

Novel Domestic Charcoal Stove with Advanced Combustion and Low CO

(Inadvertently)

**Highlights the Inadequacy of the ISO 19867-
1:2018 Test Method**

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2025 Forum on Renewable Energy Promotion
in Developing Countries (2025 FREPDC)
Beijing, 15-17 October 2025



Charcoal making is one of the few ways for farmers to make some cash.

195 million Africans use charcoal as their primary cooking fuel. Another 200 million use it as a secondary fuel, 100% locally produced.

A secondary fuel is used when the electricity supply fails, or the bottle of gas is empty.

More than 25% of people in Africa cook some or all of their meals on a charcoal stove.



The Dangers of Traditional Stoves

Charcoal stoves present a significant danger to the family. Most charcoal stoves burn the fuel poorly. As a result, there is a high level of carbon monoxide (CO) emitted by traditional stoves.

If they are used indoors, the cook is quickly overcome and might die from CO poisoning. This is a well-known risk so all cooking with charcoal is done outside or under an open shelter.

Using the metric CO/CO_2 as a measure of combustion inefficiency, a typical ceramic lined metal framed stove such as the widely available Improved Kenyan Jiko (IKJ) has a ratio of 12%-14%. This is dangerously high.



Improved Stoves

Attempts have been made to market charcoal stoves with lower CO emissions. A product from Envirofit, its Enviroflame Combustion System is said to reduce CO by ~50%-60% compared with a baseline product.

Testing using the WBT 4.2.3, the Lawrence Berkeley National Laboratory reported an average CO/CO₂ ratio of 11.8% for the traditional stove and 4.25% for the Envirofit product.

This translates to an emission rate of 16.1 g CO/MJ_D or, ISO Tier 1.

A CO Tier 1 stove is unsafe for indoor use.

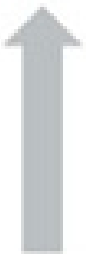


Improved Stoves

Testing at the Rwanda Standards Board stove lab found very few charcoal stoves achieve Tier 2 with the majority rated as Tier 1 or Tier 0.

There are multiple improved cooking stove projects in Africa funded by the World Bank. The minimum product requirement for CO emissions is ISO Tier 3 which is $<7.2 \text{ g CO/MJ}_D$. To date, not a single stove, local or imported, has been rated on CO Tier 3.

Table 1 — Voluntary performance targets - default values^a

	Tier ^b	Thermal efficiency %	Emissions		Safety (score) ^c	Durability (score) ^d
			CO g/MJ _D	PM _{2,5} mg/MJ _D		
Better performance 	5	≥ 50	$\leq 3,0$	≤ 5	≥ 95	< 10
	4	≥ 40	$\leq 4,4$	≤ 62	≥ 86	< 15
	3	≥ 30	$\leq 7,2$	≤ 218	≥ 77	< 20
	2	≥ 20	$\leq 11,5$	≤ 481	≥ 68	< 25
	1	≥ 10	$\leq 18,3$	≤ 1030	≥ 60	< 35
	0	< 10	$> 18,3$	> 1030	< 60	> 35

The ISO 19867-1 Test Method for Charcoal Stoves

There is the section of ISO 19867-1 describing how to test charcoal fuelled stoves.

The protocol (section 6.8.3) requires charcoal stoves be tested at either high, medium and low power, or high and low. Here is an example of the firepower during a three segment test:

