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Stoves, Tents And Carbon Monoxide – Deadly Or Not?

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Research & Testing

Stoves, Tents and Carbon Monoxide – Deadly or Not? Part 3: Laboratory Measurements for Canister Stoves



Actual canister stoves are surveyed to see which ones are clean and which ones emit too much carbon monoxide.



By Roger Caffin

May 30, 2007





Monitoring Carbon Monoxide from a stove.

Introduction

Buy a small stove these days and it is likely to come covered in dire warnings about the risk of carbon monoxide (CO) poisoning, adamant that you must not use the stove in any sort of confined space. And yet walkers have been using small stoves inside their tent vestibules in bad weather for many, many years with very few instances of trouble. What is the risk, why are all those warnings there, and how seriously should we take them?

This multi-part Series of articles explores the carbon monoxide issue. [Part 1](#) covered the basic theory underlying how stoves work and how they can generate carbon monoxide. A theory was developed as to the cause of carbon monoxide being emitted. [Part 2](#) covered an extensive amount of laboratory testing of a wide range of canister stoves to test this theory.

All the results found in Part 2 confirmed the theory: carbon monoxide is generated when the stove flame is quenched by having the burner too close to the pot. Factors such as pot diameter do not affect the result, but burner design does. Keeping the flame from hitting the pot too soon and making sure enough air is available are the keys to low CO emissions.

This Part 3 covers laboratory testing of a wide range of canister stoves, of both upright and remote canister variety, to see what sort of performance they have in the factory state. In some cases where a high CO emission was found the effect of raising the pot and increasing the air supply was checked. One [especially troubling case](#) is discussed in detail towards the end of the article.

A Look Back at Part 1

Part 1 examined the theory behind the combustion process in small stoves, focusing mainly on the three hydrocarbon fuels: butane/propane, white gas and kerosene. The conclusions were:

- Carbon monoxide can be emitted by a stove under the right conditions.
 - This carbon monoxide can present a serious health hazard.
 - The risk increased from butane/propane to white spirits to kerosene.
 - Some stove designs may be worse than others because the pot is placed too close to the burner.
 - The hazard is not inevitable: there would seem to be ways to reduce it to negligible levels.
 - Long flames and yellow flames may indicate a CO hazard.
 - Ventilation is crucial under any circumstances.
-



The CO Test Chamber

A Look Back at Part 2

Part 2 tested the theory by examining a range of canister stoves of different designs. The conclusions from this testing are as follows:

- Some stoves emit almost undetectable amounts of CO, so a clean stove is possible.
- Some other stoves emit quite a lot of CO in their factory state, so much care is needed.
- In the bad cases, increasing the separation between the burner and the pot usually decreases the CO level.
- Pot diameter does not have any significant effect on the amount of CO emitted (contrary to rumour).
- Burner design does affect the amount of CO emitted: horizontal flames are best while vertical flames are the worst.
- Inadequate air supply into the burner column (air holes too small) will raise the CO levels.
- Provided an enclosure has at least 9 – 10 square inches of air inlet and air outlet, CO levels should not be high.
- Integrated windshields may have a bad effect on the amount of CO emitted, depending on the design.

Outline and Scope of Part 3

In this article we test a range of canister stoves for CO emissions. An attempt has been made to cover as wide a range of current canister stoves as possible, within reasonable weight constraints suitable for light-weight walkers.

** Should any manufacturers wish other similar canister stoves to be included in this article they should contact the [author](#) at Backpacking Light.*

It would be nice to be able to make all measurements in a tent, but there are so many variables inside a tent (like the weather outside the tent!) that such measurements would not be very helpful. To separate out all the different influences I need to test under far more controlled conditions. So in this series the testing has been conducted in my

about each stove.

Stove	Canister Style	Fuel Feed	Burner Size	Wt (g/oz)	Inc Pot
Brunton Flex	Upright	Gas	Large	97 g / 3.4 oz	
Brunton Raptor	Upright	Gas	Small	158 g / 5.6 oz	
Coleman Xtreme	Remote	Liquid	Large	313 g / 11.0 oz	
Coleman Fyrestorm Ti	Remote	Liquid	Large	310 g / 10.9 oz	
Coleman F1 Ultralight	Upright	Gas	Small	76.5 g / 2.7 oz	
Jetboil GCS	Upright	Gas	Medium	568 g / 20.0 oz	Yes
Kovea Expedition	Remote	Gas/Liq	Large	448 g / 15.7 oz	
Kovea Moonwalker	Remote	Gas/Liq	Small	340 g / 12.0 oz	
MSR WindPro	Remote	Gas/Liq	Large	192 g / 6.8 oz	
MSR Pocket Rocket	Upright	Gas	Small	86 g / 3.0 oz	
MSR Reactor	Upright	Gas	Very large	595 g / 21.0 oz	Yes
Optimus Crux	Upright	Gas	Medium	93 g / 3.28 oz	
Optimus Stella +	Remote	Gas (only)	Medium	266 g / 9.38 oz	Yes
Primus Gravity ME	Remote	Gas/Liq	Large	243 g / 8.47 oz	
Primus EtaPower EF	Remote	Gas/Liq	Medium	608 g / 21.45 oz	Yes
Primus Micron Ti 2.5	Upright	Gas	Medium	69 g / 2.43 oz	
Snow Peak GS(T)100	Upright	Gas	Small	74 g / 2.5 oz	
Snow Peak GS200D	Remote	Gas/Liq	Medium	284 g / 10.0 oz	
Trekka/Gasmate (modified)	Upright	Gas	Large	309 g / 10.9 oz	
Vargo Jet-Ti	Upright	Gas	Small	82 g / 2.9 oz	

Notes

* Those stoves which are sold specifically to take a liquid feed are recorded as such. By and large, ‘upright’ stoves only take a gas feed as they don’t have a built-in heat exchanger.

* The entry ‘Gas/Liq’ means that the stove is advertised and sold for use with a gas feed, but as it includes a preheat tube it can also take a liquid gas feed when the canister is inverted. In practice any remote canister stove with a preheat tube can handle a liquid feed but for various reasons (e.g. lacking approval from certifying authorities) not all vendors mention this.

* The Jetboil GCS, MSR Reactor and Primus EtaPower EF stoves are all rather heavy by comparison, but they are included here because of interest in the ‘heat exchanger’ aspect. They all come with their own pots with integrated heat exchangers, and these pots are included in the ‘stove’ weight. For a fair comparison, add the weight of your favourite pot

in Part 2, with the second version being a modified version of the first one. The currently available form of this generic stove is close to the modified form (the factory changed), and this stove is included here purely for reference.

* The Kovea stoves are made by a Korean factory which also makes stoves for many of the 'mainstream' walking companies. The Kovea stoves are robust but a little too heavy for lightweight walkers. They have been included here for reference as they were a major component of the tests in Part 2, and they would be suitable for group use at a base camp.

Health and Safety Guidelines

Carbon Monoxide

This table was shown in Part 2, but it is repeated here as the key reference for gauging the danger of the CO emission level.

