Comparison of Cookstove Emissions and Performance Results Using the Water Boiling Test v4 and the new ISO 19867-1 Testing Protocols

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Abstract

- Three billion people depend upon open fires or simple stoves burning solid fuels each day for cooking.[1]
- Household air pollution from solid fuel use is the world's leading environmental health risk factor[2] and contributes significantly to emissions of ambient climate-forcing pollutants[3].
- Laboratory testing has typically relied upon the Water Boiling Test (WBT) to both guide practices and allow a unified basis by which to report stove performance and emissions data.
- In 2018, the International Organization for Standardization (ISO) 19867-1 "Harmonized laboratory test protocols" were released with the intention of establishing improved international comparability for data on air pollutant emissions, efficiency, safety, and durability.[4]
- The present study compares ISO protocol emissions and efficiency data with WBT data both concurrently and previously collected in the same laboratory (United States Environmental Protection Agency, Research Triangle Park, North Carolina) on the same fuel/stove types.
- **Data analysis is on-going**, but preliminary results suggest that compared to the WBT, the ISO protocol results in higher carbon monoxide (CO) and fine particulate matter ($PM_{2.5}$) emissions rates/factors for advanced biomass stove types.
- The inclusion of both start-up and shutdown periods within each ISO test phase allows stoves to operate at both "steady" and "transitional" conditions and contributes to these higher emissions results for these specific stove types (particularly during shutdown phase as observed by analyzing real-time data).
- However, when the old ISO International Workshop Agreement (IWA) 11-2012 and the new ISO 19867-3 tier systems for CO/PM emissions are applied to both data sets, cookstove types are similarly ranked (e.g., tier-5 for LPG, tier-4 for wood pellet, tier-0 for wood traditional and charcoal using the new rankings).

Stove/Fuel Combinations

Six distinct stove/fuel combinations were studied (Figure 1):

A) Mikachi stove burning LPG fuel
B) Mimi Moto forced-draft semi-gasifier stove burning hardwood pellets
C) Philips HD4012 forced-draft semi-gasifier stove burning red oak
D) Envirofit G3300 rocket stove burning cut red oak
E) Kenya Ceramic Jiko stove burning lump hardwood charcoal
F) a "minimally tended" three stone fire (TSF) burning cut red oak

Figure 1. Photo of the six stove types tested: (A) LPG – Mikachi, (B) Pellet – Mimi Moto, (C) Wood Fan – Philips HD4012, (D) Wood Rocket – Envirofit G3300, (E) Charcoal – Kenya Ceramic Jiko, and (F) Wood Traditional – Three Stone Fire

Test Protocols

- Both WBT (v4) and ISO 19867-1 protocols were employed.
- Key differences for the ISO protocol (compared to the WBT, Figure 2) include: a) incorporation of a shutdown period in each phase, b) incorporation of a startup period in the low power phase, and c) definition of test period durations based on burning period/time (ISO) as opposed to water temperature (WBT).
- Pollutant emissions were simultaneously measured and reported for each of the three WBT phases [(1) high power, cold-start, (2) high power, hot-start, and (3) low power, simmer] or ISO phases [(1) high power, (2) medium power, and (3) low power].
- The first phases of each protocol are herein referred to as "initial phases", and the third phases as "final phases"; the second or "intermediate" phases are not directly compared here given inherent differences in firepower.

