# ETHOS June 2003 Stove
# Testing & Design Seminar
# Summary

**Attendees:** Dr. Larry Winiarski, Stuart Conway, Dr. Tami Bond (UI), Alan Tkaczyk (UM), Dr. Alan Berrick, Dr. George Rudy, Ken Goyer; Ron Larson, Dean Still, Morgan DeFoort (CSU), Joseph Slee Hynek (ISU), Rosalie Roberts (HSU) Dr. Dale Andreatta, Peter Scott; Miguel Hatfield, Bruce Stahlburg, Jess Gingrich (CSU), Jim Thomas, Robert Winiarski and then a bit later Rob Bailis (UCB), Adriana Valencia (UCB), Dr. Paul Anderson (ISU)

For five days the members of the group heard lectures, made refractory bricks, learned from eachother, tested stoves and tried to improve them. The stoves that were tested three times were:

1.) The Three Stone Fire
2.) The Jiko
3.) The Rocket
4.) The Vesto
5.) The Wood Gas Stove
6.) Lanny Henson's Stove
7.) Ron Larson's Stoves

The tests were done by rotating participants. Stoves were tested using a Water Boiling Test adapted from VITA and Sam Baldwin (Biomass Stoves, VITA, 1987, pg. 83-84) A carbon monoxide emission test using two HOBO sensors in an enclosed room was also performed on each stove.

## Description of shortened Water Boiling Test:

1.) Indoor test. Used same pot in all tests. Measure stove, describe stove, photograph. (A 12" in diameter stainless steel pot was used).
2.) Used 700 grams oven dried wood, use same species, uniform in size. (1 kg in field)
3.) Fill pot with 5 litres water. Never use lids. (2/3rds full in field)
4.) Determine water temperature. Start fire in reproducible manner.
5.) High Power Phase: start with stove at room temperature. Record water temperature every five minutes as water is brought as rapidly as possible to a boil without being wasteful of heat.
6.) When the pot comes to a boil, record wood used, time.
7.) Low Power Phase: Reduce temperature to between 95 to 97 degrees C. Use the remainder of wood until all gone. Record time.

8.) When flame is extinguished, remove pot from stove and measure remaining water. Weigh amount of charcoal left.
9.) A minimum of three tests is necessary.

Percent Heat Utilized equals:

$$\frac{4.186Wi\,(Tf - Ti) + 2260\,(Wi - Wf)}{MwCw - McCc}$$

Multiplied by (100%).

Mw is the mass of dry wood burned, Cw is the calorific value of the dry wood in kJ/kg (18 kJ). Mc is the net weight of charcoal remaining and Cc is its calorific value in kJ/kg (23 kJ). Where Wi is the mass of the water in kilograms at the start, (Tf – Ti) is the temperature change of the water in degrees Celsius during that period, and (Wi – Wf) is the mass of water evaporated. The factor 4.186 kJ/kg°C is the specific heat of water, and the factor 2260 kJ/kg is the latent heat of vaporization of water.

**Protocol for Two HOBO Test of Carbon Monoxide Levels in 8'by 8' by 8' Experimental House with 3 Air Exchanges Per Hour**

1.) Fill pot ½ full with tap water.
2.) Make sure that the chimney attached to the pot lid exits house.
3.) HOBO's can't withstand high humidity.
4.) Try to light stove in house with glass shut. If not possible, shut glass as quickly as possible after lighting stove. The operator observed the stove through a sliding glass window and fed sticks into the stove using sleeves that did not permit air into the room.
5.) Once stove is lit, start 30 minute timer.
6.) Keep accurate count of wood used. We use kiln dried Douglas fir. Use 400 grams of wood in stoves with this capacity.
7.) After 30 minutes, stop feeding the fire and wait until there are no visible flames.
8.) Put on gloves.
9.) Remove stove from house through sliding observation window. Take out to back porch.
10.) Plug in exhaust fan and let run for 15 minutes.
11.) Set up for next test.

**RESULTS**

**Average of Three Water Boiling Tests**

| | |
|---|---|
| The Three Stone Fire | 29% |
| The Jiko | 30% |
| The Rocket | 35% |
| The Vesto | 39% |
| The Wood Gas | 48% |
| Lanny Henson's | 38% |
| Ron Larson's | 45% |

There were several helpful observations from the group concerning this test:
1.) The large pot was a efficient heat exchanger so the effect of pot skirts was minimized.
2.) The production of charcoal helps to raise scores.
3.) Weighing the water between the Boiling and Simmering phases is important.
4.) Perhaps production of excessive amounts of steam should be penalized in the simmering phase of the test.

