The Wonderwerk Strata TLUD combustor

By Kirk Harris

The Wonderwerk TLUD natural draft test stoves use a combustor section above the secondary burn area to provide time and space for the secondary flame to burn more completely. New variations of this combustor, which improve its efficiency and shorten its height, are the focus of this document.

A Wonderwerk Strata combustor on top of a Wonderwerk test stove. The combustor is 7" (18 cm) tall and has 6" (15 cm) inside and 8" (20 cm) outside diameters with the space between filled with ceramic wool insulation. Currently I am using a Stove Tec cast iron pot stand. The combustors inner workings are described below. It is capable of containing a 5 kw flame below the pot stand, allowing it to complete burning before reaching the cooking vessel. The combustor concentrates the heat of the flame in a compact volume and so the interior can become very hot, frequently red hot. The octagonal piece in the center is the outside edge of the concentrator ring which is bent downward to align the combustor when it is placed onto the stove. An earlier version (described below) of the stove in the photo successfully passed the ISO-IWA tests, both high and low power using the pilot flame turn-down method. The new combustor enabled it to pass with tier 3 and 4 ratings.

The standard TLUD combustor is a vertical tube, which sits atop a concentrator ring, which in turn sits atop the stove. The concentrator ring mixes secondary air with wood gas from the reactor, and passes the resulting flame up to the combustor. The flame usually extends upward from the concentrator in a long slender column. This is a diffusion flame, which is not a very efficient way to burn the wood gas. If the flame touches the pot, it cools and forms soot on the pot and/or smoke, and so it is desirable for the flame to complete burning before it exits the combustor. This requires a tall combustor to contain the tall flame, which increases the overall height of the stove. For a portable, free standing stove this is undesirable for safety reasons because it makes the stove easier to tip over. The Wonderwerk Strata combustor originated as an effort to shorten the height of the diffusion flame, the combustor, and thus the overall height of the stove. As it turned out the measures taken to shorten the combustor also increased its efficiency as described below.

A diffusion flame burns on its surface where the fuel inside the flame meets the air outside the flame, like a candle. I saw that air was entering the combustor at the top, descending around the wall of the combustor, and contacting the surface of the flame forming the diffusion flame. It was apparent that mixing this air into the flame as low as possible in the combustor and burning the fuel as low as possible, would finish the burning as quickly as possible, shortening the flame. Several attempts failed to work until I recalled a suggestion made by Dr. Ron Larson to use a tube with holes, and place it across the wood gas stream to mix secondary air into the gas. He had suggested using it as the secondary air entrance, however to make the combustor transferable to other TLUDs, I wanted all changes to be in the combustor, leaving the stove unchanged. I placed pipes low in the combustor just above the concentrator. The ends of the pipes were outside the combustor to allow the outside air in, and the holes in the pipes were inside the combustor to inject the air into the flame. I tried a number of pipe and hole arrangements which did not work well, producing smoke. Then I found a combination that worked quite well. Soot could pass between the holes, but connecting the holes to form slots successfully burned that soot. Two long slots (Photo B) on opposite sides of the pipe, running the length of the pipe inside the combustor, and facing slightly downward toward the oncoming flame burned the wood gas cleanly.

Excess air in the flame which dilutes and cools it down has been a problem for TLUD designers. I have been watching for signs of this, but have not seen any. The flame in this combustor does not appear to be suffering from being cooled down by excess air. It is in fact very hot, as can be seen in Photo F.