Conc, ppm	Effect
0 – 1	Normal background
9	Max allowed for short term exposure in a living room, acc to ASHRAE, USA
25	Often encountered on major roads – UK figure
30	Health and Safety limit for 8 hours – UK
35	Suggested max allowable concn for continuous exposure for 8 hr – ASHRAE, USA
100	May be encountered on major roads during weather inversions – UK figure
200	Health and Safety limit for 15 minutes – UK
200	Mild headache, fatigue, nausea, dizziness. Limit for transient exposure – USA
200	Slight headache, tiredness, dizziness, nausea after 2-3 hr – ASHRAE, USA
300	Can lead to collapse – UK MoD
400	Frontal headache, life threatening after 3 hrs

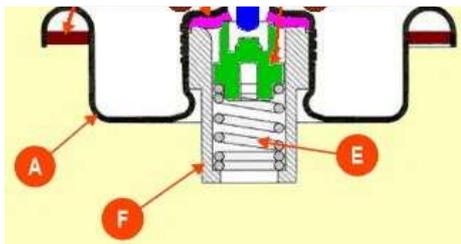
ASHRAE: American Society of Heating and Residential Air-conditioning Engineers

UK MoD: UK Ministry of Defense

Butane and Propane

Apart from hazards associated with CO levels, there are also hazards associated with the butane and propane fuel itself. These are heavy and highly inflammable gases that can accumulate at floor level if there are leaks. Fortunately the manufacturers include a very detectable trace gas in the canisters to alert the user to any leaks. My understanding is that something like a mercaptin is often used, and the human nose is extremely sensitive to such a chemical. It stinks.

There are a few more hazards to watch for other than the obvious fact that the stoves get hot. The first is that the valve on the stove can become slightly open during storage, and if you connect the stove to the canister without checking that the stove valve is shut **first** you may have a slow but extremely dangerous leak. The danger is apparent, though it may not be easy to tell that the valve is open. The Snow Peak GS(T)100 stove is well known for this behaviour as the valve must be slightly open to allow the handle to flip up for storage. Cracking the valve in this way before storage may prolong its life.



Cross-section through a standard Lindal valve.

The second hazard is rather technical and can be quite startling the first time. The canister has a sealing valve inside the spigot to which the stove is screwed: in fact the whole spigot arrangement is made by the Lindal Group and is called a Lindal Valve. A cross-section of a Lindal Valve is shown here, as parts A to F. Gas won't come out of the canister until the valve itself (green, part D) is pushed down against the spring (part E) to leave a gap between it and the neoprene seal (pink, part C). A short pin inside the screw-thread fitting on the stove pushes down on the valve to open it when the stove is screwed onto the canister, and this pin is represented by the solid vertical blue line. When the stove is screwed onto the Lindal valve fitting an O-ring in the stove connector, shown in brown with a thin blue line pointing to it, will seal the gas in.

However, there seems to be some variation in the dimensions of the Lindal valve and spigot and the length of the valve-opening pin on the stove. Some of this variation may come from the way the Lindal Valve is crimped onto the gas canister body (the author has measured actual cases of this). Ideally the top edge of the screw-thread spigot would contact the sealing O-ring inside the stove fitting just before the pin pushes down on the valve, but this does not always happen. Sometimes the pin starts to push the valve down first, before the O-ring seals. This can let liquid or gaseous butane/propane mix come hissing out of the junction between stove and canister. Need I point out that this is potentially dangerous if allowed to go on for any length of time? For this reason you should never leave a stove screwed only half-way onto a canister. Under these conditions the pin may be pressing the valve slightly open while the O-ring is not sealing. I have had a canister nearly empty itself on the workbench this way once! This means a huge quantity of gas had leaked out into my workshop: fortunately it dissipated before reaching an explosion threshold.

The message here is two-fold. Before going out in the field you should get some idea of how the stove *you* have behaves with the canister you have: does the pin open the valve early or late? In any case, when you screw the stove onto the canister you should do so with it upright and do it fairly quickly *and* fully to minimise the time when gas could leak out. One combination I found particularly prone to this brief period of leaking was the Coleman F1 Ultralight going onto a Kovea 230 g canister, although there were others. To repeat: you should either have the stove screwed on tight *or* have it totally removed from the canister.

The Measurements

The measurement protocol was extensively discussed in Part 2. What is important here is that all stoves were tested under identical conditions. Further more the measurements were not just brief spot readings but were averaged over several minutes in all cases.

Test Results – Overview

Each stove has been carefully tested in the laboratory with results as given below; most stoves have also been tested in the field. Results are given for CO emission at two or three nominal power levels: low, high and sometimes medium. Only a few stoves were tested at medium power: it was usually only done to shed extra light on strange behaviour. Test results shown are all for a large diameter [GSI Bugaboo pot](#), with the exception of the heat-exchanger stoves where the included pot was used. Exact power levels are not quoted for each test as they varied slightly between stoves, but they are approximately as follows for 1 litre (1 qt) of water).

- Medium: in between Low and High
- High: a reasonably efficient rate for boiling water or melting snow, but certainly not flat out – about 10 C/min (18 F/min).

Stove	Wt (g/oz)	Pot inc	ppm, low	ppm, medium	ppm, high	Recommended (low CO)
Brunton Flex	97 g /3.4 oz	No	160	158	142	
Brunton Raptor	158 g / 5.6 oz	No	88		286	
Coleman Xtreme	313 g /11.0 oz	No	5		5	Yes (winter)
Coleman Fyrestorm Ti	310 g / 10.9 oz	No	5		30	Yes (winter)
Coleman F1 Ultralight	76.5 g /2.7 oz	No	75		154	
Jetboil GCS	568 g / 20.0 oz	Yes	5	6	90	
Kovea Expedition	448 g / 15.7 oz	No	6		12	(Yes, winter)
Kovea Moonwalker	340 g / 12.0 oz	No	30		50	
MSR WindPro	192 g /6.8 oz	No	30		85	
MSR Pocket Rocket	86 g / 3.0 oz	No	240	220	140	
MSR Reactor	595 g / 21.0 oz	Yes	1,000		50	No
Optimus Crux	93 g / 3.28 oz	No	300		260	
Optimus Stella +	266 g / 9.38 oz	Yes	47		136	
Primus Gravity MF	243 g / 8.47 oz	No	10		100	
Primus EtaPower EF	608 g / 21.45 oz	Yes	3	8	13	Yes (winter)
Primus Micron Ti 2.5	69 g / 2.43 oz	No	40	88	90	
Snow Peak GS(T)100	74 g /2.5 oz	No	5		21	Yes
Snow Peak GS200D	284 g / 10.0 oz	No	260		130	
Trekka/Gasmate (modified)	309 g / 10.9 oz	No	120		100	
Vargo Jet-Ti	82 g / 2.9 oz	No	30	12	22	Yes

The extraordinary test results for the MSR Reactor are discussed further at the [end of this article](#).

The “Recommended (Low CO)” column indicates with a “Yes” those stoves which *in the author’s opinion* have acceptably low levels of CO emission. Those stoves the author considers especially suited for winter use are noted as well with the “(Winter)” designation. Stoves emitting what the author considers to be a dangerously high level of CO are

may be upset that their favorite stove does not get top marks. However, these are the results of the author's tests.

Please note that Backpacking Light does not express an opinion about or attempt to define an acceptable level of CO emission, nor does it make any recommendations about which stove you should choose.

General Analysis

What may be seen immediately is that some stoves are capable of emitting very low levels of CO – some under 10 ppm. These stoves are clearly safer than ones which emit over 50 ppm, and given the options, there seems little reason to accept a stove which emits potentially dangerous levels of CO – say over 150 to 200 ppm. That does not mean that the best performing stoves can be safely operated inside a completely sealed tent or building: they all need *adequate* ventilation. You have been warned!

It will be seen that many of the stoves which perform well at low power do emit a little more CO at high power. The simple explanation for this is that at high power more air is needed to avoid the flames becoming longer and being quenched by hitting the pot, but the air inlet holes are not quite large enough. As long as the increase in CO emission is not large (say not going over 50 ppm) this may be tolerable, **provided you ensure adequate ventilation!** On this score you should note that these tests were conducted near sea level. Since the air pressure drops at high altitude where these stoves are likely to be used most often, it is clear that ensuring an over-supply of air at sea level would seem a very sensible design.