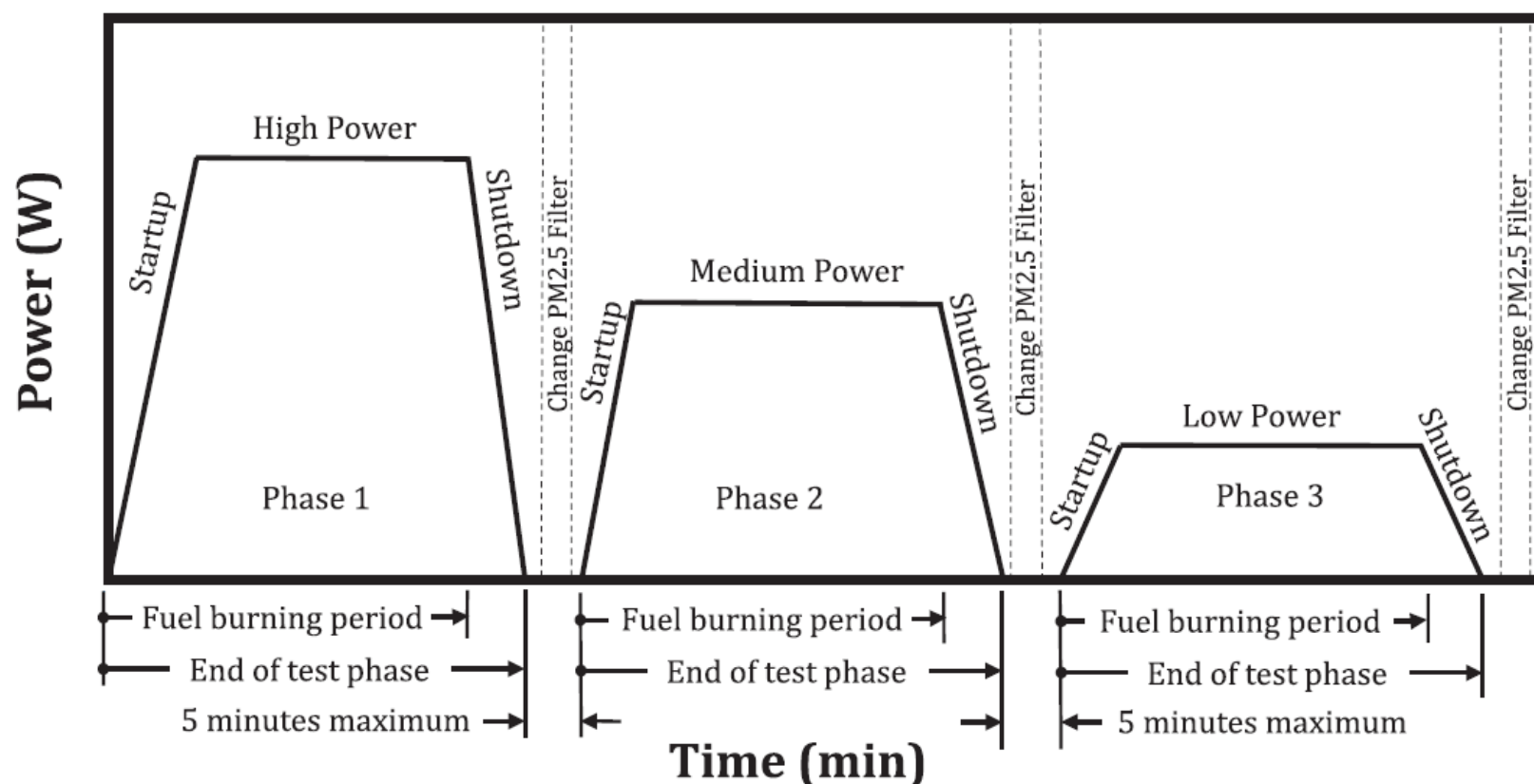


Figure H.1 — Diagram of the standard test sequence for cookstoves with a range of cooking power

The ISO 19867-1 Test Method for Charcoal Stoves

From 6.7.1 (e) : The operator is to load fuel such that after 30 minutes, the burn rate will have fallen to 50% of its measured maximum. Therefore, it is not a high-power test.

For a charcoal stove, this is an unreasonable requirement because no one uses a stove in that manner.

From 6.7.2 (e) : The duration of the “fuel burning period” in the above graphic is 30 minutes followed by an “shut down” procedure.

Traditional
Charcoal braziers
In Maputo,
Moçambique



Inappropriate Shut Down Procedure

There is no way to safely remove all the burning fuel from a charcoal stove.

The shut down period is for 5 minutes, or when the water temperature drops 5 degrees from the maximum attained, whichever comes first. “Shut down” involves closing the air control door creating a massive spike in CO.

Most charcoal stoves have a ceramic liner of some kind which retains a great deal of heat. This tends to keep the water hot, therefore a typical shut down entails waiting the full five minutes with the combustion choked of air.

There is high CO emissions during ignition – the first 20-25 minutes – and a massive amount emitted from the choked fire at the end. Traditional stoves are only burning “well” for about 5-10 minutes out of 35.



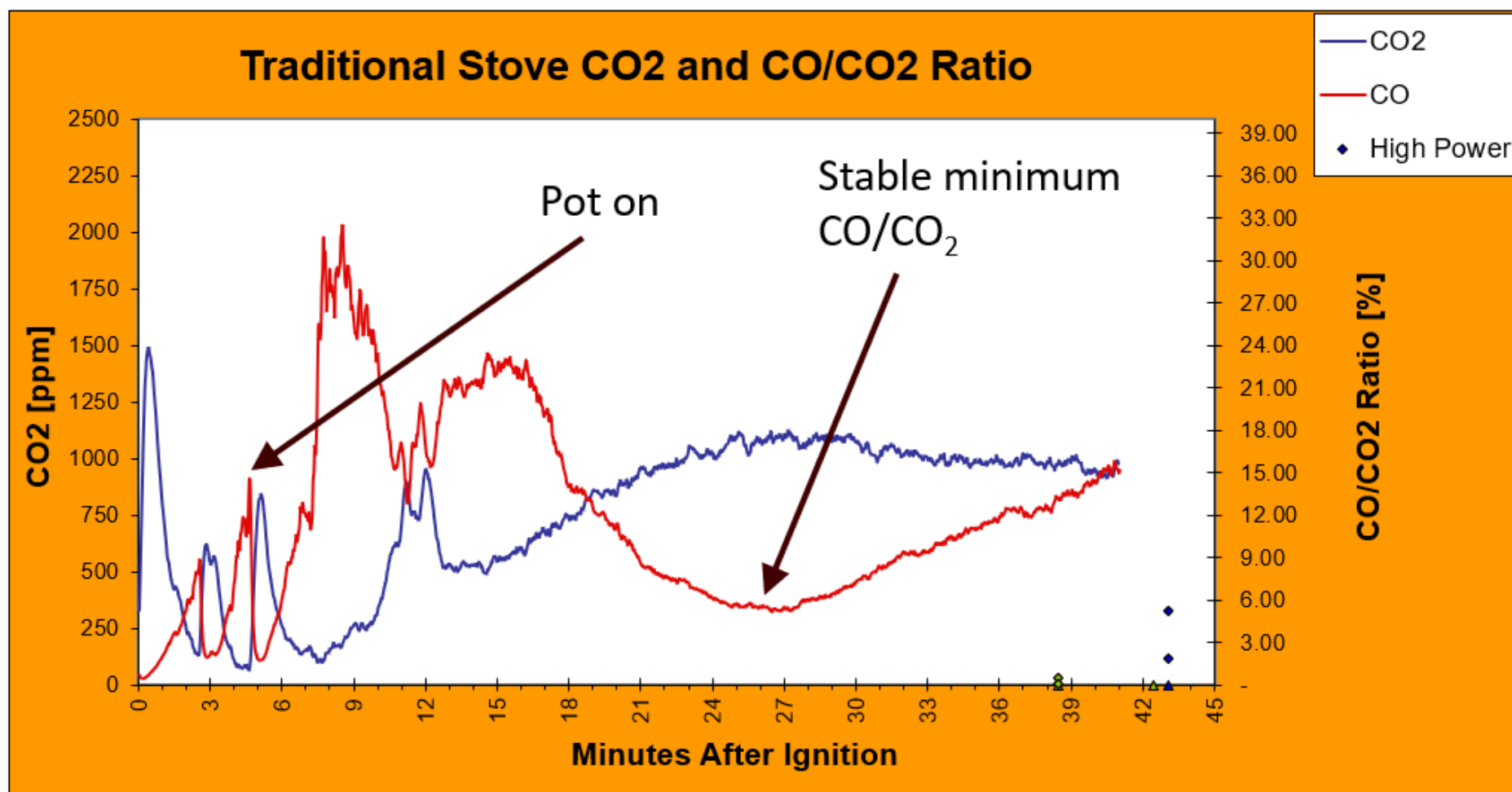
Typical Cooking

A typical pattern of use for an urban charcoal stove in Rwanda is ignition with a load of fuel, burn until the water boils, add beans, then cook at a relatively low power for 2 to 3 hours.

