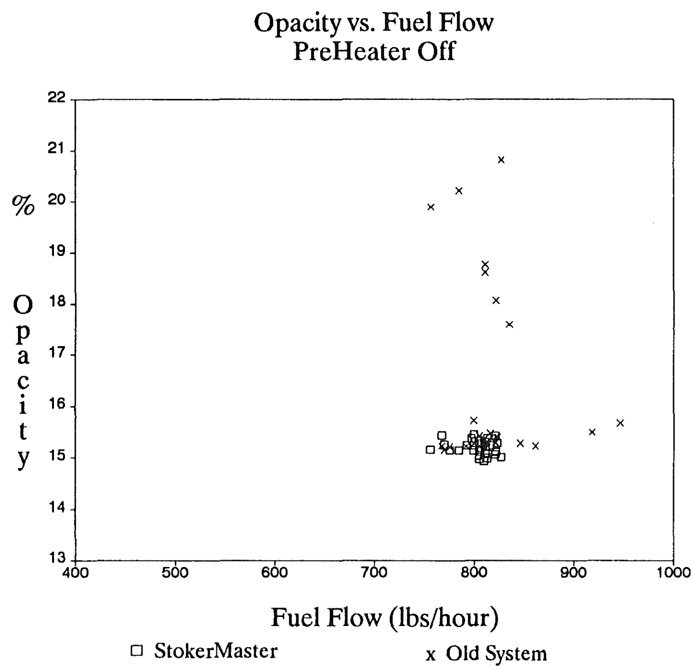


Figure 2.
This figure shows that the old control system exhibited short duration excursions in opacity while StokerMaster did not. The excursions were only into the 20 percent range, and occurred infrequently.

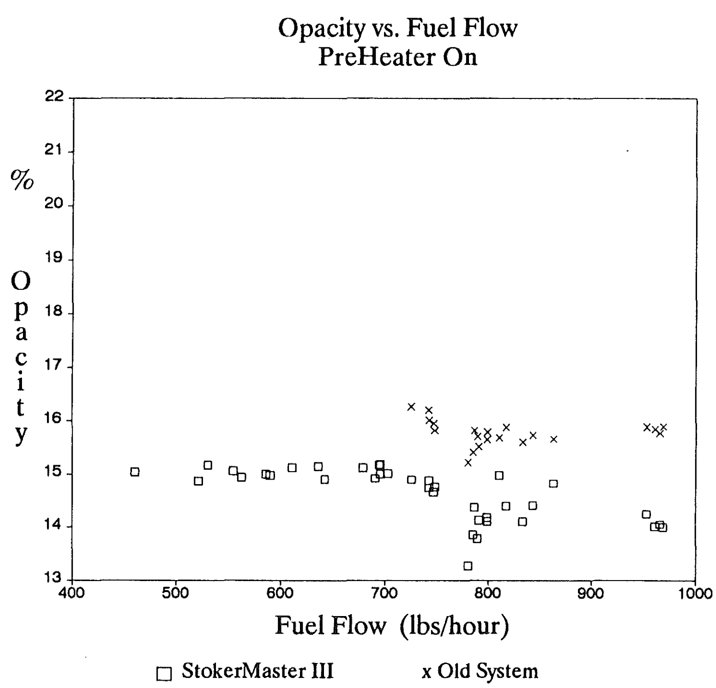


Figure 3.
This figure shows that the use of the air preheater eliminated opacity excursions, and reduced average opacity levels by about 1 percent.

Combustibles vs. Fuel Flow
PreHeater Off

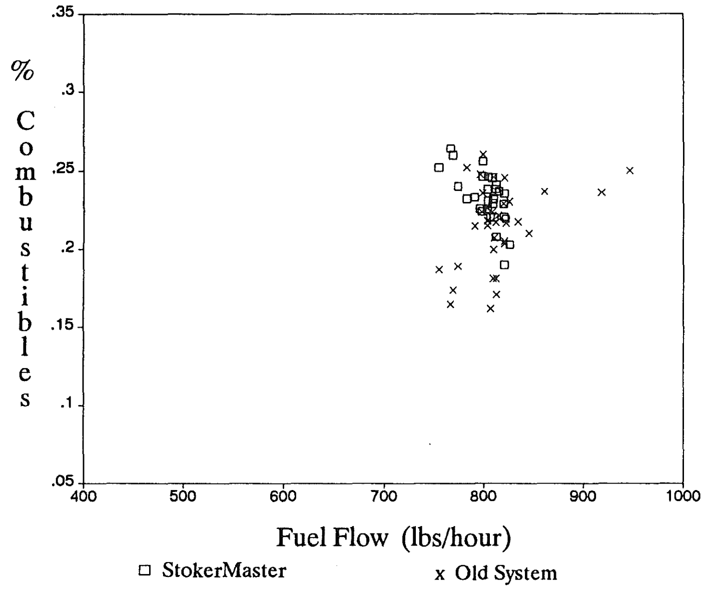


Figure 4.
This figure shows that no correlation exists (in the range tested) between fuel flow and combustible levels in the flue gas. However, the range of fuel flows does not cover the full range of boiler capacity.

Combustibles vs. Fuel Flow
PreHeater On

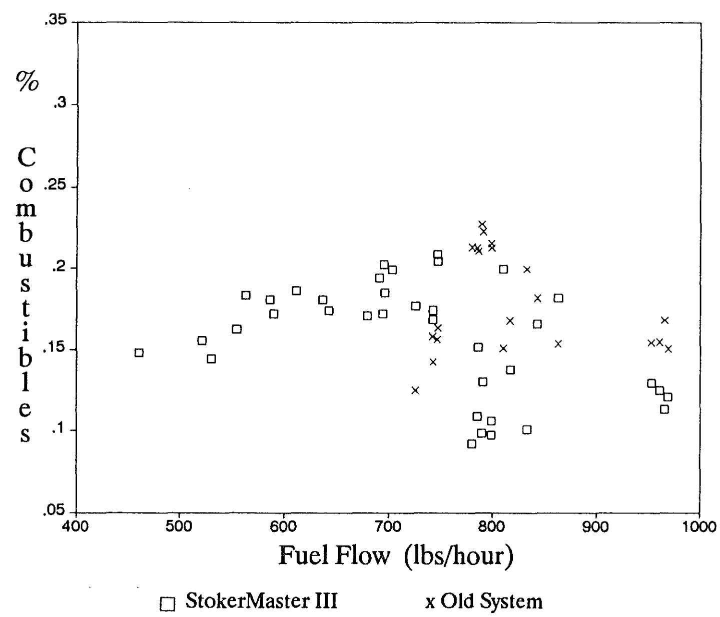


Figure 5.
This figure, when compared to Figure 4., shows that the level of combustibles in the flue gas is reduced by about 25 percent when the air preheater is used.