However, in a couple of cases it will be seen that the increase in CO emission at high power is serious, and it is appropriate to ask why this has happened. It is the author's opinion that many of these stoves simply lack adequate air inlet holes for high power operation. While doing the tests outlined in [Part 2](#) the author increased the size of the air inlet holes in a couple of stoves, and as a result the CO emissions dropped. It would be nice if all manufacturers followed up on this and increased the size of the burner column air holes at the factory. Doing so would make these stoves more useful and safer at high altitudes.

Overall, it seems to the author that most stoves could also be improved by a *slight* reduction in the size of the jet. This would make the gas velocity at the jet faster for the same stove power, and this higher jet velocity would drag more air in through the air inlet holes. This modification, if made *in addition* to increasing the size of the air inlet holes (this idea was examined in Part 2), will result in a decrease in CO emission. Since all this testing was done near sea level, at high altitude the amount of air coming in through the air inlet holes is going to be reduced anyhow, making the problem even worse. I surmise that the manufacturers do not want to reduce the size of the jet because that might reduce the (claimed) peak power output, making their stoves look inferior in the great machismo boil-time marketing game. Since I never use the stove anywhere near peak power but do care about the CO emission, I am not happy about this trade-off.

Not tested in parts 1 and 2 of this series is whether the diameter of the burner column is adequate. Obviously this cannot be tested without making up a series of burners which are identical except for the burner column, and this was beyond the scope of this series. However, given that enlarging the air holes to improve the air flow has generally helped to reduce the level of CO emissions, I cannot help but wonder whether increasing the diameter of the burner column a small amount might not also improve the air flow and reduce the level of CO emissions. I have not tested this.

What seemed initially strange is that in a couple of cases the CO emission *dropped* as the stove power was increased. This required serious thought during the research reported in Part 2. In some stoves the design of the burner includes a cup or 'windshield' under the burner, and it was found in Part 2 that this radically altered the air flow around the flames. Observation showed a major difference in flame appearance between low and high power. At low power the flames went straight up and stayed bottled inside the cup, with only a small perimeter for extra oxygen to come into the flame, while at high power the flame spread outside the region of the cup with a significant increase in perimeter or surface area. Actually, this general explanation can also be applied to the stoves where the flames went straight upwards because of

would seem to be a CO hazard anyhow.

A noticeable thing with so many of the poorer-performing stoves is that the performance would significantly improve if the manufacturer increased the clearance between the pot and the burner by 5 – 10 millimetres (0.2 – 0.4 in). While the data has not been presented here, results obtained during testing show clearly that it simply is not necessary to have the pot so close to the burner in still air. The same rate of heating is achieved with the pot slightly higher. Using the MSR WindPro as a classic example, the CO emission is decreased by half to a much more acceptable level with only a 5 millimetre (0.2 in) increase in the clearance. It would even be worthwhile to spot-weld three small bits of stainless steel to the pot supports in this case! Would the slight increase in pot height imperil the stability of the stove? Most unlikely in my experience.

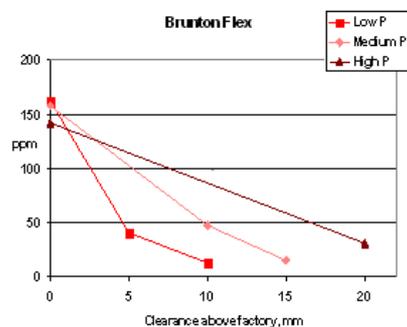
However, Joel Svedlund of Optimus International did point out that having the pot a little closer to the stove than I consider optimal may be useful if the stove is being operated in windy weather without a windshield. Under those conditions the flame gets blown sideways, and some heat can be lost. This was highlighted by Will Rietveld in his article [Performance Comparison Testing of Lightweight Canister Stoves: Controlled Data Evaluating Key Variables of Temperature, Wind, and Windscreen Use](#). While this effect is real, I suggest that using a windshield under these conditions is a *far* more intelligent solution.

Test Results – Individual stoves

Brunton Flex 97 g /3.4 oz



Brunton Flex (courtesy Brunton)



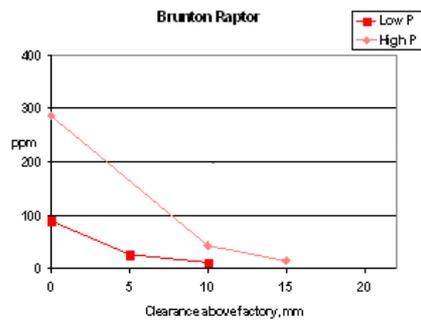
CO Emissions vs Stove Clearance

Like the Optimus Crux this small light stove also packs away very flat thanks to a folding burner head. There is a ball-joint between the burner column and head and a spring-driven sleeve to lock the head in place. The pot supports fold in over the burner face. In fact, the whole stove is quite similar to the Optimus Crux. They may share a common ancestry. But this stove is gold, not black, and the wire handler on the valve is a little different.

The CO emission rate is very high at all powers when the pot sits on the supports, but it drops as predicted as soon as the pot is lifted. In an almost text-book example, the amount of lift needed to get the CO level down to an acceptable level (say below 50 ppm) depends directly on the power level: the higher the power (or gas flow), the more clearance is needed. In fact, up to 20 mm (0.8 in) of extra clearance would be useful. A larger air inlet would also help of course.



Brunton Raptor (courtesy Brunton)



CO Emissions vs Stove Clearance

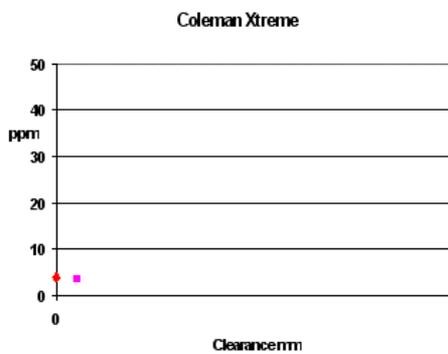
This Brunton stove is a little heavier than the Flex, but it is both very solid and includes a piezo-ignitor. It appears that the weight comes from the stainless steel pot supports and the plated brass body. The burner looks very similar to that on the Snow Peak GS100 and Vargo Jet-Ti and has the flames coming out sideways. This is better than straight up, but the clearance between the burner and the pot is still rather low – of the order of only 14 mm (0.55 in).

Testing showed that the stove is capable of a quite high power – Brunton claim 3.5 kW or 12,000 BTU, but at the cost of high CO levels at high power. Raising the pot once again reduced the CO level in a text-book manner, and again up to 20 mm (0.8 in) of extra clearance would be useful.

Coleman Xtreme
313 g /11.0 oz



Coleman Xtreme (courtesy Coleman)



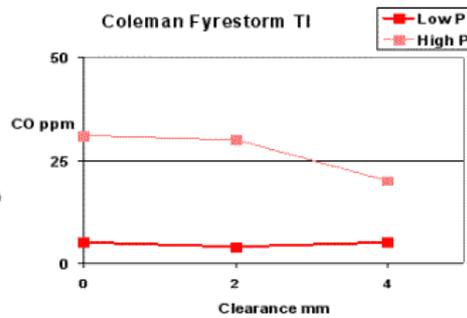
CO Emissions vs Stove Clearance

The Coleman Xtreme is a remote canister stove designed for serious winter use. For many experienced winter walkers it is the automatic choice, despite the higher weight. It is the very high reliability under conditions of acutely bad weather that appeals. It uses some special very light Powermax canisters, as shown in the picture. It can of course also be used in the summer although there are lighter options then. The big problem is locating the Powermax canisters – outside America they can be quite hard to find.

