Tests of the Cajun Rocket Pot

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November 18, 2013

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Introduction

A series of tests was done to compare the Cajun Rocket Pot (the finned pot) with an ordinary pot of effectively the same size. The finned pot has 70 round fins (pin fins) on the bottom with a diameter of 13 mm and a length of 14 mm. The diameter of the bottom of both the regular and finned pots is 248 mm. The area of the bottom of the flat pot is 0.04828 m^2, and the area of the bottom of the finned pot is 0.0883, or 83% greater. Moreover, the flow is impinging on one side of the fins, which typically gives much better heat transfer than gas flowing parallel to a surface, which is what happens over most of the bottom of a flat bottom pot. It would therefore be expected that the finned pot would have much better heat transfer efficiency.

Both pots were tested on 7 different heating devices, with the fire conditions set up to be as close as possible between pot tests. Only one test was done on each pot. There are a variety of ways to compare the effectiveness of the two pots, and as many ways were used as were meaningful for that stove.

The 7 heating methods were:

1. Natural gas range
2. Propane stove
3. High performance charcoal stove
4. Open fire burning wood
5. Simulated open fire burning natural gas
6. Fan powered stove burning wood
7. Rocket stove burning wood.

The heating methods will be described in more detail in the sections on test results for the individual stoves.

In general, possible methods for comparing the pots are:

1. Time to boil, corrected to 5000 g of water and 80 degree temperature rise
2. High power efficiency
3. High power heat transfer
4. Low power efficiency
5. Low power heat transfer
6. Overall efficiency (weighted average of high power and low power)
7. Average efficiency (simple average of high power and low power)
8. Total fuel consumed.

There are advantages and disadvantages to each of these methods, and there is no one right way to compare the pots. Some methods are not appropriate to use for some stoves, but in general, results will be given for as many ways as possible to compare the two pots. The reader can decide which is the most valid way of comparing the pots.

The tests done were mostly modified water boiling tests. The modifications were that there was no separate hot and cold start, and that the goal of the simmering phase was to keep a light simmer, rather than the usual goal of keeping the water 3°C below boiling. The simmering period was 45 minutes. For some stoves, this test method was not appropriate or possible, and the specifics of that test will be given. Some tests were done indoors, some outdoors, but all tests were done in a place sheltered from wind, and in a place that was not too cold. Thus, weather conditions should have minimal effect.

Propane Stove

A small propane camp stove was tested with the pots. The stove and pot are shown in Fig. 1. A small intense flame is produced and there is little heat transfer by radiation. Since the weight of the propane stove could be measured, efficiencies could be calculated, in addition to power, fuel used, and time to boil. The power level during the high power test was as high as seemed reasonable. The power level during the simmering phase was the lowest possible to keep the flame lit, and this typically maintained a gentle simmer. This stove did not have continuously adjustable power, there were several power settings. Since the pressure in the tank will vary, the actual power level will vary even if the valve setting stays constant. The tests were done on warms days, such that the pressure in the tank stayed moderately high.

Figure 1: The propane stove with the finned pot. The bottom of the pot was painted black before testing, to give equal radiative heat transfer as the regular pot.

For the regular pot the time to boil was 26.2 minutes (all times to boil in this report are corrected to 5000 g of water and 80°C temperature rise) the high power efficiency was 0.635, the low power efficiency was 0.604, and the overall (weighted) efficiency was 0.619. For the finned pot the time to boil was 16.6 minutes, or 0.634 times as much. The high power efficiency was 0.662, or 1.04 times as much, the low power efficiency was 0.700, or 1.16 times as much. Overall efficiency was 0.683, or 1.10 times as much as the regular pot. Total fuel consumed for the regular pot was 148 g, compared to 137 g for the finned pot, which is 0.926 times as much.

The differences in efficiency and total fuel used are small, while the finned pot shows a big advantage in time to boil. It is likely that as the high power phase of the test progressed, the temperature and pressure in the propane tank went down in the regular pot test, thus reducing the fuel flow and firepower, and increasing the time to boil by a larger factor than the ratio of the high power efficiency numbers.