Opacity vs. Time

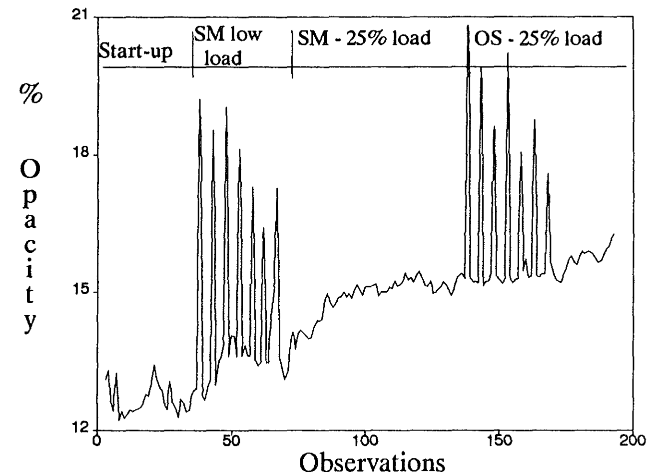


Figure 6.
This figure shows that opacity excursions exist with both systems. The excursions were eliminated by increasing boiler load on the StokerMaster, and by using the air preheater on the old system. The figure also shows that for the damper arm settings used opacity generally increases with load.

Combustibles vs. Time

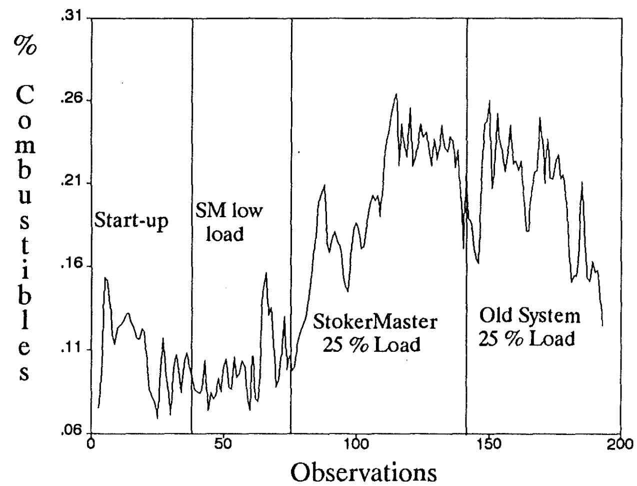


Figure 7.
This figure shows that the average level of combustibles is higher at higher boiler loads. However, the variation in combustibles levels does not seem to be explainable as a response to changes in fuel flow nor do they follow changes in opacity levels.

Steam Pressure vs. Time

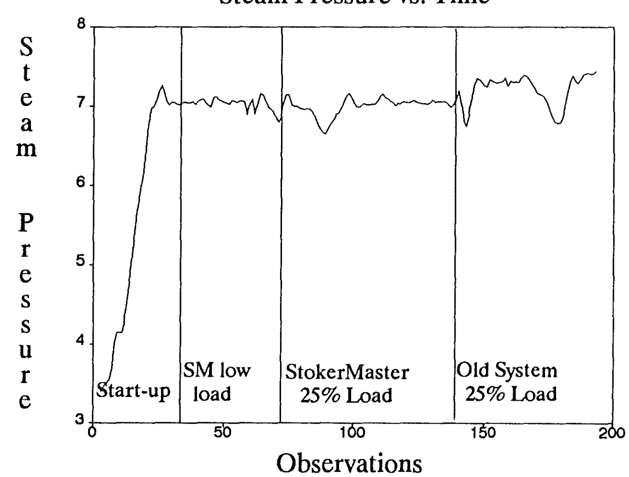


Figure 8.
This figure shows that both control systems exhibited effective control over steam pressure. The set points for the StokerMaster and old systems are slightly different at 7.0 vs. 7.2 psig. The data also shows that use of the preheater reduces the variability in pressure.

CONCLUSIONS

Air Preheater.
The tests run at the South Middle School supported EEC's claim that an underfire air preheater would improve boiler performance if the air temperature could be raised to between 210°F and 220°F. This result matched earlier work at Cohasset, and operating experience on a variety of other wood-fired boilers which showed that chip burners produce smoke when fired at low output rates.

Both control systems showed considerable improvement when used in conjunction with the air preheater. This finding is significant because the tests were performed at low outputs where the control systems were forced to modulate to hold boiler pressure. The tests indicate that air preheating might be used to achieve more efficent combustion when burning higher moisture fuels at lower percentages of capacity. Therefore, boiler operators should be able to begin burning wood earlier in the fall and continue until later in the spring if air preheaters are installed in their systems.

Ceramic Grate.
The ceramic grate used at the Middle School was fabricated by school district employees using instructions from EEC president, Vernon Christian. This grate has enabled the boiler to maintain a higher average temperature than was possible using a steel grate. Higher temperatures result in more complete combustion and higher efficiency.

StokerMaster II.
The *StokerMaster II* devices installed at elementary schools in Cohasset and Big Fork have performed well through one heating season. Previous tests have shown that the *StokerMaster II* is superior to the on/off controls usually supplied with smaller wood-burning underfeed stokers.

The current price of a *StokerMaster II* is about $3,600 FOB Kingsport, Tennessee. If installation charges can be minimized by having plant personnel perform the required work, it appears that the *StokerMaster II* can become a cost-effective option for many smaller wood-burning systems.

StokerMaster III.
Although the *StokerMaster III* performed marginally better than the old system, the tests did not provide support for the claim that *StokerMaster III* would vastly improve efficiency and emisssions. It appears that, at $15,000 installed, the *StokerMaster III* offers little economic incentive to prospective buyers at this time. Also, due to its complexity, it unlikely that installation of a *StokerMaster III* could be easily accomplished by plant personnel.

Excess Air

The oxygen content of the flue gas using the old control system and *StokerMaster III* each indicated 300 to 400 percent excess air because the air admitted through the air-swept stoker was a large percentage of the total air fed to the firebox. At higher boiler outputs the ratio of underfire to stoker air should change and the effect of underfire air damper settings should become more apparent. Operation at higher output might lead to different emission levels for each control system, since the *StokerMaster III* can control air flow and fuel flow independently. However, when operating near full load all dampers should be open, so it is likely that any differences found would be due to the manual setting of the dampers rather than control system differences.