Dr. Dale Andreatta add's:

If you measure the time to boil and the wood remaining at boil, one can calculate the power into the pot and efficiency separately for the high power and simmering phases. One can also estimate the firepower for each phase by dividing the power into the pot by the efficiency. I did this accurately for 3 tests (for which I was the tester, and thus made sure the wood left at boil was measured accurately) and the numbers are given here.

Rocket made of light bricks with short skirt, "official" test #2, 6/3 morning-Tester Dale Andreatta and Tami Bond
Boiling phase power to pot 1111 Watts (this includes the start up phase)
Boiling phase efficiency, 0.23
Boiling phase average firepower 4830 W
Simmer phase power to pot 1231 W
Simmer phase efficiency 0.44
Simmer phase average firepower 4007 W
Overall efficiency 0.307

Rocket made of light bricks with tall skirt, average gap 0.32 inches, tested 6/5 afternoon-Tester Ken Goyer and Dale Andreatta
Boiling phase power to pot 1379 W
Boiling phase efficiency 0.30
Boiling phase firepower 4597 W
Simmer phase power to pot 1241 W
Simmer phase efficiency 0.41
Simmer phase firepower 3027
Overall efficiency 0.37

Lanny Hanson stove, tested 6/6 morning-Tester Dale Andreatta
Boiling phase power to pot 817 W
Boiling phase efficiency 0.23
Boiling phase firepower 3552 W
Simmer phase power to pot 753 W
Simmer phase efficiency 0.492
Simmer phase firepower 1530 W
Overall efficiency 0.365

The graphs showing the performance of the stoves as they were tested, using a PICO data logger, are included with this report. Dr. Alan Berrick found it instructive to measure the Time Under Curve from the graphs of the Water Boiling Tests which shows the work done by the stove...Here are those figures in seconds: (Keep in mind that the Wood Gas and Ron Larson's stoves used different amounts of fuel as they were not able to contain 700 grams of wood at a charge.)

6-2-03 Run 1
Jiko 3015
Vesto 3137
Rocket 4881

6-2-03 Run 2
Three Stone 3543
Wood Gas 1007
Three Stone 3794

6-2-03 Run 3
Three Stone 2945
Wood Gas 1162
Vesto 3787

6-3-03 Run 1

Wood Gas 818
Anderson 3549

6-3-03 Run 2
Jiko 4100
Rocket 3677
Ron Larson 4058

6-3-03 Run 3
Jiko 2850
Vesto 2198
Ron Larson 2287

6-5-03 Run 1
Jiko with Skirt 3538
6-5-03 Run 2
Lanny's stove 6084

6-6-03
Lanny's stove 6540

A new testing protocol including new equations is being tested and hopefully the evolution of a more accurate testing protocol will be one of the products of the next Stove Seminar. Rob Bailis and Adriana Valencia helped to direct this effort by comparing food preparation tests with Water Boiling Tests.

## Carbon Monoxide Testing

**Procedure**

CO measurements were made in a 8' by 8' by '8 room (approximate measurements) with a 6" in diameter hole letting in fresh air and a 6" in diameter chimney removing air. The residence time of air was 19 minutes, indicating approximately three air exchanges per hour in the "house'. Stoves were set on a table at waist height. The stoves burned 400 grams of kiln dried Douglas fir. CO measures were made with two HOBO CO emission analyzers. Analyzers were placed at table height and two feet above table height two feet to the left of the stove.

Although many informal runs were made of the various stoves inaccuracies in the procedures do not allow comparison of results. On the second day of the seminar Dr. Tami Bond and Dr. Dale Andreatta took charge of the testing . The results of their testing of three stoves are as follows:

**Results**

Vesto (top burning)  34% efficient….Lower HOBO 4ppm…higher HOBO 510ppm…CO grams per kg 64……CO grams per MJ10

Vesto (bottom burning) 27% efficient….Lower HOBO 16ppm….higher HOBO 550….CO grams per kg 77….grams per MJ 16

Jiko 36% efficient….Lower HOBO 80ppm…higher HOBO 320…grams per kg 67…CO grams per MJ 10

Rocket 30% efficient…Lower HOBO 13ppm…higher HOBO 140… CO grams per kg 27…grams per MJ 5.

