Finned Pots as a Means of Increasing Efficiency

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Executive Summary

A pot with heat transfer fins has much greater surface area than pots with no fins. In theory, this could lead to greatly increased heat transfer to the pot for a given stove, and the pot would theoretically improve the performance of the stove under all conditions. While we often concentrate on the stove as the primary element of a cooking system, the efficiency of a stove is mainly determined by the heat transfer to the pot, and designing a better pot would be an easy way to make a more efficient stove.

A variety of types of finned pots were built and tested. The best designs were separated out in the lab, using natural gas to simulate a wood flame. Several types of fins can be retrofit to existing pots. The better designs of finned pots performed well over a range of conditions using simulated stoves, and sometimes also with an actual wood burning stove modified to use natural gas to simulate a wood flame. With fins on or near the bottom of the pot the finned pots typically gave around a 1.76-fold improvement in heat transfer. If the fins were on the sides of the pot a greater than 2-fold improvement was achieved.

Tests on actual stoves using wood as the fuel generally gave smaller improvements in performance, generally 1.33 or less, corresponding to a 25% or smaller reduction in fuel usage. These tests were done under a variety of conditions with a variety of stoves, including the open fire (3-stone fire).

On industrial fuel stoves using kerosene or alcohol, improvements were even less, with the finned pots giving 1.2 fold improvements or smaller. In some tests the finned pot used more fuel than an unfinned pot. The reasons for this wide range of results is not known.

It is not recommended that finned pots be pursued as a means of increasing the efficiency of stoves. Better results can probably be achieved with less effort by using skirts around the pot. These skirts could be attached to the pots with optimum dimensions.

Introduction

Previous studies (Ref. 1) show that the bulk of the heat transfer to a cooking pot is through convection. The major factors that affect convective heat transfer are the gas temperature coming out of the stove, the area of the pot, and the convective heat transfer coefficient, which is a function of a number of variables. The gas temperature and heat transfer coefficient are functions of how the stove is designed and how the stove is being run (for example, what power level) and the stove designer has limited capacity to change these variables.

This leaves the surface area of the pot as a variable. It is possible to greatly increase the surface area of a pot by adding heat transfer fins, and the purpose of this report is to relay the results of experiments regarding a number of different fin types. These experiments were done between March, 2007 and January, 2009. Most of the test reported here were conducted by me, but some test results by others will also be reported.

Test Methods

Various pots were tested under a variety of conditions. Many tests were done in the laboratory using simulated stoves. Four simulated stoves with two power levels were tested. The simulated stoves consisted of a gas burner that burned the gas in a slow fully non-premixed manner. This seems to simulate the nature of flames with natural wood in terms of flame color, size, and turbulence. This method of using natural gas to simulate a wood flame should be good for studying the heat transfer aspects of a stove, though not the pollutant formation aspects. With this arrangement many heat transfer tests can be done under steady and identical test conditions. With actual wood flames this would be impossible.

The power levels were “low” with a fire power of 1806 Watts, and “medium” with a power level of 3250 W. With a finned pot higher power levels should not need to be used, since the power input to the pot would be quite high even with a medium flame. Most tests were done at the medium power level, since there are questions of how often people in the developing world would use a low power flame, and even a question of whether one could make such a low power flame with biomass without the flame going out.

For all conditions, tests were first conducted on the same pot or a very similar pot before the fins were attached to determine baseline conditions.

The first simulated stove was an open fire, with the top of the gas burner about 5 inches (127 mm) below the bottom of the pot. This is shown in Fig. 1.

Figure 1: The simulated open fire.

As seen in Fig. 1, the burner is a set of plumbing fittings with large holes drilled into them. The small round plate on top of the burner is there to spread the flames out such that the heat rising from the burner was more axisymmetric and not as concentrated. Gas flow is measured and controlled with a rotameter.

The second simulated stove was a simulated rocket stove, where a double wall stove pipe (the riser) was added on top of the same burner as with the open fire. This is shown in Fig. 2. The riser is double wall, so that little heat will be lost through the riser walls. The riser is about 9 inches (0.225 m) tall, and the inside diameter is 5 inches (127 mm).

Figure 2: Simulated rocket stove.

In tests with this simulated stove, the bottom of the pot (not including the fins) was ¼ of the diameter of the riser above the top of the riser. This gives equal flow area through the riser and through the space between the riser and the pot.