Conversion to Wood Chips.

The South Middle School burned about 775 tons of wood pellets in 1987. The tests indicated that the school district could convert the South Middle School to wood chip burning if a new truck unloading station would be installed and the bin vibrators repaired. Based on the 1987 consumption of pellets and the current prices of pellets and chips, it's estimated that the fuel saving resulting from the conversion would be approximately $11,000 per year.

Fuel Moisture Considerations.

The school district should consider two additional factors as part of the wood chip conversion decision. These are;

storing wood in round form to reduce its moisture content, and
using a fuel purchase equation that adjusts fuel price as fuel quality varies

The moisture content of the fuel can be reduced by storing it for up to a year in log form. However, storage creates an inventory carrying charge that could add as much as $1.75/ ton to the delivered price of the fuel. Even so, wood chips should be more economical than wood pellets on a Btu basis.

It should be possible for the school district to specify maximum acceptable moisture contents when purchasing fuel in order to eliminate receipt of very high moisture material. Also, high moisture fuels, like wood chips, should be purchased using the lower heating value of the fuel to set its price. A fuel's lower heating value compensates for moisture content and its effect on boiler efficiency. Therefore a ton of fuel at a higher moisture content would cost less than the same fuel having a lower moisture content. This change would allow the school district to pay only for usable energy.

RECOMMENDATIONS

Testing of the *StokerMaster III* should continue at the South Middle School to develop methods for using wood chips efficiently in boilers designed to burn pellets. The equipment already installed will suffice for the testing, but some physical changes should be made to improve the material's handling system and the measurement of steam flow. Also, some of the instruments should be recalibrated to ensure their accuracy.

A longer term test next year with continuous emissions monitoring should yield data on:

how emission levels vary with boiler output,
how fuel use varies versus heat demand, and
how fuel moisture levels change boiler efficiency.

These data should be useful to the school district in its fuel selection decisions and should be applicable to other wood-burning facilities.

Even though the *StokerMaster III* did not generate the marked improvements its inventor expected, the tests illustrated several techniques that might be used to improve the efficiency and competitiveness of wood fuel in Minnesota. Some of these ideas -- the ceramic grate, and air preheater -- can be implemented at minimal cost to boiler owners.

The results of past tests should be presented to persons responsible for boiler operation at other locations. A seminar on the test program might be conducted in Grand Rapids so that operators from other school systems can see an existing installation and speak with operating personnel familiar with *StokerMaster* devices. The seminar could help to educate other boiler operators about low-cost techniques which may reduce their operating costs, and would give a larger number of installations the opportunity to profit from the Legislative Commission on Minnesota Resources' initiative.

Appendix A:
StokerMaster Performance Evaluation
Phase I
Cohasset Elementary School

STOKERMASTER PERFORMANCE EVALUATION

PHASE I

COHASSET ELEMENTARY SCHOOL

INTRODUCTION

In December 1986 the Department of Natural Resources in cooperation with the Pollution Control Agency requested funding from the Legislative Commission on Minnesota Resources (LCMR) for performance testing of a new boiler-control device called a STOKERMASTER. Funding for the test program was approved by the LCMR. Phase I testing of the device at the Cohasset Elementary School started in February 1987. This interim report presents the results of the Phase I testing.

PROJECT BACKGROUND

STOKERMASTER is the trademark of a series of products patented by Engineered Energy Concepts (EEC) of Kingsport, Tennessee. The product is based on an invention of Vernon Christian, president of EEC. According to the claims of the inventor, a STOKERMASTER can be retrofitted to coal- or biomass-fired boilers to reduce emission and fuel consumption.

The STOKERMASTER patent defines a technique that allows boilers with simple on-off controls to operate similar to boilers with modulating controls. The device controls the on-off cycle times of the fans and fuel stokers to achieve more complete and controlled combustion. In practice the control techniques are written into a computer program that controls operation of the boiler and its auxiliary equipment.

The State of Minnesota became interested in this device after several of its representatives met with the inventor to discuss the STOKERMASTER's applicability to wood-fired boilers installed in public facilities. The state has invested significant sums to convert schools, hospitals and other public facilities to wood firing. The impetus for the conversions was the energy crisis of the '70s and the steeply rising prices of fossil fuels. Many of these conversions are now in jeopardy because of recent reductions in the prices of natural gas and fuel oil. Also, operating experience has shown that most, if not all, of the conversions produce particulate emissions at or above allowable levels. This is a serious concern to the Pollution Control Agency since strict enforcement would likely result in conversion back to fossil fuels or increased cost to the public. According to the claims of the inventor, the STOKERMASTER offered the possibility of better compliance and reduced fuel costs. Therefore the state was interested in performing tests on the device to determine whether the claims were accurate.

PROJECT DESCRIPTION

The first task in this project was to locate test sites. A tour of several potential locations, conducted in early November 1986, indicated that Independent School District 318 in Grand Rapids had facilities in which the tests could be performed and a real interest in finding ways to preserve their investment in wood burning. Therefore, a preliminary agreement was concluded between the state and the district.

PCA, DNR and the district agreed that the most effective way to conduct the project was to divide the work into two phases. Phase I would consist of installation of a STOKERMASTER in a smaller school and data collection to determine whether the basic claims could be substantiated. The most important parts of the test would be a qualitative evaluation of the operation of the device and testing to determine its impact on particulate emissions. If the results of Phase I were positive, a Phase II test would be conducted. Phase II would be a longer term, more extensive test of fuel use and emissions in a larger wood-fired boiler. It was originally thought that the most important element to be tested in Phase II would be the use of a STOKERMASTER with an air preheater to allow green wood chips to be burned efficiently. The Cohasset Elementary School was selected for Phase I testing, and the Grand Rapids Middle School was selected for Phase II.

The Cohasset school has a 60 horsepower fire-tube boiler that was installed in 1928. The unit was originally designed to burn coal. It had been converted to burn fuel oil, but recently was converted back to solid fuels. The most recent conversion consisted of installing a Will Burt underfeed stoker, a storage bin and material-handling equipment to move wood pellets. The unit has been operated on pellets for three heating seasons. A second identical boiler fired with fuel oil is installed next to the wood-fired boiler.

