TChar Technology for Cookstoves:

Part B: Construction

Version 1.2 Dated 7 Dec 2011

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Preamble

Part A provides an essential introduction for understanding the nature and purpose of the TChar (TEE-char) micro-gasifiers, and is not repeated here. See "Part A: Introduction" at: www.drtlud.com

Making a TChar Stove

Each TChar stove has two halves: the TBase which is essentially a charcoal stove, and a TTop which is essentially a Top-Lit UpDraft (TLUD) pyrolytic gasifier (and any associated stove structure for supporting a cooking pot). There are many functional charcoal stoves that could serve as a TBase, but their qualities are highly variable. Also there already are several types of TTops to provide the TLUD function. The TChar stoves explained in this document cover a wide range of both halves. Therefore, **please be aware**:

Caution: The TChar concept is easy to implement, but to make an optimal TChar stove, scientific knowledge and understanding about both TLUD technology and charcoal stoves is essential. Readers who are not familiar with TLUD terminology (such as pyrolysis zone, concentrator ring, primary air, etc) and TLUD operations are referred to the reference materials. The GIZ-HERA manual "Micro-gasification: cooking on gas from dry biomass" (http://www.gtz.de/de/dokumente/giz2011-en-micro-gasification.pdf) provides an excellent introduction. Consult the authors or the websites www.bioenergylists.org and www.drtlud.com for abundant assistance on charcoal and TLUD stoves. YouTube videos recommended for visualization of TLUD operations are available at: www.youtube.com/user/drtlud

The TBase as a Charcoal Stove

Charcoal stoves are notoriously of poor quality and cheap. In developing countries they can be purchased for as little as US$1. Except for the 3-stove fire which is essentially free, many of the least expensive stoves around the world are charcoal stoves made of mud, ceramic, or scrap metal. Costs range from US$1 up to $20 and even $50 for some models in affluent markets. Most of the existing charcoal stoves, whether inexpensive or not, can serve as the TBase component. Their basic function is to hold charcoal lumps together so that they will burn. Some have limited attempts to control the flow of air. Figure 1 shows some of the variety of charcoal stoves.

Figure 1: Nine charcoal stoves

Single-walled metal charcoal stoves with standard types of grates.

Metal-clad ceramic charcoal stoves, similar to the Kenyan Ceramic Jiko (KCJ).

Envirofit Model CH-2200 (Left) and a Ugandan facsimile w/ similar special air flows.

Haitian charcoal stoves with no method for air control. The steel rod unit (Right) does not work well with a TTop without the addition of a sturdy, perforated disc base plate.

Note: A separate design is discussed in a later paper for a TBase that is NOT for use as a charcoal stove, but is specifically for extinguishing (quenching) the charcoal to be saved as biochar or as cool char for later burning.

Listed below are several key characteristics for a charcoal stove to be compatible as a TBase to function with a TTop to become a complete TChar stove:

1. A walled chamber which will contain the charcoal that is released from the TTop. Overall, the TBase needs to be of adequate size to hold the charcoal produced by the TTop. The TBase is normally 15 to 30 cm. in diameter with sidewall heights of 4 to 10 cm, and is usually cylindrical.

2. A bottom "grate" which will initially support the biomass fuel and later the charcoal. The size and spacing of the gaps in the grate must prevent the passage of the raw dry fuel and of the created charcoal, which often is smaller than traditional lump charcoal. Wire

mesh, expanded metal, or a perforated metal disk can be used with charcoal stoves that have wide gaps/holes in the original grate.

3. The pot-rests and handles on the charcoal stove must not obstruct the placement of the TTop gasifier.

4. The TBase needs to sufficiently stable for the cooking functions.

5. Adequate primary air inlet and preferably primary air inlet control. It is quite possible that the good traditional charcoal stoves might need to be modified to have more air coming to the smaller charcoal pieces which tend to block the flow of air. All methods of decreasing or increasing the air flow upward through the bed of charcoal are of interest. The admission of secondary air just above the middle of the glowing charcoal can increase heat output and decrease carbon monoxide emissions. Methods are under investigation.