For this stove there are a variety of ways to compare the pots. I believe the best number to use, with the fewest confounding factors, is the overall efficiency. In this measure, the finned pot was 1.10 times better than the regular pot.

Gas Range

The pots were tested on my gas range. It was impossible to measure the gas flow, therefore efficiencies can not be calculated. In order to have the same firepower for each test the test was done as follows. The range was lit and the flame adjusted to a high but reasonable power level. The stove was allowed to stabilize in temperature for a few minutes. Without changing the power level, one pot was placed on the stove and brought to boil and the time was measured. That pot was removed, and the stove was allowed to restabilize. The second pot was placed on the stove and brought to a boil. Thus, the firepower was very close to being the same for both pots. No low power test was done. Quantities measured were the time to boil and the rate of heat transfer to the water (in Watts).

Gas flames with burners of this type typically produce very hot, intense flames. There is little heat transfer by radiation. The flames passed easily between the fins of the pot, as they did for all tests. The finned pot sat higher above the flames than the flat pot by an amount equal to the height of the fins, and this was also common to all tests.

The results are that for the regular pot the time to boil was 32.2 minutes, while for the finned pot it was 27.9 minutes, or 0.867 times as much. The power input to the regular pot was 1128 Watts, while that of the finned pot 1227 Watts, or 1.088 times as much. The total fuel used during this phase would be proportional to the time to boil, but is unknown. Either the power input to the water or the time to boil are valid ways to compare the pot.

Typically, as a pot of this size with no lid approaches the boiling point, the heat loss is about 700 W, most of which is by evaporation. The finned pot, having about 100 W more heat input, also has 100 W more net heat input. While the actual heat input to the finned pot is only 8.8% more than the regular pot, the net heat transfer near the boiling point is greater by more than 20%, thus the time to boil is 13.5% faster for the finned pot.

Charcoal Stove

The charcoal stove tested was the Tank Stove, made by Burn Manufacturing. This is a high performance charcoal stove with a small insulated combustion chamber and good air flow control. Being a batch feed stove, the fuel consumed was the entire batch, which was set to be the same for both tests. Thus, total fuel consumed is not a meaningful number for comparison. The fuel consumed during the test was estimated by measuring the weight loss of the stove and allowing 3% for ash residue. This number should be meaningful, and will be reported, as well as the high power efficiency, the low power efficiency, and the overall (weighted average) efficiency.

For this test a lid was used on the pot, as is the standard for charcoal stoves. Charcoal stoves typically start out at high power, then as the fuel is consumed they steadily drop in power. Thus, it is nearly impossible to boil water on charcoal without a lid, and a lengthy simmering period would be even more difficult without a lid.

This raises a point which affects the low power efficiency greatly. Typically, the heat transfer to the water is measured by measuring the amount of water, the temperature rise of the water, and the evaporation of the water. Without a lid, these factors accounts for the vast majority of the energy that goes into the water. With a lid however, during the simmering phase the evaporation rate can be low, and other sources of heat loss from the pot which are difficult to measure, convection and radiation, become comparable to the evaporation. Without a lid, if the temperature is maintained just below boiling, or if there is a light simmer, the evaporation rate is about 1 kg in 45 minutes. With a lid, if a light simmer is maintained the evaporation rate will be about 200 g in 45 minutes. The low power efficiency will thus be artificially low for both pots, because there is a lot of energy going into the water that is lost by convection and radiation and is unaccounted for.

For charcoal stoves, a high proportion of the energy transferred to the pot, something like 50%, is transferred by radiation, and fins will not help with radiation. Thus, we expect the finned pot to produce smaller benefits for a charcoal stove than for wood stoves.