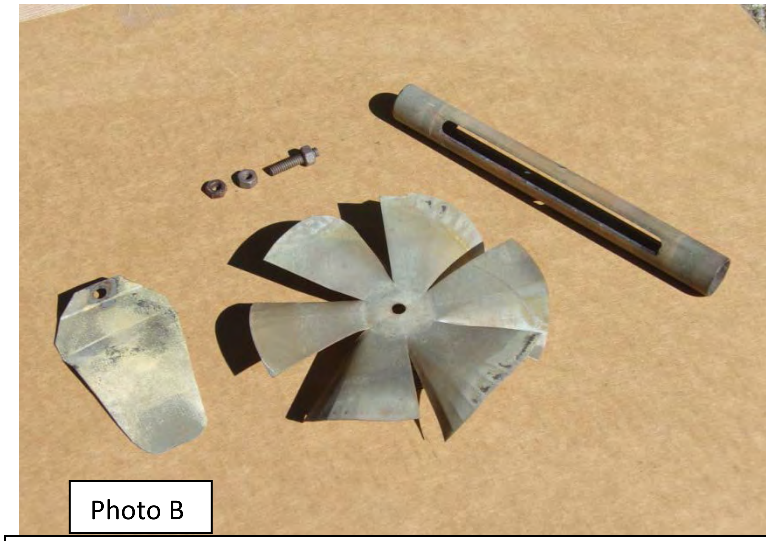


Photo B

Here is the pipe with slots laid out for clarity. The fan and deflector are explained below. The parts are designed to fit into a 6” (15 cm) diameter inside wall by 8” (20 cm) outside wall combustor. The fan diameter is 6” (15 cm) and the pipe is 8 ½” (21.5) long with two 5 ¾” (14.5 cm) slots. The fan is 1” (2.5 cm) above the pipe which is 1” (2.5 cm) above the concentrator ring.

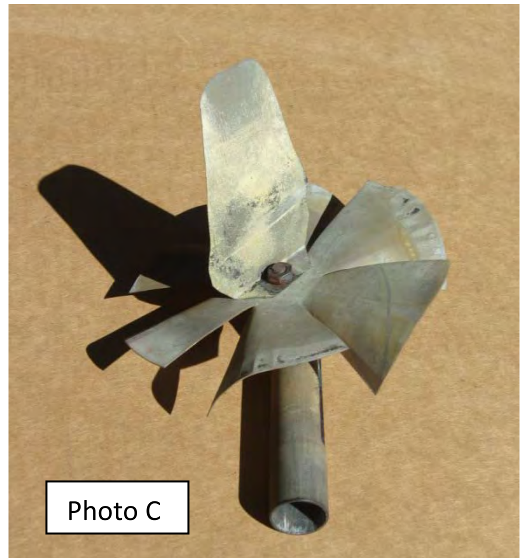


Photo C

Here the pieces are assembled as they will be inside the combustor. The flame rises past the pipe, then the fan and then the deflector. Two of the stationary fan blades are located directly over the pipe to give the best results.

As the flame passes the pipe it accelerates around it. This increased velocity is accompanied by lower pressure because of the Venturi effect. Atmospheric pressure pushes air into the ends of the pipe, through the pipe, then out of the slots and into the fire to fill this vacuum. Thus both the draft and the Venturi effect act to bring air into the combustor. I suspect that the use of the Venturi effect works very well for mixing the gasses because the air is pushed <u>INTO</u> the flame to fill the vacuum. The draft is driven by buoyancy, which produces no vacuum, so the air is pushed <u>AT</u> the flame where the gasses may travel side by side without mixing. Therefore the gasses must be mixed mechanically, like with the concentrator, but may never achieve thorough mixing.

This brings to the front the major principle which enables the pipe arrangement to work. It is a variation of the Venturi gas mixer. Venturi gas mixers are not new, but are commonly used in industry, home heaters, Bunsen burners, wind and water flow gages, and more. Approaching the design of the combustor by finding ways of using Venturi mixing allows considerable creative potential for design. I know of two ways that Venturi mixers work. One method is by reducing the cross section area of the flowing gas, thus increasing its velocity and decreasing its pressure. This is what the pipe method does. The other is by forcing the fluid through an orifice and thus creating a high velocity, low pressure spray, as in a Bunsen burner. Both use pressure difference to effectively entrain one gas <u>INTO</u> the other, producing excellent mixing.

Another advantage of the pipe system is that the flame follows a pathway consisting of two thin curved “sheets”, one on either side of the pipe, exposing considerable surface area for the air to enter. This combination achieves very thorough mixing. Photo D shows a fragmented flame rather than full sheets of flame. This is because the secondary flame is not uniform, and will not fill the curved sheet pathways at all points at all times, however the flame will usually always follow this path. It’s kind of like a roadway, there is not always a car on the road, but when there is it follows a pre-defined path. The flames in photo D lie within, but do not fill these curved sheet pathways.

Photo D

This photo shows the flame with the stationary fan removed for clarity. The flame is coming toward us, out of the picture. It emerges from below the edges of the rectangular concentrator hole and approaches the pipe as it rises. It then curves away from the pipe, blown by the air from the pipe. Looking through the wall of the combustor from the end of the pipe, the flame pathway would look like this: _)O(_

Also note the mineral wool insulation.

