Technology Reviews (*)

Stoves, Tents and Carbon Monoxide – Deadly or not? Supplement 1: The MSR Reactor

Roger Caffin revisits the carbon monoxide emissions performance of a production model MSR Reactor stove.

By Roger Caffin

April 29, 2008

Master Index

This is a master index for this many-part series. It lists all the parts of this series, all the stoves tested, and all the updates (new stoves, changes, etc) issued after the initial pages were published.

An early MSR Reactor kit, photo courtesy
MSR

Introduction

In Part 3 of this series, a pre-production version of the MSR Reactor stove was tested and found to emit well over 1,000 ppm of carbon monoxide (CO) at low power. This is a potentially deadly rate of CO emission. In my opinion, the cause was that the air flow into the combustion space was being stalled, so that not enough oxygen was available for full combustion.

My results were sent to MSR shortly before the stove was to be released. At MSR's request, I sent the pre-production stove back to them so they could examine it. I was told by a representative from MSR after their examination that the pre-production unit I had been sent was not meant for actual use and testing: just for examination, and that the jets on it were wrongly set up. This had not been obvious when I inspected the jet region myself, but perhaps the design is very sensitive in this regard. I also have to question the whole idea of sending out slightly defective units meant just for looking at but not for testing: to me that is weird!

The release of the Reactor stove was then delayed while MSR considered the problem and what to do about it. Once they had decided on their course of action and implemented what MSR thought to be the appropriate modifications, the stove was released. In due course I was sent a production stove for repeat testing, and this testing of the production version is reported here.

My Original Analysis and Recommendations

In my analysis of the performance of the pre-production version, I suggested that one to reduce the emission problem would be for the exhaust holes around the base of the pot to be enlarged downwards by a factor of at least two, to reduce the back pressure on the air inlet. I was able to demonstrate a huge improvement in CO emissions by increasing the available exhaust area. In production terms, this would require a change in the dies used to stamp the holes in the guard around the base of the pot. It could be done for existing pots too, but would require either a large number of milling operations per pot, or a complex disassembly of the pot, repunching, then reassembly of the pot (by welding). A repeat anodizing would probably also be needed, for cosmetic reasons if nothing else. This exercise would likely be quite expensive.

I also suggested that the small holes in the stainless steel screen covering the air inlet area might be contributing to the problem. The fuel is injected from a nozzle behind the screen. It flows through an aluminium venturi tube to the mixing chamber under the sintered bed. The diagrams in the original report in Part 3 of this series illustrate this. Actually, the region in front of the venturis. Every extra bit of air would help. Changing the holes in the stainless screen in the region of the jets would be a simple and fairly inexpensive punching operation.

Purely as a matter of general interest, you can see that the stove has been through several changes during its development. The valve mechanism shown in the second photo (below) is different from the valve mechanism shown in the first illustration, which came from MSR. The problems of designing a new stove should not be lightly dismissed.

MSR Measurement Approach for CO Emission

I have taken the fairly simple approach of measuring the CO concentration in the exhaust air stream. A representative of MSR told me that MSR prefers the more sophisticated approach of looking at the volume of CO emitted in time. What this effectively means is that CO concentration is multiplied by the exhaust gas flow rate, (I believe they determine this rate from the chemistry of the combustion process). This approach allows MSR to scale down the CO concentration obtained at a simmer.

I agree that the MSR approach will give a better understanding of the total amount of CO emitted, but I cannot help believing that this is not the full story. If all the CO is to be collected in a sealed tent or building, the MSR approach is the correct one. However, if you are using the stove in a tent pitched outdoors (or in a leaky mountain hut) with ventilation above the stove, I do not think the MSR approach is really that much more relevant in comparison to the one I use. I am going to assume that any user who has read this series of articles will know to ensure he has adequate ventilation. On the other hand, turning the stove down from full-bore to a gentle simmer (which is difficult with this stove anyhow) will produce a cooler exhaust air stream, which may have less of a tendency to push its way out of the top ventilation in your tent. It is not an open and shut case by any means, and both methods have merit.

The new air slots in the stainless steel screen.

