Interpretation of CO and PM Emissions Data from TLUD Gasifier Cookstoves.

Paul S. Anderson, Ph.D., Biomass Energy Foundation, psanders@ilstu.edu

A presentation for the 2009 conference of ETHOS,
Seattle-Kirkland, WA, 23-25 January 2009

Introduction

Since 2005, high quality quantitative data on emissions from cookstoves have been accumulating. For data to be properly comparative, both a standardized cooking task and reliable emissions measurements are required. The principal test continues to be the standard five-liter Water Boiling Test (WBT), about which much has been written and debated. Equipment for reliable emissions measurements has been gathered, installed, tested, and accepted for operation at the Aprovecho Research Center (ARC) in Cottage Grove, Oregon, USA. No known equivalent site exists anywhere else in the world. Sincere thanks are given to the Shell Foundation, other financial donors, the ARC organization, and the numerous scientists who assisted in the establishment and operation of those emissions hoods. While the ARC facilitated the gathering of data presented here, the author is responsible for interpretations and any errors or omissions.

Dozens of different stoves have been tested to various degrees with the ARC equipment and methodologies. Hundreds of separate test results have been collected. The two measured emissions are carbon monoxide (CO) and particulate matter (PM). This report is focused upon those emissions from four categories of cookstoves:

1. The traditional "three-stone fire," which provides baseline data.
2. "Simple improved cookstoves" that utilize basic combustion that is confined in various stove structures made of ceramics, mud, or metal.
3. "Rocket stoves" that utilize clear principles and designs that provide significant control over the amount of wood in the area of combustion, with some restriction on the flow of air to the combustion area.
4. "TLUD (top-lit updraft) gasifier stoves" that essentially separate in time and location three processes of biomass burning (pyrolysis, char-gasification, and combustion). They also emphasize separate control of primary and secondary air supplies. Robert Flanagan, a TLUD stove developer in China, has coined the term "third-generation cookstoves" for these stoves that have the capability to easily create and save charcoal for use as a "biochar" additive to improve soil fertility (as in "terra preta") and to remove permanently carbon from the atmosphere.