The Middle School has a new "Sidewinder" boiler. This unit has an overfeed air-swept fuel feeder and a steel grate. The boiler has modulating controls on the induced draft fan damper. Earlier air-quality tests showed emission levels double the state standards. The boiler manufacturer challenged these tests and claimed the boiler was not tuned properly before the tests. Nonetheless, the project team decided that the earlier tests justified a second look at the Middle school boiler.

PHASE I TESTING

Between the time the project was approved and the start of testing, several workplan changes occurred. The major changes were these:

1. Selection of continuous emissions monitoring (CEM) to collect more data on the performance of STOKERMASTER, and
2. Installation of an air preheater that would allow for short tests of wood chips.

Both of these changes were important in that they allowed the investigators to (1) collect more and better data, (2) detect and quantify the impact of changing test conditions, and (3) study a wider variety of test conditions, particularly performance at low and intermediate loads. These modifications were later found to be critical to the success of the project, because unusually warm weather curtailed testing and eliminated the possibility of conducting Phase II tests in the spring of 1987.

A STOKERMASTER control device was installed at Cohasset in mid-February. For the next three weeks the district collected quantitative data on the operation of the unit, and qualitative data on its operability. These initial tests showed that the unit was reliable, and that it appeared to produce less clinkering and ash deposition in the tubes and flues. The district was satisfied with its performance, and indicated that it seemed to produce a better fire.

On March 17, Interpoll Inc., a Minnesota company which specializes in emissions testing, installed continuous emissions monitoring equipment at Cohasset. The sensors and gas collectors were installed in the boiler breeching (see figures 5 and 6). The sample collection points were selected using ease of access and cost as the criteria. They were satisfactory for this work, since the major reason for testing was to find differences between the old and new control systems; i.e., strict compliance testing was not necessary.

The emissions data was fed to an Omega analog-to-digital conversion board connected to an IBM personal computer. The A/D conversion updated every 10 seconds, and 5-minute averages were stored on floppy disk. This timing made it possible to observe rapid changes on the computer's screen, and collect data on cycles that would have been lost if longer averaging times had been used.

Emissions data were collected for 10 days while several fuel and control systems tests were conducted. On the 10th day Interpoll conducted particulate sampling tests on the old and new systems. The complete record of the data collected is contained in Interpoll's report. The DNR has the same data on disk and in spreadsheet format. The CEM data provided most of the results covered in the balance of this report.

In general, the equipment performed well and was extremely reliable. The only drawback was that some of the sensors reacted at different speeds. For example, the opacity readings were virtually instantaneous whereas the carbon monoxide readings required 1½ to 2 minutes for any changes to be fully measured. This was a minor inconvenience, but it did mean that some parameter measurements lagged other parameter measurements. For example a high 5-minute average for CO usually lagged a high 5-minute average for opacity.

The following tests were conducted:

3/17 Installation and calibration of continuous emissions monitoring equipment.

3/18 Adjustments to underfire air and the boiler in an attempt to reduce the oxygen content of the flue gas. The changes included:

a. Installation of a new damper and two-position controller in the underfire air plenum.
b. Closing and taping all barometric dampers.
c. Installing new gaskets in the furnace doors.
d. Reinstallation of the 3600-rpm motor on the underfire air fan.

3/19 The morning was spent making sure that the two-position damper was operating properly. At noon the old low-pressure fan was reinstalled and the boiler was set to run with the old control system. Some slight adjustments to the pressure switches were needed to ensure that the old and new systems used the same on-off pressures. The boiler ran overnight on the old control system.

3/20 The fan originally installed with the Will Burt stoker was removed and the old system was run with the new high-pressure fan and with the two-position damper locked into the fully open position. This ensured maximum air flow while the stoker was on. The boiler ran overnight in this configuration. This test allowed separation of the effect of the control system from the effect of the new high-pressure fan.

3/21 The boiler was set to run over the weekend using the new control system with the new fan. It ran in this configuration all Saturday and Sunday.

3/23 The boiler was shutdown Monday morning for installation of the air preheater. Hot water for the preheater was taken from the crossover point used to equalize water levels between the wood-fired and oil-fired boilers. Water was returned to the boiler water inlet pipe. The heater was installed downstream of the underfire air fan so that only ambient air would move through the fan. The installation was completed in the early afternoon, and some preliminary tests of the system were conducted. The heater was shut down overnight for safety reasons. The boiler ran overnight on the new control system.

3/24 The air preheater was tested using pellets as fuel. The heated air was delivered to the retort at 185 to 200 deg F. Some air leaks were noted; so the heater was again shut down overnight for safety reasons.

3/25 Unscreened hard wood chips were tested. The chips were hand loaded into the bin feeding the stoker auger. The auger was run at a higher speed because chips have a lower bulk density. The chips tended to bridge in the hopper and required constant operator attention to ensure even fuel flow to the retort. The morning test was conducted without the air preheater, but the air preheater was used for the afternoon tests. Wood-chip firing ended at 6:00 pm. The preheater was turned off, and the boiler was set to run on the new system overnight.

3/26 Green, screened aspen chips were obtained for this day's tests. The chips were of uniform size and fed easily from the bin to the retort. Again, the morning was used to test combustion of chips without the preheater, and in the afternoon the preheater was used. The feed augers were set to maximum speed because of low energy content of the fuel, and the underfire air temperature was controlled to the 193 to 205 deg. F. range. Aspen chip tests were discontinued at 5:00 pm. The old fan was installed so that the boiler could run overnight on the old system in preparation for particulate testing the next day.

3/27 The test program for this day called for two 1-hour particulate sampling runs with the old control system and two 1-hour runs with the new control system. All runs were conducted at maximum boiler output. Employees of Interpoll Inc. completed the tests, and late in the afternoon all of the CEM equipment was removed. The boiler was set to run on the new control system. This completed the Phase I test program.

PHASE I RESULTS

Particulate testing

Four one-hour runs were conducted: two with the old controls and two with STOKERMASTER. The old and new control systems showed very similar flue gas flow rates. The values for dry standard cubic feet per minute were 1036 and 1077 for the old system and 1054 and 1087 for the new system. Flue gas compositions were also similar with the old system showing 0.4 percent higher CO_2 readings, and 0.3 percent lower O_2 readings. The new system showed CO readings averaging 1716 ppm vs 321 ppm for the old system. These data are consistent and the higher CO readings with the new system are probably caused by elimination of overfire air, and a reduction of turbulence above the fuel bed.

The most significant finding was lower particulate emissions with the new system. The dry catch emission factor for the old system was 0.314 lb. of particulate per million Btu. The same factor for the new control system was 0.178 lb./mmBtu. The opacity averages were similar, and both were quite low at 5.84 percent for the new vs. 6.00 percent for the old. The new system showed consistently lower opacity readings.