The work on TChar stoves has focused little on the TBase variations except to conduct test firings on a representative wide variety of existing charcoal stoves acquired around the world. The early opinion is that none of the charcoal stoves allows sufficient control of the flow of primary air during the TLUD phase of burning. The Envirofit CH-2200 has the best closure, but seems to lack air flow control during the charcoal burning phase. (The CharBowl stove is an exception to the above generalizations: www.bioenergylists.org/en/node/3069)

The TTop unit of TChar Stoves

The TChar concept is based on the TTop, regardless of the charcoal stove as its base. A TTop usually has two concentric vertical cylinders, an inner one for the dry biomass fuel and combustion chamber/riser, and an outer one that channels in the secondary air and provides some insulation value. The bottom of the inner cylinder rests lightly upon the grate of the TBase to hold the fuel in place. Appropriate holes or gaps are made for secondary air to enter near the top of the inner cylinder. Some form of concentrator (lid, top, or ring) is usually desirable to improve combustion.

According to how the TTop is placed onto the TBase (charcoal stove), four different types of positions of TTops have been identified in relation to the wall of the TBase, as shown in Figure 2. *Note: The first three are explained, but are not recommended as products.*

1. GRATE-SUPPORTED (Positioned only on the grate – Lacks stability and air control)
2. INSIDE (Inserted just inside the TBase wall – Friction fit causes problems)
3. OVER (Over-fitting just outside of the TBase wall – Friction fit causes problems)
4. ON (Placed onto the upper edge of the TBase wall – Very functional)

Figure 2: Four different types of positions of TTops

1. GRATE-SUPPORTED: One of the simplest TLUD device is an empty tin can turned upside down so that the former bottom becomes the top into which is cut a hole to be a concentrator lid. (See Figure 3.) Using a punch or "church key" can opener, a ring of holes is made for the secondary air to enter under the concentrator. A short riser (chimney) on top will greatly enhance the natural draft. Fill the can with dry biomass fuel and carefully invert it onto the grate of a charcoal stove. Ignite it at the top, and it will function as the TLUD half of an ultra-simple TChar device. This is sometimes referred to as "tincanium" technology. It is extremely inexpensive and simple and a great educational tool. But the disadvantages are significant: lack of stability, extremely hot wall of the canister, lack of a handle(s), safety concerns, and susceptibility to surrounding air flows/breezes/winds.

Figure 3: GRATE-SUPPORTED TTop, showing simple tincans as TTops

2 & 3. INSIDE and OVER: (See Figure 4)

INSIDE = Inserted just inside the TBase wall;

OVER = Over-fitting just outside of the TBase wall;

The earliest prototypes of two-walled TTops are shown in Figure 4. They are not recommended for replication because they rely upon pressure fitting to hold them into place. With metal expansion from heating, plus slight dents or pressure, they can become difficult to separate from the TBase units. Also, they require more work (manual or mechanical) to produce than later designs. Finally, they can easily leak air between the touching side-walls, making good air control more difficult or impossible.

Figure 4: INSIDE (left) and OUTSIDE (right) positions of TTops

4. ON (placed onto the upper edge of the TBase wall): Essentially, there is a simple contact between a surface and either another surface or an edge (but not an edge to edge contact), permitting a reasonable seal between the TTop and the TBase. This recommended design can have several physical ways to accomplish the task. One way has been named “Standard” and is shown in Figure 5 and described in detail later in the Part B documentation.

Figure 5: Examples of TChar stoves with a TTop that rests ON a TBase

Sizes of TChar stoves

Frequently, stove sizes and costs (both for the unit and for operation) are roughly directly proportional. Many stove sizes are possible, depending on the intended application of the heat, including family size, institutional size, small-task size.

Diameter of TTop Fuel Cylinder (inches) (centimeters)	**Classification**	**Comments**
2 or less < 5	Tiny	Works, but probably will not be made because too small.
3 to 4 6 to 10	Small	For small cooking or with dense fuels like pellets
5 to 6 11 to 16	Medium	Common size; works well. A test unit with a 5-inch diameter TTop and 12 inches of fuel height worked exceptionally well with both an Eco-Recho and an Envirofit CH-2200. The base in each had a steel mesh added to have smaller holes so that the small charcoal did not fall through.
7 to 8 17 to 21	Large	Also common, when more heat is needed. Large Eco-Recho
9 to 12 22 to 30	Institutional	Becoming too large to move the full pot down to the charcoal burner, so the charcoal burner will need to be moved up to a position under the separately supported pot. Alternatively, 2 TLUDs can be interchanged, and the produced charcoal can be placed into a different burner or be extinguished for later use or to be used as biochar in soils.
13 to 24 31 to 61	Biochar barrel	Special TChar designs are discussed separately.