Owing to a good burner design coupled with a good burner to pot clearance it has very low CO emission levels at all power levels, so the graph is not very interesting. It is an excellent choice for a tent when the weather is bad.



Coleman Fyrestorm Ti



CO Emissions vs Stove Clearance

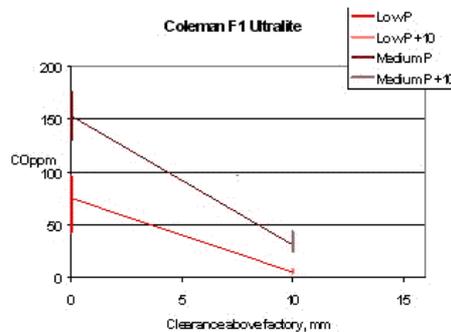
The Coleman Fyrestorm Ti is a new remote canister stove designed to work with standard screw-thread canisters, and it too is suited to serious winter use. It has a large diameter burner with a moderate flame tilt. An integral part of the design is that the common screw-thread canister is deliberately used upside down to give a liquid-feed. As a small bonus the stove comes with a tank for use with white gas, although it is unlikely anyone would bother with white gas after the carefree experience of using it with a canister. It can of course also be used in the summer. I find it curious that the two canister stoves designed for use in winter with a liquid feed both come from Coleman: what do they know that the other manufacturers have missed out on so far? A very strange situation.

Like the Xtreme it has very low CO emission at low power. At high power the CO emission does rise slightly, but not to a serious degree. Perhaps a slightly larger set of air inlet holes might improve this.

Coleman F1 Ultralight
76.5 g /2.7 oz



Coleman F1 Ultralight



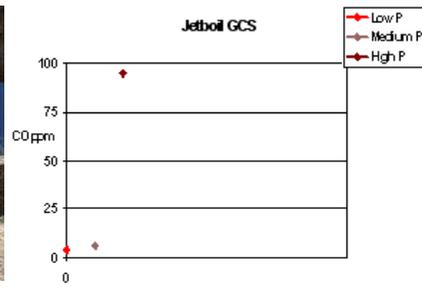
CO Emissions vs Stove Clearance

The Coleman F1 Ultralight is an upright canister stove designed to work with standard screw-thread canisters. It is up there with the best on weight, and has a small diameter burner with a moderately tilted burner face. It has two novelties: the use of plastic just under the burner head, and the fact that the burner head can be completely removed for storage. The plastic ring under the burner head allows the pot support arms to be safely locked in their splayed position.

However, the narrow burner column, small air inlet holes and limited tilt on the burner face mean the flames are slightly starved of air, and this shows up in the higher CO emission levels. Increasing the pot clearance by 10 mm radically improves the performance as may be seen in the graph. The effect of increasing the diameter of the burner column and/or increasing the size of the air inlet holes has not been tested, but could be expected to also be beneficial.



Jetboil GCS system



CO Emissions vs Stove Clearance

The Jetboil GCS is an upright stove with a custom heat-exchanger built into the supplied pot. It and the similar Jetboil PCs are the first ‘heat exchanger’ stoves to reach the market. The two-man Jetboil GCS is very similar to the one-man Jetboil PCS except for the two-man pot. The burner is actually fairly conventional: it is the pot which is unconventional, with a finned heat exchanger on the base. The stove has very good low and medium power CO performance, but the plastic housing which Jetboil added to the basic Primus-built stove tends to block the air inlets and this raises the CO emissions to an unacceptable level at high power (when more air is required). In the CO emissions graph some of the values have been artificially offset from the vertical axis for clarity.

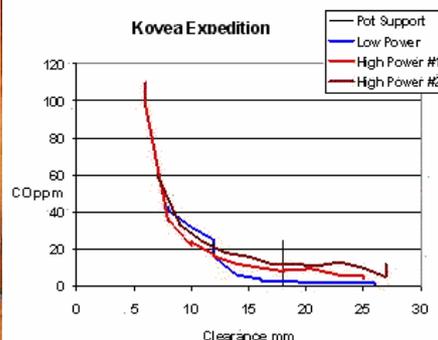
While not as powerful as many other stoves (despite the somewhat fantastic marketing claims) it does gain some efficiency from the heat exchanger, but the assembly is quite heavy and there are precious few situations where the increased efficiency could ever make up for the increased weight. There is almost no way to get any thermal feedback from the stove to the canister, so inevitably it performs very poorly in cold conditions. It would die completely in the snow unless you sit there holding the canister in your hands. In addition it does not work as well with a somewhat used butane/propane canister as with a brand new iso-butane/propane canister. Consequently this is not a stove for winter use, and it has to compete with the likes of the Snow Peak GST100 at 74 grams (2,5 oz) in the summer.

Kovea Expedition

448 g / 15.7 oz



Kovea Expedition



The CO Emissions vs Stove Clearance

The Kovea Expedition is a remote (screw-thread) canister stove with a preheat tube, but Kovea only specify it as being ‘anti-flare’. They do not mention that you can invert the canister for winter use, but I have found that it works just fine in winter with the inverted canister. The connection between the hose and the valve on the canister swivels by design, so inverting the canister is so easy. I wish other manufacturers would include this feature on their hose connections! I know Kovea make some very good and very light stoves for other customers, so I am at a bit of a loss as to why they make their own brand so heavy. While this stove is far too heavy for an ultra-light walker, it would however make a very reliable base-camp stove for a group in the winter.

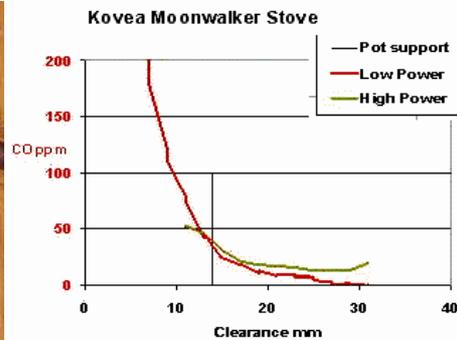
presented solely for interest. Getting the pot closer than the factory configuration would not be realistic in practice.

Kovea Moonwalker

340 g / 12.0 oz



Kovea Moonwalker



The CO Emissions vs Stove Clearance

The Kovea Moonwalker is another remote canister stove, also equipped with a preheat tube. It too works fine with the canister inverted. Like on the Expedition, the connection between the hose and the valve on the canister swivels, so inverting the canister is again easy. It has a different burner design from the Kovea Expedition, smaller in diameter and pointing the flame more upright, and it gives a slightly higher emission of CO at both low and high powers compared to the Expedition. The CO level would probably be acceptable in a well-ventilated position. Note that the graph again includes results for the pot placed closer to the burner than possible in the factory configuration.

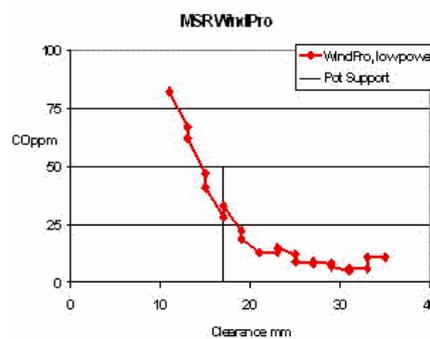
While lighter than the Kovea Expedition, it is still too heavy for an ultralight walker, which is a pity as it folds up nicely. The weight comes from the quite solid but heavy steel and brass it is made from. Kovea should consider working this stove over to reduce its weight and should replace the steel with titanium and the brass with aluminium.