In the simulated rocket stove there was no flow channeling after the gases left the top of the riser. The third simulated stove was the same riser but with a “base”, that is, a base under the pot. This simulates a rocket stove with a wide flat top that forms a channel of some type under the pot. This would be similar to the 6-brick rocket stove. The test unit is shown in Fig. 3.

Fig. 3 The simulated rocket stove with base.

In the tests with a finned pot the fins will be touching the base, which will determine the dimensions between the bottom of the pot at the top of the riser. In the baseline tests with unfinned pots this dimension was held constant. This dimension is roughly constant over the entire bottom of the pot.

The fourth way in which stoves were tested was an actual Chinese rocket stove that was modified to use natural gas as the fuel. This is shown in Fig. 4. Here, the bottom of the pot, with or without fins, was set on the pot supports of the stove. The top of the Chinese rocket stove is tapered, such that the gap between the bottom of the pot and the top of the stove is greater near the center of the stove, and decreases to a smaller value near the edges of the pot.

Fig. 4 The Chinese rocket stove, modified to run on natural gas.

In all tests some type of "reference temperature" was measured. This is more or less the temperature of the gases when they first hit the pot or the fins under the pot. The purpose of measuring this temperature was as follows. When a finned pot is used it will restrict the flow of gases somewhat, especially with the simulated stoves that had risers (which was all but the open fire). This will mean there is somewhat less excess air available at the fire, and a hotter overall temperature coming off the fire, especially in the stoves with risers. The finned pot will see increased heat transfer for two reasons, the presence of the fins and the increased temperature coming out of the riser. The reference temperature was measured in order to separate out these effects.

In all tests reported here, the change in the reference temperature between the finned and unfinned pots was not too great, thus, the increase in heat transfer was primarily due to the fins rather than due to a decrease in excess air through the simulated stove. In real cooking with wood, one would not want the fins to restrict the flow of air through the stove very much, as this could lead to a large increase in pollutants.

In all lab tests a known quantity of water was heated from room temperature to some temperature well below boiling. The rate of temperature rise of the water was calculated. The pot had a lid, and evaporation should be minimal. The power going into the stove was calculated, and this was the primary result. For the Chinese rocket stove, which had significant thermal mass, the test was started after a short warm up phase which was the same for all tests.

The factor or improvement for the finned pot would be the ratio of the power going into the finned pot to the power going into the unfinned pot under the same conditions. Tests was also done under less precise conditions with other types of fuel, and these will be explained later in the sections on the various types of pots.

Description of Pots

A number of different types of pots were built and tested by this author, but only the four most successful types will be reported here. I will also report a few other tests that were done with other pots from other sources. The types of pots that were tested were:

1. Bottom finned pots designed by the author.

2. Side finned pots with radial side fins designed by the author.

3. Side finned pots with perforated metal fins on the sides designed by the author.

4. Slit fin pots designed by the author.

5. A commercially available pot for the camping market from the Jet-boil company.

6. A cast iron finned wok from an unknown source.

Bottom Finned Pots

Two different pots were used which had fins brazed to the bottom. These pots were similar to each other in diameter and performed similarly, when comparing the heat transfer with fins to the heat transfer for the same pot without fins. The results given here are for the second "optimized" design, which turned out to be not much better than the previous "unoptimized" design. A photograph of the final design is shown in Fig. 5.

Fig. 5: The final design of the bottom-finned pot.

The pot is a carbon steel (not stainless steel) 8-quart (7.5 liter) pot with a diameter of about 22 cm. It was enamel coated, but for the purposes of a test prototype the enamel had to be broken and ground off to attach the fins. There is apparently some sort of primer under the enamel that was mostly left on. The brazing metal adhered well to or through this primer.

There were 16 long fins and 32 short fins attached to the pot. The long fins are about 26 mm by 76 mm (in the radial direction) and about 1.6 mm thick. All fins are carbon steel. The short fins are about 26 mm by 38 mm (in the radial direction) by 1.6 mm thick. The total fin area is about 0.126 m^2 when you account for the fact that both sides of the fin are exposed to heat. This is about 3.3 times the bottom area of the pot, which is typical of the large increases in area that are achievable with finned pots. Previous studies (Ref. 1) have shown that most of the heat transfer is through the bottom of the pot, so the effective "size" of a pot is determined mainly by its bottom area.