The results are that the fuel consumed during the regular pot test was 162 g, and this did not include a significant amount of fuel consumed during the lighting phase. It is reported that most users try to get a very strong fire going before putting the pot on a charcoal stove, so as to reduce the time to boil. The fuel consumed was measured by weighing the stove when the pot was placed on the stove and when the test ended, and allowing for 3% ash.

The time to boil for the regular pot was 22.4 minutes, the high power efficiency was 0.445, the low power efficiency was 0.252, and the overall efficiency was 0.41. In calculating the high power efficiency and overall efficiency, the energy content of the fuel consumed before the pot was placed on the stove was not counted. With charcoal, the first part of the fuel consumed has less energy than the last part of the fuel, therefore there is some error in this method, but the same methods were used for both pots. Since the purpose of this study is to compare the pots, not to study the stove, this was deemed to be the best calculation method.

The air door was completely closed for most, but not all, of the simmering phase with both pots.

For the finned pot the fuel consumed during the test was 164 g, slightly more than for the regular pot. This will be somewhat dependent on how hot the charcoal was burning during the test. The time to boil was 24.2 minutes, or 1.08 times that of the regular pot. Both of these factors suggest the finned pot is worse than the regular pot, however these results depend on the combustion, which is influenced by semi-random factors such as fuel lump size and orientation, amount of lighter fluid used, amount of air flow, thoroughness of the lighting process, and many others.

The high power efficiency was 0.456, or 1.026 times that of the regular pot. The low power efficiency was 0.289, or 1.15 times that of the regular pot, and the overall efficiency was 0.422, or 1.03 times that of the regular pot. With a lid, the vast majority of the energy is used during the high power phase, thus the overall efficiency is skewed toward the high power efficiency.

For both stoves there was a considerable amount of charcoal left at the end of the simmering phase. The water boiling test could have been done with less fuel, leading to higher efficiency, but at the cost of a longer time to boil. Likewise, had the pot been placed on the stove earlier, less fuel could have been used, at the expense of longer time to boil. The stove was operated in the manner that I believe most users would use it, that is, minimizing time to boil regardless of fuel use.

For this stove there are a variety of ways to compare the pots, but I believe the best “apples-to-apples” number is the high power efficiency. For this, the finned pot was 1.026 times better.

Open Fire Using Wood

In this test 3 bricks were used to support the pot above a wood fire. More than any other test, the results here depend on the skill of the user and on how the fire is maintained. The goal was to keep a large but reasonable fire going in the high power phase, and to maintain a gentle simmer during the simmering phase. The wood was mostly natural wood from my maple or crabapple trees, but some dry cut lumber was used. The wood was very similar between tests. The fire was well-tended, and the wood was small, so as to give fine fire control. See Fig. 2 for a view of the open fire setup.

Figure 2: Open fire setup with the regular pot. The distance from the bottom of the pot to the base of the system was 6 inches (15 cm).

To calculate the high and low power efficiencies one must estimate the energy released from the fuel. This was done by measuring the amount of fuel remaining in the fuel bin and also estimating the amount of unburned wood and the amount of unburned charcoal in the fire at the start and end of the test period.

For the regular pot the results are that total fuel burned was 1942 g, and the time to boil was 35.4 minutes. The high power efficiency was 0.187, the low power efficiency was 0.172, the overall efficiency was 0.180.

For the finned pot the total fuel consumed was 1218 g, or 0.63 times as much. The time to boil was 27.5 minutes, or 0.78 times as much. The high power efficiency was 0.205, or 1.095 times as much. The low power efficiency was 0.236 or 1.37 times as much, and the overall efficiency was 0.219, or 1.216 times as much.

For this method there are a variety of ways to compare the pots. The one with the fewest confounding factors would be the overall efficiency, for which the finned pot was 1.216 times as good. However, the users might find total fuel consumed or time to boil to be more important, both of which showed the finned pot to be better than the regular pot by a larger margin. There may be a number on confounding factors here related to how the fire was run that cause this situation. More tests would be needed to average out these confounding factors.