MSR WindPro

192 g / 6.8 oz



MSR WindPro



The CO Emissions vs Stove Clearance

The MSR WindPro is a remote canister stove with a preheat tube over the burner. It looks exactly like the MSR liquid-fuel Simmerlite with a gas fitting rather than a tank fitting. It can work with the canister inverted. However, the connection between the hose and the valve on the canister does not swivel, and this makes inverting the canister a bit difficult: the hose kinks and fights back. If Kovea can put a swivel at the canister fitting, MSR should do so too.

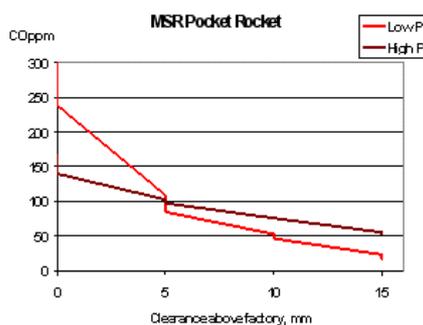
give it a warning smell. They seem to freeze around the valve. This is usually cleared by quickly operating the valve a half turn either way and back, but having to do this is annoying. Why does it happen with this stove but not the Coleman Xtreme or Fyrestorm?

The graph shows only the low power performance: the high power performance is essentially the same. Projection back below the factory pot support height is shown out of interest: it would not be realistic in the field. If the pot supports were given just a little more height this would be a very reasonable winter stove, provided you can manage the valve clearing.

MSR Pocket Rocket 86 g / 3.0 oz



MSR Pocket Rocket



The CO Emissions vs Stove Clearance

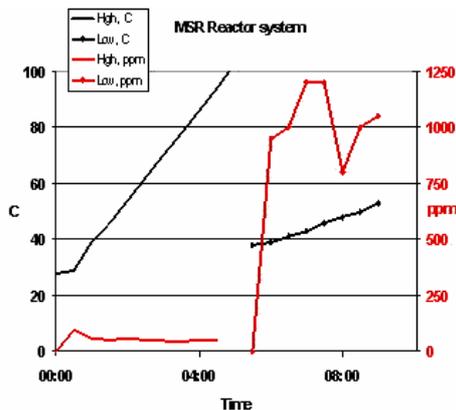
The MSR Pocket rocket is a light upright stove suitable for 3-season use. While it is light, the pot supports prove in the field to be a bit too light, and have been known to bend under a high load. You need to be a bit careful about this.

Sadly, while it burns well it has to be said that its CO emission performance is not in the acceptable range. Increasing the pot to burner clearance would help, but even 10 millimetres (0.4 in) extra would not let it match the performance of the best stoves. The problem lies with the design of the burner head: it focuses the flame into a small vertical column, and this limits the space for extra air to diffuse into the flame. Also the internal diameter of the burner column is also rather small at about 10 millimetres (0.4 in) compared to the more common value of about 12.0 – 12.5 millimetres (0.5 in), and I believe this may also be a significant restriction on the air supply. An increase in the size of the air inlet holes might improve the performance a bit too.

Increasing the clearance between the pot and burner gives more perimeter and allows more inwards diffusion of extra oxygen, and the CO emission drops. What is very interesting about this burner is that at high power at the factory clearance the CO emission is actually lower than at low power. Observation shows that the increased gas flow at high power spreads the flames right out, giving them a much greater perimeter or surface area through which to absorb extra oxygen – so the CO level drops. However, with an increased clearance between the burner and the pot the flames no longer have to spread out so much and the perimeter is reduced, and the CO level actually seems to rise as the power goes up. This is strange, but seems to be how it is.



MSR Reactor



The CO Emissions vs Stove Clearance

The MSR Reactor is the third ‘heat exchanger’ stove to reach the market. Unlike the other two (which rely on flames), the MSR Reactor relies partly on a large-area infra-red radiating surface. It has had a big PR build up, and one is tempted to suggest that this is a reaction to the success of the Jetboil stove. One thing is for certain: the prototype stove tested has a huge amount of power at full throttle. MSR claim a boil time for one litre of 3 minutes: our testing of the prototype unit supports that claim without any hesitation, as shown in the black trace on the left hand side of the graph. It screams straight up to boiling! It is possible that the unit tested actually allowed a greater power output than was intended, and this may have had some other consequences. However, the high power output and the integrated design are not without problems.

The first problem is that the system is rather heavy. While the Jetboil pot has a heat exchanger made from aluminium shim spot-welded to the base, the MSR Reactor pot base is machined from solid aluminium. To be sure, this helps very significantly with the heat transfer, but one has to say that they do not seem to have had the desires of the ultra-light walker in mind. Rather, it seems the race for mega-power has been a dominant factor in the design.

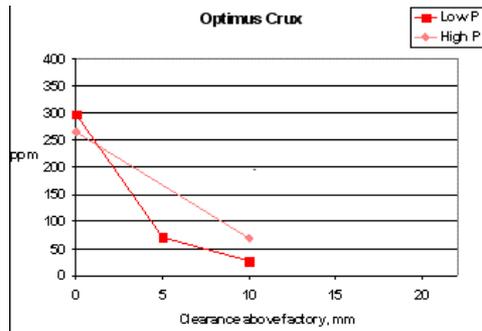
The second problem is that the prototype stove was incapable of gentle simmering. Trying to get a genuinely low power resulted in the flame which was heating the radiating surface (a sintered porous bed by all appearances) flickering badly and blowing out a few times. This is due to the design of the radiating or glowing burner face: it simply cannot handle really low power as the surface does not get hot enough for reliable combustion to be maintained. In my opinion it is not safe to try to run the MSR Reactor like this owing to the risk of the flame being blown out. I found I could only safely get the power down to a heating rate of about 5 – 6 C/L/min. At that rate the gas consumption is still significant and such a power level is far too high for gentle simmering of a stew: it would burn.

However, the **really big problem** is the level of CO emission at low power. At high power I found a level of about 50 ppm, which is quite reasonable considering the *high* power concerned. I had expected that the low power emission would be lower than this, as with most other stoves, but it absolutely soared to around 1,000 ppm, peaking at 1,200 ppm for a while. Note that in this case the horizontal axis of the CO emissions graph is time, not clearance. This graph shows the results from one test run; other tests runs were conducted with a variety of conditions and they all confirmed this level of CO emission. In the author’s personal opinion this level is potentially lethal. Whether production models will be better is at this stage unknown.

This prototype stove seems quite safe to use for boiling water at a furious rate: it does that excellently. But I do not believe the unit tested is safe for use at low power, either in calm conditions in the open or especially in any sort of hut or tent, and this is a matter for the user to seriously consider.



Optimus Crux (courtesy Optimus)



The CO Emissions vs Stove Clearance

This small light stove packs away very flat thanks to a rather cute folding burner head. There is a ball-joint between the burner column and head. Also the pot supports fold in over the burner face. They are small and the pivots are very stiff at the start, but they seem quite solid. For some strange reason each of the two small screws holding the burner onto the ball joint seems to be spaced off with nut each. I do this when the screws are too long for the job and I can't be bothered to cut them short, but surely there must be a better reason for it here. The bases and valve assembly, and the burner head, are all black. Inspection of the stove design shows that the flames point almost straight upwards and that there will be very little clearance between the burner face and the bottom of the pot – in fact only about 12 mm (0.5 in). Both these design features were found in Part 2 to be danger signs for carbon monoxide emission.