Parts of each fin were slit into sections, with each section being about 1 cm long. Each section will start a new boundary layer, and the average boundary layer thickness will be less than if the fins were not cut into sections. The pot was built by hand brazing the fins to the bottom of the pot with an oxy-acetylene torch. This took about an hour. The fins were spaced as closely together as possible. With such an arrangement it would be impossible to thoroughly clean the bottom of the pot.

Results-Bottom Finned Pots

In the laboratory over 3 different test conditions done at medium power the improvement of the bottom finned pot over the non-finned identical pot averaged 1.76. The 3 test conditions were the standard burner with base, the standard burner, and the simulated open fire. There was little scatter between the 3 tests. Low power tests gave similar improvements.

Encouraged by these results, the same pot was tested on other stoves. On an alcohol stove a heat transfer test was done similar to the natural gas tests in the sense that fuel use and heat transfer were measured over a limited time. This is different from a standard water boiling test, but the results should be comparable. For these tests the evaporation was measured as part of the heat transfer to the water.

Since the stove could not be run at strictly constant power, the efficiency was used as the primary result. For the bottom fin pot the heat transfer efficiency was 0.55. For a non-finned standard pot (the standard pot is a stainless steel pot and has a somewhat larger diameter of 9.6 inches or 24 cm) the efficiency was 0.57. Thus, the fins appear to provide little or no benefit on that alcohol stove. This is perhaps to be expected, since the efficiency is already very high.

On a Ghana wood burning stove, several pots were tested, again efficiency as the primary result. This was similar to the alcohol stove test, except that a correction was made to account for the charcoal remaining at the end of the test. For the bottom finned pot the heat transfer efficiency was 0.21. For the standard pot (of somewhat larger diameter) the efficiency was 0.25. Again, the finned pot appears to provide little or no benefit.

On a kerosene stove, the finned pot also saved no fuel when compared to an identical pot. This was for a water boiling test with 45 minute simmer. One possible explanation for this is for both the kerosene stove and the Ghana wood stove the fins raised the bottom of the pot by about 26 mm, presumably leading to cooler flame temperatures by the time the flames hit the pot. An unfinned pot was tested in a raised condition on the kerosene stove, and this led to a 19% increase in fuel usage over the same pot in its normal position.

A number of tests using wood on the Chinese rocket stove were done using the standard water boiling test with 30 minutes of simmering. In one set of tests done by this author in January 2009, the fuel use went from 779 g with a standard pot (with larger diameter than the bottom finned pot) to 581 g with the bottom finned pot. This is 75% of the fuel usage, thus, 25% of the fuel was saved. The time to boil was reduced from 46 minutes to 31.5 minutes, though this is also a function of how large a fire was built and on the initial water temperature. The initial water temperature was about the same in both tests.

Other tests were done by Dean Still and Nordica MacCarty. In one pair of tests the wood usage decreased from 684 g to 532 g and the time to boil was reduced from 26 to 18 minutes. (This pair of tests had a higher initial water temperature than the previously reported pair of tests, hence the time to boil and the total fuel would be less.) The fuel usage for the finned pot was 78% that of the standard pot. They noted that the standard pot with a skirt used slightly less fuel than the finned pot.

Side Finned Pots with Radial Fins

A series of tests was done with a small pot with radial side fins, as shown in Figs. 6 and 7. Here, a series of radial pieces of aluminum sheet were clamped to the pot with a silicone heat transfer compound in the attachment area to transfer heat. Measurement of the fins temperatures showed that the heat transfer through the connection was good. The spacing on the fins was about 5 mm, which was about the optimum. The fins were about 76 mm tall, and extended about 32 mm out from the pot, about 6 mm of which was taken up by the clamping arrangement. The area of the fins exposed to hot gas was about 26 mm radially by 76 mm tall.

The exposed area of the 60 fins was 0.22 m^2, which is 13 times the bottom area of the pot. Test were done with the fins in one piece 76 mm tall, then with the fins cut into 3 25-mm sections and with the sections staggered, then with the 25 mm pieces bent to create a curvy flow path.