## Conclusions

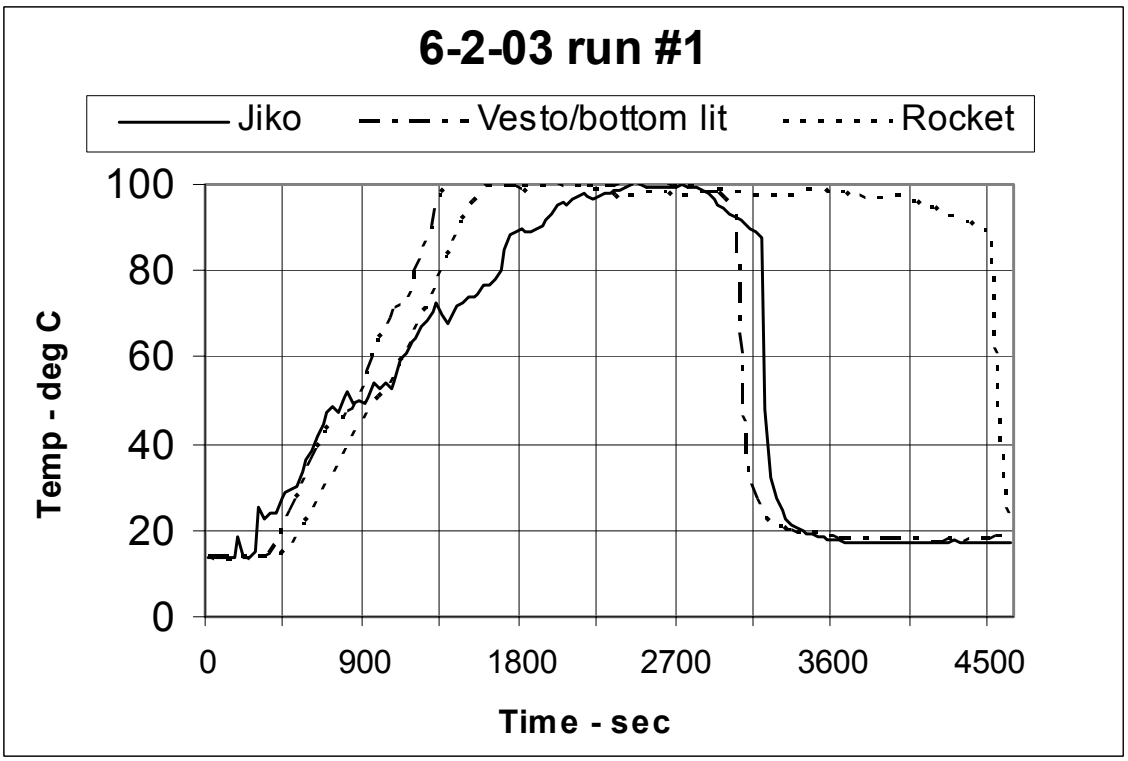
CO levels in the enclosure were highly stratified. This was observed from comparing the higher and lower readings from the two HOBO analyzers. When placed side by side the HOBO's displayed almost identical readings. The group concluded that differences in stove geometry such as stack height could cause large variations in the CO readings which might not be representative of the stove performance. Even using two analyzers did not seem to remove the possibility of error.

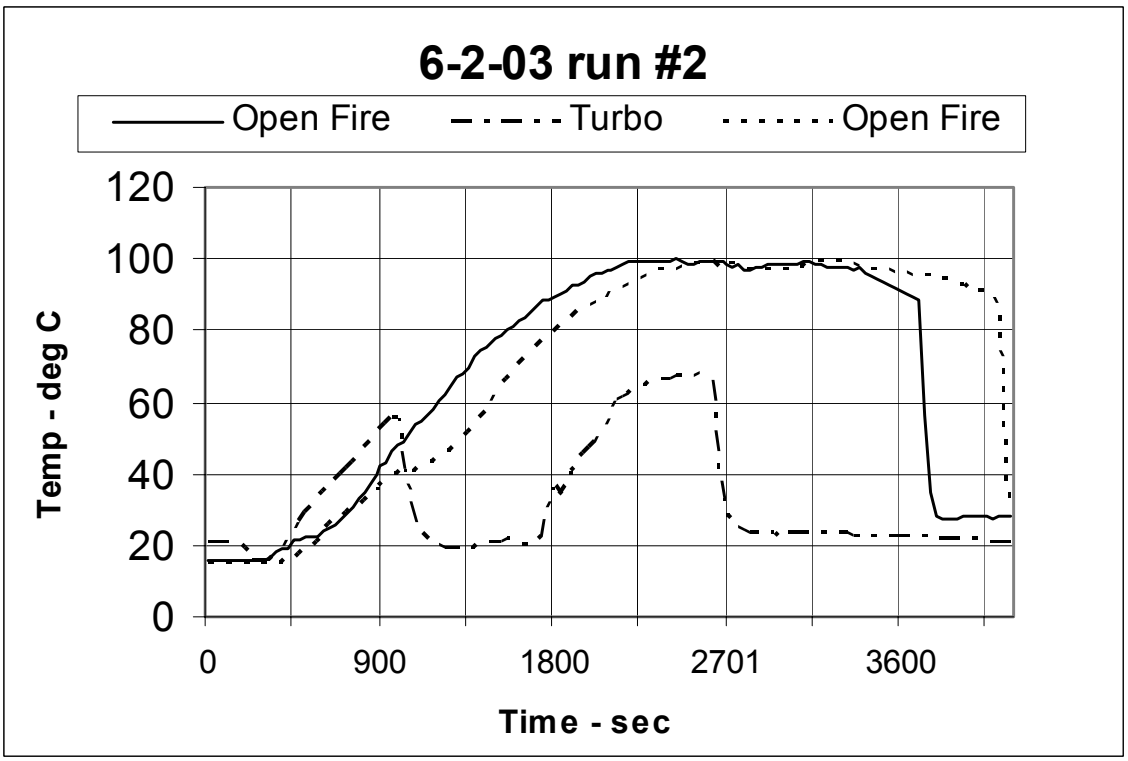
The group decided that a hood/fan arrangement that pulls the air in the room through a pipe might be more accurate. Dr. Dale Andreatta very kindly offered to build this testing apparatus which will soon be available to ETHOS members at the Aprovecho lab. The experimental house will continue to be used to study the effect of hoods and chimneys on indoor CO concentrations.