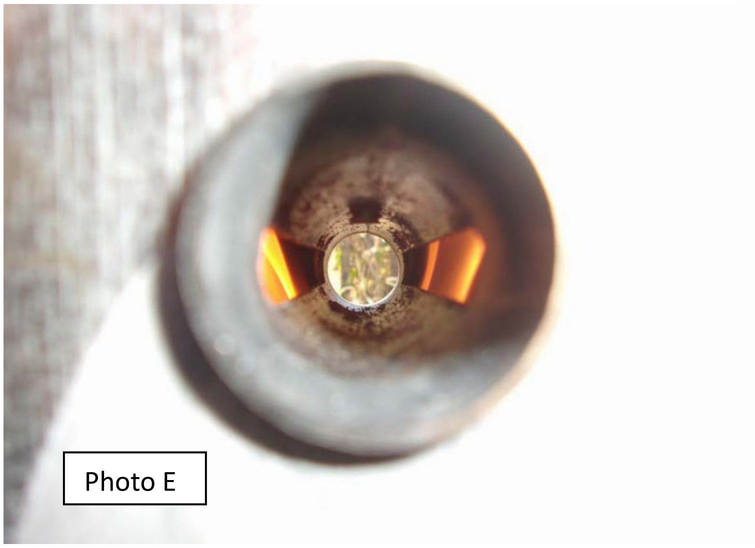


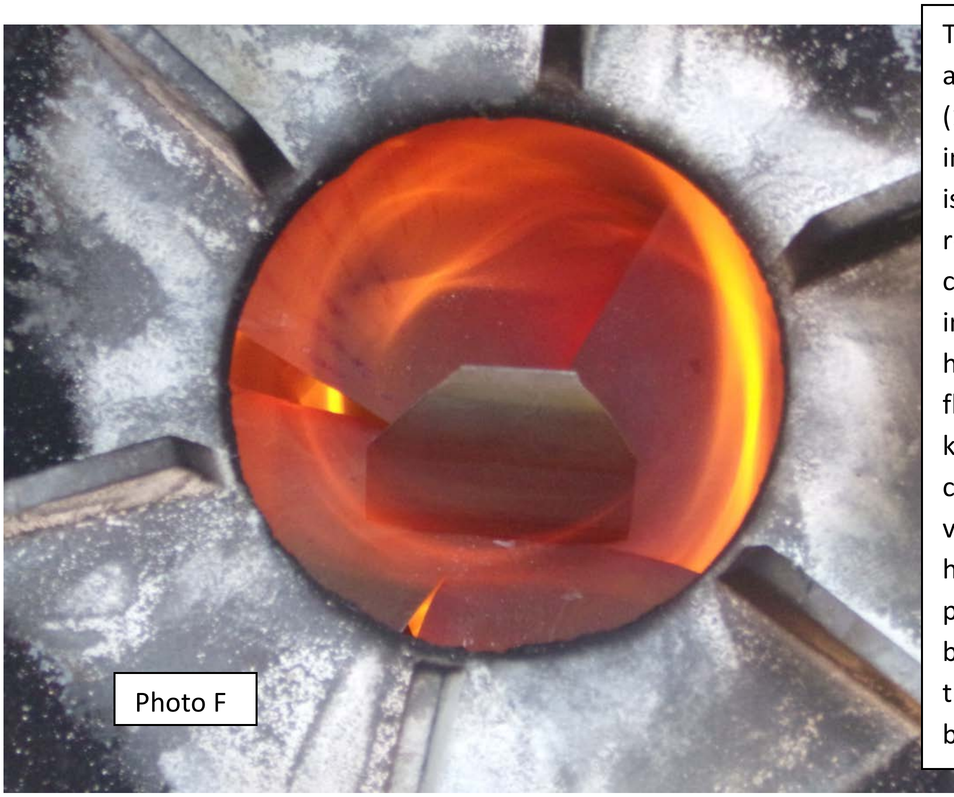
Photo E

This is the view looking into the end of the pipe. Visible are the slots and the flames passing the slots. The screw in the top of the pipe holds the stator fan and the deflector. At the very center are the plants in the background, visible because we are looking through the pipe which is open at both ends.