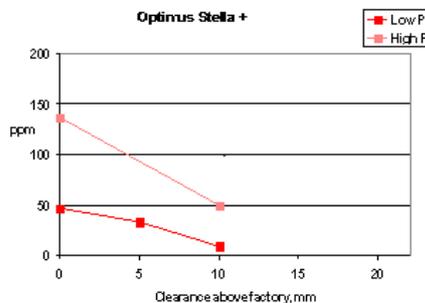
The stove comes with a little folded tag attached with a cable tie, warning in many languages of the carbon monoxide hazard. Indeed, the stove does emit a fair bit of CO at the factory clearance, but this drops according to theory as the clearance is increased. It is not clear why the clearance, which is only 11 mm (0.43 in) has to be that small. Certainly, as the clearance increases the area available for inwards diffusion of oxygen at the side of the flame increases greatly.

There is little difference between low and high power for CO emission at the factory clearance, with the level dropping slightly as the power goes up. Inspection of the flame shows a lot more spread under the pot at high power: this of course creates a far greater surface area for oxygen to get to the flame.

**Optimus Stella +
266 g / 9.38 oz**



Optimus Stella + (courtesy Optimus)



The CO Emissions vs Stove Clearance

The burner section of this stove is basically the same as the Optimus Crux, but the valve section at the bottom has been replaced with a mechanism to support the rather spacious tripod legs and the fuel line connection. The fuel line has a plastic braid mesh over it and a wire running down inside this mesh. This carries the pulse from the piezo mechanism

in the CO levels found.

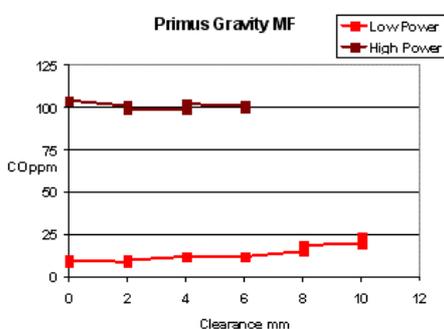
One thing which must be made quite clear is that this stove does *not* have a preheat tube, and can *not* be used with the canister inverted. Don't try it. The same warning tag as found on the Optimus Crux is found on this stove too. However, Optimus have included a windscreen with this stove: the canister is remote after all. The operation of the remote valve and piezo ignitor are rather nice too.

The CO levels found for the Stella + are much lower than for the almost identical Crux. Why is this so? If you look at the CO levels for the Crux at about +6 mm spacing (over the factory value) you will see they are very similar to those for the Stella + at the factory clearance. In fact, the physical clearance between the pot and burner face for the Crux is about 11 mm and for the Stella + it is about 17 mm. The difference is 6 mm. This is a rather graphic demonstration of the effect of increasing the clearance!

Primus Gravity MF 243 g / 8.47 oz



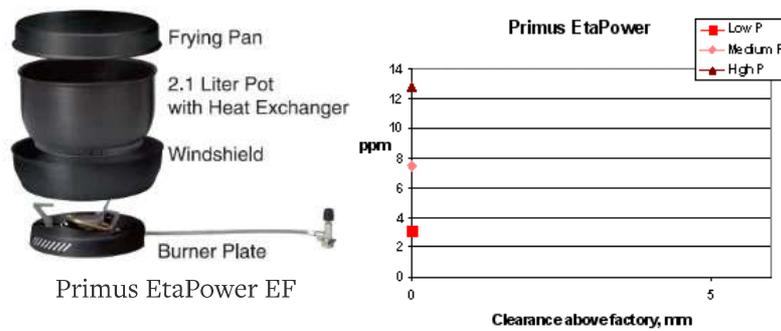
Primus Gravity MF



The CO Emissions vs Stove Clearance

The Primus Gravity MF is a remote canister stove designed to also work with both white gas and kerosene fuels. It has a preheat tube for this of course. It runs quite well with the canister inverted, but there is no swivel on the hose to allow easy inversion (shame!). However, the hose can be rotated at the stove end to facilitate this by slackening off the nut there – as long as you retighten it securely afterwards! Be **very** careful about this if you try it. The folding legs look light, but seem quite strong. The whole stove is very low to the ground, making it very stable.

While the stove has good CO emission levels at low power, the emissions do rise at high power to a level which is not acceptable. I have had problems running this stove with the common 'liquid fuels' and I attributed these to an inadequate air supply arrangement at the jet. This is consistent with the CO emission levels. It may be that an exploration of the 'non-standard' air inlet arrangement might allow improved performance – but this would certainly be outside the warranty. This limited performance is a pity as the stove is quite light for a 'remote' canister unit.



The CO Emissions vs Stove Clearance

The Primus EtaPower EF is the second ‘heat exchanger’ stove to reach the market, and the only one to offer a liquid feed suitable for winter use. Primus claim greater fuel efficiency than either Jetboil or MSR, but fuel efficiency has not been tested in this article. The stove part weighs 254 grams (8.96 oz); the enclosing windshield weighs 116 grams (4.09 oz); the 2.1 L heat-exchanger pot weighs 237 grams (8.36 oz). A large potlifter (45 grams, 1.59 oz) and a frying pan lid (146 grams, 5.15 oz) are included in the package. There is also a padded hat-box cover for the whole system, but this weighs 280 grams (9.88 oz) by itself and seems a bit excessive. I suspect that most light-weight summer walkers will find these weights rather high, despite the efficiency.

It is true that the integrated windshield is a valuable concept, although many [lighter windshields](#) are available. However, I suspect that many walkers might find the convenience of the integrated version worth the weight in winter. A valuable bonus is that the canister connection swivels on the hose, making it very easy to rotate the canister upside down to get a liquid feed. Yes, the stove does have the required preheat tube needed for this. If you take just the stove, windshield and 1.8 L pot the total weight of 608 grams (21.45 oz) is not too far different from some of the other remote-canister stoves suited for winter use. I suggest this stove system could do fine for a group of three people in winter.

Primus claim in the English version that both the pot and the lid are coated with titanium, which is clearly wrong. I am told they are coated with a titanium-reinforced non-stick coating – presumably a variation of the normal Teflon. It is supposed to be very tough. Primus need to clarify this in their literature.

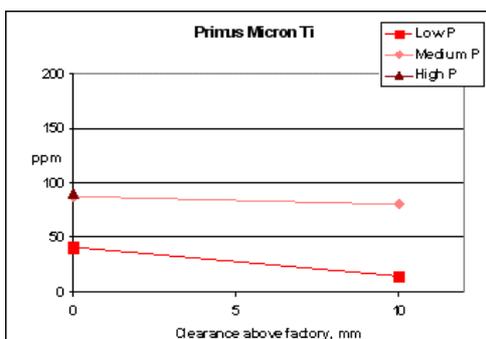
The EtaPower stove bears considerable resemblance to the old Trangia concept: there are several large round parts which nest together when packed and which click together for use. I would recommend using a bit of cotton cloth between the layers when all packed together to prevent any scratching.

The really big surprise with this stove is the level of CO emission. It is wonderfully low, both at low and high power. Clearly Primus has got the airflow around the burner right. What’s more there is plenty of power there for melting snow. The unit was not tested with increased clearance between pot and burner as this did not seem necessary, so the data points are all on the vertical axis at 0 mm.

It would be a shade wickered to point out that the Greek eta symbol used on the stove looks a little like a truncated ‘golden arch’.



