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# Summary report of the In-Home Emissions and Efficiency Performance of Five Commercially Available Masonry Heaters

Prepared for: The Masonry Heater Association

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# Executive Summary

### General

Emissions regulations for residential woodburning devices have become tighter in. recent years. In 1986, the EPA established a woodstove certification program that went into effect in two stages in 1988 and 1990. Masonry heaters, which essentially function as high-mass, rapidly burning woodstoves with a large heat storage capacity, were exempted from this program by virtue of their large mass.

More recently, certain airsheds in the west, with extensive residential woodburning, have been declared in nonattainment by the EPA for airborne particulate matter of less than 10 microns in diameter ($PM_{10}$). State Implementation Plans (SIPs) have been written to develop air pollution reduction strategies to bring these areas into compliance. Unfortunately, masonry heaters have not been included in this process because they cannot quality for EPA certification due to their large mass. Hence, they have not been placed on the EPA's Reasonably Available Control Measure (RACM) Emission!; Reduction Credit list. Accordingly, state and local governments have excluded masonry heaters from their own lists of emissions reduction control strategies. Recently the EPA, in recognition of this problem, instituted an "in-home" emissions test option for "non-affected" residential wood combustion RWC devices such as masonry heaters. These-tests provide more realistic emissions and efficiency information than lab tests and their results can be used to obtain emissions reduction credits.

### Objectives and Methodology

'This project's main objective has been to sample a representative population of commercially available masonry heaters in homes. The data will be used by EPA to produce a masonry beater AP-42 emissions value which will be used to calculate an emissions reduction credit. A second objective has been to explore these heaters as potentially very clean burning technologies that can qualify as low-emitting Best Available Control Measures (BACM).

Particulate (PM) and carbon monoxide (CO) emissions and net efficiency were measured on five masonry heaters in western Oregon and Washington in 1991 and 1992 using OMNI's Automated Woodstove' Emissions Sampler (AWES). Each heater was operated by the homeowner in his normal fashion and was fired seven to ten times during the week-long test. In four of the five houses the heater was the only source Of heat.

### Results

PM emissions for the five heaters averaged 3.2 g/kg, 1.8 average daily g/hr, and 3.2 normalized[1] average daily g/hr. These PM values are higher than field value!; from certified pellet stoves and lowet than from Phase IT EPA certified noncatalytic woodwtoves.

CO emissions averaged 74 g/kg. 50 average daily g/hr, and 74 normalized daily g/hr. These values are comparable to Phase II EPA certified noncatalytic woodstoves.

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[1] Emissions values are "normalized" for easy compnrsion to 1 dry kg/hr burn rate, the average in-home burn rate for certified noncatalytic woodstoves.

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The average net delivered efficiency was 58%, which is midway between conventional and EPA certified Phase II woodstoves. Average heat output was 7425 BTU/hr and burn race averaged 0.68 dry kg/hr.

Following EPA procedures and using the most recent field data, the average masonry heater emissions reduction credit is 81% compared to 91 % for certified pellet stove5 and 64% for certified noncatalytic woodstoves. The average of the three overtire air masonry heaters equaled the pellet stove value, suggesting that they could qualify as low-emitting devices under BACM.

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# Introduction

There has been increased tightening of emissions regulations on residential woodburning devices in recent years. In 1984, the Oregon DEQ established the first U.S. woodstove certification program, followed in 1986 by the EPA, which established a similar program that went into effect in two stages in 1988 and 1990. Masonry heaters, which essentially function as high-mass, rapidly burning woodstoves with a large heat storage capacity, were exempted from this program by virtue of their large mass.

In more recent years, certain poorly drained airsheds of the west that experience extensive residential woodburning have been declared by the EPA to be in nonattainment for airborne particulate matter of less than 10 microns in diameter ($PM_{10}$). State Implementation Plans (SIPs) have been written to develop strategies for reducing air pollution to bring these areas into compliance. Unfortunately, masonry heaters and other "non-affected" residential wood combustion (RWC) devices have "fallen through the cracks" of this process because they cannot become EPA certified. Hence, they have not been placed on the Reasonably Available Control Measure (RACM) Emissions Reduction Credit list. Since "non affected" devices have not been placed on the emissions reduction credit list, state and local governments have excluded them from their own lists of emissions reduction control strategies. Recently the EPA, in recognition of this problem, has instituted an "in-home" emissions evaluation option for "non-affected" RWC devices such as masonry heaters. These tests not only provide a more realistic emissions and efficiency evaluation than lab tests can but the results from such tests can be used to obtain emissions reduction credit as *long* as *the* emissions are sufficiently low.

The current project's main objective has been to sample a representative population of masonry heaters that are commercially available in the U.S. The data will be used by the EPA to produce an AP-42 emissions value for masonry heaters. An emissions reduction credit will then be calculated from the AP-42 value. A second objective has been to explore these heaters as potentially very clean burning technologies that can qualify as Best Available Control Measures (BACM).

A total of five masonry heaters have been evaluated in western Oregon and Washington by OMNI in the past year and their results are summarized in this report. These heaters include a Biofire 4x3, Grundofen, Royal Crown 2000, Contraflow and Tulikivi KTU 2100. Combustion air for the first three heaters comes from above the grate (overfire air) and from below the grate for the other two (underfire air). A diagram of the Contraflow is shown in Figure 1. This can serve as a generalized masonry heater diagram in that all heaters are massive structures weighing typically more than 900 kg and their flue gases pass through a labyrinth of masonry passageways before exiting the home. All units are fired for a short period (2-5 hours) once or twice a day depending on the home's heat demand. Photos and additional details of each heater can be seen in the individual heaters' reports (References 5-9).

Each masonry heater emissions test was designed to be as representative as possible of that heaters typical performance in homes. The heater was operated by the homeowner as he normally did. No coaching was provided by the installer or manufacturer. The homeowner either used his own wood or douglas fir supplied by OMNI if he had been using unrepresentative lumber such as scraps (two cases). Since the heater was the sole source of heat in four of the five houses, the homeowner generally loaded wood at a frequency needed to meet the home's heat demand. This ranged from one to two burns per day.