An additional advantage for this design is that the cook can monitor the fire by looking into the pipe. If the stove has turn-down this is very important. If there is a flame visible in the pipe, then the stove is stable. If there is no flame passing the pipe then the stove is turned to low, is in danger of going out and must be turned up.

At the same time that I was working on burning the wood gas low in the combustor I was working on a way to direct the flame so that it would take a longer path through the combustor, giving it more time to complete burning before exiting the stove. I tried various baffle combinations, but again nothing worked, until I remembered my earlier experiences with vortices. I tried using a vortex, spinning the flame like a cork screw. Several tries failed, until the basic old fashion electric fan blade arrangement succeeded (Photos B and C). This stationary fan sits just above the pipe to direct the flame into a swirling vortex. The flame takes a spiral path through the combustor, giving it a longer path and more time to finish burning before exiting (Photo F).

The combination of these two techniques, injecting air low in the combustor and spinning the flame into a vortex, allowed a high power flame to be compacted and contained in a much shorter combustor. Then I noted that the interior of the combustor, the pipe, the fan, and the walls were glowing red hot (Photo F). Burning the wood gas low in the combustor and concentrating the flame into a small space had created a very hot flame. Insulating the combustor wall increased the heat even more. Everything is there to provide a very efficient flame; fuel, oxygen, good mixing, time and space to burn, and lots of heat. Very little wood gas makes it past this combustor.



This photo shows a flame of about 5 kw contained in a 7" (18 cm) tall by 6" (15 cm) inside diameter combustor. It is traveling about ¾ of a revolution around the combustor. Note the metal inside the combustor is red hot from the concentrated flame. The deflector, which keeps the flame out of the center, is foreshortened in this view. The white on the pot holder is the ash from burned paint. This was a test of a four bladed fan, but I have found that 6 blades seem to work better.

The combustor works best if the flame takes the long path around the wall of the combustor. If the flame moves to the center, it forms a tall skinny flame which extends out of the combustor. To keep the flame in the combustor, it must be kept out of the center. A sheet metal deflector is placed in the center of the combustor above the fan to achieve this (Photos B, C and F).

Putting all these restrictions in the flames path at first seems self defeating. It would appear that it would impede the flow of the flame. Add to this that the combustor is now shorter, thus reducing the draft. Yet it does work if the arrangement is carefully designed. The stator fan blades must be close enough to each other to create the vortex, and yet far enough apart to allow free passage of the flame. The concentrator hole must be shaped to focus the flame onto the pipe, yet again open enough to allow free passage of the flame. The restrictions are set one above the other so the flame only has to negotiate one at a time. The added flow resistance can then be offset by increased burning low in the combustor and the accompanying increase in draft. The concentrated flame low in the combustor is hot all the way through the combustor, rather than a little bit at a time like the tall diffusion flame, thus increasing the draft. The spinning flame is in fact quite dynamic and almost, but not quite, resembles a forced air flame.