Emissions at Less Than Full Load

Figures 1 and 2 show 5-minute opacity averages vs. the percentage of time the stoker operated during the 5-minute period. The graphs show that when the stoker is operating 100 percent of the time, both systems exhibit similar opacity readings. However, the STOKERMASTER has low opacity readings when the stoker is operating less than 100 percent, whereas the old system shows a definite tendency for higher opacity while the stoker is operating less than 100 percent.

These graphs are important because they verify one of the claims of the inventor. The higher opacity readings on the old system are indicative of smoldering when the stoker and fans are off, and the boiler is operating on natural draft. The STOKERMASTER exhibits better control, because the underfire air fan is on all the time while the boiler is operating in the modulating pressure range, and the stoker turns on and off in response to timed signals from the controller.

Wood Chip Tests

Table 1 shows the analyses of the fuels used during the test program. The data show that the hardwood chips used in the test were dryer than normal. The data on hardwood chips is suspect, because the Btu content of the fuel is extremely high. Interpoll rechecked its figures and came to the same conclusion, but the Btu figures for hardwood chips are still suspect.

FIGURE 1

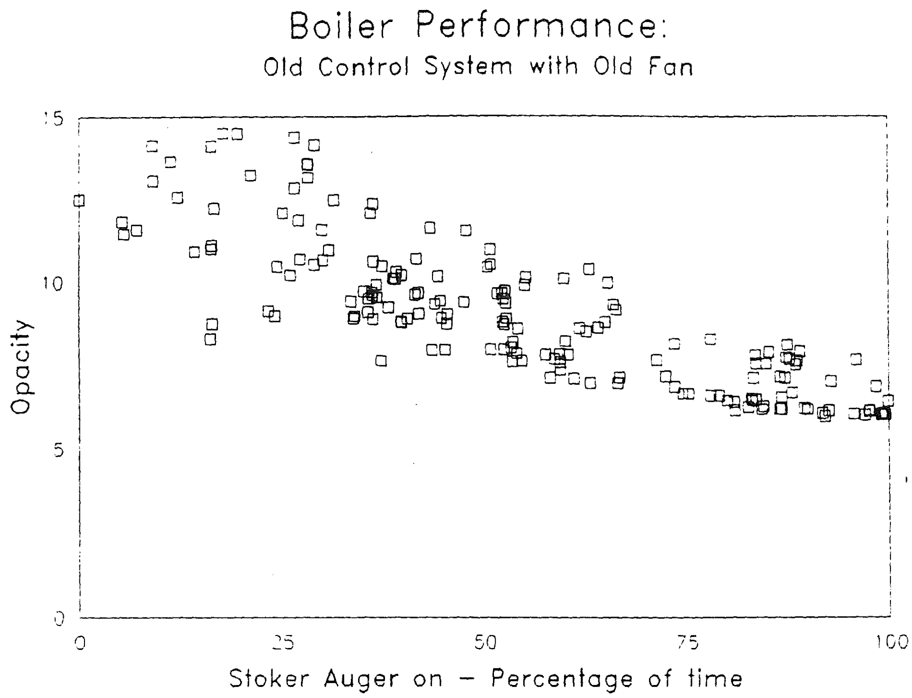


FIGURE 2

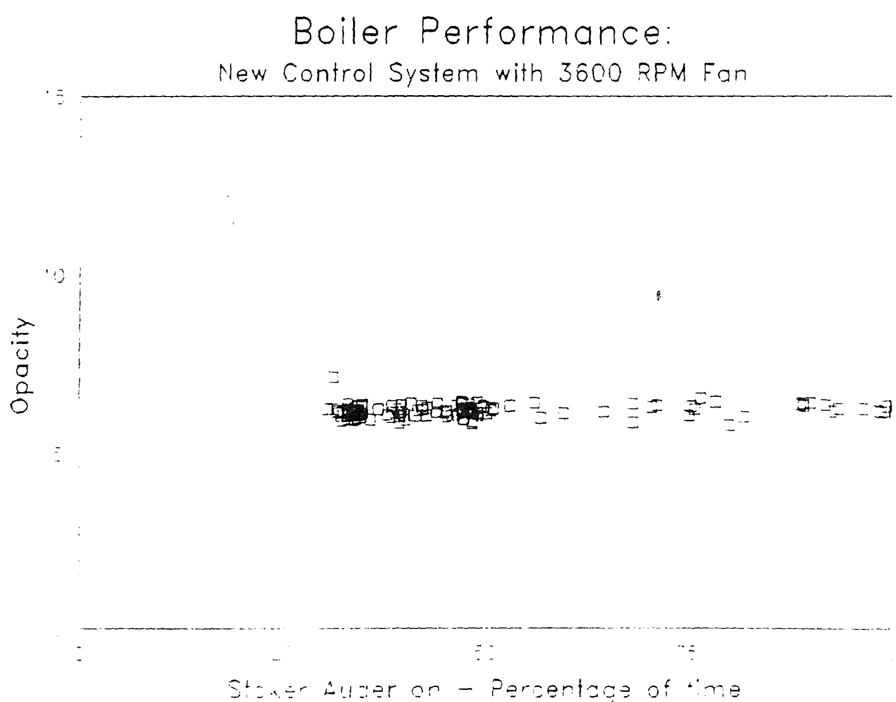


TABLE 1

STOKERMASTER TEST -- COHASSET ELEMENTARY SCHOOL
Fuel Analyses -- as Received

PROXIMATE ANALYSES - Wt. %

Fuel	Date	MC	Ash	VolMatl	Fixed C	Btu/lb	Sulfur
Pellets	3/19/87	4.87	2.23	76.67	16.23	8196	.08
Pellets	3/20/87	4.98	2.10	75.64	17.27	8219	.03
Pellets	3/21/87	5.24	2.12	76.72	15.92	8222	.03
Pellets	3/22/87	4.94	2.19	75.94	16.93	8209	.06
Pellets	3/23/87	5.30	2.10	75.27	17.33	8148	.05
Pellets	3/24/87	5.28	2.16	75.72	16.85	8163	.02
Pellets	3/25/87	5.43	2.13	75.22	17.23	8149	.05
Pellets	3/27/87	5.39	2.25	76.01	16.35	8194	.03
Average		5.18	2.16	75.90	16.76	8188	.04
Hard Wood	3/25/87	29.96	.40	57.20	12.43	6879	.04
Aspen chips	3/26/87	48.85	.40	41.67	9.08	4226	.04