Simulated Open Fire Using Natural Gas

The purpose of using this test was to reduce the number of confounding factors as much as possible, while still staying somewhat like a real world situation. Also, this method was also used because it gives test results quickly. This was the only test in which the water was not boiled. Instead, it was heated for a short time, only as long as necessary to get an accurate power measurement.

In this test a natural gas burner was used, as shown in Fig. 3. The gas was burned in a low speed fully non-premixed manner, such that the character of the flame resembled a wood flame. Unlike an actual wood fire there was no pile of coals radiating heat to the pot. The natural gas flow was measured and controlled, thus, exactly the same fire conditions were used for each pot. Two power levels were used, generally considered low and medium power. The low power firepower was 1806 W and the higher power level was twice this, or 3612 W.

Figure 3: Simulated open fire.

The pot held a known quantity of water, and the temperature rise over a given number of minutes was measured. The pot had a lid and did not approach the boiling point, therefore evaporation was minimal and was not measured. The heat going into the water, in Watts, was measured, and the efficiency calculated.

The results are that for the regular pot the lower power efficiency was 0.483 and the higher power efficiency was .419. For the finned pot the low power efficiency was 0.535, 1.108 times that of the regular pot. For the higher power the efficiency was 0.458, or 1.093 times that of the regular pot. The average of these numbers gives a 1.10 efficiency improvement. All of these efficiency values are considerably higher than for a wood burning open fire, even without the effect of the wood radiation. It must be concluded that this is not a particularly good surrogate for an open fire. Still, the comparison between the two pots should be valid.

Rocket Stove Burning Wood

In this series of tests, a high mass rocket stove was used, and the fuel was mostly cut lumber with a few small pieces of natural wood used as kindling. The pot sat higher on the stove, as the bottoms of the 14 mm tall fins sat on the pot supports. The stove with the finned pot subjectively seemed to burn significantly cleaner, suggesting that more air was passing through the fire. This would be consistent with the higher pot. One might therefore expect that the finned pot would produce a cooler flame due to the increased excess air, and therefore the finned pot might produce lower efficiency. The system is shown in Fig. 4.

Figure 4: The ceramic rocket stove with the finned pot, using wood as the fuel.

This was the only high mass stove tested, and the energy needed to heat the body of the stove will be the same regardless of the pot design. The mass of the stove is about 18 lbs (8.2 kg). This is a second reason why the finned pot might be expected to perform no better to the regular pot.

The results were that for the regular pot the time to boil was 21.2 minutes, the high power efficiency was 0.276, the low power efficiency was 0.337, and the overall efficiency was 0.308. The total fuel used to complete the test was 969 g.

For the finned pot the time to boil was 20.0 minutes, or 0.94 of the regular pot. The high power efficiency was 0.278, or 1.01 times that of the regular pot. The low power efficiency was 0.354, or 1.05 times that of the regular pot. The overall efficiency was 0.320, or 1.04 times that of the regular pot. Finally, the total fuel used was 1021 g, or 1.05 times more than the regular pot. The total fuel usage will be somewhat of a function of how the stove is used. While I tried to run the stoves in the same manner for both pots, for the finned pot considerably more water was evaporated during the simmering phase, which would require more fuel despite the increased heat transfer efficiency.

The best single number to compare the pots would be the overall efficiency, in which the finned pot was 1.04 times better than the regular.

Fan Stove

A Wood Gas stove (Tom Reed Stove) was tested. This stove is intended to be a batch feed stove using wood pellets as fuel, but the fuel bowl is too small to complete the water boiling test. Thus, the stove was started with a batch of pellets, but small pieces of wood were added to extend the running time of the stove. In the end, less than half of the wood consumed was pellets. Since the added fuel had to be small to fit into the fuel bowl, only small pieces of wood could be used, and the fuel was added nearly continuously throughout the test. This stove is shown in Fig. 5.

Figure 5: The Wood Gas stove without the pot in place.