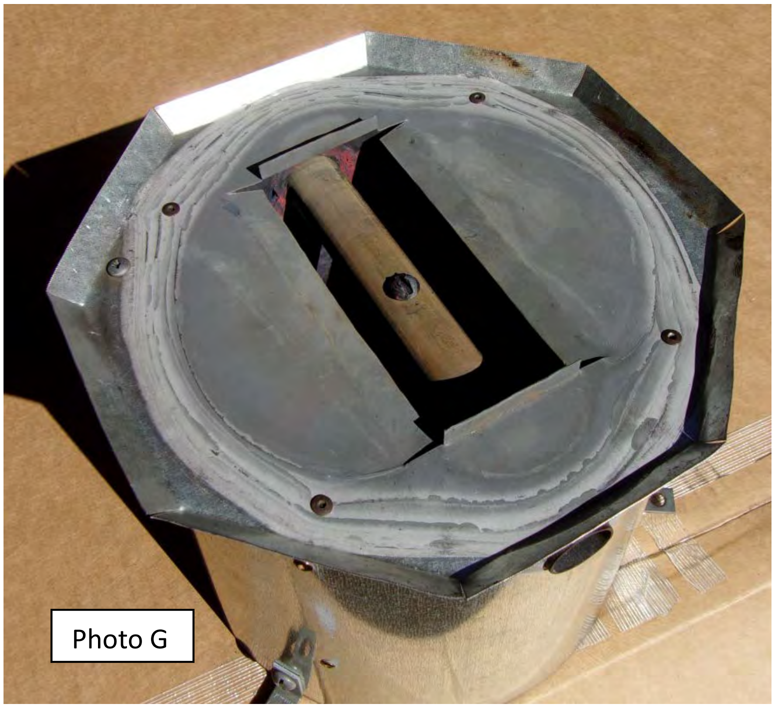


Photo G

This photo shows the concentrator from the bottom side. The angled edges of the rectangular hole and the pipe are visible. The angled edges direct the flame inward at the pipe forming the thin sheet pathway that the flame follows. The screw in the pipe is plugging a hole from a previous experiment. The flaps on the ends of the concentrator hole keep the secondary air from blowing the fire to the center, allowing the entire length of the slots to be used. The rectangle does not have radial symmetry, but the flame doesn't need that symmetry.

The stove which originally passed the ISO-IWA low power test at Aprovecho's stove camp in July 2014, used a 5 pipe star shaped arrangement with the pipes welded at the center (Photo H). I used this arrangement because I could not at first make a single pipe work. The single pipe could not inject enough air, thus causing smoke. In a 6" diameter combustor, the 5 pipe design provides 20" (50 cm) of slot while the single pipe provides only 11.75" (30 cm) of slot.

Photo H

This photo shows the 5 pipe arrangement used on the stove that first passed the ISO-IWA low power tests. This arrangement is difficult to build, so it was important to find how to get the much simpler single pipe arrangement to work. The 5 pipe design uses 5/8" (2 cm) ID pipe with 3/16" (.4 cm) wide slots. The single pipe arrangement uses 7/8" (2.3 cm) ID pipe with 5/16" (.7 cm) wide slots.

Since then I have found how to make a single pipe work. It depends on how the air is directed at the pipe. Angling the edges of the concentrator hole directs the flame directly at the pipe (Photo G), so that all of the flame passes near the pipe and receives air. If the edges are not angled, much of the flame passes at some distance from the pipe and does not receive air. The single pipe design is much simpler and cheaper to build than the 5 pipe design.

The pilot flame supported turn-down arrangement (method 2 in my paper on TLUD turn-down), enabled the stove to pass the low power ISO-IWA tests, and this combustor allowed the stove to do it with very good tier ratings for both high and low power levels (see attached Aprovecho test results). The combustor works well for both high and low power levels. If however the stove is turned to low and goes out as a result, this combustor can do nothing to help keep the flame alive. Also if the stove is on a low setting when the hydrocarbon fuel is almost used up, the flame will go out producing lots of smoke for a short period of time and the combustor does nothing to help with this problem. If the stove is on a high setting at this point, the transition to char burning is smokeless. Whether the combustor helps to burn all the carbon monoxide in a char flame is something that still needs testing.

Additional efficiency is achieved by the heat being so concentrated and active close to the pot. This increases heat transfer into the pot, both by the exhaust gasses energetically impacting the pot and by direct radiant heat to the pot. Radiant heat is efficiently absorbed by the soot on the pot (reflected by a clean pot) and transmitted into the food. Extracting heat from the exhaust gasses into the pot by convection is less efficient, and so lots of heat is carried away by the exiting gasses. If a substantial amount of heat can be converted from convection heat into radiant heat, it might be possible to get more of the heat into the pot. I am currently experimenting with this concept.

This combustor can be used on other TLUDs. It has been tried on a Champion stove with good results. It does not however work with a rocket stove. With the help and advice of Dr. Larry Winiarski we tried it on a rocket stove at the 2014 Aprovecho stove camp. The rocket stove already has excess air, and just needs mixing of the wood gas with the existing air. This combustor had no effect on the rocket stove.

The word strata, in an archeological site such as Wonderwerk Cave in South Africa, refers to layers of material laid down over time. The Strata combustor adds several layers of function to the TLUD stove, the angled edges of the concentrator hole, the pipe mixing in late secondary air, the fan spinning the flame, and the short insulated combustor where the spinning flame is concentrated. Thus came the name Wonderwerk Strata.

The Wonderwerk Strata combustor works to increase the efficiency and decrease the height of the Wonderwerk stove. Variations will very likely work with other TLUD stoves. It is quite simple in concept and design, and fairly easy to construct, making it an option to be considered.