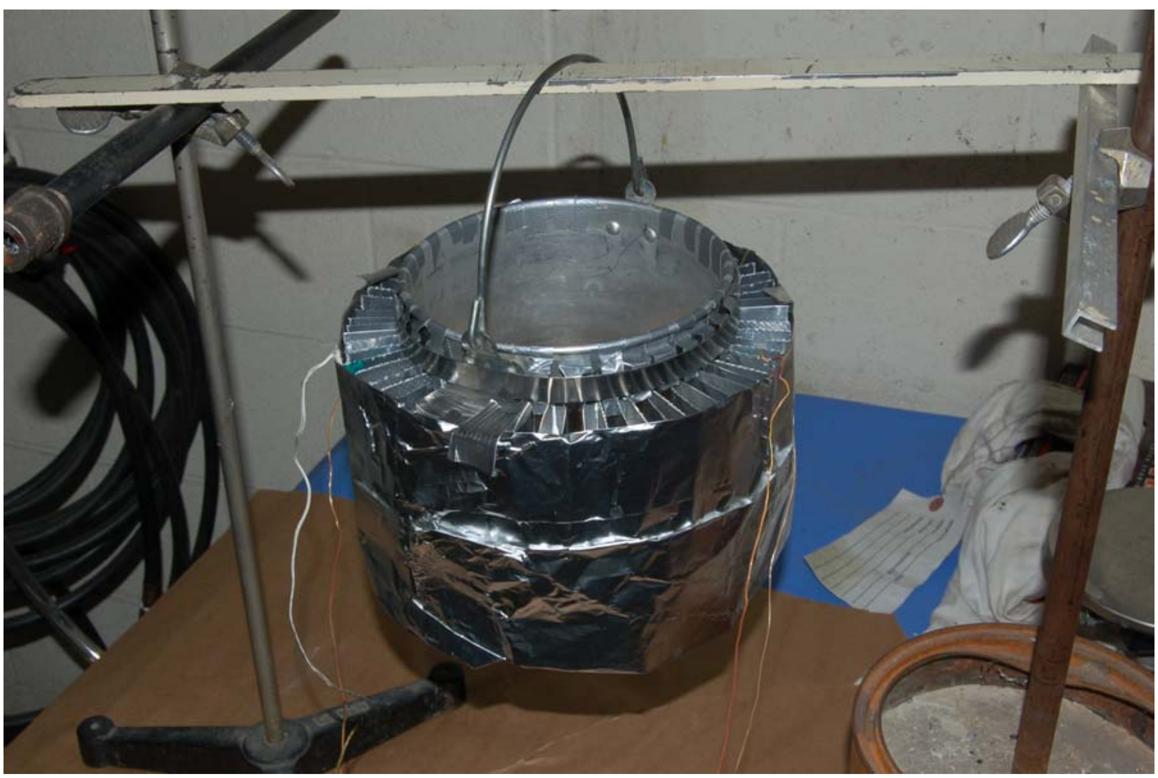

Fig. 6: A small aluminum pot with radial fins attached to the side and surrounded by a skirt.