Primus Micron Ti 2.5



The CO Emissions vs Stove Clearance

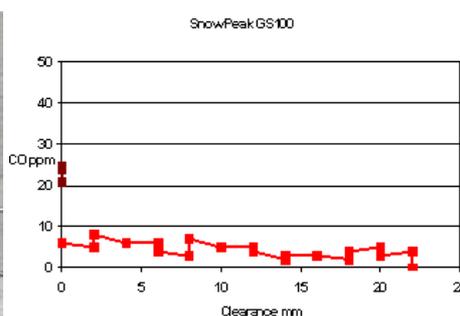
The Primus Micron Ti is a rather slender upright stove which Primus claims is made ‘primarily from titanium and aluminium’, although I have to point out that 37 grams (54%) of the weight is found in the brass valve assembly. That said, it is one of the lightest stoves tested. It has a novel concave burner which is meant to focus the flame inwards for small pots, and the pot supports fold up and down, clicking into the up position. The ‘2.5’ in the name probably refers to the weight in ounces. The power rating of 2.2 kW or 7,500 BTU is a bit low compared to similar small upright stoves, but this is not really a problem as few people ever use a stove at full power.

The slender burner column and the concave burner both suggest that there might be some deficiency in air supply, and the performance figures bear this prediction out. The CO levels are a bit higher than one would wish. Exactly why one would want to focus the heat onto the central section of a pot is not clear either: in my opinion this mainly enhances the chance of burning the pot. The CO emission level drops a little as the clearance is increased, but due to the narrow column of flame the drop is not great. However, the stove has a reasonable heating power and can be turned down to a very low simmer. The high power performance was about the same as the medium power performance.

**Snow Peak
GS(T)100
74 g /2.5 oz**



Snow Peak GS(T)100



The CO Emissions vs Stove Clearance

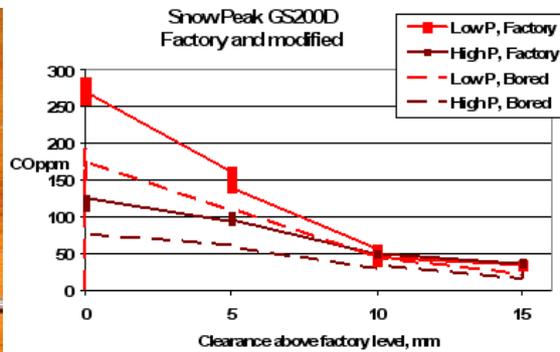
The model designation GS(T)100 refers to both the stainless steel GS100 and the titanium GST100 versions: they are identical upright stoves except for some of the metal used. Unlike so many other stoves, the GS(T)100 stove has a nearly vertical burner face which throws the flames out sideways. This means the flames do not really ‘hit’ the pot and get quenched, and this is reflected in the excellent level of CO emission at both low and high power. Also there is good clearance between the burner holes and the pot. The CO emission does rise slightly at high power, which suggests the stove has been optimised for low to medium power operation – which makes a lot of sense to the author. The author admits to some bias here: this is his preferred summer stove.

levels of these stoves, I do not see why other canister stove manufacturers should not be held accountable for poorer and more hazardous performances.

Snow Peak GS200D
284 g / 10.0 oz



Snow Peak GS200D



The CO Emissions vs Stove Clearance

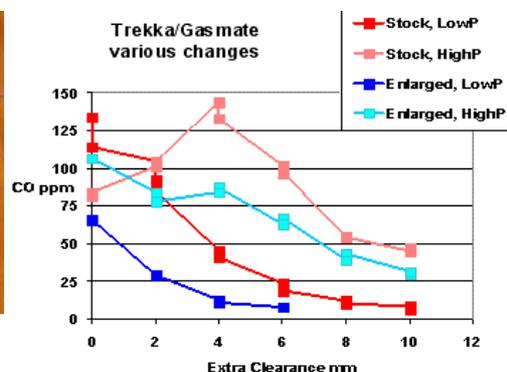
The Snow Peak GS200D is a remote canister stove with a preheat tube. It can be used with an inverted canister quite easily as the valve swivels on the end of the hose. The GS200D has been phased out by Snow Peak, and another model will replace it sometime in 2007. This new model was not available for testing unfortunately. My wish is for a GST100 burner with the GS200D preheat tube and increased clearance!

Unfortunately, while the Snow Peak GS200D is a nicely made stove and quite light, the CO emissions are not good at all. Several factors seem to be involved in this poor performance, including a restricted air supply. The graph shows solid lines for low and high power performance in the factory state, plus dashed lines for the same after the air inlet holes were bored out from 6 millimetres (0.24 in) to 6.5 millimetres (~0.26 in) to give a 17% increase in air inlet area. The degree of improvement in CO emission for this fairly small change is really significant. It would be nice if the replacement model has this change. It will be seen that there is a ‘cup’ under the burner. Removing this cup did not improve the performance significantly.

Trekka/Gasmate (modified)
309 g / 10.9 oz



Trekka/Gasmate (generic)



The CO Emissions vs Stove Clearance

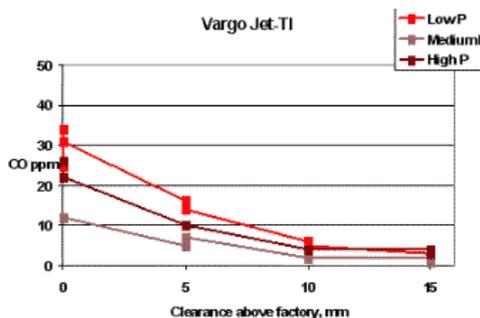
This very heavy and very cheap upright stove would not qualify for inclusion in this survey except for the fact that it was used for a lot of the research work in Part 2. The original model tested was a very poor performer in several ways, but it was ‘somewhat improved’ along the way, especially by increasing the air supply through the air inlet holes. It is not really

Performance figures for both the factory and the modified versions are given here. They show the improvement made by increasing the air supply, but they also show a very strange sort of behaviour at high power as the clearance is varied. This behaviour is known to have been caused by the metal ‘windshield’ under the burner bottling up the flames and restricting the diffusion of extra air into the flame. Increasing the air hole size can be seen to reduce this effect somewhat at stock clearance. Perhaps this is really a good example of the ‘you get what you pay for’ principle?

Vargo Jet-Ti
82 g / 2.9 oz



Vargo Jet-Ti

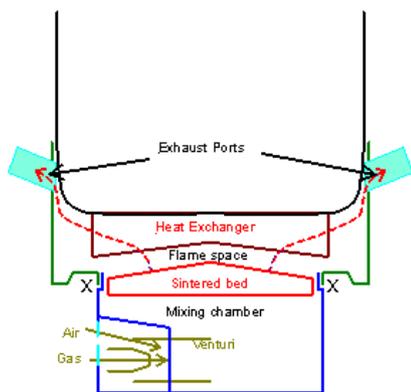


The CO Emissions vs Stove Clearance

The Vargo Jet-Ti is a very robust but quite light upright burner with fairly good performance. Yes, it uses a lot of titanium. Any resemblance between the Vargo Jet-Ti and the Snow Peak GST100 must be purely coincidental of course. Actually, they are slightly different in many small details.

The behaviour of the Jet-Ti combines the expected and the surprising. The CO emission was a little high at the factory clearance, but it decreased nicely as the clearance was increased. One could wish for an extra 5 mm on the pot supports. However, the level of CO emission at low power was higher than at either medium or high power, and this was unexpected. Two different factors could have come into play here. Careful observation showed that at very low power the flames went straight up – more so than with the Snow Peak GST100. At medium and high power the flames blew out sideways similar to the Snow Peak GST100. So the first possibility is that as soon as the fuel/air mix gained any significant velocity the flames went out sideways to gain a far higher perimeter, and therefore more air became available to the flame. The second possibility was that the fuel jet velocity at very low power was so low that it was not really successful at dragging enough air into the burner column through the air holes. Perhaps both factors count. Which factor predominates is not known, although a rather high peak power rating is claimed for the stove. This may mean the jet size is just a shade too large for optimal operation. Perhaps slightly larger air inlet holes might help. But it does not matter really, as long as you ensure you have a bit of ventilation.