OMNI's Automated Woodstove Emissions Sampler (AWES) and datalogger were used to conduct the sampling. By doing so, a direct comparison can be made to numerous published studies on woodstoves, fireplaces, and pellet stoves. This system collected samples for PM, carbon monoxide (CO) and

# Contraflow Heater

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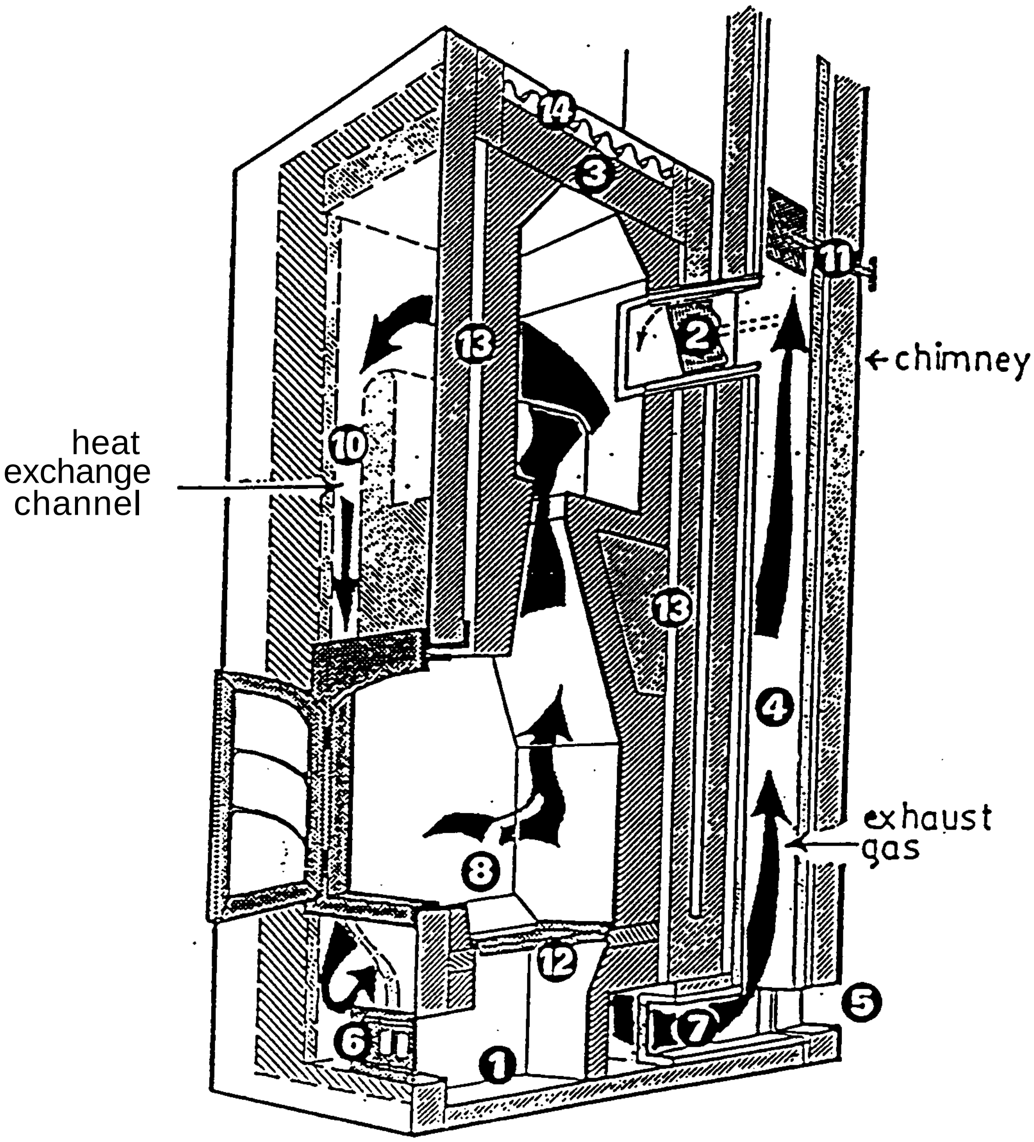


1. ASHBOX
2 BYPASS DAMPER
3: CAPPING SLAB
4. CHIMNEY
5. CLEAN-OUT
6. COMBUSTION AIR
7. EXHAUST GAS

8. FIREBOX
9. FIREBOX DOOR
10. HEAT EXCHANGE AREA
11. SHUT-OFF DAMPER
72. GRATE
13. EXPANSION JOINT
14. INSULATION

More detail in caption

Figure 1

efficiency determinations. In addition to producing emissions and efficiency results, the AWES uniquely collects real-time temperature information on the home's ambient temperature and the stack temperature above the flue damper. Real-time data on stack oxygen content and fuel loading patterns were also collected. Results for each of the heaters are illustrated in Appendix A of the heaters' individual reports. During testing of the Biofire and Tulikivi two AWES were operated simultaneously. The average results of these two tests are presented in this report.

The AWES was specially modified for masbnry heater sampling. Due to the anticipated low concentration of emissions in masonry heater flue gases, a large volume of these gases had to be sampled in order to collect an adequate amount of particulate catch. In this project, about 900 liters were collected. This meant that the AWES was operated one minute on and two minutes off throughout the sampling period. Additionally, a Tedlar bag was used to collect an integrated flue gas sample for the week-long sample period so that CO and carbon dioxide ($CO_2$) could be measured. More details of how procedures were modified for masonry heaters are provided in the Methodology section.

Two masonry heaters, a Contraflow kit heater and a locally designed and built "Russian" heater, were evaluated by Barnett (1990) in the Western States Clay Products fireplace and masonry heater project. The issue of how to present emissions results for masonry heaters was discussed at length in that report. Because masonry heaters are only burned for short periods, the emissions rate concept used for woodstoves of grams per hour is not considered as appropriate as other means of expressing emissions data. Instead, the concept of average daily grams per hour was adopted. Emissions values were also normalized to a 1 kg/hr bum rate, the average Phase II EPA woodstove rate, and presented as normalized average daily grams per hour. The normalized value (which equals the g/kg value) is a more appropriate way to express emissions since it eliminates burn rate as a variable, placing all heaters and Phase II woodstoves on a relatively "level playing field". Additionally, the efficiencies of all of these burning devices are very similar, further supporting the use of this approach. This procedure is followed in this report.