MSR Changes and Commentary

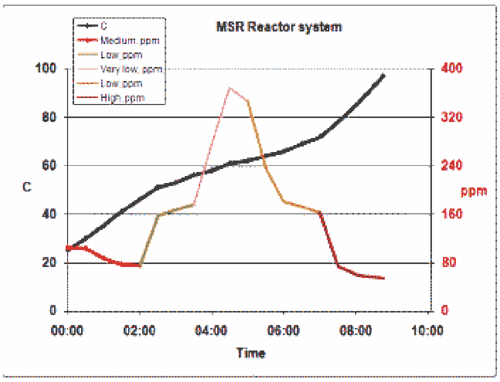
MSR did not implement the recommendation I had made to increase the exhaust area in order to reduce the pressure build-up between the pot and the burner. This would have been a rather expensive exercise if many pots had already been produced, and it seems likely that the quantity held in stock this close to the product release would have been high. As explained below, this may be a reasonable commercial decision.

MSR did implement the recommendation to reduce the restriction on the air flow due to the small holes in the stainless steel screen around the burner. In the pre-production version, the bright steel shim around the burner was perforated with just the small round holes. These have since been enlarged into slots on either side of the control valve. A close examination shows that the original stainless steel surround has been modified, rather than a new one being made, as traces of the original holes are still evident. It is possible to see the brass jets through these slots. The new production version is shown to the right with the slots.

jet is fitted to a stove, this can easily have the effect of altering the amount of air dragged into the gas stream to be too much or too little. It may be that the jets on the production model were also improved, but I have no knowledge of what was done here.

MSR made one other change to the Reactor stove system which I did not expect. The Reactor now comes with three different sets of prominent warnings about the CO hazard and not using the stove in a tent. This approach to dealing with the design problem seems to be more concerned with protecting the company from legal problems than protecting the user from the CO hazard, and I discuss it later. I admit that the approach has left me a bit unhappy, which will show.

Testing the Production Version of the MSR Reactor



CO emission and Temperature versus time.

Heating Rate and CO Emission

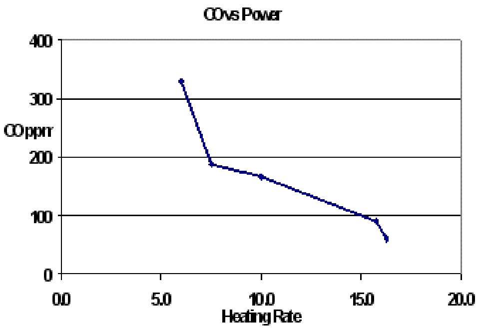
The stove was put through the same test regime this time as for the last time, as outlined in Part 3 of this series. As may be seen in the performance graph to the right, the level of CO emission is certainly reduced. The peak CO emission (of about 350 ppm) is still to be found at the simmer, rather than at full power, while the CO emission level at 'full power' is around 80 – 100 ppm. To summarize, the CO emission at a simmer has been reduced to about one third of the previous level.

The first graph shows the Reactor being tested at a range of power levels, while the second graph shows the CO emission rate plotted against the heating rate, measured in degrees Centigrade per minute for one liter of water (C/L.min). Even higher power output may be possible: this stove is about the most powerful stove I have tested. Whether such extreme power is really what a walker needs is another matter: it might be useful when melting snow, except that the canister would freeze very quickly if operated this way in the snow. I will digress briefly to explain why this is so:

The temperature of the canister did not seem to change over a test run. Since the radiant burner is very well screened from the canister, this is not unexpected. However, combining this with the shrouded design of the burner does mean that this stove will not provide much feedback heat to the canister. Accordingly, I expect it to suffer from the usual upright stove problem of the canister cooling down as gas evaporates, especially in cold weather. This cooling gets worse the faster the gas evaporates, which means that the MSR Reactor would not be a good choice for use in the snow, or even in very cold weather.

On the other hand, operation at the low power setting shown in the graph looked a bit unsafe to me: the flame was flickering a bit over the surface of the burner at the minimum power, and I was concerned that any further reduction could result in the flame accidentally going out. This would allow unburned gas to escape and build up – an extreme simmering.

Looking at the actual emission of CO at the different power levels, we can see that the high power operation with an emission level of 80 – 100 ppm may be tolerable provided the stove is operated outdoors. On the other hand, operation at low power releases a lot of CO, making the stove quite dangerous if operated in any confined space. The warnings given by MSR about the use of this stove in a confined space should be heeded: it would be dangerous. Unfortunately, a lot of my cooking involves a gentle simmer for a period of time.



Heating Rate versus CO emissions.