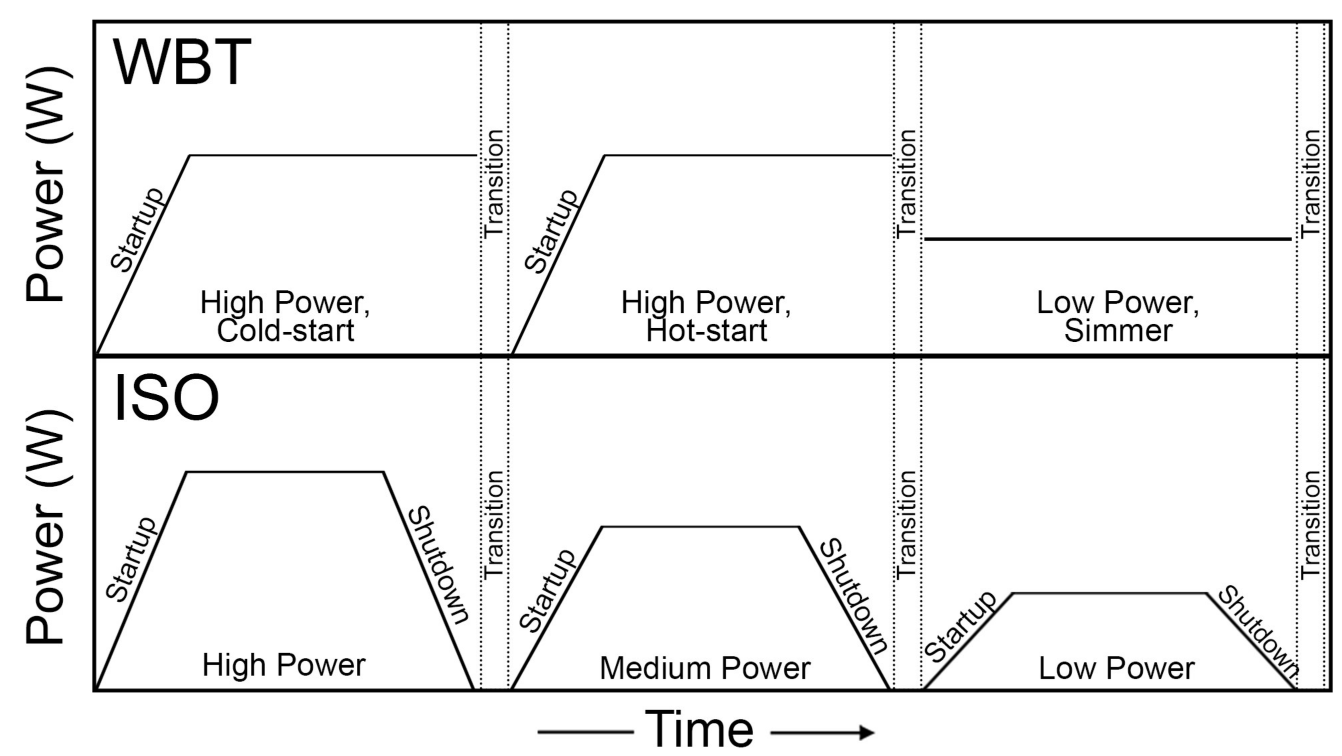

Figure 2. Representative overview of Water Boiling Test and ISO protocols in terms of stove firepower.

Emissions Characterization

- CO, carbon dioxide (CO_2), methane (CH_4), total hydrocarbons (THCs), and nitrogen oxides (NO_x) were continuously monitored with infrared and flame ionization detector analyzers.
- $PM_{2.5}$ mass was measured gravimetrically with a microbalance. The $PM_{2.5}$ was sampled isokinetically and collected onto both polytetrafluoroethylene (PTFE) membrane and quartz fiber filters (QFF) positioned downstream of $PM_{2.5}$ cyclones at a flow rate of 16.7 lpm each. A second QFF downstream of the PTFE filter was used to compensate for the gas-phase artifact. QFF were analyzed for organic and elemental carbon content (OC-EC) using a Sunset Labs OC-EC analyzer and the IMPROVE protocol.
- An engine exhaust particle sizer (EEPS) measured particles of mobility diameter range from 6.0 – 523.3 nm at 1 Hz.
- To explore real-time trends (and to help identify which periods during testing contributed to differences between protocols), instantaneous emission factors ($IEF_P = Q\Delta[P]$) were calculated and analyzed, where IEF_P is the instantaneous emission factor for pollutant P, Q is the flow rate in the duct ($m^3\ s^{-1}$), and $\Delta[P]$ is the background-corrected mass concentration of pollutant P.
- IEFs were normalized with respect to both test duration and mass of pollutant emitted for CO, THC, and particle number using an approach similar to Preble et al. (2014).[5]