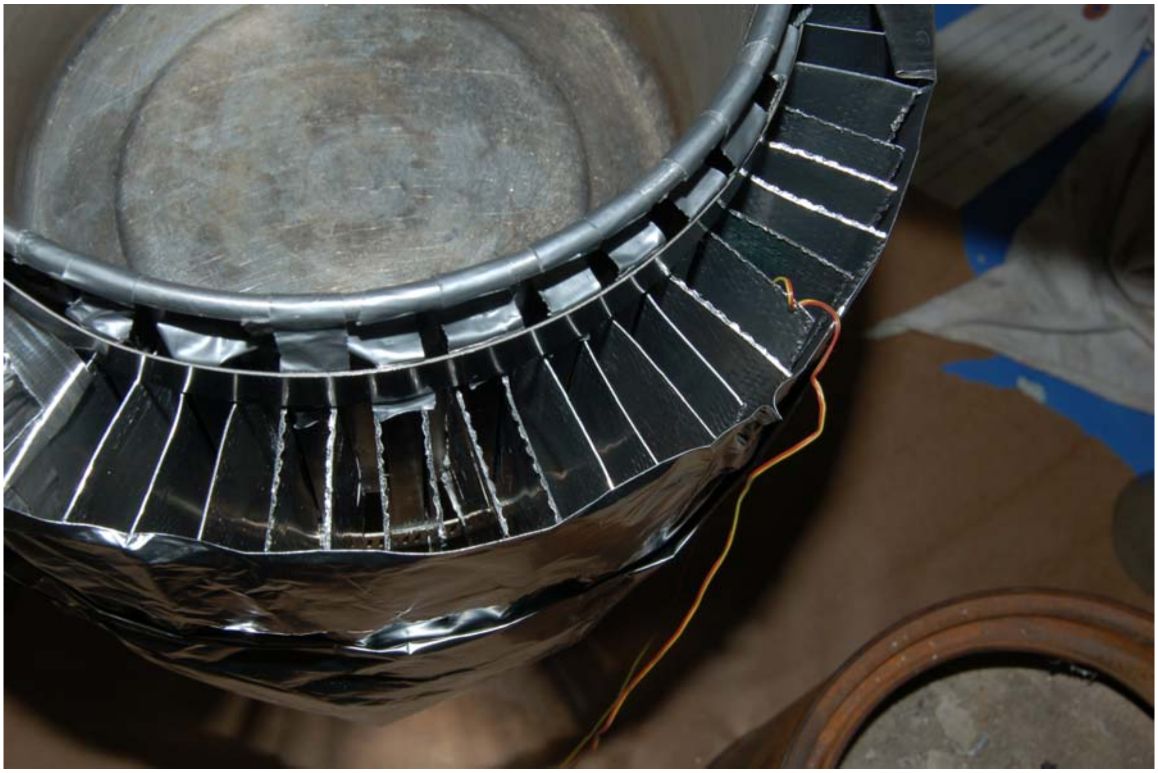

Fig. 7: Close up of the top of the fins. This was one style of fins that was used, other styles were also tested.

On the small pot only low power tests on the simulated open fire were done, with low power being 1806 W of fire power. The diameter of the pot was 5 ¾ inches (15 cm). The heat transfer to the basic pot was 306 W, for an efficiency of 0.17. A second test with done with the sides of the pot insulated, and this gave 85% of 306 W. Thus, 85% of the normal heat transfer went through the bottom of the pot.

Results-Radial Side Fins

The best result achieved was a 2.47 fold improvement in total heat transfer. This was with the curvy fins. The straight fins cut into 25 mm sections but not curved gave an improvement almost as good. Preliminary tests showed that it is important to have the skirt present in order to channel the hot gases between the fins. The pot with skirt but no fins gave only a slight improvement in efficiency over the basic pot, though the gap on the skirt was far larger than the optimum had there been no fins. Thus, the bulk of the 2.47 improvement was due to the fins not the skirt. Given that the efficiency of the basic small pot is low, we would expect fins to give a large increase in heat transfer. On a larger pot the fins would not have provided such a large increase in heat transfer.

The small pot was also tested on alcohol stoves. It was expected that the alcohol stoves would be very low in power, and that the finned pots would provide substantial improvement. The stove tested was actually just a small alcohol-burning canister with no stove structure, and tests were done with either 1 or 2 canisters under the pot.

Also tested with alcohol was the commercially available Jet-boil pot of slightly larger diameter. This pot has a ring of fins around the bottom of the pot. Both power and efficiency were measured, but only the efficiency numbers are given below, as the power level will depend on how the stove was running which is a function of how quickly the alcohol started evaporating.

In 2 tests on a 1-canister system the side fin pot gave improvements in efficiency of 1.20 and 1.10. The Jet-boil pot gave an improvement in efficiency of 1.43 in a single test. On a 2-canister test the finned pot gave an improvement of 1.28 while the Jet-boil pot gave an improvement of 1.31. These were significantly lower improvement that on the simulated open fire. Fire power levels were in the range of about 1000 W per canister.

Side Finned Pots with Perforated Metal Fins

As a rule of thumb, heat transfer occurs best when hot gases pass close to the metal surfaces to which they are transferring heat. The ultimate concept in terms of forcing gases to pass close to metal surfaces is to use perforated metal fins, that is, fins with small holes and where the gases are channeled so that the gases are forced to pass through the holes. Convective heat transfer coefficients are typically 3 to 10 times higher than when gases merely pass by the fins, as with the other fin arrangements given here. Typically, the holes are 30% of the fin area, so the flow restriction through the holes is not large.