Technical Analysis

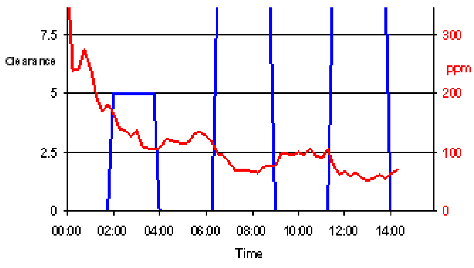
The effect of the power output on the CO emission is obvious – and the opposite of most other stoves. With other stoves, there often seems to be a limit in the amount of air sucked into the burner at high power, meaning the flame is slightly starved for oxygen at high power. With the Reactor, the problem is more complex. I do not think it was getting enough air at high power, despite the modifications around the inlet – and that was near sea level. At high altitude this problem is likely to be worse.

At low power I think there may two problems. It may well be that the ability of the jets to suck in enough air at low speed is still inadequate. I tested this in the previous report by injecting extra air at the jets and found an improvement with increased air flow. There may be a second problem as well: at low power, the face of the burner does not get really hot all over and parts of it may be cold enough to actually quench the flame. Without more detailed experiments I cannot tell which of these is more significant.

If you refer to the original test results for the MSR Reactor, you will see that another change was also examined: making a gap between the pot and the burner to reduce the back pressure in the combustion chamber. This allowed the jets to suck in more air and caused a significant reduction in the level of CO emission. In the previous report, I suggested that the exhaust holes on the pot should be enlarged to reduce the back pressure. MSR has chosen to not change the size of the exhaust holes around the pot, and this is examined in some detail next.

The Exhaust Holes on the Pot

The question is whether decreasing the pressure inside the combustion chamber would further reduce the CO emission level. This was tested in exactly the same way as before, by raising the pot slightly off the burner. That is, an extra exhaust air gap was created. The results of doing so are shown in the graph to the right, with both the CO level and the clearance being plotted. The heating rate averaged to about 8 C/L.min, which is about medium for most stoves, but fairly low for the Reactor.



CO emissions and Clearance versus time.

The results are nowhere near as dramatic as with the pre-production version of the Reactor. It is possible to see a slight oscillation on the CO emission as the clearance is stepped up and down, but the effect is small this time. The CO level goes down by about 25 ppm when the clearance is raised from 0 to 10 mm. In my opinion, this effect is barely worth worrying about relative to the overall CO emission level. As a result, I have to say that it seems fairly unlikely that increasing the size of the exhaust holes around the base of the pot would significantly reduce the CO level any further. I can understand MSR deciding to not incur the huge cost of re-machining every pot in stock for such a small improvement in CO emission.

What is not clear from these new results is what actually caused the small variation in CO emission this time when the clearance was increased from 0 mm to 10 mm. One possibility is that it was because of improved incoming air flow, due to the reduction in back-pressure in the space between the burner and the pot, thanks to the increased exhaust area available. An alternative explanation is that the reduction in CO emission was due to an increased availability of oxygen coming into the space between the burner and the pot through the gap, so that more late-stage burning could occur. It is not possible to tell which applies without more complex testing, which I have not done.

Summary of Analysis

Obviously, I would like to see an improvement in the amount of air dragged in by the jets, to reduce the high overall CO emission. My interpretation of the rest of these results is that the size of the burner may be contributing to the problem: it seems to be too large in area for normal walker use. A smaller burner might limit the peak power, but it could also mean the burner face would stay hotter and cause less flame quenching at low power. However, this is purely speculation on my part.

Transient Effects

As seen in the last graph, the overall CO emission level started very high but decreased slowly over time. This is not an artifact of the measurement system (I checked), so it must represent a real decrease in the CO emission over time. Why does this happen? We know that CO emission is often due to the flame being quenched (cooled) too soon, usually by a cold surface.

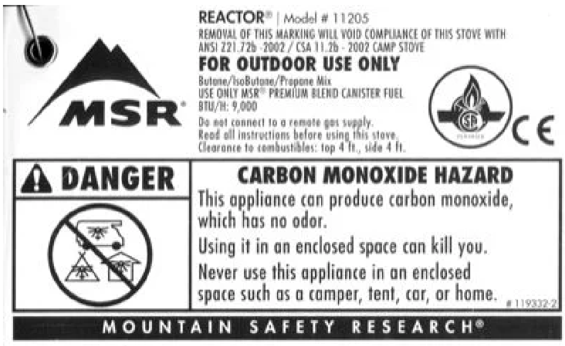
The base of the pot is cool relative to the flame temperature, even when the water in the pot is boiling, but I do not believe that the change in the pot temperature over time played a part in the change in CO emission. After all, the change in pot temperature as the water heated up is miniscule compared to the very high temperature of the flames and could not lead to such a large effect. However, watching the surface of the radiant burner and the mesh over the top of the burner through the clearance gap during testing showed that both the outer edges of the burner face and the edges of the mesh heated up quite slowly. These parts are inside the combustion zone, and their temperatures are going to be far more critical in quenching. In fact, the slow heating of the edge of the burner correlated well with the time taken for the CO emission to fall. I believe this is a significant the source of the CO emission at low power.