Emissions reduction credits following the EPA calculation procedures will be presented in this report. Masonry heaters credits will be compared to other forms of residential wood combustion (RWC) such as conventional and noncatalytic woodstoves and certified pellet stoves.

# Methodology

## Emissions Sampling

### The Modified AWES Emission Sampling System for Masonry Heaters

Figure 2 shows a schematic of the AWES/data logger system as modified for masonry heater sampling. The AWES unit draws flue gases through a 38 cm (15 in.) long, 1.0 cm ($^3/_8$ in.) O.D. stainless steel probe which samples from the center of the flue about 214 cm (7 ft) above the base of the firebox. This location is above the flue damper. The sample then travels through a 1.0 cm O.D. Teflon line, and a heated U.S. EPA Method 5-type filter for collection of particulate matter, followed by a sorbent resin (XAD-2) trap for semi-volatile hydrocarbons. Water vapor is removed by a silica gel trap. Flue gas oxygen concentrations, which are used to determine flue gas volume, were measured by an electrochemical cell manufactured by Lynn Instruments.. The AWES uses a critical orifice (Millipore #XX500001) to maintain a nominal sampling rate of 1.0 liters per minute (0.035 cfm). The flow rate

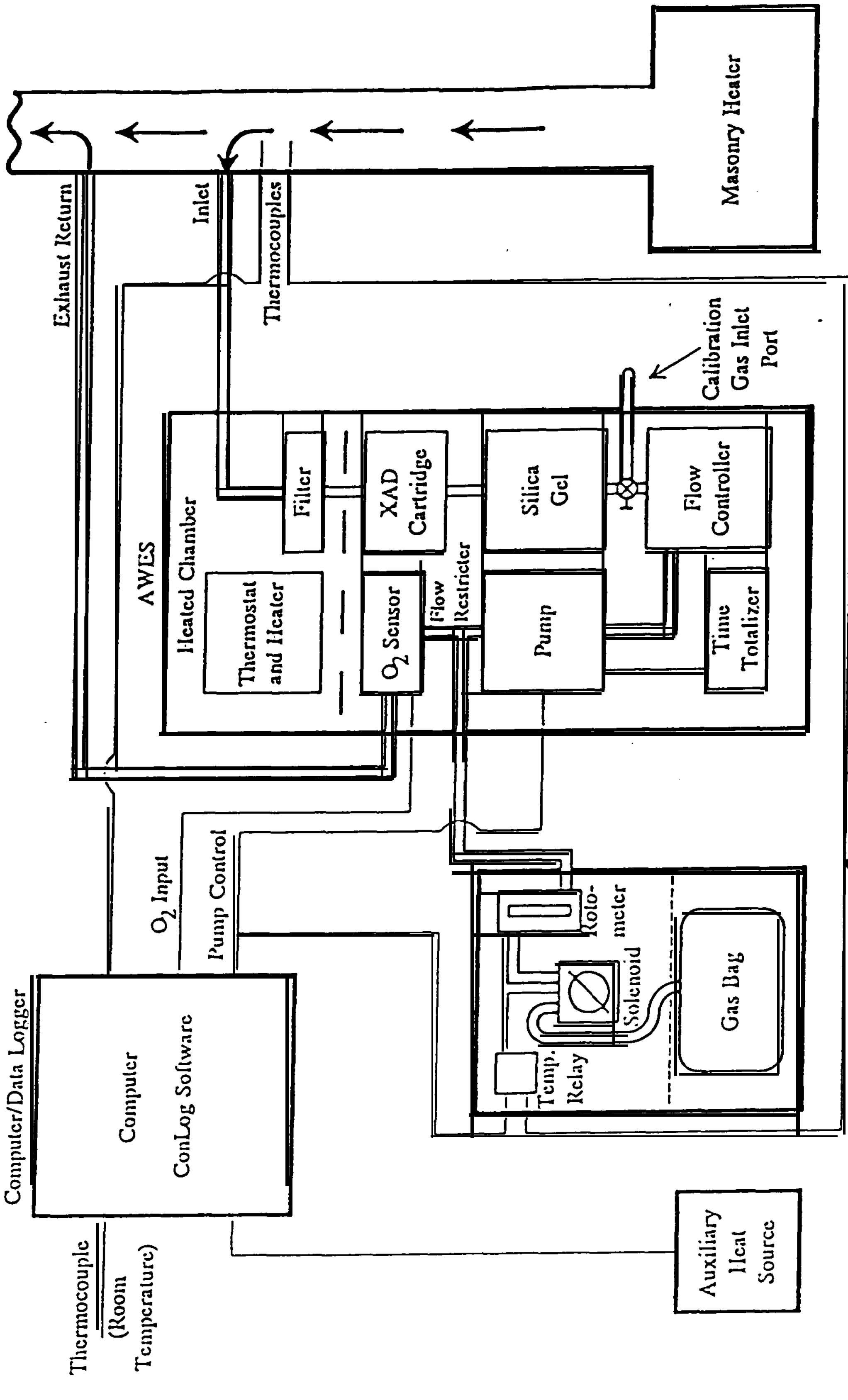


Figure 2 Schematic of AWES/Data LOG'r system.

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Date: February 19, 1992

Drawing: 80119-01.DRW

Not to Scale

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through each AWES critical orifice is measured with a bubble flow meter to determine the exact sampling rate.

The AWES unit returns particle-free exhaust gas to the flue via a 0.6 cm ($^{1}/_{4}$ in.) Teflon line and a 38 cm (15 in.) stainless steel probe inserted in the flue. Some flue gas exiting the AWES is pumped **into** a **22-liter** Tedlar bag (for later gas analysis) under positive pressure, since the inlet to the bag is on the positive pressure side of the pump. The flow, to the bag was controlled by a solenoid valve connected to the pump circuit and a rotameter with a flow-controlling orifice. The solenoid valve **is** open only when the pump is activated. Thus the bag receives effluent gas at all times when the AWES pump is on. 'The rate of flow into the bag is controlled by a fine metering valve which was adjusted to acquire the optimum amount of gas over the entire test without over-pressurizing the bag. Flow is measured using a bubble flow meter.