For the regular pot the results were that the total fuel consumed was 709 g, the time to boil was 28 minutes, the high power efficiency was 0.383, the low power efficiency was 0.402, and the overall efficiency was 0.391.

For the finned pot, the time to boil was 21.8 minutes (0.779 times as much) the total fuel used was 675 g (0.952 times as much) the high power efficiency was estimated at 0.535 (1.40 times as much) the low power efficiency was estimated at 0.440 (1.095 times as much) and the overall efficiency was 0.476 (1.22 times as much). Some discussion is needed, however, for these efficiency numbers.

At the start of boil the stove was weighed, and by comparing this weight to the empty weight of the stove, the amount of fuel left in the fuel bowl was calculated. For the efficiency calculations it was assumed that all of this weight was unburned charcoal. To calculate the energy released during the high power phase, the energy content of the charcoal was subtracted from the energy content of the fuel that had gone into the bowl up to that time. For the finned pot, boiling was achieved more quickly and there was still 100 g of something still in the fuel bowl. This was assumed to be charcoal, but at that point only 394 g of wood had gone into the fuel bowl. Typically, the remaining char fraction for stoves of this type is about 1/7 of the wood fuel input, therefore it is likely that not all of the remaining 100 g was char, some of it was unburned wood. Therefore, the estimated energy released from the fuel during the high power phase was too low, leading to an overestimate of the high power efficiency. The energy released during the low power phase was overestimated, leading to an underestimate of the low power efficiency. The overall efficiency should be accurate. For the regular pot the time to boil was longer, and the amount of fuel left in the fuel bowl at the start of boil was 44 g, and it is reasonable to assume that this was charcoal.

The weight of the ash (typically about 1% of the wood) was also neglected in this calculation. Since the pot was on the stove from the moment the fire was lit, the energy content of the lighter fluid was included in the calculation.

The best way to compare the pots for this stove will be the overall efficiency, for which the finned pot is 1.22 times better.

Gasifier and Plancha Stoves

These stoves were not tested. Gasifiers are batch feed and are difficult to test in a valid manner unless the air control is very good. Plancha stoves where the pot sits on a hole in the plancha and is exposed to direct flames will be similar to a rocket stove. Plancha stoves where the pot sits directly on the plancha will have poor heat transfer with or without fins, probably worse with fins.

For the gasifier, the results with a finned pot should be similar to the results for the fan stove or the rocket stove. For the stove with a plancha and a hole, the results should be similar to the rocket stove.

Other Factors

There are other factors that affect the performance of the finned pot besides the effect of the fins on convective heat transfer. This section looks at various differences between the pots and what may or may not have had a small effect on the results.

The overall size of the pot was very similar to the regular pot. The diameter especially was very close, and the height was similar. Minor differences in dimensions will have negligible effect.

The finned pot was aluminum, while the regular pot was steel. Aluminum is a better conductor, but all metals are much better conductors that water or gases, so the difficult parts of the heat transfer process are getting the heat to the pot, mainly, and also getting the heat into the water, secondarily. In other words, getting the heat through the pot, from the outside surface that touches the gases to the inside surface that touches the water, is very easy and efficient, no matter what metal is used.

The finned pot was heavier, and aluminum has a higher specific heat. The energy needed to heat the pot was not included in the efficiency calculations. The finned pot weighed 1838 g, and the specific heat of aluminum is 883 J/kg °C. Thus, it takes 130,000 J to heat the pot from 20 degrees to 80 degrees. The steel regular pot weighed 750 g, and the specific heat of steel is 434 J/kg °C. It thus takes 26,000 J to heat the pot. These numbers are both small compared to the 2 to 4 MJ of energy transferred during the tests, and are therefore not significant factors.

One other factor was that during the early tests before the finned pot had been exposed to wood flames, the sides were very shiny, as seen in Fig. 1. The radiative losses from the sides of the pot were therefore less than for the regular pot, which had a black surface. This factor would give the finned pot a slight advantage in the early tests. These radiative losses are generally small and will not be a significant factor.