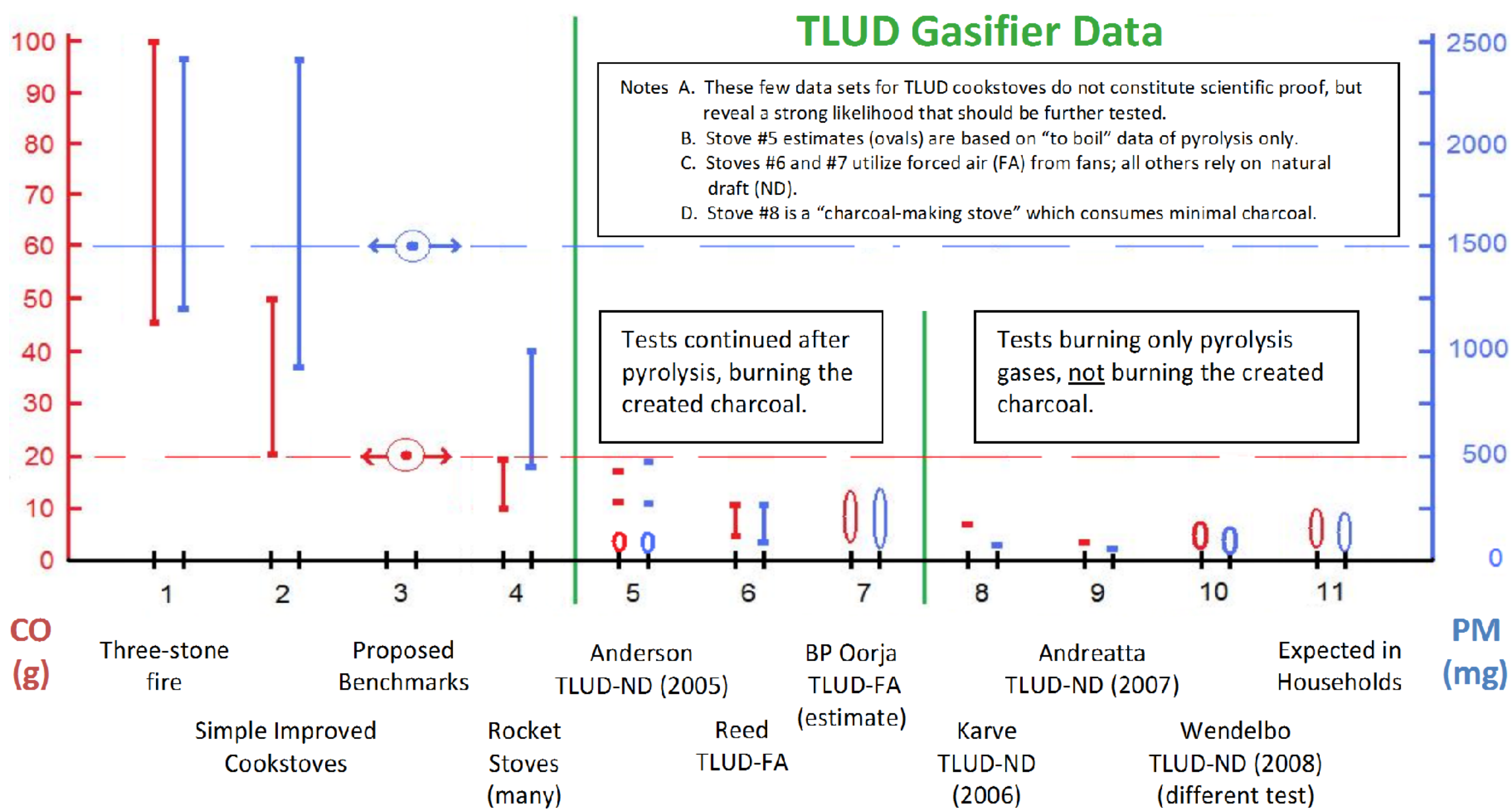
The Data on Emissions

The available data are not equal in quality. Some are highly rigorous and from frequently repeated tests. We can have confidence in their values. That is the case of the data for the first three stove types named above.

Some data are from singular or seldom replicated events, as in the testing of TLUD cookstoves, so they are not as "trustworthy." On the other hand, these new sets of data are our first glimpses of what could become well-accepted results in the future. New data should be more rigorously analyzed and understood. Therefore, these few data sets for TLUD cookstoves do not constitute scientific proof, but reveal a strong likelihood that should be further tested. The same data are presented here in both graphic and tabular forms in the same numbered order.

Emissions of Carbon Monoxide (CO) & Particulate Matter (PM) from TLUD (Top-Lit UpDraft) Gasifiers and Other Cookstoves

(Measured by the Standard 5-Liter Water Boiling Test (WBT))



Prepared by: Anderson, Wendelbo, Reed, and Belonio (2008) for the “Beyond Firewood” Conference. (Revised for ETHOS 2009)

Acknowledgement: The authors thank the Aprovecho Research Center, Cottage Grove, Oregon, USA where the vast majority of these tests were conducted with financial assistance from The Shell Foundation and others.

Table of Results of Emissions Testing of TLUD Gasifiers and Other Cookstoves

Data from the standard 5-liter Water Boiling Test (WBT)

[Data in italics are derived estimates that are shown as ovals on the graph.]

Number	**Stove Type**	**CO (grams)**	**PM (mg)**
1.	Three-stone fire (many tests)	45 to 100	1200 to 2400
2.	Various simple improved cookstoves	20 to 50	900 to 2400
3.	**Proposed benchmarks for maximum emissions**	**20**	**1500**
4.	Various Rocket stoves (many tests)	10 to 20	450 to 1000
	TLUD Gasifier Data (ND = natural draft; FA = forced air)		
	Operated to consume the created charcoal:		
5.	Anderson TLUD-ND (2005) (2 tests)	12 & 17	300 & 475
	(The "operational error" of intentionally burning the charcoal became known later;.)		
	(Calculations estimated from pyrolysis-only data:)	*3 to 8*	*25 to 180*
6.	Reed TLUD-FA (a few tests 2005 - 07)	6 to 12	80 to 315
	(charcoal intentionally burned during "trickle feeding" of fuel after pyrolysis.)		
7.	BP Oorja TLUD-FA *(data not available;)*	*6 to 16*	*70 to 340*
	(Expected to be similar to Reed data. BP does not recommend char removal.)		
	Operated NOT to consume the created charcoal:		
8.	Karve TLUD-ND (2006) (3 tests averaged)	8	70
	(This low-power "charcoal-making stove" does not burn charcoal well.)		
9.	Andreatta TLUD-ND (2007) (1 test)	2.5	25
	(Properly operated for pyrolysis only, but not maximized for heat transfer.)		
10.	Wendelbo TLUD-ND (2008) (1 different test)	*3 to 10*	*25 to 200*
	(A Controlled Cooking Test -CCT; interpreted results are close to the Andreatta data.)		
11.	Expected data in household usage *(estimated)*	*4 to 12*	*40 to 250*