## The Data Logger System

**The** data logger system, known as the CONLOG data logger system, is a second-generation data logging and emission sampler controlling system developed in 1990 by OMNI. The system (Figure 3) consists of a host personal computer (PC) containing a data processing board, a terminal box, and specialized data acquisition software.

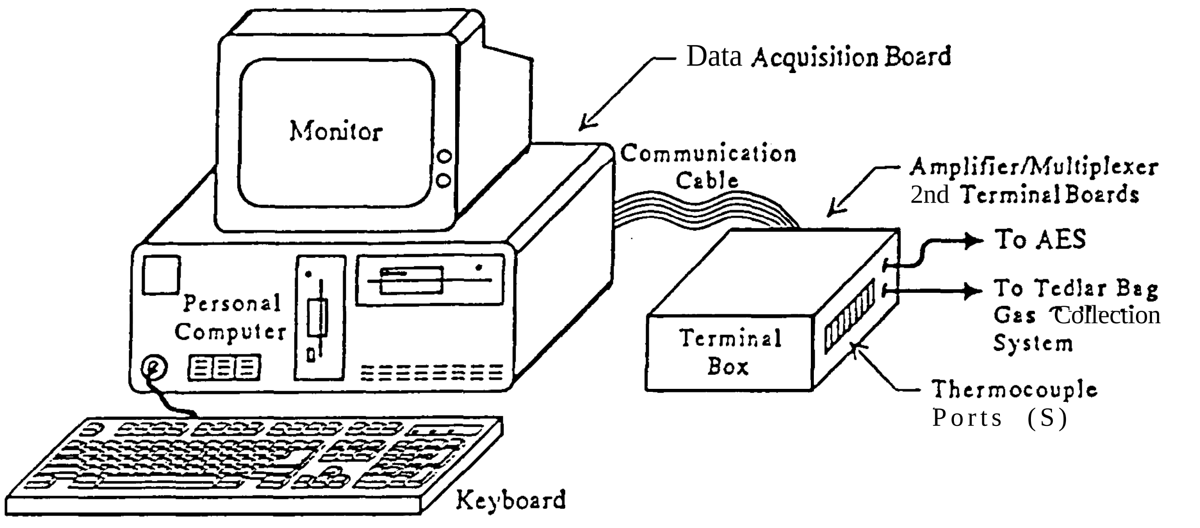


Figure 3. The ConLog data logger system.

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The CONLOG software is written in a high-level programming language (C) and can be programmed to control, collect, and store the following software settings and data:

- Establish starting and ending date and length of sampling period
- Establish pump cycle length and thermocouple (TC) cycle recording interval
- Record date and time at pre-selected intervals
- Record up to eight temperatures, including flue gas temperature, averaged over pre-selected intervals
- Record ambient temperature (room temperature), averaged over pre-selected intervals

- Record flue gas oxygen measurements, averaged over pre-selected intervals
- Save tile as an ASCII file with PRN suffix on 3.5" disk

Instantaneous readings of real-time data are also displayed on the system status screen of date, time, temperature for TCs 1 through 8, and flue gas oxygen percent. The most recent 15 sets of recorded data are also displayed.

For masonry heaters, temperature, etc. are recorded at five-minute intervals. The sampling pump is operated for one minute on followed by two minutes off. This procedure ensures the sample of about 1,000 liters during burning periods, which is needed for clean-burning devices.

The CONLOG system uses external sensors which generate analog voltages that are processed by the PC microprocessor's data acquisition board. For this project, a type K ground-isolated, stainless-steel-sheathed TC (Pyrocom1K-27-5-U) was used to monitor flue gas temperature at 213 cm (7 ft) above the base of the firebox in the center of the flue gas stream.

The keyboard and screen were left installed in the home during the sample period. The presence of the display screen's real-time data generated considerable interest on the part of the participants in the project and was a positive experience. The CONLOG program was software-locked to prevent possible interference. However, historically, on a few occasions homeowners have been given the password and "walked through" minor program modifications over the telephone to solve a problem that may have occurred during a sampling period. This proved successful and saved considerable field technician time.

## Equipment Preparation and Sample Processing Procedures

Prior to emissions testing, the AWES unit was cleaned and prepared with a new fiberglass filter and XAD-2 sorbent resin cartridge. This was done in OMNI's laboratory facility at Beaverton, Oregon. After the sampling period, the stainless steel sampling probe, Teflon sampling line, filter holder, and XAD-2 cartridges were removed from the home and transported to OMNI's laboratory for processing. The components of the AWES sampler were processed as follows:

1. Filters: The glass fiber filter (102 mm in diameter) was removed from the AWES filter housings and placed in a petri dish for desiccation and gravimetric analysis for particulate catch.

2. XAD-2 sorbent resin: The sorbent resin cartridge was extracted in the Soxhlet extractor with dichloromethane for 24 hours. The extraction solvent was transferred to a tared glass beaker. The solvent was evaporated in an ambient air dryer, the beaker and residue were desiccated, and the extractable residue was weighed on a Mettler AE160 balance.

3. AWES hardware: All hardware which was in the sample stream (stainless steel probe, Teflon sampling line, stainless steel filter housing, and all other Teflon and stainless steel fittings) through the base of the sorbent resin cartridge was rinsed with a 50/50 mixture of dichloromethane and methanol solvents. The solvents were placed in tared glass beakers. The solvents were evaporated in an ambient air dryer, desiccated, and weighed to determine the residue fraction weight.

EPA Method 5 procedures for desiccation and the weighing time schedule were followed for 1 through 3 above.

OMNI personnel serviced the sampling equipment at the start and end of the sampling period. At the start of each sampling period, the AWES unit was installed; leak checks were performed; the thermocouples, scale unit, and oxygen cell were calibrated; and the data logger was programmed with the proper sampling interval and start/stop times. The data logger was programmed to activate the AWES units for one minute on and two minutes off for seven consecutive days. At the end of the sampling period, final calibration, and leak-check procedures were performed, and the AWES, sampling line, filter housing, XAD-2 cartridge, sampling probe, and Tedlar bag were removed and sent to the lab.