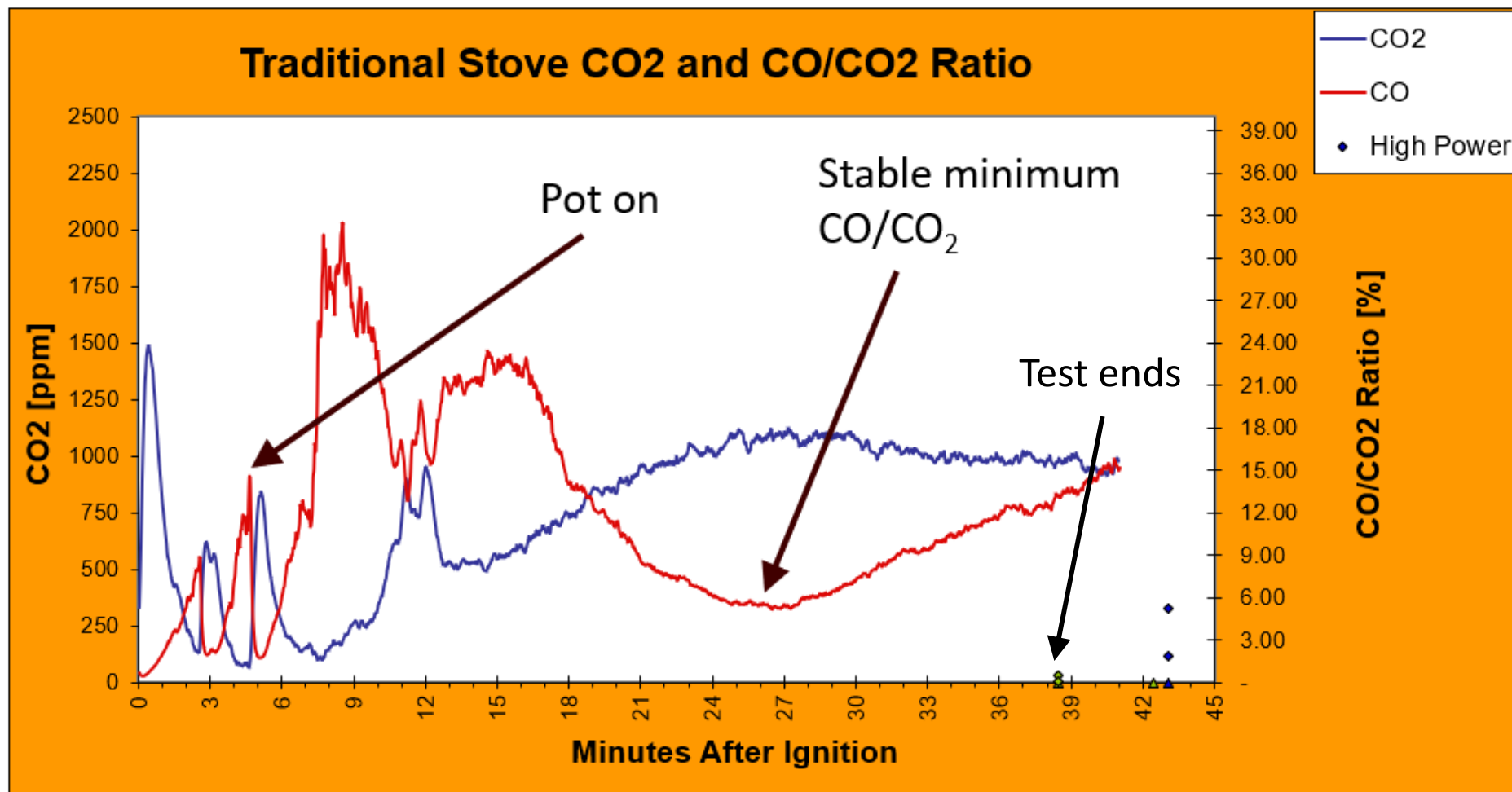


Typical Emissions from Charcoal Stoves - Traditional

Average is CO/CO₂ ratio for this product is 11.8%. This stove is rated ISO Tier 0. Just as the fire finally is burning properly, the test ends, and the fire is restarted.