There is a relationship between the volume of the TTop where the charcoal is produced and of the TBase that is to receive the charcoal for cooking or for extinguishing. The relationship is: The volume of fuel in the TTop should not exceed double the volume for receiving the charcoal in the TBase. Typically, the volume of charcoal is about 50% of the volume of the raw fuel if the fuel is something like woodchips or pellets. It appears that there is much less shrinkage with bamboo chunks. If the fuel is loose grasses, the charcoal volume is much less because the fine charcoal breaks and collapses into a more compact size. The ratio of fuel to char volumes depends strongly on the type of fuel. The TTop needs to be sized appropriately depending on the fuel and TBase.

Since typical TTop and TBase units have cylindrical fuel/char chambers, their respective volumes are easily calculated using the following formula: **Cylinder Volume = pi*d^2/4*h**, where pi=3.142, d=cylinder diameter, and h=cylinder height. The following chart lists four volume-to-cylinder-height relationships (shaded rows) for cylinder diameters ranging from 3 to 10 inches (or 7.6 to 25.4 centimeters). [Note: 1 ft^3 = 1728 in^3 = 7.48 gal = 29.92 qts; 1 liter = 1000 cm^3]

Cylinder Volumes								
dia (in)	3	4	5	6	7	8	9	10
dia (cm)	7.6	10.2	12.7	15.2	17.8	20.3	22.9	25.4
area (in^2)	7.07	12.57	19.63	28.27	38.48	50.27	63.62	78.54
area(cm^2)	45.6	81.1	126.7	182.4	248.3	324.3	410.4	506.7
qts/ft	1.47	2.61	4.08	5.87	8.00	10.44	13.22	16.32
liters/m	4.56	8.11	12.67	18.24	24.83	32.43	41.04	50.67
ft/gal	2.72	1.53	0.98	0.68	0.50	0.38	0.30	0.25
cm/liter	21.9	12.3	7.9	5.5	4.0	3.1	2.4	2.0

TChar Stove Construction

The TChar stove consists of the TTop and the TBase. The TBase is either a charcoal stove or a metal container (steel bucket, flat bottom steel cookpot, galvanized cylinder with flat bottom) to catch and save the charcoal at the end of the gasifier phase. (We'll call it a quench base. The char can be quenched, that is stopped from burning to ash, with water or by smothering the char in an airtight container. This will be detailed in a later paper.)

TTOP

The TTop consists of five basic parts:

1) **Inner cylinder.** A sheet metal tube. The bottom part of the cylinder is the fuel holder. The top part is the combustion chamber/riser. 2-4 in. (5-10 cm) below the top are the secondary air holes (2-3 rows of ¼ in to ½ in. (6-13 mm) holes spaced ¾ to 1½ in. (19-38 mm) around the cylinder). Primary air flows freely into the bottom of the cylinder through expanded metal-screen or perforated metal that prevents the small fuel and char particles from falling through. The cylinder sits lightly on the screen which sits on the TBase. (We are working on an adjustable telescoping base for the inner cylinder to allow a TTop to be used on different depth bases. We have not yet finalized a design.)

2) **Concentrator ring.** A sheet metal/plate ring that fits easily inside the inner cylinder just above the secondary air holes. It is held above the level of the secondary air hole by screws through the inner cylinder or a hook or hooks that hang from the top of the inner cylinder. It should be removable to make it easy to fill the inner cylinder with fuel. The inner hole is 2-3 in. (50-76 mm) smaller than the outside diameter and might or might not have wavy or toothed edges to increase turbulence for better combustion.

3) **Outer cylinder.** Another sheet metal tube with diameter usually 2 in. (5 cm) or more larger than the inner cylinder. It serves to preheat secondary air, act as a heat shield, and improve stove stability. With a charcoal stove base it would normally be shorter than the inner cylinder by the depth of the stove. (With a quench base, it would be shorter or the same length depending upon the design details of the base. Design in progress.) It should be equipped with one or two heat resistant handles for lifting the hot TTop to drop the hot char into the TBase. Some type of secondary air inlet(s) is/are necessary in the base of the outer cylinder. The total area of the inlet(s) should be slightly less than the total area of the secondary air holes in the inner cylinder.

4) **Upper ring.** A sheet metal ring that fits snugly against the inner and either snugly against or overhanging the outer cylinder, it is secured to the cylinders by friction and/or other attachment method at or near the top of the stove. (In the standard design the inner and outer cylinders will be rougly flush with each other at the top.) It serves to hold the cylinders in place relative to each other, prevent fuel from falling between the cylinders during filling, and to force secondary air to use the secondary air holes.

