ROCKET STOVES – CONTROLLING DRAFT

(Variations in chimney height and air flow openings in a modified "rocket stove".)

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INTRODUCTION

The "rocket elbow", developed by Larry Winiarski and Aprovecho Research Center, has resulted in increased efficiency and reduced air pollution in cookstoves used in Third World countries. The search for even cleaner combustion in "rocket stoves" requires that several conditions be achieved at the same time. Temperatures must be high enough and maintained for long enough to allow for full combustion. It is thought that a temperature of 1200 F or higher is necessary to burn such compounds as methane. There must be the proper amounts of fuel and air for complete combustion to occur. The fuel and air must mix thoroughly for a good burn to take place. Air velocity must be high enough to produce high temperatures but not so high that the flame blows itself out. All the above conditions must be maintained for long enough for combustion to be completed

Previous experiments have shown that very high temperatures can be obtained by directing more air up through the "charcoal" at the bottom of a rocket elbow and minimizing the air entering above the fuel feed level. The highest temperatures (over 1800 F) were obtained using a relatively short 12" rocket chimney and were accompanied by copious black smoke.

A single experiment at Aprovecho in June of this year suggested that when a good insulating material is available, very little heat is lost in the passage of gases through even a long tube. In this case there was a drop of only 100 F when gases passed through a four-foot long series of fiber ceramic "riser sleeves".

One problem with using tall "rocket elbows" is that the greater draft created by the tall chimney tends to draw in excess air and cools the exhaust gases. High velocity airflow may be even faster than the propagation speed of the flame and the fire can "blow" itself out.

The purpose of this experiment was to see if the draft in a modified rocket stove could be controlled so that high temperatures could be produced and then be carried through the length of a long "rocket" chimney. It was hoped that this process would result in cleaner and more complete combustion while maintaining the high temperatures essential to efficient cookstoves

A modified "rocket stove" was adjusted so that the airflow through the fuel feed area was held at a minimum. Airflow through the bottom or charcoal layer of the stove was adjusted to openings ranging from 100% to 10% of the cross sectional area of the combustion chamber. Exit gas temperatures were measured for 12",24" and 36"chimney heights. The experiment was then repeated using baffles at the top of the stove chimneys to control airflow while the bottom was left completely open. High T, Low T ,and estimated mode T were recorded for 3 runs. Notes were made of the visual appearance of smoke and flame as well as other unusual observations.

RESULTS

(average of three runs)

Experiment #2 Draft and chimneys (controlled from below)

Height	%open	Ave. high T	Ave. low T	Ave. est. mode T	visible smoke	flame	comments
12	10%	1595	1261	1433	yes	lots	
12	20%	1637	1313	1483	yes	lots	
12	40%	1579	1164	1450	yes	lots	
12	60%	1620	1329	1508	yes	lots	
12	80%	1780	1474	1667	yes	lots	
12	100%	1845	1488	1692	moderate	lots	

24	10%	930	693	825	little	at times	decreasing
24	20%	1018	843	933	at times	at times	clean
24	40%	926	693	828	little	no	
24	60%	797	548	683	little	at times	burned clean
24	80%	1068	696	875	at times	at times	soot burning off
24	100%	1066	733	900	no	no	soot burning off
36	10%	734	547	700	no	no	
36	20%	814	458	638	no	no	
36	40%	x	x	x	no	no	fire went out
36	60%	835	333	400	no	no	decreasing
36	80%	857	455	675	no	no	very active decreasing
36	100%	559	372	450	no	no	soot burning off

Experiment #3 Draft and chimneys — Draft and Chimneys — (controlled from above)

Chimney Height	%open	Ave. high T	Ave. low T	Ave. est. mode T	visible smoke	flame	comments
12	10%	1494	1293	1400	lots	cherry	secondary flame around pot
12	20%	1641	1457	1517	yes	yes	
12	40%	1786	1569	1675	lots	lots	
12	60%	1810	1520	1692	lots	lots	
12	80%	1791	1545	1692	lots	lots	
24	10%	1446	1253	1350	lots	some	burns back
24	20%	1599	1312	1475	yes	some	blow torch effect when pot removed
24	40%	1794	1582	1692	yes	yes	
24	60%	1756	1442	1625	some	some	
24	80%	1451	1037	1250	some	some	pretty clean
36	10%	1353	1213	1283	lots	some	burns back
36	20%	1474	1286	1392	lots	yes	
36	40%	1493	1219	1383	little	some	pretty clean
36	60%	1268	1011	1158	little	some	burning clean,soot burning off
36	80%	1185	880	992	no	no	clean burning, soot burns off

EXPERIMENTAL EQUIPMENT AND PROCEDURE

STOVE

A rocket stove was constructed of sheet metal using a 5"diameter by 12"tall ceramic fiber "riser sleeve" for an insulated chimney. The feed magazine was 3" high by 4 ½" wide with an adjustable flap at the top to control the free air entering above the level of the feed shelf. This flap was fixed at 1/8" above the level of the feed sticks. Two inches below the feed shelf level a stainless steel screen (1/8" mesh) was placed as a grate for the "charcoal" which fell from the burning sticks above.

The entire bottom of the stove (below the feed shelf) was encased in an army surplus "ammo can" Air flow upward through this screen was controlled by a sliding damper in the side of the ammo can. Adjustments on this damper were marked for cross sectional openings of the damper equal to 10%,20%,40%,60%, 80% and 100% of the cross sectional area of the 5" tube.

Height of the "rocket elbow" was increased as required by adding additional 12" sections of riser sleeve.