Advanced Biomass Stoves Likely Influenced by Protocol Choice

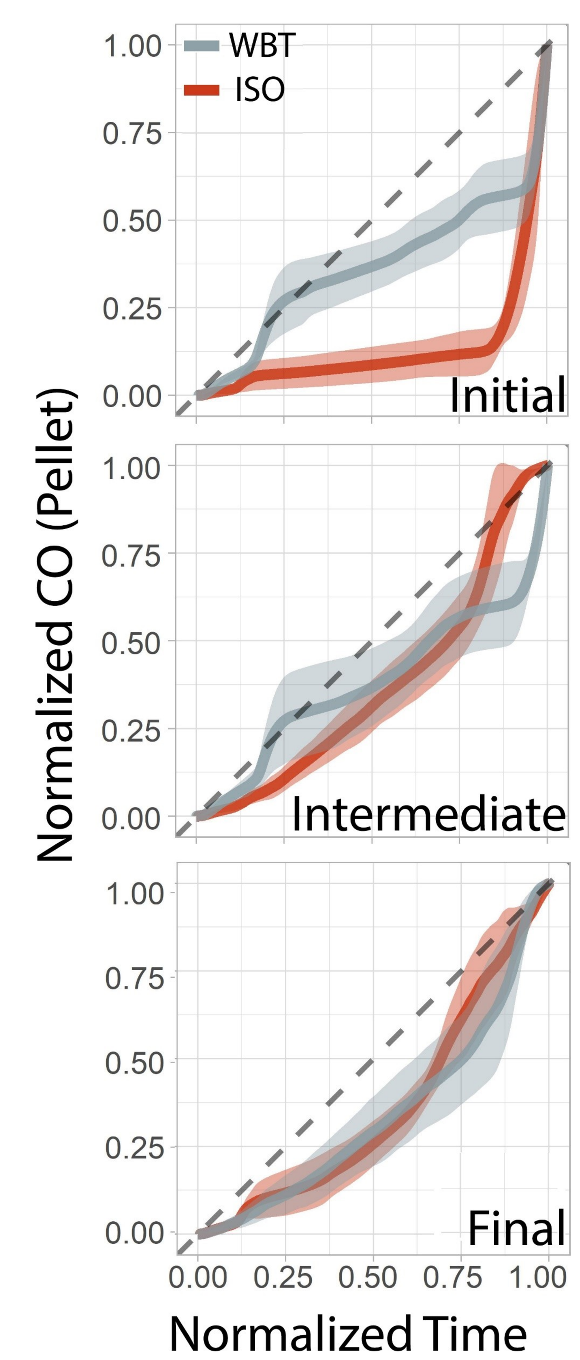

Figure 3. CDF for CO for the pellet stove/fuel combination.

- Emissions results for the advanced biomass stoves (pellet and wood fan) are likely the most influenced by protocol choice. These gasifier stove types are sensitive to operation[6] and expected to emit high levels of CO during the char burnout phase (defined as the "shutdown period").
- The impact of the inclusion of the shutdown period in the ISO protocol is explored in Figure 3, which plots example cumulative distribution functions (CDFs) of instantaneous emission factors for CO for the wood pellet stove/fuel combination.
- The pellet stove emits on average ~3/4 of all CO emissions during the shutdown period (of the high power phase) when utilizing ISO protocol.
- Cumulative particle number emissions are similar between protocols, and therefore protocol choice in general influences gas-phase emissions as opposed to particle-phase.

Voluntary Performance Targets

- The influence of protocol choice on overall "rankings" (in terms of ISO 19867-3 'Voluntary Performance Target' tiers) of cookstove/fuel combinations was explored.
- With the ISO protocol, emissions are averaged over a longer period of time, and therefore emission factors and rates are likely lower for many stove types with the ISO protocol, as emissions during startup are higher than during steady-state.
- However, those stove/fuel combinations strongly influenced by shutdown emissions (e.g., advanced biomass stoves) may have higher emissions metrics compared to the WBT.
- Preliminary results suggest that the traditional stove types, wood rocket stove, wood fan stove, pellet stove, and LPG stove remained consistent with former WBT test data, and aligned with ISO/IWA tiers 0 ("worst"), 1, 3, 4, and 5 ("best"), respectively.

Implications

- Real-world cookstove interventions are typically guided by laboratory test data, an understanding (and acceptance) of the ISO protocol is needed to best inform decision-making and eventually policy. This survey-type study suggests that test results for advanced biomass stoves, which offer the potential for large emissions reductions using largely available and accessible fuels, may be strongly influenced by adoption of the new ISO protocol.

References

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