emission (around 5 ppm) and stay this low. This is in marked contrast to the Reactor. The Primus EtaPower system is an integrated heat-exchanger system with heat-absorbing fins near the top of the flame path. The CO emission from that system peaks at about 16 ppm when the stove is lit, but the CO emission drops back to under 5 ppm within a minute. Another heat-exchanger stove system (yet to be reported on at the time of this report) has the fins on the pot too close to the flames and does produce a much higher level of CO emission. That high level is sustained, as the fins never get hot enough to avoid quenching the flame.

It may be tempting to suggest that the very high level of CO emission from the Reactor is "just a transient effect." Unfortunately, most users will probably be heating just one pot of water at a time and will therefore have to endure the initial high level of CO emission every time they use the stove. In addition, the length of the 'transient effect' is a significant fraction of the heating time for a liter of water. The best solution would be to run the stove hard, getting the burner hot quickly, and to do this outside even in bad weather.

Hazard Warnings

A fuel stove represents several hazards. There is a concentration of highly inflammable fuel, some very high temperatures, and dangerous exhaust products such as carbon monoxide. All stoves I have tested (with the exception of a few small alcohol stoves) rightly carry some sort of warning about these hazards. However, this particular stove carries far more warning labels than any other I have tested, and which I find problematic. My concern is whether MSR is trying to handle the CO risk by legal warnings (to protect the company) rather than addressing the source of the CO emission (to protect the user). I have detailed all the warning labels below, and I leave it to the reader to decide. I admit that my personal opinion may be apparent.



The white swing tag attached to the stainless steel screen.

Swing Tag

MSR added a robust swing tag of heavy synthetic paper to the revised version of the stove. The tag carries a large warning about the CO hazard. It is attached to the stove with a crimped loop of stainless steel wire, threaded through holes in the stainless steel screen and through a riveted eyelet in the paper. To remove this extremely inconvenient tag requires cutting the very tough stainless steel wire, and prominent text on the tag warns that such removal "will void compliance of this stove with [standard...]." A similar tag on a recent Coleman stove is held in place by a conventional and easily removable split key-ring, and while that one carries a similar warning, the warning is relegated to a back page.

Comment

My understanding is that this tag may be a legal requirement in some jurisdictions: I have seen it on a few other stoves. The MSR representative assured me in all seriousness that I am meant to leave this swing tag permanently attached while using the stove in the field. It is really quite inconvenient having it flapping around, and I cannot imagine any smart move: it is tantamount to teaching customers to ignore all of MSR's warnings. I note that Coleman seems to have no problem using a removable split ring for the attachment.

Yellow Note

Also included in the box containing the stove was a small, bright yellow slip of paper. This slip of paper carries further warnings about the CO hazard. In fact, the contents of this slip of paper are quite revealing, and I have paraphrased the contents here.

> ## IMPORTANT SAFETY INFORMATION
>
> "The MSR Reactor is a unique stove that relies on radiant burner technology…We designed the Reactor to be used outside, not in tents or other enclosed spaces.
>
> It is important to know that under certain conditions, the Reactor can produce more Carbon Monoxide than other backpacking stoves. Like similar radiant burner appliances, the Reactor produces more Carbon Monoxide at low output, or "simmer," than at medium or high output. When any stove is used inside a tent or other enclosed spaces, oxygen is consumed and Carbon Monoxide is produced. Using a stove inside a tent or other enclosed space will kill you…
>
> Never use the Reactor or any other stove inside an enclosed space such as a tent, camper or house. **The Reactor is FOR OUTDOOR USE ONLY."**

Please read and retain this insert with your Reactor Instruction Manual

IMPORTANT SAFETY INFORMATION

The MSR Reactor® is a unique stove that relies on radiant burner technology. This technology makes the Reactor very efficient and effective by reducing cooking time and providing you with the ability to cook in harsh environmental conditions without a significant effect on stove performance. We designed the Reactor to be used outside, not in tents or other enclosed spaces.

It is important to know that under certain conditions, the Reactor can produce more Carbon Monoxide than other backpacking stoves. Like similar radiant burner appliances, **the Reactor produces more Carbon Monoxide at low output, or "simmer," than at medium or high output.** When any stove is used inside a tent or other enclosed spaces, oxygen is consumed and Carbon Monoxide is produced. Using a stove inside a tent or other enclosed spaces will kill you. The Reactor stove should always be used outside in an open space where there is an abundant and frequent exchange of fresh air.