A pot of water was suspended 1 ¼" above the top of the "chimney" to simulate actual cooking conditions.

In the second half of the experiment, dampers were constructed from coffee can tops which had round openings cut in them equal to 10%, 20%, 40% 60% and 80% of the tube area. The tops could be placed over the chimneys to create the appropriate constriction.

FUEL

Douglas Fir was sawn in ½"wide by ¾"high by 12"long pieces and dried in an oven at 200F for a minimum of 8 hours.

FEED MAGAZINE

An automatic feed mechanism was constructed to feed 6 sticks at a time into the feed opening of the stove. This device used 5 oz fishing weights to maintain constant pressure on the 6 evenly spaced rows of wood being fed into the stove. Contrary to all expectations, this apparatus was remarkably trouble free. This arrangement allowed the cross sectional area of the wood entering the stove to be held constant at 2.25 square inches (12% of the total).

THERMOMETER

A VEI brand digital thermometer with a 1/8" diameter stainless steel probe was used to measure and record exit temperatures from the stove. The thermocouple was fixed 1" below the top of the rocket chimney and directly in the center of the tube. This thermometer has a "record" feature which included a timer and records the highest and lowest temperatures for a given time period.

ENVIRONMENT

Tests were conducted in a sheltered outdoor area at Neskowin, on the Oregon coast. Tests were conducted over the course of several days in late July and early August, 2002. Temperatures and weather conditions were fairly constant and wind was minimal.

PROCEDURE

- Outside air temperature and weather conditions were recorded.
- The feed magazine was loaded and the fire was started using ½ a sheet of newspaper and a small amount of finer wood. New sticks were added to the magazine as fuel was consumed.
- The stove was allowed to run for 30+ minutes to allow a stable state to be reached.
- After each new setting of adjustments was made, the stove was allowed to run for 2 minutes before recording was begun.
- Temperatures were recorded for a period of 5 minutes for each setting. During this time the thermometer was observed and a visual estimate was made of the mode temperature. At the end of this period, the estimated mode T, actual maximum T and actual minimum T were recorded. Note was made of the visual appearance of smoke or flame at the top of the chimney.
- Adjustments were made to the damper settings and the procedure was repeated until all six variations had been recorded.
- A new section of 12" riser sleeve was added to the 'rocket elbow" and the procedure was repeated.
- At the end of each run, the coals were allowed to burn off from the screen. Very little charcoal remained and the screen stayed fairly open and clean.
- The procedure for the second half of the experiment was identical except that the bottom opening was left completely open and the top of the chimney was restricted using coffee can tops with holes cut in them.
- Three runs were made for each setting and the results averaged. In a few cases, the fire went out on one run and only the successful runs were averaged. An X indicates that the fire was extinguished.

OBSERVATIONS

Controlling draft from below

Increasing the height of the “chimney” resulted in a decrease in exit temperatures for all air opening settings. It is possible that this is caused by increased flow of cold air entering the stove above the fuel feed level.

Increasing the % opening on the 12” chimney produced higher exit temperatures. With the 24”and 36”chimneys, the relationships were not obvious and not linear.

It was impossible to keep the fire going with the 36”chimney at the 40% opening. It was difficult to do so at the 60% and 80%settings. The easy and obvious explanation for this is that the increased draft and air velocity in the high chimney “blows” the fire out. I had trouble convincing myself that it was that simple. Just before the flame dies out there appears to be very little rush of air in the combustion chamber and the flame is quite tranquil.

The 12” high chimney produced much flame and black smoke at all settings. There was a buildup of soot on the pot.

The taller chimneys produced little or no smoke but the exit temperatures were disappointingly low. With the taller chimneys set at the 80% and 100% openings, it was observed that the soot on the bottom of the pot sometimes reignited and appeared to burn off with a “sparkle”.

Controlling draft from above

Restricting airflow at the top of the “rocket chimneys” was much more successful than trying to do so from below. Exit temperature at all settings and for all height chimneys were considerably higher than before.

The 12” high chimney produced almost identical high temperatures at 40%, 60%, and 80% openings. Much smoke and flame produced heavy sooting of the pot.

The 24” high chimney produced the highest temperatures at the 40% opening but smoke and flame were still significant. The 60% setting produced temperatures, which were almost as high, and smoke and flame were considerably reduced. This was probably the best overall compromise for high temperatures and reduced smoke.

The 36” high chimney burned quite cleanly at all but the most restricted air settings. The exit temperatures were lower, but remained above the 1200 F level. Soot was observed burning off at the more open settings.

When the exit was necked down to 10% it was obvious that the stove was being choked for air. The fire tended to burn back out the feed tube and black smoke seeped out through small cracks between the riser sleeves.

At the 20% setting on the 12” and 24” chimneys, a secondary burn was observed at times around the pot. In one case when the pot was temporarily removed there was a spectacular “blowtorch” effect. I think these settings essentially turn the rocket stove into a gasifier.

CONCLUSIONS AND RECOMMENDATIONS

Controlling draft at the exit point of a “rocket elbow” is much more effective than trying to do so from the point at which air enters the elbow.

It is possible to produce high temperature exit gases (above 1200 F) and maintain their temperature through the length of a long combustion chimney.

High temperature and “dwell time” by themselves are not sufficient to produce dependably clean combustion. It may be necessary to further mix the exit gases (either by turbulence or by other means) in order to aid combustion in rocket stoves.

Higher temperatures and cleaner burns are sometimes obtained by partially blocking the flow of gases through a rocket stove. It may be possible to use mixing devices or jets of air to achieve this blocking effect and improve combustion at the same time.

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