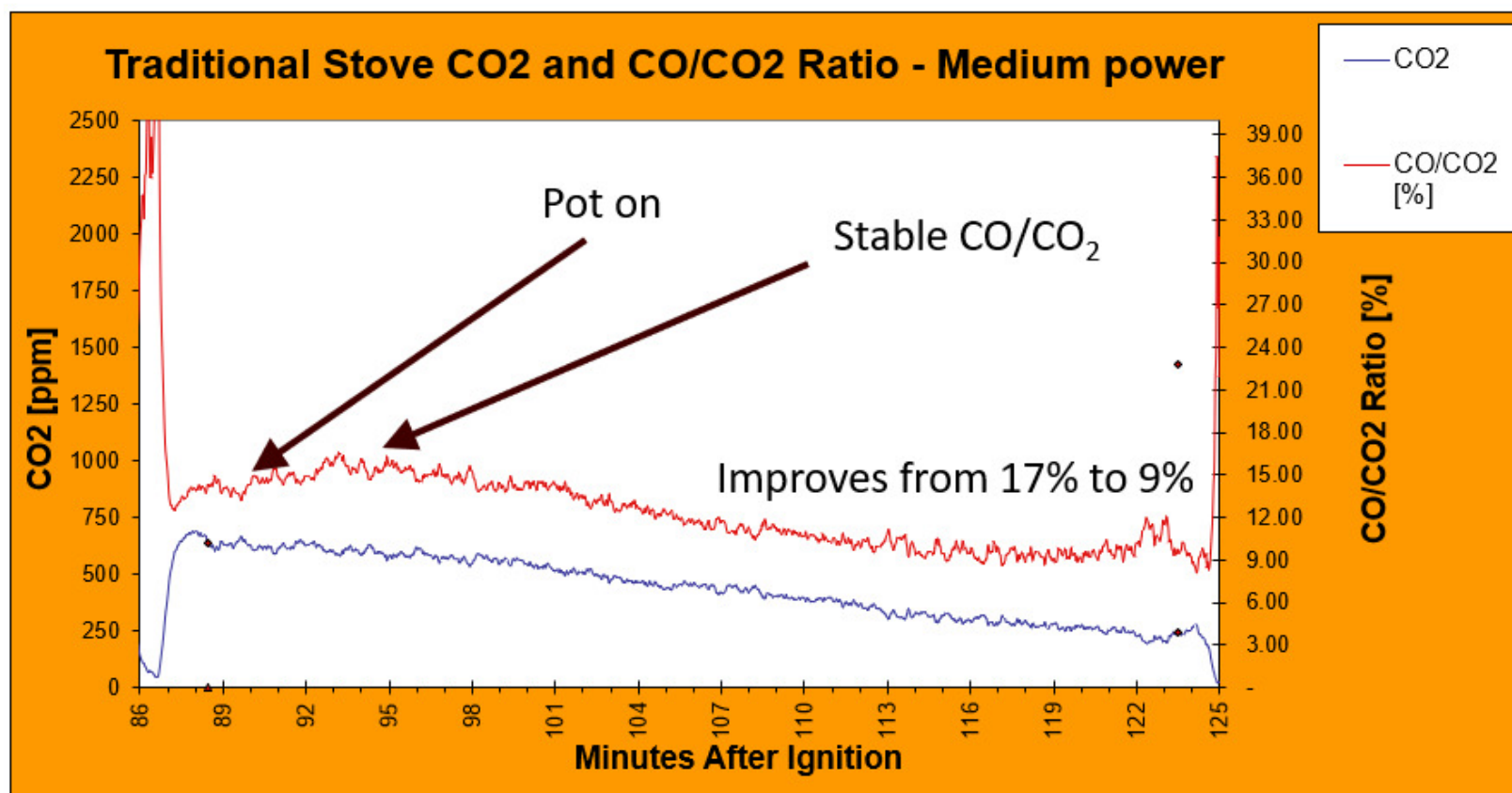
Typical Emissions from Charcoal Stoves - Traditional



The CO/CO₂ ratio peaks above 30%. The stable minimum is achieved 26 minutes after ignition at ~6%. The CO₂ concentration is highest at this time because the fire is burning well at high power. After 26 minutes the power starts to drop, and the ratio rises as the fuel mass declines.

Typical Emissions from Charcoal Stoves – Traditional

After the fire is restarted at Medium Power, the CO/CO₂ ratio is higher than it was a few minutes prior, improving for 28 minutes, then stabilizes at 9%. What this demonstrates is that it takes ~25 minutes for this product to create stable, high-power combustion, and that at medium cooking power, it produces 1.5 times more CO.

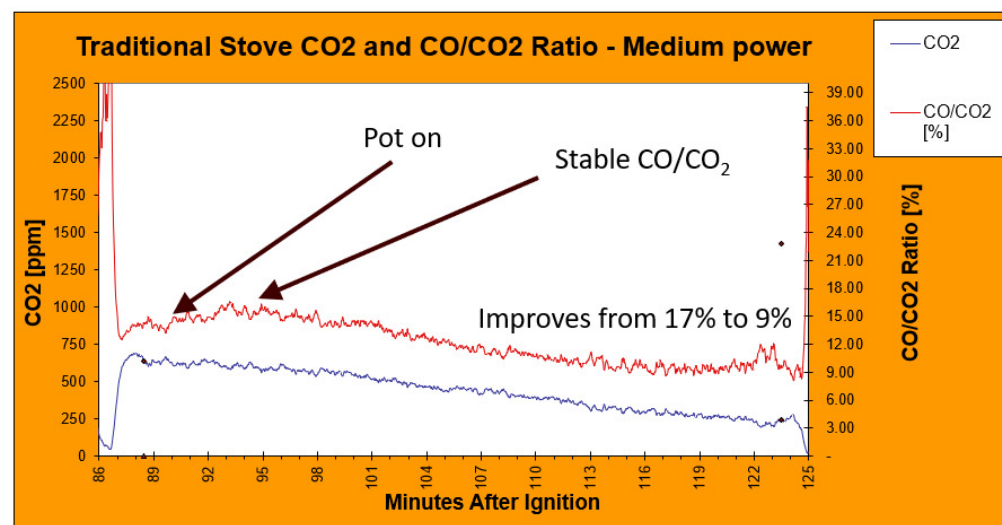
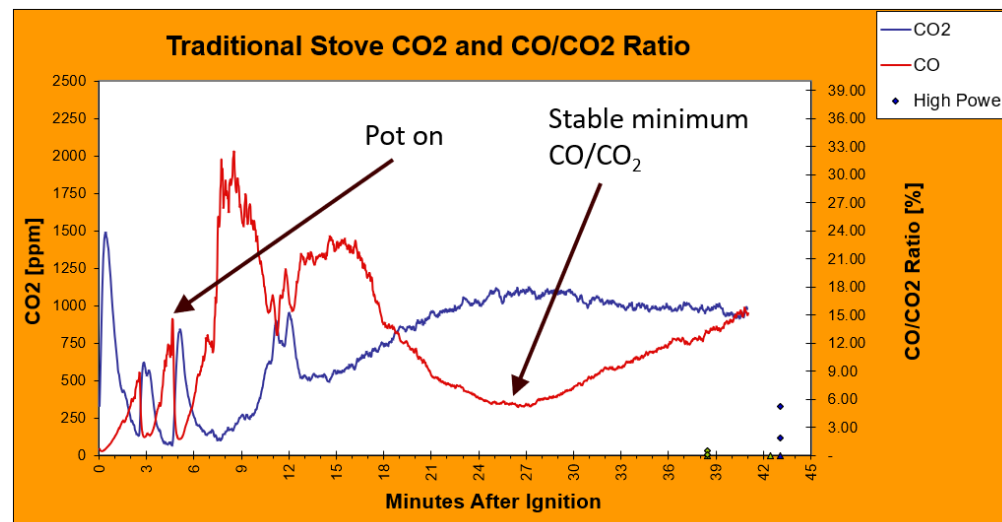