Further comments on the MSR Reactor Performance



This stove represents a quite radical change in stove design, and this is shown in the simplified cross-section diagram to the right. The stove is meant to use the heat of the flame to make a sintered bed (red) glow bright red, converting some of the very high temperature of the flame into what *might* be a more usable form of infra-red radiation. In addition, the hot exhaust gases (red dashed lines) from the sintered bed and flames are meant to pass through the heat exchanger fins (brown section) on the bottom of the pot (in black) and pass out through exhaust holes in the metal ring (dark green) around the base of the pot. The flows through the actual exhaust holes are symbolised by the light blue rectangles at the arrow tips of the dashed heat flow lines. The exhaust holes are shown in 'real life' in the picture below as well.

However, this design entails certain compromises which are illustrated by the poor ability of the stove to simmer. Basically, such an infra-red heater design is just not able to operate at very low power. However, experimental results suggest that the high CO emission level at low power is mainly a function of poor design, in an unexpected part of the stove.

Obviously one does not make such a statement lightly, and a lot of testing was done on the prototype stove sent to us to work out why the CO level was so bad at low power (averaging 1,000 ppm). Once the problem was understood the seriousness of it and the cause of it were fully communicated to MSR, who requested that we return the stove so they could test it themselves to see if it was faulty. They promised an immediate replacement. The stove was returned forthwith to MSR, but we are still waiting on the replacement at the time of publication. We were informed that the high power performance of the unit under test was above specifications.

A key point to note in this design is that the hot exhaust gases are not immediately released to the atmosphere, as happens with most other stoves. The hot gases are instead bottled up inside the flame space under the pot for a while. It may be that the idea here is to keep the hot gases in close proximity to the heat exchanger fins, to allow greater heat transfer. Obviously there will be a slightly raised pressure inside the flame space, and it is this pressure which forces the hot exhaust gases out through the exhaust holes referred to above. This works, but at a cost.

On the basis of the results of several experiments it seems to the author that the air flow through the inlet venturis (shown in the photo below as well) stalls at low power as a result of raised pressure inside the stove, in both the flame space and in the mixing chamber. This means that the air supply to the flame is grossly impeded, and the fuel is burning in a seriously oxygen-starved combustion cycle. Lack of oxygen results in the second phase of the combustion cycle (CO to CO₂) just not being able to occur, and so huge quantities of CO are released.



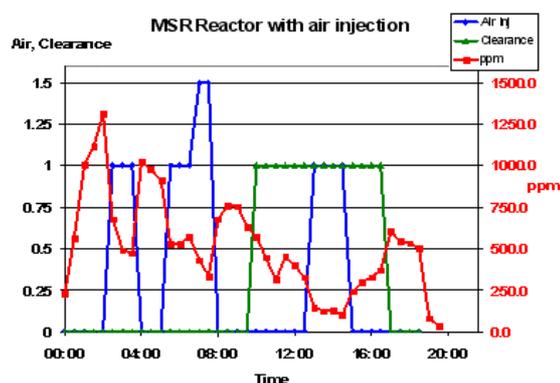
MSR Reactor Pot with
an exhaust hole
outlined in red

The author has encountered this problem once before while stove testing. The stove takes a certain amount of air and fuel vapour, burns the fuel vapour and generates a very much increased volume of hot expanded exhaust gases. The increase in volume is greater than you might think. To get rid of this huge volume of hot exhaust gas requires an exhaust space – the exhaust holes in the ring around the pot. One of these is outlined in red in the photo to the left. The larger the exhaust holes, the lower the pressure inside the flame space required to force all that hot exhaust gas through them. This is similar to considerations of the exhaust port size on car engines.

the air flow through it. The result is a high back-pressure between the burner and the pot. It is this high back-pressure which is causing the air flow coming in through the venturi to stall. So if the high back pressure was removed the air flow would not stall and the CO level would fall.

One might well ask why this happens at low power (giving a CO level of 1,000 ppm) but not at high power, where the CO level is only 50 ppm. The reason proposed is that at high power the blast of fuel vapour through the jet is much more powerful, and this increased jet power can drag more air in despite the back pressure opposing it. In effect, at high power there is more driving pressure through the venturi tube which overcomes the back pressure, so that the air flow does not stall.

Such an explanation requires serious proof of course. An experiment was devised to provide a good demonstration. Clearly, if high back pressure in the Flame Space is causing the air flow through the venturi to stall, reducing the back pressure should reduce the CO level. It is easy to reduce the pressure in the flame space: just lift the pot a little distance above the stove and create a gap at the point X in the outline drawing above. Even a 10 mm gap here would provide a huge exhaust space around the base of the pot. This might not be as effective in transferring heat to the fins on the pot, but what we are after here is proof of the principle. An alternative approach would be to force extra air into the venturi tube, no longer relying on the drag from the small jet of fuel vapour. This could be done by directing a controlled stream of compressed air into the venturi along the line of the light green arrow. In car engine terminology this is turbo-charging the carburetor.



MSR Reactor stove showing air inlet arrangement

The graph here, actual results from a single test run, shows both ideas being tested. The red line shows the CO concentration as recorded above the stove in the test chamber in the normal manner. The green line for clearance shows where the pot was raised by about 12 mm (1/2 in) at the 10 minute mark. The blue line shows where the compressed air supply was turned on and off, starting with it being turned on at 2 minutes and off again at 4 minutes. Other cycles followed. You will note that during the second cycle of having the compressed air on, at a point (6.5 minutes) and half way through the on period, the flow was increased by about 50%. This was done by adjusting the control valve on the compressed air supply.

The key results from the experiment are as follows: every time the compressed air was turned on the CO level dropped. Every time the compressed air supply was turned off, the CO level rose. When the compressed air supply was increased at the 6.5 minute mark, the CO level dropped even further. When the pot was lifted at 10 minutes to create a whole new exhaust area, the CO levels dropped even further. They rose again when the pot was dropped back onto the stove as the back pressure was restored.

This sort of on/off testing is commonly used in research and is called "correlation testing." It is the author's opinion that there is enough evidence in this single graph alone to say the problem is substantially as outlined. However, several other test runs were conducted before the stove was returned, and they gave the same results.



MSR Reactor stove
showing air inlet
arrangement

I would argue that the problem could be significantly mitigated if the exhaust holes were enlarged downwards by a factor of at least two. This would help them clear the base of the pot. However, increasing the exhaust area by a factor of at least four or even eight would be better. In production terms this simply requires a change in the dies used to stamp the holes. It could be done to a completed pot with a small mill or even a humble router.

The air inlet area as shown in the photo here may also contribute to the problem. The fuel is injected from a nozzle behind the stainless steel (SS) screen at the tip of the blue arrow. It flows through the aluminium venturi tube pointed to by the red line, to the mixing chamber under the sintered bed. Actually, the stove has “twin carburetors”: there is also one to the left of the valve hole. The red horizontal line points to the outlets of the two venturi tubes. Back pressure certainly causes some of the problem, but the way the SS screen masks the air inlet region may also be a factor. The author would like to see the holes in the SS screen increased in size in the region in front of the venturis. Every extra bit of air helps.



Categories:

[Research & Testing](#)



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. :-)

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 **Discussion**