## Data Processing and Quality Assurance

The data file stored on the data logger's 3.5" computer diskette was sent to OMNI's lab for computer analysis. The data file was reviewed immediately to check for proper equipment operation. The data logger data files, log books, and records maintained by field staff were reviewed to ensure sample integrity, which was excellent for this project.

The data logger file was used in conjunction with the AWES particulate sample to calculate particulate emission rates, daily temperature profiles of the flue temperatures, heater operation time, bum rates, etc. In addition, the computer program output for each file includes graphical representations of parameters and parameter interrelationships (see Figures A-5 and A-6).

### *Particulate Emissions Calculations*

The basic particulate emissions equation produces grams per dry kilogram of fuel burned (g/kg). The basic g/kg equation includes the following components:

1. Particulate mass: The total mass, in grams, of particulate caught on the filter, XAD-2 resin trap, and in the probe rinse. Particulate mass averages about 0.040 grams but varies considerably.

2. Sample time: The number of minutes the sampler operated during the sampling week when the stack oxygen was less than 20.6%.

3. Sampler's flow rate: This is controlled by the critical orifice in the sampler. Flow values vary slightly for the various samplers and average about one liter per minute.

4. Stoichiometric volume: The volume of smoke produced by cornbusting one dry kilogram of wood. This value is calculated using a carbon balance for each sample but averages about 4,900-5,000 liters at standard temperature and pressure for masonry heaters.

5. Dilution factor: The degree to which the sampled combustion gases have been diluted in the stack by the presence of excess air. The dilution factor is obtained by using the sample period's average oxygen value in the following equation. Dilution factors range from about 2 to 5.

$$\text{Dilution Factor} = ((20.9/(20.9 - \text{Average oxygen}))$$

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$$\text{Emissions (g/kg)} = \frac{\text{(Particulates)(Stoich. Vol.)(Dilution Factor)}}{\text{(Sample Time)(Sampler Flow)}}$$

## Uncertainty in Emissions Results

Particulate emissions values are presented along with associated uncertainty levels. Each measurement used in the emissions calculations has some degree of uncertainty associated with it, and these uncertainties are propagated to determine the amount of uncertainty attached to each calculated particulate emissioh rate. Criteria, procedures, and calculations used in evaluating uncertainty are summarized in a previous report (Bamett and Fields, 1991). Within the low range of emissions values encountered in this project, uncertainty is generally about 20% of the stated value. This is consistent with data gathered independently during a similar pellet stove project (Bamett and Roholt, 1990) by operating five AWES sampling systems simultaneously while burning a pellet stove.

The issue of sample-blank-induced error was previously investigated at length by Bamett (1990). The values determined in that study have been used here. They include a probable error at the 95% confidence level of ±4.88 mg and an average blank value of 3.9 mg.

Oxygen-cell-induced error was also investigated by Barnett (1990). The 95% confidence level of the probable error contribution to emission values of ±7% is used in this study.

For a detailed treatment of these and other sources of uncertainty and QA procedures utilized, see Appendix C of Bamett and Fields (1991).

## Efficiency Calculations

Woodstove efficiency was determined using the "Condar method" described by Bamett (1985). This method uses CO and PM emissions, stack dilution (based on excess air), stack temperature, wood type, and wood moisture to calculate combustion, heat transfer, and overall efficiencies, as well as net output in BTU/hr.

This method has been used in all previous field studies of woodstoves, masonry fireplaces, pellet stoves, and masonry heaters. The stack temperature probe was placed in the masonry heater's flue immediately above the flue damper near the home's exit location for the flue, so the measured efficiency included essentially all of the heat energy that the heater contributed to the home.

# AWES Modifications for Masonry Heater Emissions Testing

A modification in data reduction procedures has been made for masonry heaters. All previous AWES sampling of woodstoves used 100 °F stack temperature as the cutoff point to mark the start and end of a combustion cycle. Since masonry heaters maintain high stack temperatures long after combustion ceases, this procedure could not be used. Review of the stack temperature-stack oxygen regression results from computer files of the noncatalytic stoves in the 1988-1989 Northeast Cooperative Woodstove Study (Barnett, 1990) and the 1990 Klamath Falls Pacific Energy Project (Barnett, 1990a) indicated that 100" stack temperature at the end of a burn cycle was associated with 20.6% oxygen in the stack. Therefore, the masonry heater computer program was modified to separate burning from nonburning periods using the 20.6% oxygen criterion rather than 100" stack temperature. A sensitivity analysis using 0.1% increments from 20.5% to 21.5% indicated a low sensitivity to the cutoff setting. All results (g/kg and

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average daily **g/hr)** were within a 5% range. Grams per hour were significantly affected, of course, because **g/hr** = g/kg x bum rate **(kg/hr).** Grams per hour, however, is not considered to be a very suitable form for presenting emissions results for masonry heaters **(Barnett, 1991).**

The sampling period was modified to accommodate the low emissions of masonry heaters. A sampling frequency of one minute of sampling out of every fifteen minutes at a flow rate of one liter per minute has been found to provide optimal sample catches for analysis from clean-burning **cordwood** stoves during a one-week period. A shorter sampling frequency of one minute out of three minutes at the same flow rate **wàs** selected to obtain optimal sample catch from one week of masonry heater sampling. For example, this provided for an average particulate catch of about 50 mg from a **900-liter** sample for masonry heaters. If the sample had been 100 liters the catch would have been only 5.5 mg, and only 1.7 mg if the sample had been 30 liters.

The final modification was the addition of a flue gas Tedlar bag collection system (Figure 4). Carbon dioxide, carbon monoxide, and oxygen data are generated from this collection system, allowing for calculation of carbon monoxide emission factors. Tedlar bag gases were measured using an NDIR analyzer. For the Royal Crown, Biofire and Tulikivi tests, the Tedlar bag collection system was left on for the entire test. Every three minutes it operated for one minute. This causes the collected gases to be more dilute than those emitted during just the combustion phase. Thus, in Tables 1, 2 and 3 of Appendix A the $O_2$ values are artificially high and the CO and $CO_2$ values low. **This** method of gas collection does not affect the calculated CO emissions values at all, however. The Tedlar collection system was turned on and off by the homeowner of the Grundofen at the start and end of each bum. For the Contraflow the system was actuated by thermocouple in such a way that the combustion phase was collected plus some of **the** non-burning interval to assure that all of the combustion phase was accounted for.