Typical Emissions from Charcoal Stoves

These two charts show the high and medium power tests. The CO/CO₂ ratio improved to 6% and, if it had been fueled properly, this would have continued for some time, but the test requires that the fire be running low on fuel after only 30 minutes.

When extinguished and restarted with less fuel, the ratio started high again, and improved for 25 minutes, but never reached the former low level of 6%.

Note that as the burn rate decreased, the ratio improved to 9% but at no time improved to be better than Tier 0.



Historical performance

This type of performance has been observed for many years. There are few stoves that have any significant deviation from this profile. There are two important lessons we learn from this:

- The ISO test is not representative of anyone's typical use, which is one ignition and several hours of burning, including the time taken to get to good combustion which is ~25 minutes.
- If a stove could get to a low CO/CO₂ value, the test does not reflect this, no matter how low it would go, because it is repeatedly being stopped and restarted. This is made even worse (more misrepresentative by the requirement for the firepower to drop 50% after 30 minutes from ignition.

It would be more useful if the ISO rating was relevant to typical use.



The first locally designed CO-Tier 3 charcoal stove
Uganda, 2025.

Historical performance

When developing stoves the thing to look for as improvements are:

- decrease the time to ignite the fuel fully
- produce a fire with a low CO/CO_2 ratio indicating that the air flow and combustion conditions are optimised.

On the right is shown a “lighting cone” which is used immediately after ignition.

The lower end of the cone bypasses the secondary air inlet, creating a strong draft on the fire fed by primary air only. Depending on the type and size of charcoal, it can fully ignite the fire in 4-8 minutes.



Lighting cone, handle not shown

Improving performance

The “lighting cone” was successfully adopted in Lao PDR by SNV and is used ~90% of the time.

Tests in Cambodia indicate that this reduces PM and CO during ignition by about 90% if it is left in place until the charcoal is fully ignited.

The Lao PDR version has a single wooden stick for a handle.



Improving performance

To reduce the CO/CO₂ ratio it is necessary to limit the air supply to the bottom of the fuel (primary air) and provide preheated secondary air above the fuel in a balanced ratio approximately 1:1. The secondary combustion of gases is seen above the fuel.

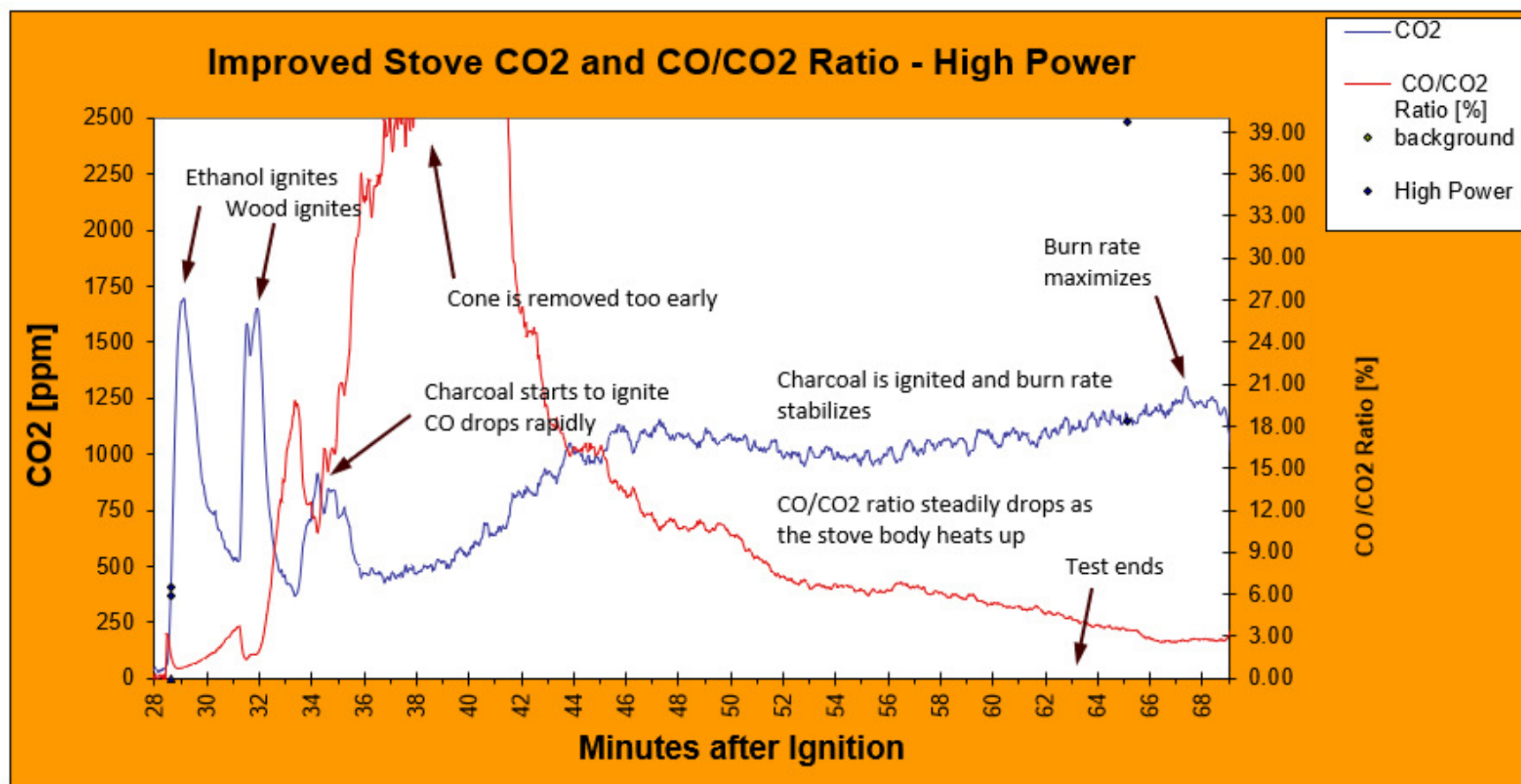


To see the video click this link:

https://www.newdawnengineering.com/website/library/Papers%2bArticles/CAU/CAU_FREPDC_2025/Green%20charcoal%20stove.mp4

Typical Emissions from Improved Charcoal Stoves

During a 30 minute test conducted according to ISO 19867-1 a high-performance stove will give the following emission profile:



The CO/CO₂ ratio peaked above 30%. The stable minimum is only achieved at <3% after 40 minutes because of poor ignition (operator error). The CO₂ concentration is steady after 18 minutes because the fire is burning well at high power. As the stove body is heated, the CO drops and would remain low for a long time, but the ISO test method never discovers this.

Improving performance

During training sessions in Uganda in 2024, charcoal stoves with a high combustion efficiency were developed for the first time. The concepts taught were applied by several companies and tests of their products conducted in April 2025 showed a sustained CO/CO₂ ratio under 1%, peaking at 0.6%.

Key to getting this level of performance is achieving the correct primary/secondary air balance of 1:1 and an excess air target of 80%-100%. Both targets were achieved with the 3rd version of this stove. The thermal efficiency is >40%.

Two companies achieved a ratio under 1% with the same combustion chamber and slightly different body designs. In theory, they should be ISO Tier 3 or 4, but the test reports Tier 1.

Ambient Temp:	33 °C
Stack Temp:	32 °C
Oxygen:	10.2 %
CO:	381 PPM
CO ₂ :	6.4 %
Hydrocarbons:	0 PPM
NO:	99.4 PPM
Excess Air:	111 %
Air/Fuel Ratio:	11.54
Lambda:	2.06
Equival Ratio:	0.48



Improving performance

A locally produced institutional stove fuelled by large charcoal briquettes – about 2 kg each is shown. The flames under the pot were very short of air with 13% CO/CO₂.

It was modified by adding a centre hole 5 cm in diameter supplying additional air to the flames and elevating the pot 70mm to provide flame space.

The 25 cm diameter briquettes have several holes 2 cm in diameter and one 5 cm hole in the centre.

These changes produced a sustained minimum CO/CO₂ ratio of 0.06%, a drop in CO emitted of 99%.



Significant Issues

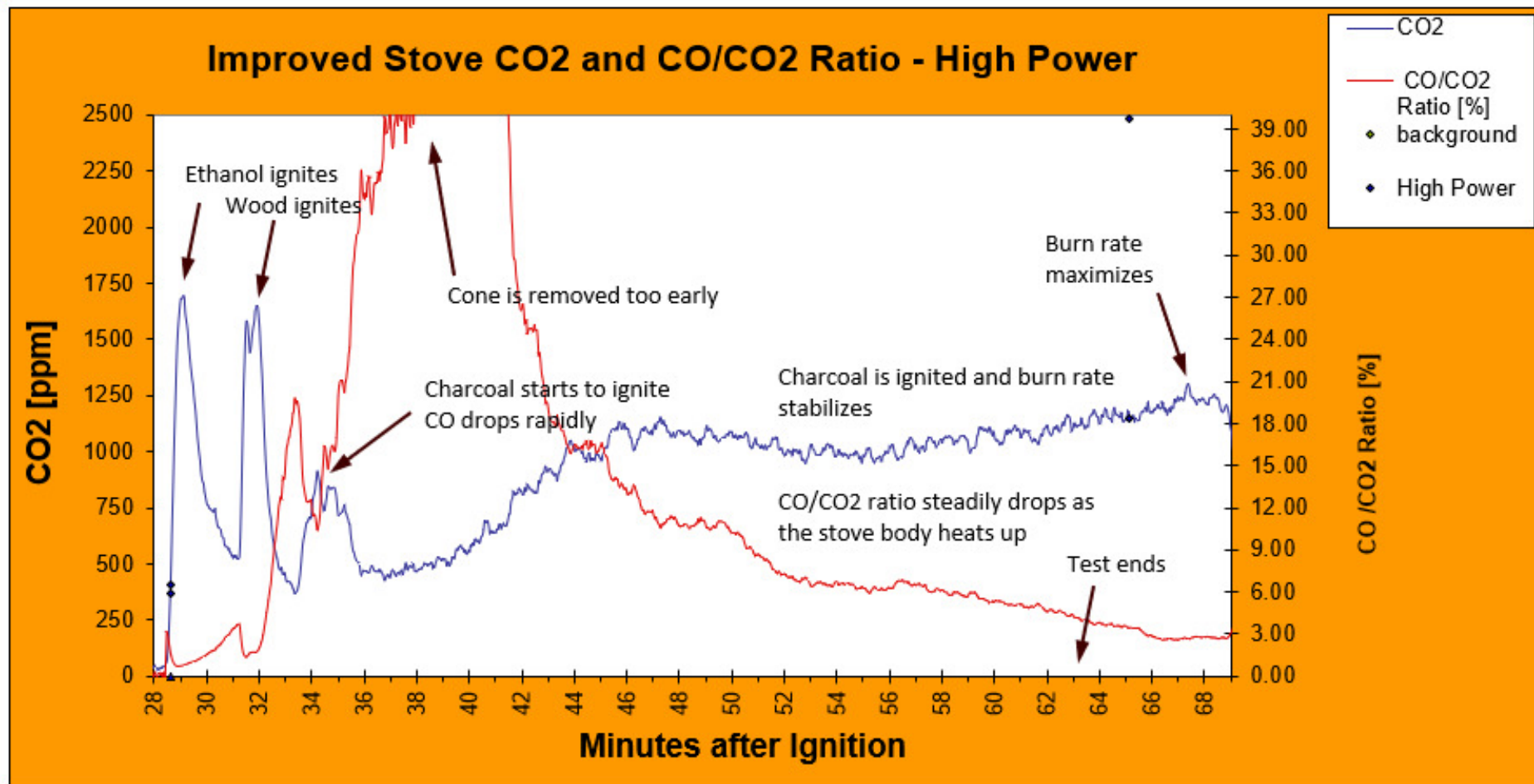
It was of course expected that we finally had African stoves which would easily pass Tier 3 for the first time. It was disappointing to hear from the lab that they were given Tier 1 ratings.