There are at least a dozen TLUD gasifier cookstoves that are noteworthy, but only five have available data on emissions tests. A sixth (the BP Oorja stove) is included in the table/graph because of its commercial prominence and similarity to the Reed Woodgas Campstove. TLUD cookstoves of note include several by Belonio (FA), S.B. Reddy's Indian Magh series (FA or ND), Anderson's Juntos B+ (FA), the Chinese Daxu stove (ND), Flanagan's Biochar TLUD-ND, and the PP-Plus TLUD-ND by Anderson, Wendelbo and Servals LTD in Chennai, India. Photographs are on page 6. Comparisons will be in a separate document.

Notes and Interpretations

A. The total number of times that TLUD gasifier cookstoves have been rigorously tested for emissions is less than ten. Most tests were single runs, not the average of three repetitions to show consistency or improve measurement precision. At best we can speak of evident “trends.”

B. The ovals on the graph and the italics on the table represent “estimated ranges” calculated with differing degrees of confidence. The BP Oorja TLUD (#7) is highly similar to the Reed TLUD (#6) in their major characteristics of size of fuel chamber and fan-forced primary and secondary air. Their differences of overall physical size, electronic components, and the BP cast iron insert to protect the chamber walls should have minimal or no impact on emissions. The BP stove has not yet been available for testing at ARC, and BP has not responded to the author’s requests for emissions data. If the BP emissions are actually higher than the estimates, one interpretation could be that the BP product design simply did not accomplish what Reed’s TLUD-FA has established as being possible in a commercial product.

C. The Anderson TLUD (#5) has total-test data points and also oval ranges because it was operated differently during the “boil” and “simmer” segments of the WBT, with separate data for each segment. The boil segment uses higher heat and only the pyrolysis gases were combusted. Those figures were used to make the estimates. The simmer stage mainly was the slow burning of the created charcoal, resulting in the majority of the CO and PM emissions that are included in the total-test data. Graphic and numeric data from Stove Camp 2005 are at: http://www.bioenergylists.org/stovesdoc/ethos/2005camp/camps2005.htm

D. The Wendelbo TLUD (#10) has oval ranges because it was tested with a controlled cooking test (CCT) for preparation of a measured amount of “posho” (corn mush). The test was conducted using only the pyrolysis gases (no burning of the created charcoal), and the estimates were extrapolated from quantified measurements.

E. The Expected-in-Households estimates (#11) are conjectures by the author based on the other provided data. One assumption is that the users will NOT burn much of the created charcoal in the TLUD cookstoves.

F. The TLUDs intentionally operated to consume the created charcoal have considerably higher emissions levels (4 to 10 times higher) than do those operated to not consume the charcoal.

G. No test of a TLUD cookstove has produced emissions above the proposed benchmarks for either CO or PM even when the charcoal is burned in the TLUD device.

Explanation of the Three Processes of Biomass Burning in TLUD Gasifiers

Unlike all other cookstoves, the TLUD gasifier stoves are able to control in separate places and times the three processes that occur in biomass burning.

A. Combustible gases are liberated (or created) as the “pyrolytic front” moves slowly and uniformly from the top-lit ignition downward to the bottom of the fuel pile. Carbon is also created but accumulates above the pyrolytic front during this pyrolysis stage. The rate of production of the gases in somewhat controllable by restricting or enhancing (such as gentle blowing) the flow of primary air that enters under the fuel pile and rises to the zone of pyrolysis where its oxygen sustains the chemical reactions releasing moderate heat and the combustible gases that move upward.

B. Concurrently with the pyrolysis process (but in a separate location), the combustible gases move to the upper section of the TLUD where secondary air enters to provide oxygen for the combustion of those gases. Because this is a mixing of air with gases, there is no cooling of the solid fuel that is creating the gases lower in the gasifier, resulting in cleaner combustion. Depending on the TLUD design, some control of the secondary air is possible.