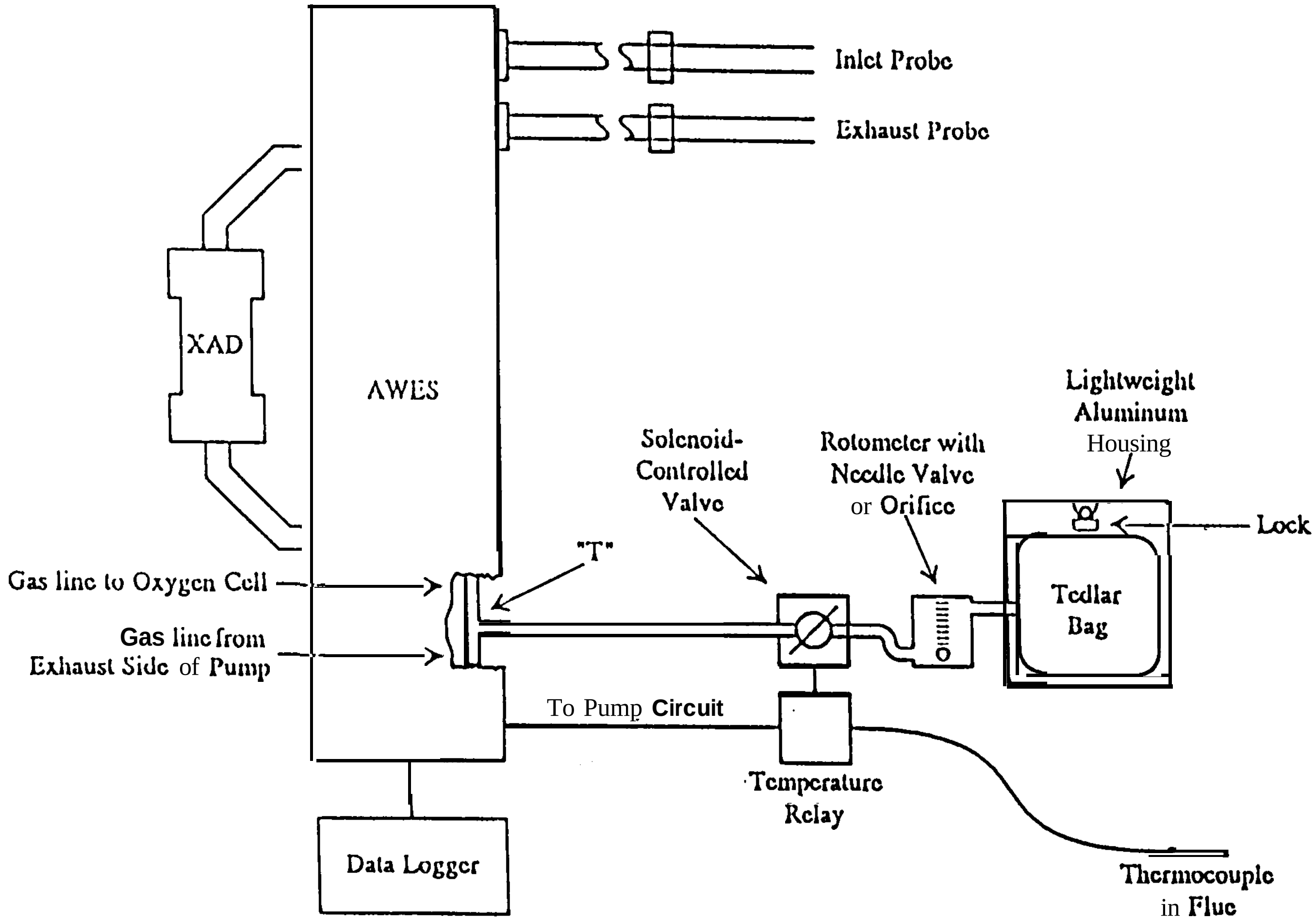


Figure 4. Schematic of AWES system modified for masonry heater application.

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# Emissions Results

PM emissions for the five masonry heaters averaged 3.2 g/kg and 1.8 average daily g/hr (Table 1). Normalizing the grams per hour emissions to a 1 kg/hr burn rate as described in Barnett (1991) yields 3.2 average daily g/hr. The average daily burn rate was 0.68 dry kg/hr. The 95% confidence limit for each test is generally about +/- 20% of the emissions value. The 95% confidence limit for the five heater average is +/- 2.8 g/kg. Tables I through 7. in Appendix A contain the results from each heater's emissions test.

Table 1. Summary of emissions and efficiency results for the five masonry heaters.

| Heater Model | PM | | CO | | Burn Rate | Net Efficiency (NET EFFICIENCY) |
|---|---|---|---|---|---|---|
| | g/kg | Ave. Daily g/hr | g/kg | Ave. Daily g/hr | Ave. Daily kg/hr | Ave. % |
| Biofire | 1.9 | 1.8 | 72 | 68 | 0.95 | 54 56 |
| Grundofen | 1.4 | 1.5 | 83 | 92 | 1.1 | 60 60 |
| Royal Crown | 1.4 | 0.3 | 69 | 15 | 0.21 | 65 65 |
| Contraflow | 5.6 | 4.2 | 40 | 30 | 0.75 | 54 58 |
| Tulikivi | 5.7 | 2.3 | 107 | 44 | 0.41 | 59 59 |
| Averages | 3.20 | 2.02 | 74.2 | 49.8 | 0.68 | 58.4 58.4 |

STAN: 62.5

A bimodal distribution of emissions values may be present. The overfire air heaters tend to cluster in the 1-2 g/kg range with the underfire air heaters in the 5-6 g/kg range. This hypothesis is supported by experience with woodstoves where underfire air stoves have distinctly higher emissions than overfire air units. The relatively high 95% confidence interval may be reflecting this bimodality. It should be noted that the two manufacturers of underfire air heaters are currently redesigning units to be overfire air.

Average CO emissions were 74 g/kg, SO average daily g/hr, and 74 normalized average daily g/hr.