When investigating this unexpected result, the following influences were identified:

- The ignition was not according to the ISO protocol.
- The instructions provided by the manufacturer were not followed.
- The lighting cone was not properly deployed in that the fuel was not well ignited before the cone was removed.
- The charcoal used for product development was significantly different from the charcoal used during testing.

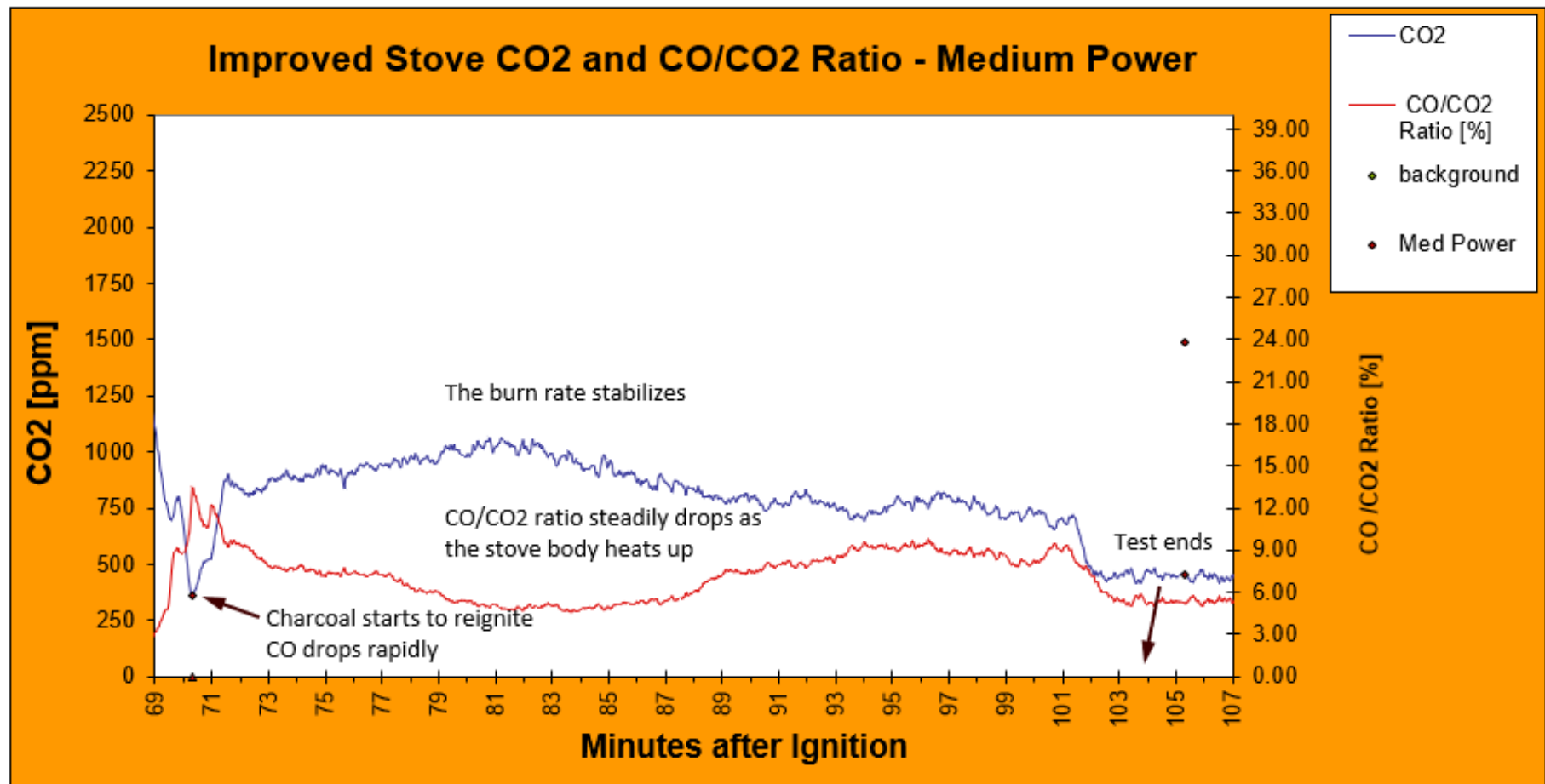
As a result, the fuel took so long to get going, that even after the 30 minute test was over, the fire was still developing.