Never use the Reactor or any other stove inside an enclosed space such as a tent, camper or house. **The Reactor stove is FOR OUTDOOR USE ONLY.**

Please READ, UNDERSTAND, AND FOLLOW all instructions and warnings inside the Reactor instruction manual and on the fuel canister.

MSR

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The yellow warning slip in the box.

Comment

I am pleased to see that MSR is acknowledging the risk and warning the user that this stove will produce elevated levels of CO, especially at low power. However, the bald statement that '"using a stove inside a tent will kill you" is false: thousands of walkers cook inside their tents daily as a matter of course. I have done so for the last ten or twenty years, especially with canister stoves. I am still alive – and so are most other walkers. Yes, a very few people have died when they used a stove inside a sealed tent – usually one which has been really sealed up with no air flow at all – which is very different from just "inside a tent."

In addition, you should think about the number of houses which use a gas stove inside the kitchen for all the cooking, the number of caravans and mobile homes which use an LPG stove inside for daily cooking, and the number of kerosene-powered radiant heaters used inside homes. These are all similar gas stoves, and all fit into the same "enclosed space" rule which MSR is describing.

the MSR product warnings. This is dangerous, especially in this case, because the Reactor stove does produce far more CO than most any other stove I know of.

The warning sticker on the pot.

Pot Sticker

Finally, MSR has added a very large warning sticker on the side of the special Reactor pot. This not only repeats the warning about using the stove in a tent, but adds a fire warning and an explosion warning in large graphics, then goes on to warn about windscreens and use by children under ten years of age. The sticker can be removed, albeit with some difficulty. I am not sure what it would smell like if it gets rather hot.

Comment

In my personal opinion, there are too many warnings with this stove: there is a risk that the user will tune them out completely. The risk portrayed by all these warnings stands in stark contrast to the fact that gas cooking is routinely used in millions of homes – and customers know this. On the other hand the CO emission from this stove is potentially and particularly dangerous.

Summary

Clearly the production version of the MSR Reactor is much improved over the pre-production version. However, I must point out a few things here.

One cannot help feeling that MSR – or at least the company's lawyers – are really, really worried about this stove. I have never before seen such a density of prominent alarmist warnings on a single stove. We know stoves have to be handled with some care, but the warnings' effect simply convinces me that MSR is really worried about this stove in particular. So where does that leave me, the customer?

The power of this stove is due to the novel radiant burner system. This burner is also the source of the high levels of carbon monoxide. While the technology is fascinating, I have to ask whether the trade-off between power and CO emission is in the best interests of the average walker. In particular, I note:

- The stove emits a relatively high level of CO under all conditions, but especially at a simmer. It should only be used outdoors.
- The best performing upright stove (Snow Peak GST100) produced something like 5 ppm at a simmer, compared with 300 ppm for the Reactor.

80 – 100 ppm for the Reactor.

- Two other heat exchanger stoves tested (Primus EtaPower EF and Jetboil GCS) produced something like 3 – 5 ppm at a simmer, compared with 300 ppm for the Reactor.
- The best performing heat exchanger stove (Primus EtaPower EF) produced something like 13 ppm at full bore, compared with 80 – 100 ppm for the Reactor.

It is extremely difficult to get the Reactor to simmer – some might say simply impossible. The lowest stable power I was able to get was in what I would call the medium power range for most other stoves. This is less than helpful, as many walkers do a fair bit of gentle simmering in their cooking.

In my experience, the power available from the MSR Reactor is considerably more than would ever be really needed, unless you are trying to melt vast quantities of snow. However, using fuel at the high-power rate is going to cool the canister down quite quickly. In sub-freezing conditions outside on the snow, that means the butane will be cooled to below its boiling point, and the stove could quickly stop functioning. This is a well-known problem with upright canister stoves in the snow. The use of an iso-butane canister will push the operational temperature down a bit more, as iso-butane boils at a lower temperature, but to rely on the weather only going a little below freezing when you are on a multi-day trip in the snow is optimistic. I am left uncertain what market really suits this stove. It is a nice technology, but is of what value to walkers?

Categories:
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By Roger Caffin

Research Scientist. Been walking all my life, mainly off-track - we don't have 'trails' here, and I always go with my wife. Summer and winter, lowland and highland, Australia and Europe. Forced into UL gear by heavy packs and increasing age. :-)

Discussion