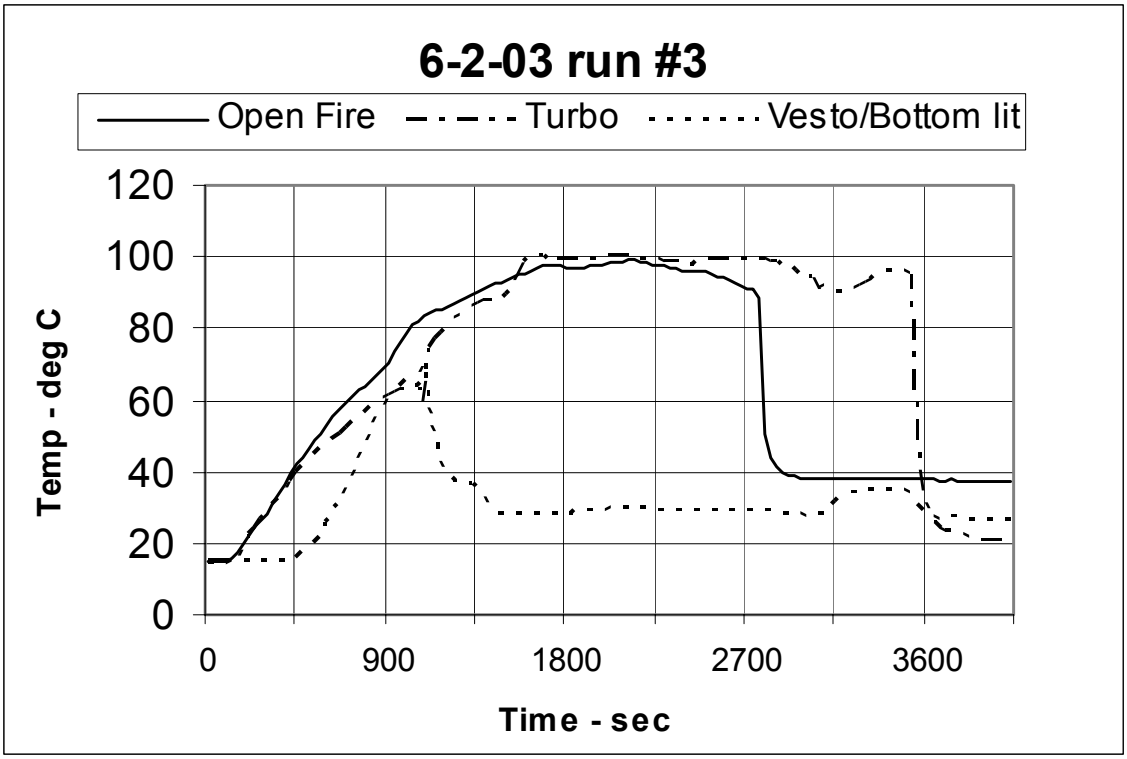
**ENDNOTES**

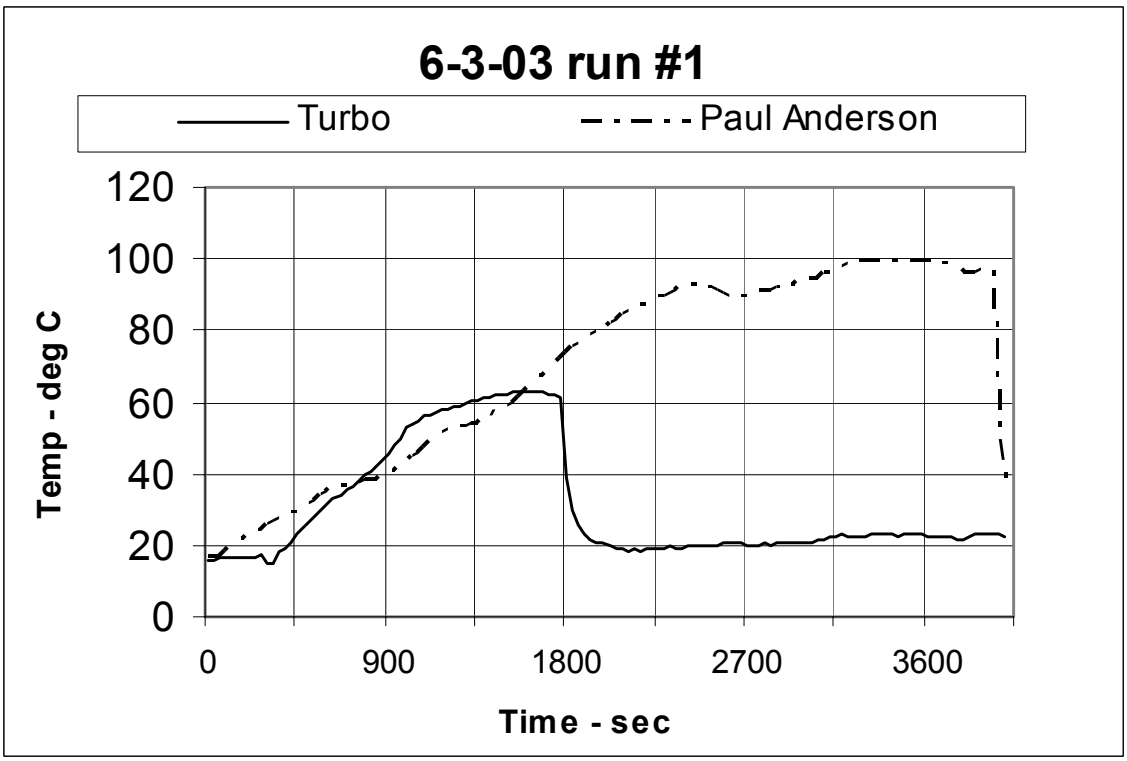
Side by side testing and elbow rubbing by stove designers and builders creates a shared body of experience that fosters a consensus of knowledge. ETHOS both hopes to provide a forum for this valuable activity as well as to harness the tremendous energy and problem solving ability of volunteers from all parts of the stove community. Listening to the enthusiasm of the participants as problems are addressed is contagious. Thanks to everyone for such an exciting couple of weeks! I learned a lot…