ULTIMATE ANALYSIS - Wt. %

Fuel	Date	MC	Ash	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur
Pellets	3/19/87	4.87	2.23	47.93	5.81	38.88	.20	.08
Pellets	3/20/87	4.98	2.10	48.04	5.75	38.89	.20	.03
Pellets	3/21/87	5.24	2.12	47.75	5.71	38.96	.20	.03
Pellets	3/22/87	4.94	2.19	47.83	5.79	39.02	.18	.06
Pellets	3/23/87	5.30	2.10	47.76	5.79	38.82	.18	.05
Pellets	3/24/87	5.28	2.16	47.81	5.73	38.85	.15	.02
Pellets	3/25/87	5.43	2.13	47.66	5.76	38.80	.18	.05
Pellets	3/27/87	5.39	2.25	47.42	5.71	39.03	.18	.03
Average		5.18	2.16	47.78	5.76	38.91	.18	.04
Hard Wood	3/25/87	29.96	.40	38.69	4.86	25.91	.15	.04
Aspen chips	3/26/87	48.85	.40	25.26	3.14	22.28	.03	.04

LOWER HEATING VALUES AND COSTS

	Btu/lb	$/ton	$/mmBtu
Pellets	8133	55.00	3.38
Hard wood chips	6564	19.00	1.45
Aspen chips	3713	17.00	2.29

ANALYSES-MOISTURE FREE

	Ash	VolMatl	Fixed C	Btu/lb	Sulfur
Pellets	2.23	80.96	16.80	8677	.03
Hardwood chips	.57	81.68	17.75	9822	.05
Aspen chips	.78	81.47	17.75	8262	.07

	Ash	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur
Pellets	2.23	50.38	6.03	41.12	.21	.03
Hardwood chips	.57	55.24	6.94	37.00	.21	.05
Aspen chips	.78	49.38	6.14	43.57	.05	.07

Table 2 summarizes the CEM readings for the various system tests conducted. The data from the two tests with hardwood chips showed opacity and CO readings in the same range as those obtained with wood pellets. The operating data indicate that hardwood chips could be used if they were sized for proper feeding and if the storage bins and conveyors were modified for proper handling.

The data in table 2 for aspen chips validates the need for a Phase II test in a larger boiler. The data show that the combustion of green chips is improved significantly by the use of preheated underfire air. The opacity readings dropped from about 21 percent to less than 11 percent.

Figure 3 shows that the stoker was barely able to keep up with heat demand, and that opacity readings ranged from 7 to 40 percent. With the air preheater on (figure 4) the stoker operated less, and the opacity range narrowed, such that only two opacity measurements were in excess of 20 percent.

The effect of preheated air when coupled with the new controls as shown in figures 1 through 4 provide a strong indication that wood chips might be burned more efficiently using a STOKERMASTER control system. This, of course, must be validated by additional testing in a larger boiler.

TABLE 2

CONTINUOUS EMISSIONS MONITORING TEST RESULTS

Cohasset Elementary School

March 23-27, 1987

TEST	OXYGEN	C-DIOXIDE	C-MONOXIDE	FLUE TEMP	FAN	AUGER	OPACITY
Installed new air preheater and tested- 3/23							
Ran overnight, new system, pellets, no preheat	16.59	4.08	947.93	159.[illegible]	4.08	2.38	6.17
Pellets air preheater on- 200 deg. F.- 3/24	16.32	4.27	856.31	160.03	3.98	1.72	6.07
Run overnight on new system- 3/24-25	16.46	4.09	899.54	158.02	4.08	1.74	6.14
Start of Hardwood chip test, no preheat-3/25	16.40	3.90	842.01	165.12	3.96	3.27	8.06
Hard wood chips with preheat	16.56	3.95	753.89	157.80	4.05	1.35	6.46
Ran overnight with pellets, New system- 3/25-26	16.59	3.96	823.74	160.41	4.08	1.96	6.16
Run with Aspen chips no preheat, new system- 3/26	16.83	3.66	2,490.88	175.98	3.67	3.47	20.93
Started preheat with Aspen chips- 193 deg. F	15.82	4.54	2,590.28	179.85	3.74	2.75	10.32
Run all night on old system with old fan-3/26-27	16.68	4.01	485.95	186.24	.00	2.27	8.94
Particulate test old controls- 3/27	13.94	6.76	321.42	257.47	.00	3.95	6.33
Particulate test new controls	13.81	6.62	1,716.63	216.78	3.95	3.95	5.84