5) **Lower ring.** A sheet metal ring that fits snugly over the inner cylinder near the bottom. It could fit snugly inside the outer cylinder or extend past it, depending upon the base geometry and primary air flow regime. It is secured to the cylinders by friction and/or other attachment method. A wider lower ring will make the stove more secure until it overhangs the edges of the base. It is possible to use holes in an extension past the outer cylinder for primary air control. (Otherwise the primary air will come through the TBase.)

Some method of securing the TTop to the TBase during the gasifier phase might be desirable to improve stability and safety. Some sort of cam latches or turnbuckles could be used. It is important that they can be quickly and easily undone at the end of the gasifier phase to allow the TTop to be lifted off the TBase.

Inner cylinder sizing
As the diameter of the inner cylinder increases, the heat output for a given fuel increases. As the height/length of the cylinder increases the burn time increases (and the heat output may drop some due to increased air resistance). Inner cylinder diameters of 4-10 in. (10-25 cm) are probably reasonable. Height/length could range from 12 in. (30 cm) for denser fuels and shorter burns, to 30 in. (76 cm) for lighter fuels (like peanut shells) and longer burns. Very long/tall stoves may need additional structure of some kind for safety/stability.

Inner cylinder thickness and material
The inner cylinder gets very hot, especially near the bottom at the end of the gasifier phase. Thicker steel sheet metal will increase durability. Galvanizing may also help some, but the zinc will melt during stove operation and may not increase life much. Stainless steel would be more durable but probably too expensive. 24 ga sheet steel is probably a good starting point.

Outer cylinder sizing
Length will depend on the inner cylinder and base geometry. Diameter would normally be 2-4 in. (5-10 cm) more than the inner cylinder**.**

Outer cylinder thickness and material
The outer cylinder could be thinner than the inner cylinder. Galvanized steel sheet should be used to enhance durability and appearance. Too thin and it is easily dented/bent. 28 ga galvanized is probably a good starting point.

Concentrator ring thickness and material
24 ga minimum. Galvanizing may extend life; stainless preferable for durability.

Upper ring thickness and material
The upper ring can fit snugly between the inner and outer cylinders or overhang the outer

cylinder with attachments. It can be flat, or domed or ridged for greater stiffness. 24-30 ga recommended; galvanized optional.

Lower ring thickness and material
The lower ring needs to fit snugly against the inner cylinder. It needs to fit snugly against the outer cylinder or extend past it. It can be flat, or domed or ridged for greater stiffness. 22-28 ga recommended; galvanized optional.

SHEET STEEL GAUGE AND THICKNESS						
type	**gauge**	**30**	**28**	**26**	**24**	**22**
plain	inches	0.0120	0.0149	0.0179	0.0239	0.0299
steel	mm	0.305	0.379	0.455	0.607	0.759
galvanized	inches	0.0157	0.0187	0.0217	0.0276	0.0336
steel	mm	0.399	0.475	0.551	0.701	0.853
stainless	inches	0.0125	0.0156	0.0187	0.0250	0.0312
steel	mm	0.318	0.396	0.475	0.635	0.792

ADDITIONAL COMPONENTS

Pot support
Some method of supporting a pot above the stove is necessary. This can be as simple as an X of notched, crossed bars (which need to be cut down in the center for curved bottom pots) on top of the stove. Notched bars interlocking in a triangle with extended edges is another possibility. Holes in the bars inside the triangle may be necessary to get clean combustion with flat bottom pots. A separate structure for pot support (rebar supported by concrete blocks, for example) is another possibility.

Handles
Some sort of heat resistant handle(s) for safely and easily removing the TTop from the TBase are recommended. Long horizontal handles can be a safety hazard. Two short horizontal or vertical handles with wooden or coiled wire grips are probably best. Vertical handles need sufficient clearance and possibly an additional heat shield.

COSTS

TTop cost
Depending on materials and labor, the costs could be between $4 and $20.

Fuels and their costs
TLUDs can use a wide variety of dry, chunky biomass. Some are “free” notwithstanding the efforts of those who collect them. (This could change as materials previously considered as worthless waste are found be valuable resources.)

At least one biomass fuel type is typically abundant in a given region (except barren deserts).

We assume that appropriate supply lines develop as the market demand assures the sale of the fuels.

Compared with the price of traditional charcoal, we estimate TCharcoal to be one-half to one-third of the price, depending on whether the charcoal prices are in bulk, per bag, or per "lugar" or *marmit*.

Add in the "collateral costs" of traditional charcoal associated with the destruction of environment, even to the point of soil loss and damage to the infiltration areas for groundwater supplies, and TCharcoal comes out even better.