On the down side, the best heat transfer occurs when the holes are small, which means they would tend to clog easily with fly ash (flying ash particles) and/or soot, or possibly spilled food. The perforated metal is more expensive then ordinary sheet metal, though this is compensated for by the fact that the area of the highly efficient fins would be less. Heat must be conducted in the metal in a zig-zag path around the holes rather than in a straight line, so that the fins are somewhat less efficient. Regardless, the best results of all the finned pot tests were achieved with perforated metal fins. The holes size was 1/16th inch (1.6 mm). A typical perforated metal fin is shown in Fig. 8. This type of design could be retrofit to an existing pot.

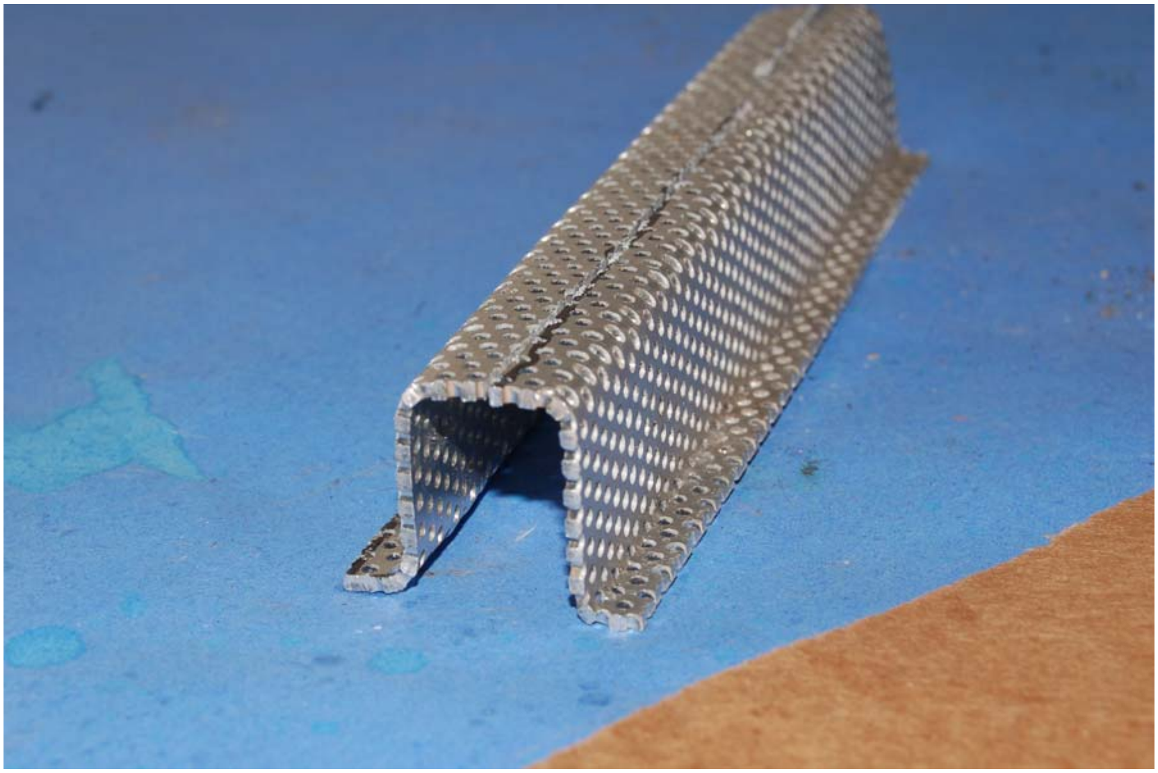
Fig. 8: A typical perforated metal fin. The bottom side would be clamped or soldered to the sides of the pot.

The fin shown in Fig. 8 forms a channel. With a large number of the fins clamped or soldered to the sides of a pot, the bottom of the channels would be left open and the space between channels would be blocked on the bottom. A ring around the entire base of the pot would force all of the hot gas up through the fin channels. The fin channels are blocked on the top, and thus all of the gas is forced to flow through one of the small holes. Then the gases flow easily away from the pot, either up or outward radially. The bases of the fin channels were soldered to the sides of the pot so as to conduct heat to the pot. The assembled pot is shown in Fig. 9.

Fig. 9: A portion of the standard-size pot with perforated metal fins. The channels through the fins are blocked at the top, as shown.