FIGURE 3

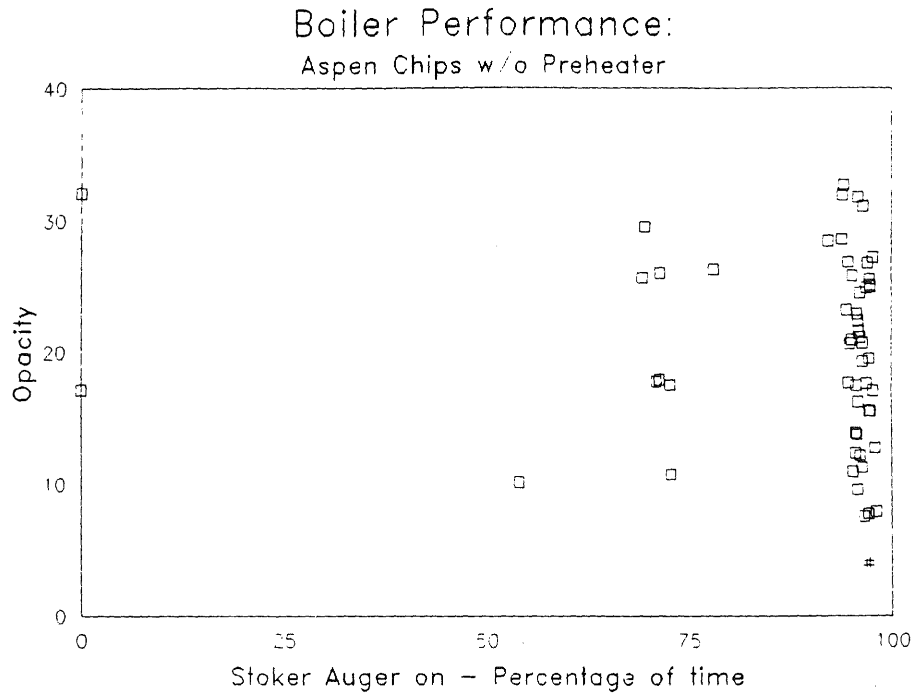
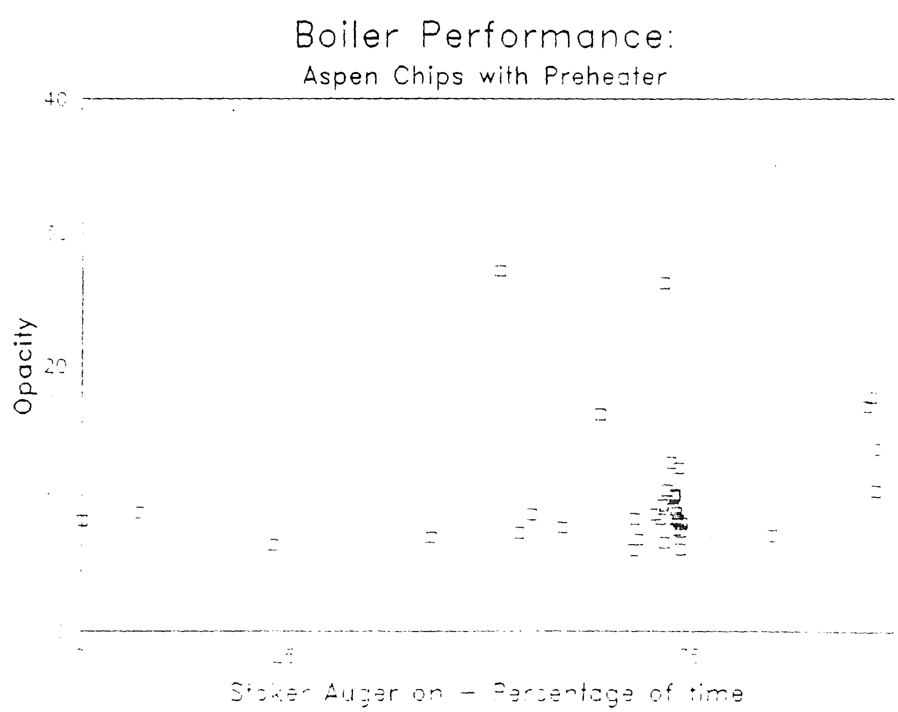


FIGURE 4



The old control system was not tested with green chips because previous tests indicated smoldering would be excessive. As it was, the fuel-handling system could supply barely enough fuel to keep the boiler pressure in the operating range. The inability to burn chips with the old system was a major constraint in Phase I that will not affect Phase II.

Fuel Savings

Fuel consumption comparisons were made using the percentage of time the stoker operated relative to the outside air temperature. It was decided that nights were the best comparisons, since that would minimize differences caused by sunny vs. cloudy days, and school use patterns. The data are, at best, indications since only short, 15 to 16-hour periods were compared and the number of such comparisons was quite small; i.e., the total test lasted only 10 days.

Notwithstanding all the qualifications, the STOKERMASTER control system appeared to use less fuel than the old control system. The data in table 3 show the results of six nights, three on the old system, and three on the new. In each case the percentage of time the stoker was on was linearly adjusted to a base temperature of 32 deg. F. This is at best a rough approximation, but the raw and adjusted data do show a consistent pattern that indicates lower fuel consumption with the new control system. The data also shows fuel savings when the old system was operated with a new high pressure fan.

TABLE 3

FUEL CONSUMPTION COMPARISON

Date	Confirguration	Fuel	Min. Temp. Deg. F	Auger On	Auger Pct	Adj. Basis to 32°F
3/19-20	Old controls/old fan	Pellets	32	2.16	52.9	52.9
3/20-21	Old controls/new fan	Pellets	33	1.96	48.0	49.5
3/21-22	New controls	Pellets	31	1.89	46.3	44.9
3/22-23	New controls	Pellets	35	1.79	43.9	48.2
3/25-26	New controls	Pellets	32	1.96	48.0	48.0
3/26-27	Old controls/old fan	Pellets	31	2.27	55.6	54.0

		Fuel Savings Pct
New system/new fan	47.0	12.1
Old system/new fan	49.5	7.5
Old system/old fan	53.5	---

Quantitatively the indicated savings are 12.1 percent with the new system, and 7.5 percent with the old system and the new fan. These data are consistent with figure 1 which shows a relationship between high opacity readings and stoker operation, i.e., indications of poorer combustion. The STOKERMASTER shows fuel saving advantages when operating at less than full load.

Observation

The operators at Cohasset have said that the new control system causes less clinkering and buildup in the boiler tubes. Pellet burning with the new system results in almost no clinkering, and the ash remaining is fine and gray.

Ash Sampling

Daily ash samples were collected as part of Phase I, but the ash analysis may be unreliable. In several cases the ash sample was collected after the fire box was scraped clean. This practice increased the chance of contamination with partially burned fuel from the retort. The data collected in Phase I show indications of contamination; so no real conclusions about ash analyses can be made.

Cohasset Elementary School
Boiler Breeching
(Plan View)