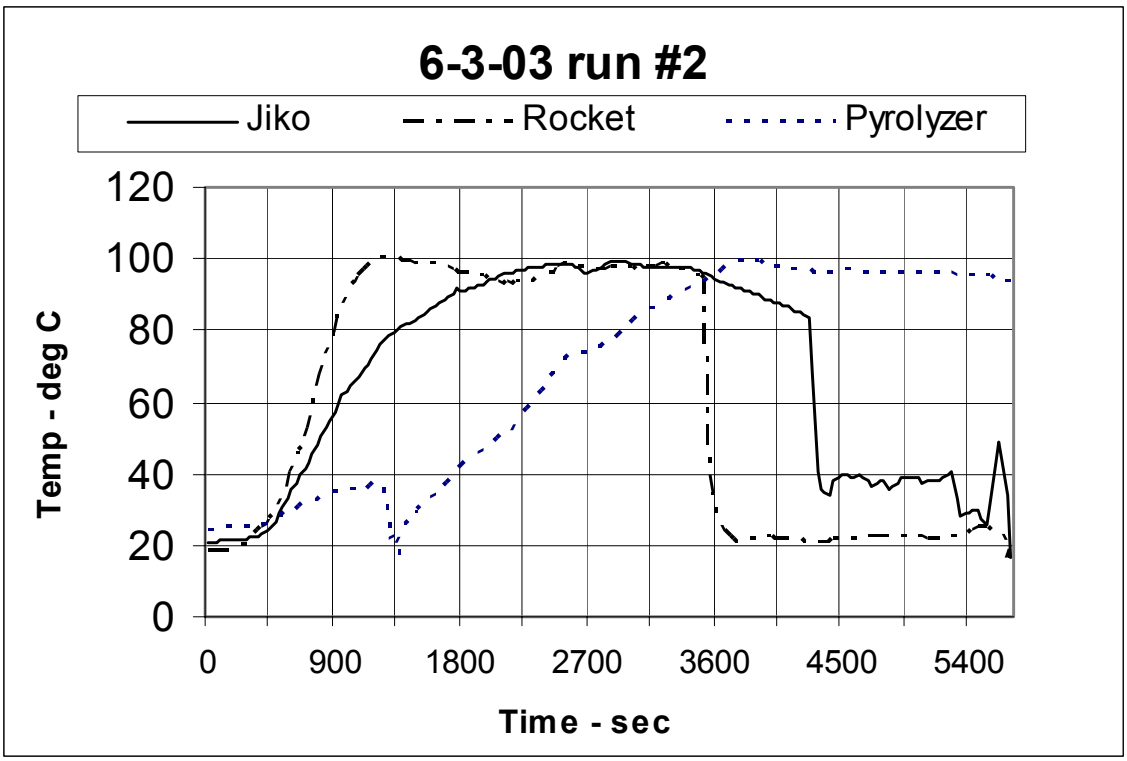
Dean Still

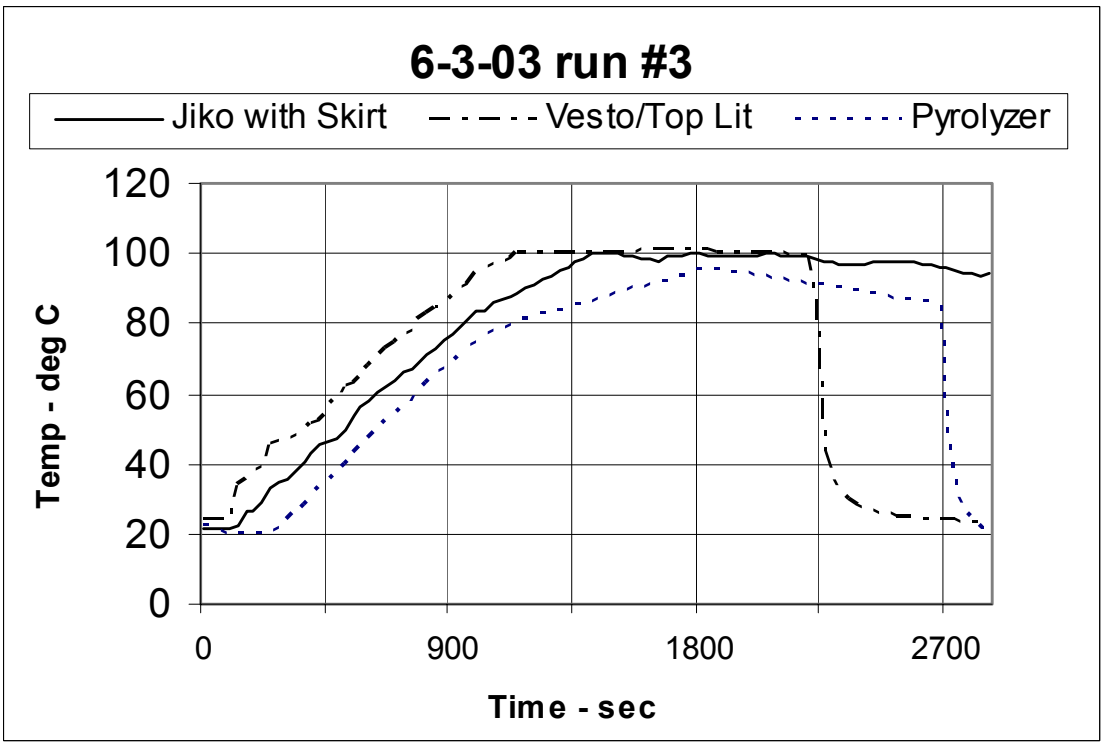

6-2-03 run #1
Jiko
Vesto/bottom lit
Rocket
100
80
60
40
20
0
Temp - deg C
0
900
1800
2700
3600
4500
Time - sec