Comparatively, the average PM emissions (Figure 5) were somewhat higher than emissions from certified pellet stoves (1.7 g/kg) as tested in homes (Barnett and Roholt, 1990) and considerably lower than EPA' 1990-certified Phase II noncatalytic woodstoves (AP-42 value of 7.0 g/kg). The average masonry heater emissions are 81% lower than the EPA's AP-42 emissions value of 14.9 g/kg for conventional woodstoves (Table 2).

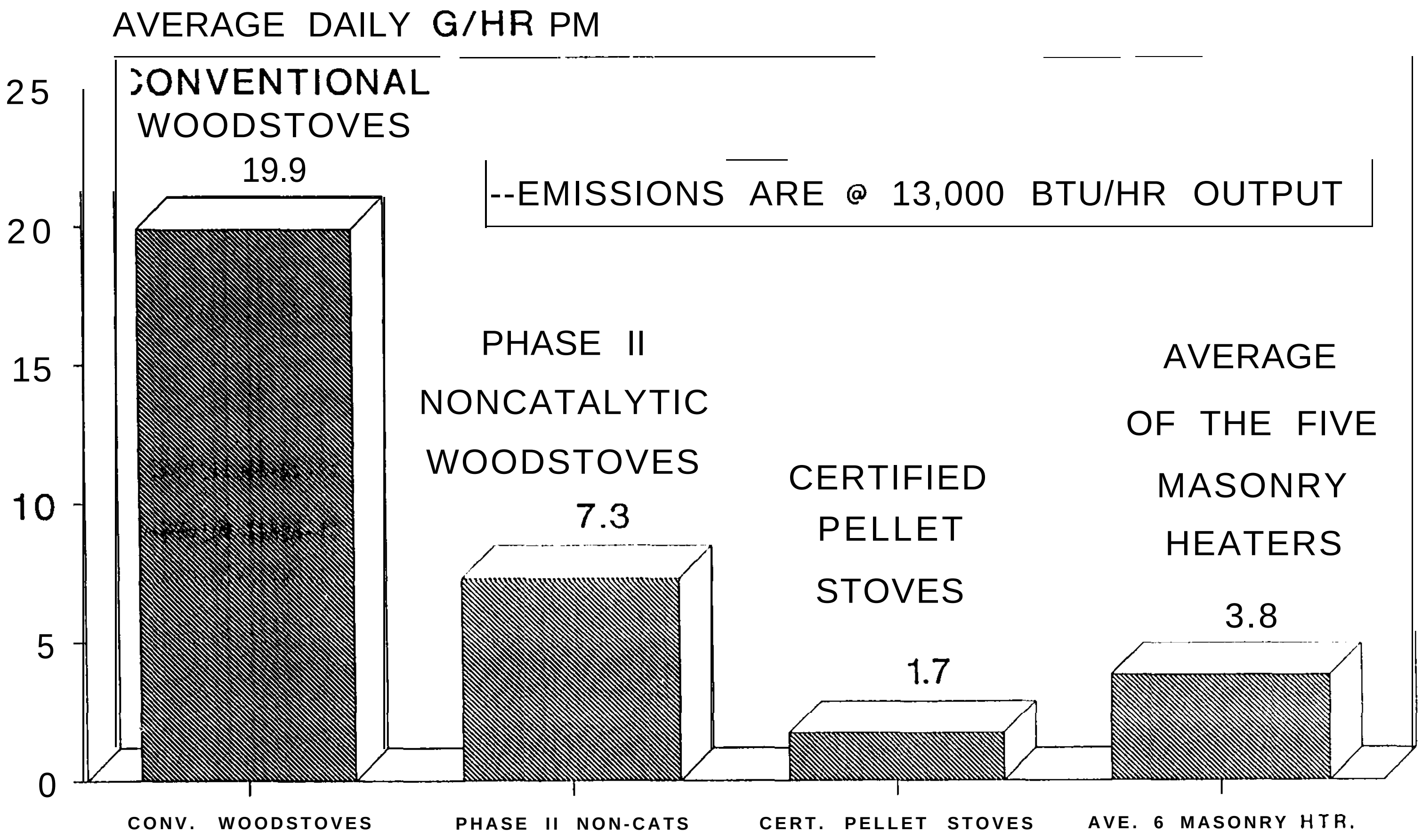
CO emissions are comparatively not as low as PM emissions. They are comparable to Phase II certified noncatalytic woodstoves but significantly lower than conventional stoves (McCrillis and Jaasma, 1991 and Reference 15).

# Efficiency



59.6
56.5

# AVERAGE DAILY G/HR PM FOR CONVENTIONAL NONCAT WOODSTOVES, CERT. PELLET STOVES, AVE. OF FIVE MASONRY HEATERS.




**See Tables 2 and 3 for data and data sources.**

Figure 5

The average net delivered efficiency of the five masonry heaters was 58%. This efficiency is about midway between the 50-55% average for conventional woodstoves and the 65-70% average for Phase II woodstoves as measured in homes (References 1,10,14,15). The average heat output was 7425 BTU/hr.

The design of the heat transfer systems are generally not quite as effective as Phase II noncatalytic stoves (Figure 6). Improvement could he made by reducing the excess air so that stack oxygen averages about 15-16% and aiming for an average stack temperature of 300 to 350°.

# Emissions Reduction Credits;

The EPA detailed calculation procedures for emission reduction credits in June, 1991 (Reference 16). These procedures have been applied to the masonry heater data and the results are compared to those of conventional and Phase II stoves and certified pellet stoves in Table 2. Sources for the data are shown in Table 3. Perhaps the most important comparison for he masonry heaters Is with certified pellet stoves. All of the pellet stove data was collected by OMNI (Barnett and Roholt, 1990) and averages from that report are used here. Specifically, an average of the pellet Whitfield and Crossfire used. Each brand is given equal weight in the average even though four of the former and two of the latter brand were studied,

Table 2 also illustrates emissions rates calculated for a net output of 13,000 BTU/hr, the value EPA considered average for home woodstove burning when it developed its woodstove certification program. This calculation accounts for both the emission factor and the net efficiency as measured in homes.