When attached to the same small pot as used with the radial side fins, perforated metal fins gave a 2.78 fold increase in heat transfer in the best test, and this set up had considerable room for further improvement. As with any test with a small pot, the high improvement was partially because the basic pot was not very efficient, having a small surface area.

A standard size pot was also used with perforated metal fins soldered to it. The heat transfer improvement in the tests under standard conditions with low or medium power was about 2.2, with further room for improvement up to about 2.4. This was by far the highest for any test of the standard size pot.

A test was done at the August 2008 "Stove Camp" in Oregon in which this pot was used on a Chinese rocket stove burning wood. The finned pot used 54% of the fuel of a standard pot without fins. This was in a standard water boiling test with a 30-minute simmer. The high power phase gave an estimated efficiency of 42% with the finned pot and the simmering phase gave an estimated efficiency of 54%. The fraction of fuel saved during the high power and simmering phases was similar.

On a 3-stove fire the same finned pot saved only 9% of the fuel compared to a previous test with an unfinned pot, however the tests were not conducted in the same way. The height of the pot above the fire was significantly greater with the finned pot, which would lead to reduced efficiency.

In a controlled cooking test of posho done in August, 2008, the Chinese rocket stove with finned pot made posho with 78% of the fuel required to make the same amount of posho with the same stove with a regular pot with skirt.

The same pot was tested on a kerosene stove and performed poorly. The finned pot was tested on a kerosene stove, and compared to the kerosene tests results in Ref. 2. The kerosene stoves were not the same between the two tests, but the finned pot used 33% more fuel.

Slit Fin Pots

With this type of fins two bands of relatively thick aluminum sheet metal are clamped around the bottom of the sides of the pot. The bands are 100 mm tall, and about 50 mm of the bands are hanging down below the bottom of the pot. The aluminum sheet is typically about 1.6 mm thick. This type of arrangement is retrofittable to an existing pot, as long as the bottom 50 mm of the sides of the pot are undented.

In the area where the fins are clamped to the pot, a heat transfer compound must be used to fill in the small gaps between the bands and the pot. Measuring the temperature of the outer band with an infrared thermometer shows that heat transfer between the bands and the pot is good and the temperature of the bands is not too much above the temperature of the water in the pot.

The bottom 50 mm of the bands are cut into slits around 5 mm wide. The slits are the fins, and they are then bent inward and/or twisted to allow the hot gases to pass over and through the slit fins. A variety of bending and twisting arrangements were tried, and this seemed to make little difference in lab tests.

Figure 9 shows the overall arrangement of the system, and Fig. 10 shows a close up of the fins. Hose clamps were used for the lab tests, but a less expensive option could be used to build the clamping arrangement into the band itself, and bolts would be used to provide the clamping force.

Fig. 9: Overall view of the slit fin pot being tested on the simulated rocket stove. Note that the standard pot was used.

Fig. 10: Close up of the slit fins.

If desired, pot supports could be built into the finned section by leaving 3 areas of about 25 mm width unslit. A later prototype used this technique, and the sections were strong enough to easily support the weight of the pot and its contents.

Results-Slit Fin Pots

This pot was also tested in a variety of conditions, both in the lab and on real stoves. In the lab, the average improvement in heat transfer at medium power was 1.76, averaged over 3 conditions. Those 3 conditions were the standard burner with base, the standard burner, and the simulated open fire. Results at low power were similar, and there was little scatter among the 3 tests. By coincidence, these results were nearly identical to the bottom finned pot.

Encouraged by these results the slit fin pot was tested over a variety of real stoves burning various fuels. On a Chinese rocket stove operated by Nordica MacCarty and/or Dean Still, the fuel was reduced from 684 g to 521.5 g, for 76% of the fuel usage. This was for a standard water boiling test with 30 minute simmer. The time to boil was reduced from 26 minutes to 18 minutes, though this will depend on how big a fire is used. They note that a pot with skirt used slightly less fuel than this finned pot.

On a similar stove, the same pots (finned and unfinned) were tested by this author in January, 2009. The initial water temperature was lower in these tests, but other test conditions would be similar. The unfinned pot used 779 g of wood, while the average of two finned pot tests was 659 g, or 85% as much. Time to boil was reduced from 46 minutes to 37.5 minutes with similar starting temperatures.