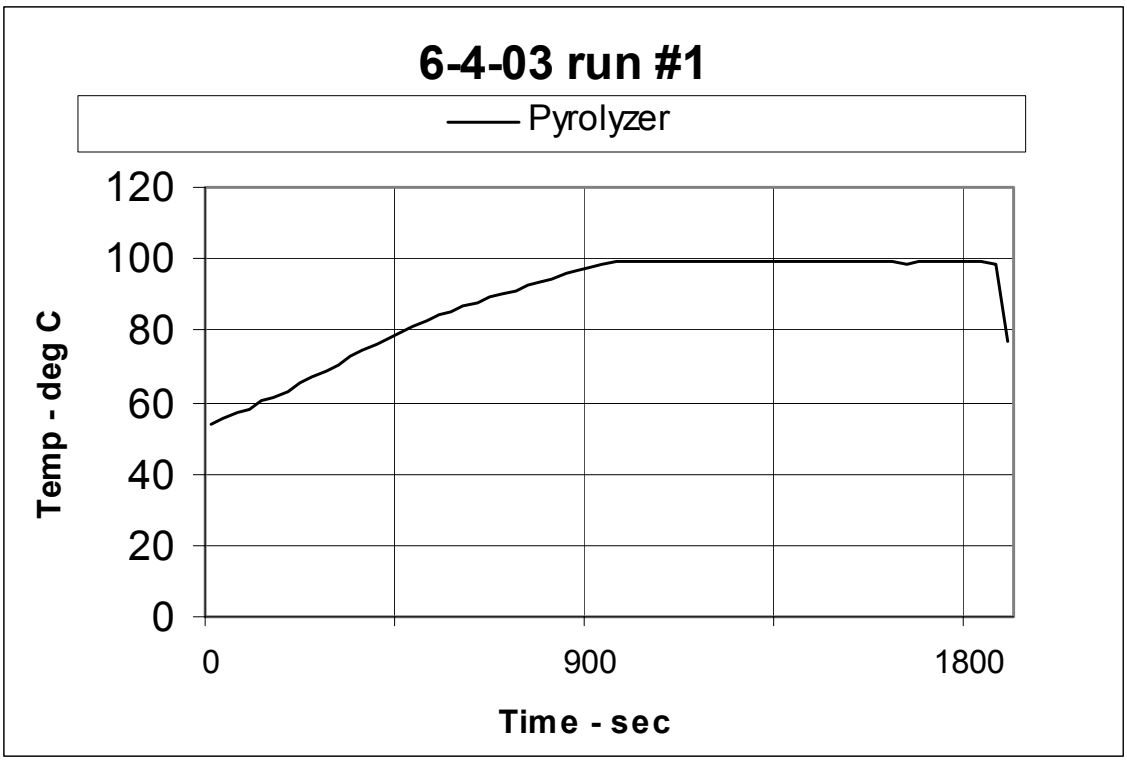

6-2-03 run #2
Open Fire
Turbo
Open Fire
120
100
80
60
40
20
0
Temp - deg C
0
900
1800
2701
3600
Time - sec


6-2-03 run #3
Open Fire
Turbo
Vesto/Bottom lit
120
100
80
60
40
20
0
Temp - deg C
0
900
1800
2700
3600
Time - sec