Significant Issues – High Power



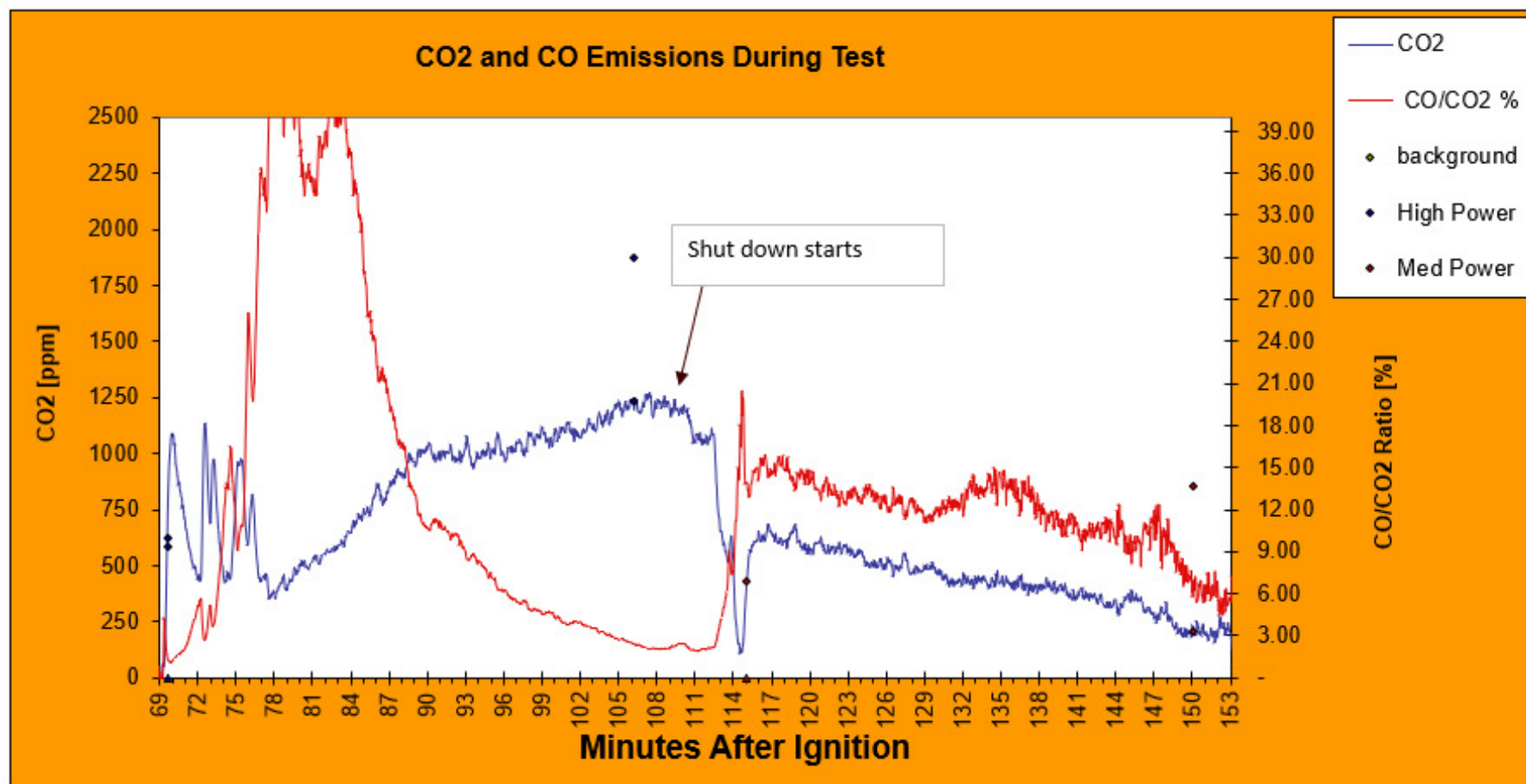
The ignition was improper, the cone removed too early, the fire developed well *in spite of this* reaching almost full power only 10 minutes after removing the cone. As the stove body was heated, the CO production dropped because the secondary air was getting more pre-heat. Shortly after the test ended the ratio dropped to 3%.

Significant Issues – Medium Power



The fire is extinguished for weighing the fuel and re-lit (using the same fuel). Again, the burn rate stabilizes at medium power in about 10 minutes, a significant improvement over traditional stoves. The fire never recovers to the previous state. The aggregate rating for CO: Tier 0.

Significant Issues – High and Medium Power



A different test of the same stove with the same issues during ignition:

The ratio drops below 3% but by then, the test is over. The ISO tests the technician's skill at igniting the charcoal, not the stove's ability to burn it. At no time does the test show the fully ignited, hot stove condition seen during normal cooking.

Conclusions

Testing of stove performance should be done according to the context in which it will be used. Performance cannot be predicted from a brief test.

A lighting cone should always be used to minimize the influence of the tester. The instructions should state that the fire be ignited properly before the lighting cone is removed.

The test should run uninterrupted from beginning to end, replicating the firepower and duration(s) during the preparation of a typical meal, varying the firepower as appropriate. This is usually done by adding or removing fuel.

The stove shown on the right cooks for 8 uninterrupted hours.



4-briquette institutional stove at a school in Kampala, Uganda

Recommendations

The ISO 19867-1 test method should not be used for rating charcoal stove performance.

The CSI test method developed by Indonesia and China for World Bank projects should be used. This consists of a social science research component to establish what should be done during the test that reflects typical use, and a technical component setting out the test measurements and calculation of outputs based on the Heterogeneous Test Protocol (HTP 3.076).

The ISO voluntary targets (Tiers) were developed in an opaque manner and should be verified in terms of methods and numerical targets as they seem to be unrelated to the ISO test method that references them.

The method in the published ISO document for calculating “average performance” is not valid and is in the process of being corrected. It should in any case be replaced by the CSI methodology.

The Heterogeneous Test Protocol developed by the University of Johannesburg, 2013 and further developed at CAU, Beijing, West Campus should be used exclusively for determining the performance of stoves burning high carbon fuels.

Thank you!

The author acknowledges these organizations for their assistance with this work:

Ugandan Ministry of Energy

UECCC and their Technical Committee

World Bank Office Uganda

ESMAP

Mubende Stove Company

Rwanda Standards Board

Crispin Pemberton-Pigott

New Dawn Engineering Inc.

Canada

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Photo: A portable, all-metal charcoal briquette burning stove. The typical burn time for the briquette is 8 hours. Elevating the pot dramatically reduce the CO produced. CO is combustible fuel! Modification of the briquette holes reduce CO it less that of an LPG stove.