The results in Table 2 indicate that the emission reduction credit for the five-heater average is 81%. This is closer to pellet stoves than Phase II noncatalytic stoves. However, the three overfire air heaters as a group have an average emission reduction credit of 91%, equivalent to certified pellet stoves. Since these three heaters equal certified pellet stove emissions reduction credits (Table 2), they could qualify as low-emitting devices under BACM.

Table 2. PM Emission Reduction Credits and Emissions Rates.[a]

| RWC Device | Emission Factor (g/kg) | Net Efficiency (%) | Emission Rate (g/hr) (@ 13,000 BTU/hr) | Emission Reduction Credit (%) |
|---|---|---|---|---|
| Conventional | 14.9 | 52 | 19.9 | 0.0 |
| Noncatalytic | 7.0 | 67 | 7.3 | 63.5 |
| Certified Pellet | 1.7 | 69 | 1.7 | 91.4 |
| All Masonry Hearers (5) | 3.2 | 58 | 3.8 | 80.7 |
| Overfire Masonry Heaters (3) | 1.6 | 60 | 1.9 | 90.7 |

a. Emissions rates are normalized to 13.000 BTU/hr net heat output.

Table '3. Data Sources for PM Emission Reduction Credits and Emission Rates.

| KWC Device | Emission Factor (g/kg) | Net Efficiency (%) | Emission Rate (g/hr) (@ 13,000 BTU/hr) | Emission Reduction Credit (%) |
|---|---|---|---|---|
| Conventional | AP-42 | RACM 6/91 | Calculated | Calculated |
| Noncatalytic | AP-42 | OMNI Field Ave. | Calculated | Calculated |
| Certified Pellet | Ref. 8 | Ref. 8 | Calculated | Calculated |
| All Masonry Heaters (5) | This report | This report | Calculated | Calculated |
| Overfire Masonry Heaters (3) | This report | This report | Calculated | Calculated |

a. The OMNI field efficiency average is Phase II stoves in Klamath Falls, Oregon, studied in 1990 and 1992 (Reference 11).



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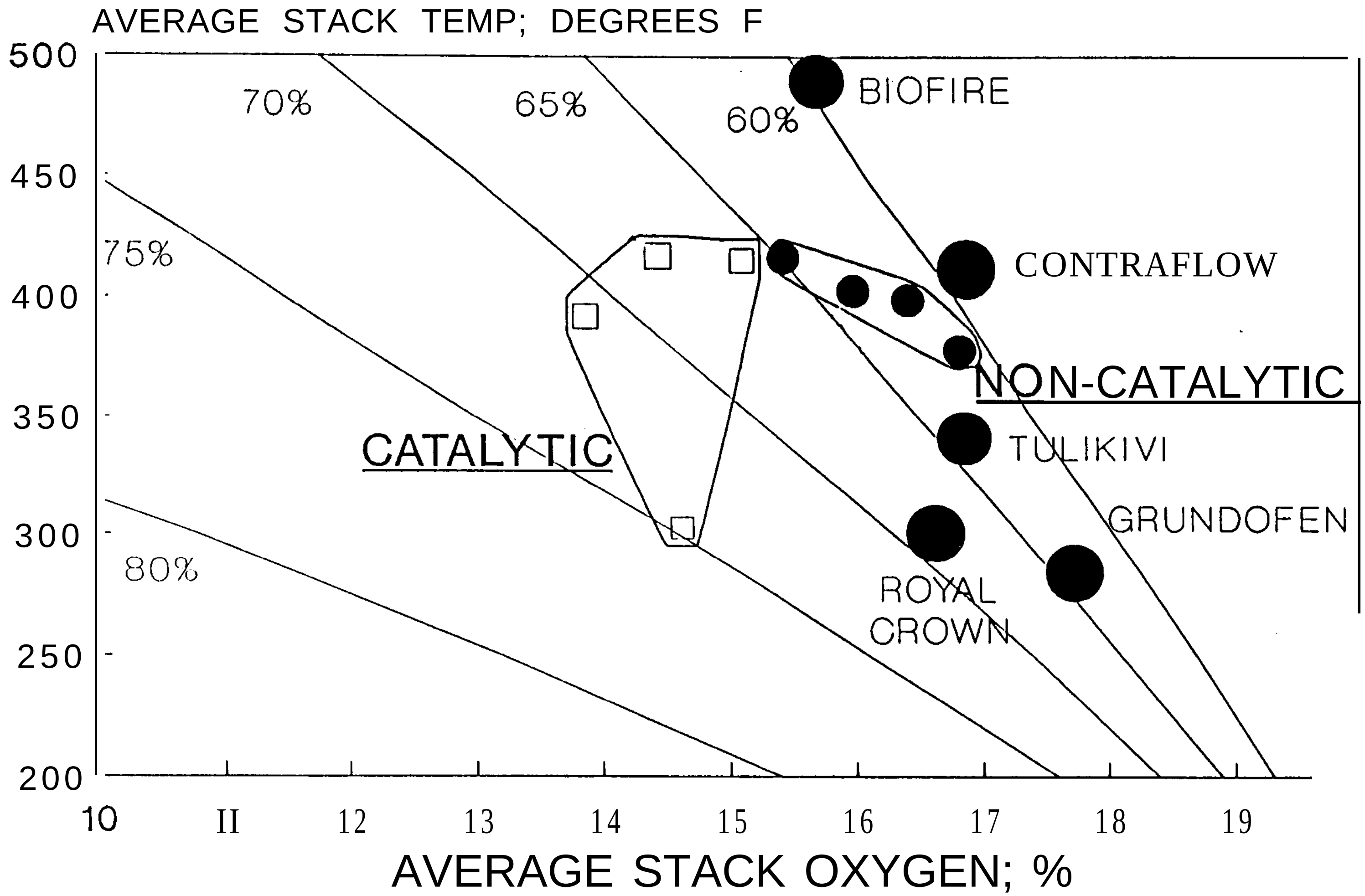
# HEAT TRANSFER EFFICIENCY DIAGRAM: FIELD STUDIES:CAT, NON-CAT STOVES, MASONRY HTR

(Stack temp for woodstoves measured 1' above stove. Stack temp is lower at top of pipe.)




Woodstove studies: 1989 NCWS, 1990 WHA.

Figure 6

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