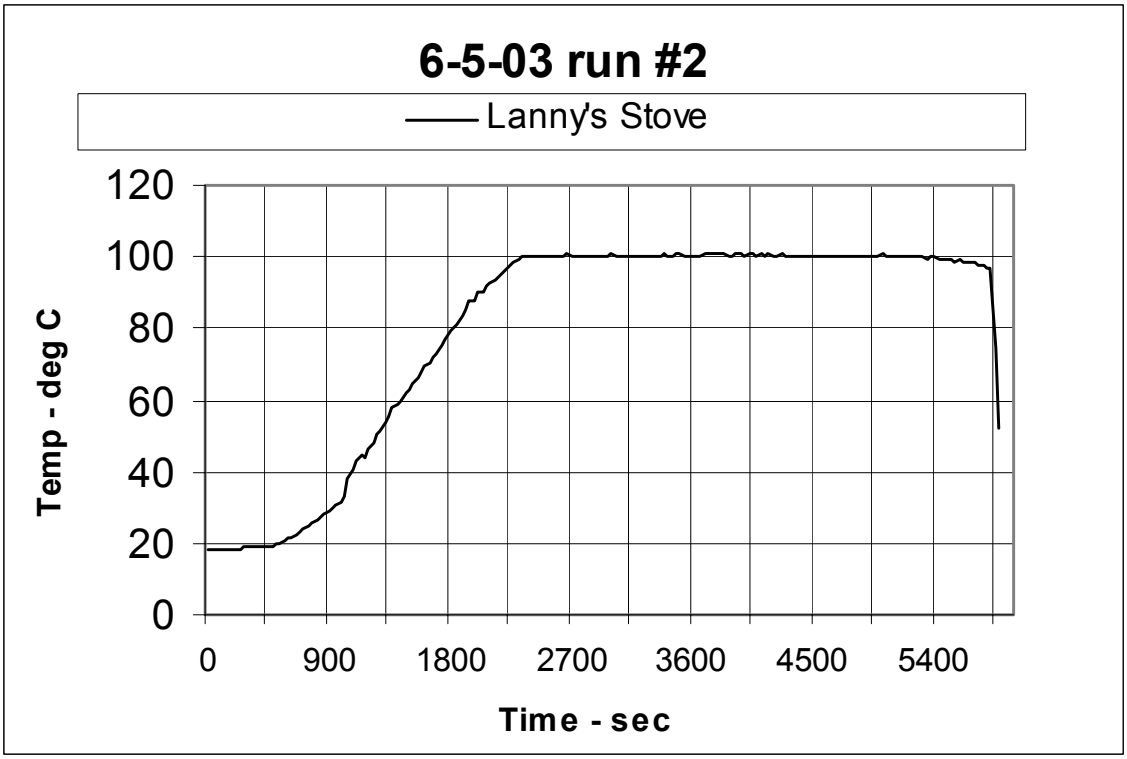

6-3-03 run #1
Turbo
Paul Anderson
120
100
80
60
40
20
0
Temp - deg C
0
900
1800
2700
3600
Time - sec

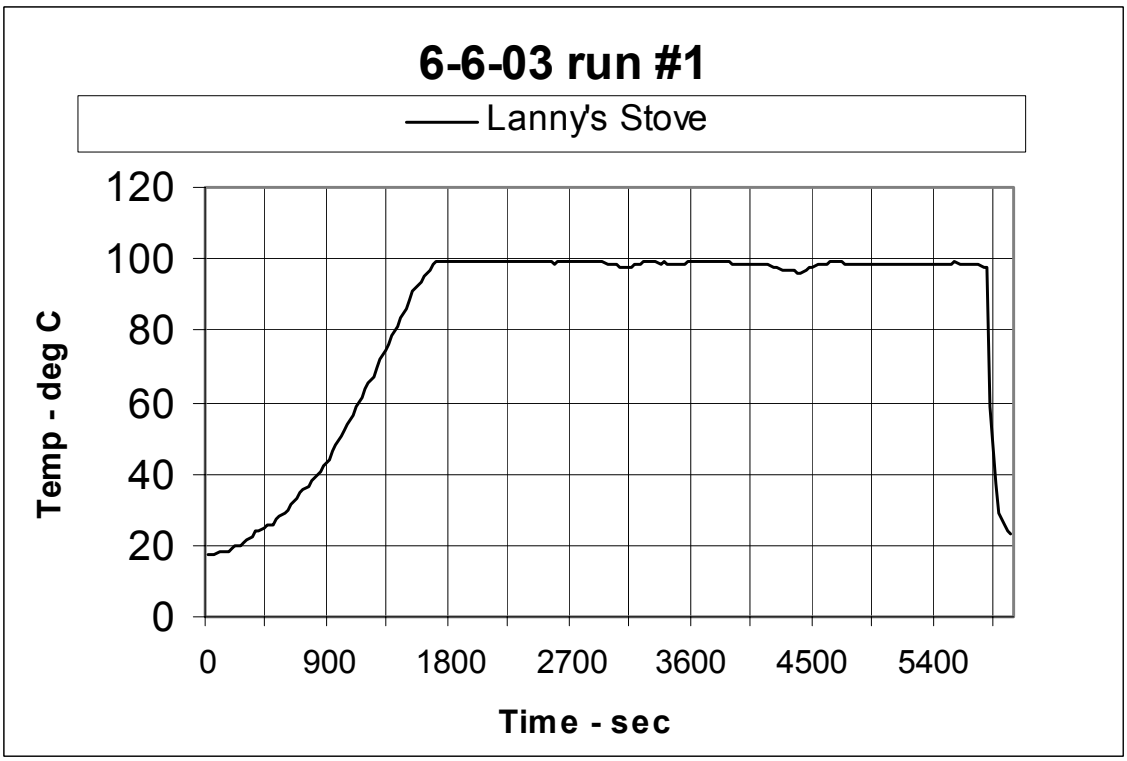

6-3-03 run #2
Jiko
Rocket
Pyrolyzer
120
100
80
60
40
20
0
Temp - deg C
0
900
1800
2700
3600
4500
5400
Time - sec


6-3-03 run #3
Jiko with Skirt
Vesto/Top Lit
Pyrolyzer
120
100
80
60
40
20
0
Temp - deg C
0
900
1800
2700
Time - sec


6-4-03 run #1
Pyrolyzer
120
100
80
60
40
20
0
Temp - deg C
0
900
1800
Time - sec


6-5-03 run #1
Jiko with Skirt
120
100
80
60
40
20
0
Temp - deg C
0
900
1800
2700
3600
Time - sec


6-5-03 run #2
Lanny's Stove
120
100
80
60
40
20
0
Temp - deg C
0
900
1800
2700
3600
4500
5400
Time - sec


6-6-03 run #1
Lanny's Stove
120
100
80
60
40
20
0
Temp - deg C
0
900
1800
2700
3600
4500
5400
Time - sec