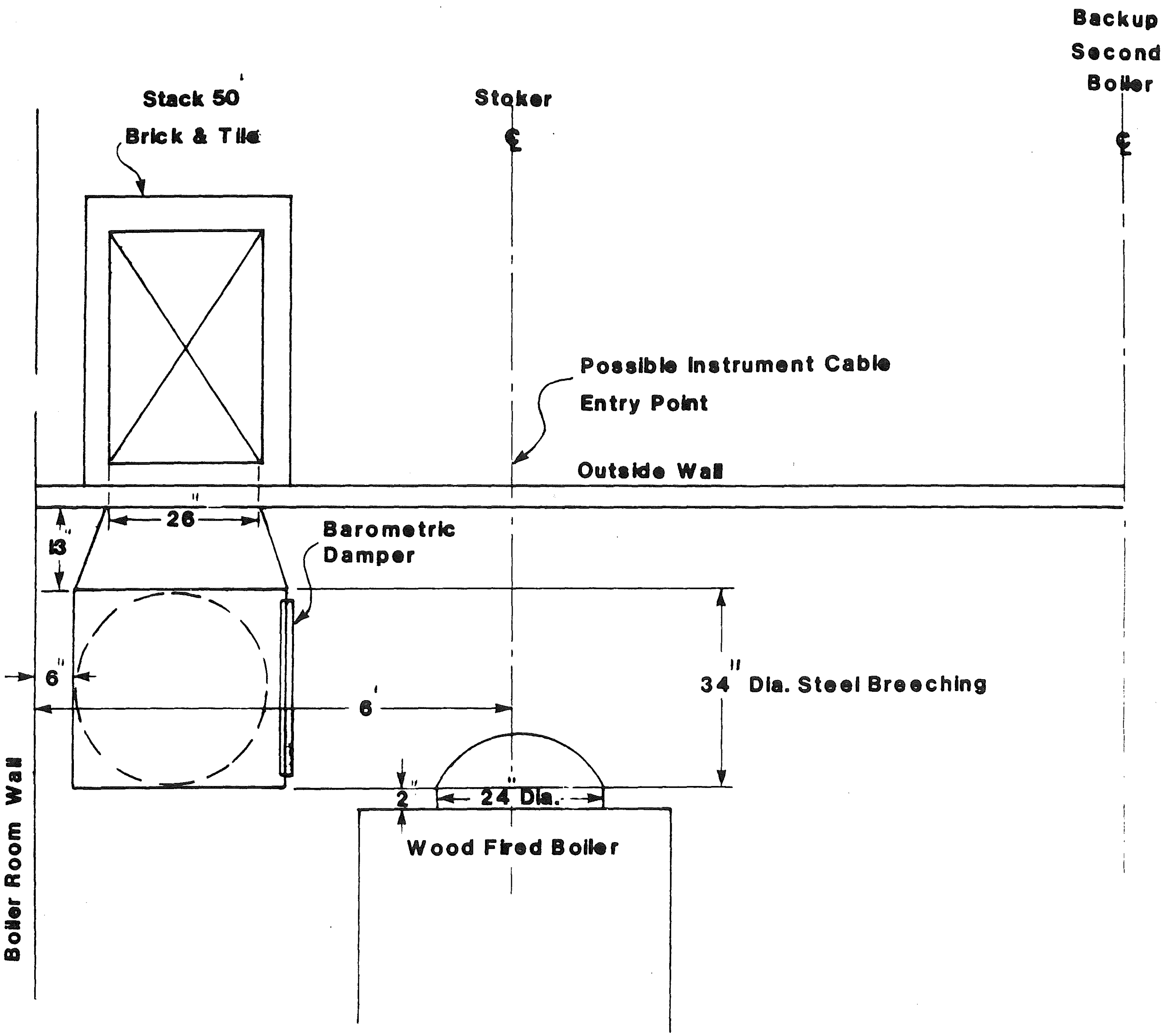


FIGURE 5

Cohasset Elementary School
Boiler Breeching
(Elevation)

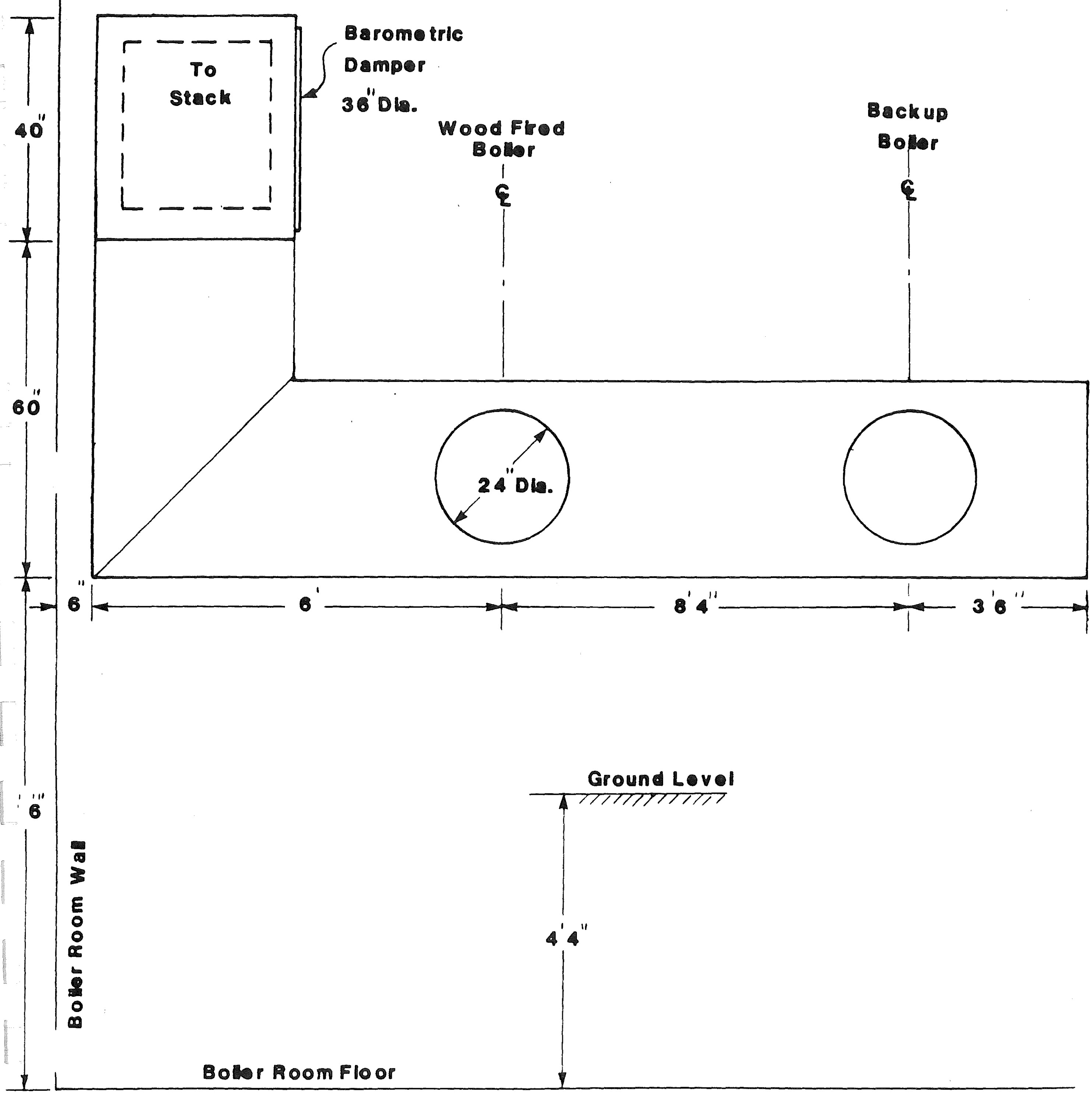


FIGURE 6