Dean and Nordica tested the same pair of pots (finned and unfinned) on open fires (3-stone fires). The open fire with standard pot used 1776 g of fuel while with the finned pot 930 g was used, or 52% as much. These were for a water boiling test with a 30-minute simmering phase. They note that a pot with a short skirt used slightly more fuel that the finned pot. As with any open fire test, the results will be highly dependent on how the fire is operated.

On an alcohol stove a brief heat transfer test was done. The fuel used to heat water was measured, along with the temperature rise and evaporation of the water. The heat transfer efficiency can be calculated. For the standard pot that efficiency was 0.57, while for the slit fin pot the efficiency was 0.56.

On a Ghana wood-burning stove tests were done in which a fixed amount of fuel was used to heat water and the heat transfer efficiency was measured, again accounting for the char remaining at the end of the test. The efficiency for the standard pot was 0.25, while that of the finned pot was 0.26. The pot sat higher on the stove and this may have allowed to flame to become more diluted, and thus cooler by the time it hit the bottom of the pot.

On a kerosene stove a pair of water boiling tests was conducted with 45 minute simmering time. For the unfinned pot the fuel usage was 281 g, while for the finned pot the fuel usage was 314 g, 112% as much. Thus, the finned pot used more fuel. This is possibly because the finned put sat higher, allowing more dilution air to enter the flame.

The Finned Wok

A cast iron wok with fins on the bottom was obtained from an unknown source. This is shown in Fig. 11. The fins were about 10 mm tall, probably not tall enough for optimum heat transfer.

Fig. 11: A cast iron finned wok that was tested.

Limited testing was done on the wok in January, 2009. A wok of similar size without fins was also obtained. Two pairs of tests were done, both on a Chinese rocket stove. Each pair of tests included a test with the finned wok and a test with the unfinned wok under similar conditions.

In the first pair of tests a fixed amount of fuel was used to heat a known quantity of water. The amount of energy that went into the water was determined by the temperature rise of the water and the amount that evaporated. Heat lost by conduction or convection from the wok was not measured, however this should be small, and similar between the pair of tests. The efficiency was then calculated by dividing the energy that went into the wok by the energy contained in the fuel, with a correction made for the considerable amount of remaining char at the end of the test. In this pair of tests, the finned wok had an efficiency of 0.213, which was 1.84 times the efficiency of the unfinned wok. The power level was about 2700 W for both tests.

In the second pair of tests 3 liters of water was heated to a boil and held at simmering temperature for 30 minutes. Hence, this was essentially the standard water boiling test, except with 3 liters of water instead of the usual 5. The total energy into the water was again measured by measuring the temperature rise of the water and the amount evaporated. The amount of fuel used was measured, again with a correction for the char remaining at the end of the test. Again the efficiency was calculated. The efficiency of the finned wok was 0.35, which was 1.24 times the efficiency of the unfinned wok. The time to boil was reduced from 27 minutes to 17, though this will also be a function of how the stove was operated. The average power level over the entire duration of the test was about 1800 W for both tests. The power level would have been higher during the heating phase and lower during the simmering phase.

It appears that operating the stove at a lower power level increases the efficiency of the unfinned wok, which leads to a smaller increase in efficiency of the finned wok over the unfinned wok. These water-based tests may not represent how the wok is actually used in practice.

Summary

A variety of types of finned pots were built and tested. Better designs were separated out in the lab, using natural gas to simulate a wood flame. The best designs performed well over a range of conditions using simulated stoves. The finned pots typically gave around a 1.76-fold improvement in heat transfer if the fins were on or near the bottom of the pot, and a greater than 2-fold improvement when the fins were on the sides of the pot.

Tests on actual stoves using wood as the fuel generally gave smaller improvements in performance, with fuel savings generally less than 25%, corresponding to a 1.33 or smaller increase in heat transfer. These tests were also done under a variety of conditions with a variety of stoves, including the open fire. There were a couple tests with finned pots or woks that performed very well.

On industrial fuel stoves using kerosene or alcohol improvements were even smaller, with the finned pots giving 1.2 fold improvements or less. In some tests the finned pot used more fuel than an unfinned pot. The reasons for this wide range of results are not known.

It is not recommended that finned pots be pursued as a means of increasing the efficiency of stoves. Better results can probably be achieved with less effort by using skirts around the pot. These skirts could be attached to the pots with optimum dimensions.

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