Traditional charcoal production literally wastes, as smoke, 60% to 80% of the energy content of dry biomass. (ref: http://www.burndesignlab.org/why-stoves/the-problem-of-charcoal/) Those two-thirds of the energy is actually what is providing the thermal energy released in the TLUD phase of the TChar operation.

> Example. In numerous cultures, one US dollar of traditional charcoal is consumed each day as cooking fuel. For ease of figuring, we will assume one kilogram of charcoal has an energy value of 30 kJ (28.5 BTU).
>
> Wood with approximately 90 to 100 kJ of energy was consumed to make that traditional charcoal, being approximately 4 to 5 kg of very dry wood or 6 to 7 kg of air dried wood with 15 to 20% moisture content (MC).
>
> In contrast, the needed 30 kJ of energy for the cooking task is found in approximately 2 kg of air dried woody biomass (including twigs, wood chips, and briquettes of sawdust with binder of recycled paper in pulp form). Even allowing 3 kg of biomass fuel for the cooking task, the total fuel consumption of the TChar stove is less than half of the original wood needed to make the traditional charcoal.

The favorable impact to halt or reverse deforestation is clearly evident.

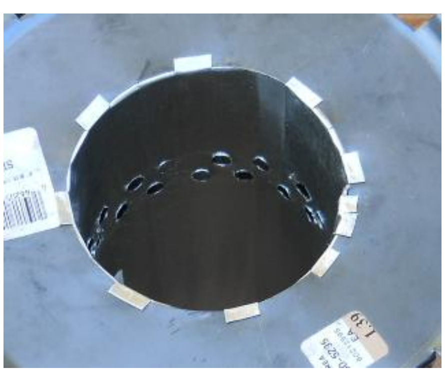
Detailed Construction – an example

Comments and photographs below show fabrication with galvanized sheet metal stovepipe/duct and collars, but the same construction information relates to stainless steel, black stovepipe, and different gauges/thicknesses, including metal plate for the rings. The discussion below plus photographs show two "Standard" units with very typical dimensions for the pairs of cylinders, being 5 and 9 inch diameters and 4 and 8 inch diameters.

The lengths of the cylinders are 15 inches (18 cm) for the inner one and 12 inches (30 cm) for the outer one. The horizontal pieces can be rings or squares or other shapes. They each extend beyond the diameter of the outer cylinder and have a hole in the center for the inner (fuel) cylinder (but please note and do not cut off the attachment tabs on the lower ring.)




Make the two rings or squares with an outer diameter or length of 10.5 in. (270 mm) or more. Note that the bottom one will be sitting on top of the charcoal stove and bearing the weight of the stove, fuel and probably cookpot. It needs to be of reasonable strength/thickness. Plan ahead for how the rings will be joined to the cylinders. Consider the approach as shown in the figures below. Left is the upper ring, right is the lower ring. The holes are cut differently for joining.




Make an inner (fuel) cylinder that is 5 inches (125 to 130 mm) in diameter and 15 inches (380 mm) long. While the metal is still flat, make 2 rows of quarter inch diameter (about 6 mm) holes that are 3-3½ inches down from what will be one the top of the cylinder. (See photograph on left above.)

Make the outer cylinder 9 inches in diameter (230 mm) and 12 inches (305 mm) tall.

Note that the central cylinder extends downward from the lower ring. That length is the only measurement that should be done carefully. The central cylinder should barely reach the grate of the charcoal stove when the TTop is fully resting on the top edge of the charcoal stove. If too short, the fuel could fall through the gap. If too long, the lower ring cannot reach to the charcoal stove, and then the TTop becomes unstable. Note in the closeup view of the bottom that the bottom edge of the central cylinder has been shortened by bending out some tabs on the bottom of the cylinder.

Add at least one handle. Be aware that the handle does get hot when the stove is in use.

A concentrator ring is inserted into the inner cylinder just above the rows of secondary air holes. It has approximately a 3-inch hole in the center and hangs from two sheet metal hooks.

Onward

There is much more to the TChar story, and we are documenting it as fast as we can. We are simultaneously doing research and development and learning more nearly every day. This document is currently planned to have five parts:

A. Introduction – Released in November 2011
B. Construction – This part, to be updated as needed.
C. Implementation, costs, etc. – Assistance for planning and realizing projects.
D. Further Developments – Already recognized, but still on the drawing board.
E. Results and Reports – Documentation of impact (to be given in several stages).

All interested parties are urged to contact the authors who will assist others to participate according to their goals and conditions.

Anderson, Roth, and Fairchild, December 7, 2011