C. The third process is “char-gasification” that essentially occurs after pyrolysis ends. It is the transformation of charcoal (reasonably pure carbon – C) plus the oxygen (O_2) of primary air into mainly mixtures of CO and H_2 (hydrogen), with subsequent reactions to create mainly CO_2 and H_2O (carbon dioxide and water). Some of the CO can escape, giving the relatively high levels of CO emissions that characterize charcoal-burning stoves. Also, as the solid charcoal becomes gases, microscopic solids known as particulate matter (PM) are released and can be carried upward with the moving gases, escaping the stove and becoming measurable emissions.

The process-focused breakdown above illustrates why the charcoal-burning stage is the source of the vast majority of the relatively small amounts of CO and PM emissions in tests of TLUD gasifier cookstoves. Therefore, to have exceptionally low emissions (as shown by the data for stoves numbers 5, 8, 9, and 10), simply eliminate the charcoal burning process, which is the final stage. TLUD gasifiers can be constructed to permit easy removal of the fuel canister at the time of transition between pyrolysis and char-burning. The advantages are three-fold:

1. Exceptionally low emissions of CO and PM will reduce health risks.
2. The TLUD fuel canisters will have extended durability when not subjected to the extreme, forge-like heat of the char-gasification process.
3. Meaningful quantities (approximately 20% of the raw-fuel weight) of charcoal (biochar) are created, and this material has two uses:
    a. Suitable to be made into charcoal briquettes for combustion in stoves designed for charcoal burning. (The atmospheric CO_2 balance is then “carbon neutral.”)
    b. Suitable for sequestration as an enhancer of soils while (potentially) earning special carbon credit for true “carbon negative” removal of CO_2 from the atmosphere.

Three disadvantages of charcoal removal relate to:

1. Batch operations with handling of the fuel chambers, (a TLUD characteristic).
2. A modest increase in stove-cost to facilitate the easy removal of created charcoal.
3. Removal of about thirty percent of the energy potential of the cooking fuel.

Of course, the option remains to burn the charcoal in the TLUD and accept the higher emissions that are still lower than any other household biomass-burning cookstove.

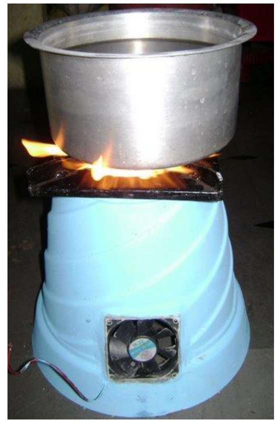
Conclusion

At best, the limited amount of data presented here on emissions from TLUD gasifier cookstoves can only indicate trends or likelihoods. On the other hand, the limited data are quite consistent and attract attention because the quantities of harmful emissions are one-tenth or less than from all biomass cookstoves except Rocket stoves. Indeed, the low emissions rival those of charcoal-burning and kerosene (paraffin) cookstoves widely used in impoverished urban areas.

The author acknowledges his bias from close involvement with TLUD stove design, development, projects, and testing. He is personally satisfied that these results and interpretations about CO and PM emissions will withstand the necessary scrutiny by other researchers and agencies advocating improved cookstoves. While he will be supportive of further testing with his time and refinements of TLUD devices, additional evaluation of TLUD emissions should be done by those who challenge or lack confidence in these findings.

Successful implementation of biomass cookstove projects to serve the needs of low-income societies and other people depends on more than the benefits of low emissions. Those challenges will be the driving forces for TLUD gasifier efforts in the coming years.






TLUD gasifier cookstoves. [Clockwise from upper-left corner.]

1. Reed Campstove *#6
2. BP Oorja *#7
3. Reddy Magh-CM1
4. Anderson Juntos B
5. Drummond-Cedar
6. Flanagan Biochar
7. A&W Servals PP-Plus
8. Wendelbo Peko Pe *#10
9. Anderson Champion *#5
10. ARTI Agni (based on Champion)
11. Karve Sampada Charcoal Maker *#8
12. Daxu (China)

1 – 5 have Forced Air. 6, 9, 12 have a chimney.
1, 2, 7, 8, 10, 11, 12 have or had commercial production.
*#__ indicates emissions data in table/graph (some models vary).