PATENTS AND DESIGNS ACT, 1911

Form 3A

Complete Specification. Section 4.

(To be supplied in duplicate with Form 1, 1A, 1B, 1C, 1AC, 1BC or 1CC.)

(1) Integrated Modular System for Micro-Gasifier Cookstove/Furnace

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(3) The following specification describes the nature of this invention:-

Integrated Modular System for Micro-Gasifier Cookstove/Furnace

Integrated Modular System for Micro-Gasifier Cookstove/Furnace

ABSTRACT

The innovation is an integrated, modular design system for top-lit updraft (TLUD) gasifiers (Figure 1) used for pyrolyzing biomass fuels to create pyrolytic volatiles and residual char. The modules are: (A) a base for regulating primary air intake and removing char (Figure 2), (B) a gasifier reactor in the middle, and (C) a gas burner on top. The three modules stack on each other, C on B on A, to produce a systematically working stove/furnace. The purpose of the modular design is to offer flexibility to makers and users, so that stoves/furnaces can be made for various income levels, can be adapted to particular applications, and are easy to repair or modify. Two important features are: (i) that it is possible to use materials that are locally available including metal, concrete, clay, and mud; but because bulky materials can reduce portability, (ii) it should be easy to remove char from the gasifier without having to move the installation. (Char is an automatic by-product of TLUD gasification with useful many useful applications.) Two examples of natural draft TLUD gasifiers are given. Existing TLUD gasifiers are not deliberately modular, can't be build from bulky materials, and are made of materials that many countries would have to import.

BACKGROUND OF THE INNOVATION

TLUD gasifiers for biomass and coal use an oxygen-limited fire to pyrolyse fuel particles, creating volatile gases, and leaving behind a residual char that is rich in carbon. Unlike regular combustors, TLUD gasifiers can be used to separate two combustion processes in space and time: (A) the production and combustion of volatiles formed by pyrolysis, and (B) the combustion of char. The operator can prevent the combustion of the char, and collect it for later use. Char has useful applications as an adsorbent, microbial habitat, insulator and source of energy. Pyrolytic volatiles can be burned for heat, and/or used as a chemical feedstock.

A "top-lit updraft gasifier" (TLUD) consists of a reactor (usually a vertical cylinder) that is batch-loaded with biomass fuel or coal to create a fuel bed. At the bottom of the reactor is a grate through which primary air enters, and moves upwards through the fuel bed. The fuel is ignited on top, resulting in an ignition front that is sustained by oxygen by the primary air rising from below. The ignition front develops temperatures of 500-1200 °C which pyrolyzes the fuel particles creating volatiles (gases such as H_2, CO, CO_2 and light hydrocarbons; and suspended droplets of tar and fine solids) and a solid char residue. The ignition front burns about 25% (or more) of the volatiles to create heat for pyrolysis. However, the supply of primary air is restricted so that there is not enough oxygen (in the fuel and air) to burn the remaining volatiles and char. Thus, the ignition front in a TLUD is a "migratory flaming pyrolytic front" that moves down through the fuel bed creating volatiles, and leaving a bed of char above. The yield of char is usually between 15 and 25% of the original fuel dry matter. Pyrolysis volatiles rise through the bed of char, and can be ignited above in a gas burner to produce useful heat. When the ignition front reaches the grate at the bottom of the reactor, the pyrolysis of raw fuel is complete. At this point, the fire can be put out (and the char collected), otherwise the char will burn from the bottom upwards. TLUD gasifiers are also called "pot stoves" and "inverted down-draft gasifiers". When the TLUD is used for heating/cooking, a gas burner is built into the reactor, or mounted on top. Secondary air is supplied to support the combustion of the pyrolytic volatiles.

This innovation is an outcome of the “Colloquium on Biochar in Bangladesh,” hosted and promoted by the Christian Commission for Development in Bangladesh (CCDB), in Dhaka, July, 2013. Following the Colloquium, it was decided to form a public network of rural extension workers, technicians, homestead gardeners, students and scientists called “The Bangladesh Biochar Initiative” (BBI). It was concluded that, for households, making biochar as a by-product of cooking in TLUD cookstoves was the only environmentally sustainable method, because no additional biomass would be consumed. In fact, the TLUD would increase fuel efficiency (lowing fuel consumption) and reduce polluting emissions compared to the traditional chula, and reduce outdoor air pollution compared to improved chulas. Because of the multiple uses of char (as an adsorbent, microbial habitat, insulator and fuel), the char-making function of the TLUD could become a 'keystone' function in the well-being of households and their communities. The broad implications of TLUD/char technology stimulated a new approach to the study and deployment of cookstoves we called "Cook Stove Ecology" as a sub-discipline of human ecology. All that being said, the big challenge for households was not how to use char, but how to make it. How could we build TLUD cookstoves that are affordable for communities in Bangladesh and around the World, who don't participate in the Global economy, and can't import foreign TLUDs and their parts? The present innovation provides a method for adapting the TLUD technology for local manufacturers and local needs. This will help to maintain national self-sufficiency in cooking. Producing biochar will help to maintain national self-sufficiency in food.

GLOSSARY

- **Biochar:** is char that is used as an adsorbent for plant nutrients and is added to soil via composing (etc.) to improve biological activity and plant growth.
- **Buoyancy:** also called the “chimney effect” or the “stack effect” is the pressure caused in a gravitational field by the difference in weight of low-density gases (in hot flames), and the weight of surrounding higher density gases (in the room). Buoyancy is the driving force behind “draft” or the flow rate of air into the stove, and the upward flow of gases within the stove and out of the burner riser.
- **Char:** is the carbonaceous residue left after pyrolyzing biomass fuel. It is rich in large polycyclic aromatic hydrocarbons, that may be organized into honeycomb graphene sheets, as well as graphitic domains. It also contains mineral ash. If the char is used as charcoal, most of the carbon is oxidized, and only ash remains.
- **Fuel bed:** is the collective mass of fuel loaded into a reaction chamber. The fuel bed is converted into a char bed by the migratory flaming pyrolytic front.
- **Grate:** is a surface at the bottom of a combustion chamber, usual made from metal, and contain holes for the passage of primary air.
- **Ignition front:** is general term for a fire moving into fuel, for which a migratory flaming pyrolytic front is a special, oxygen-limited case.
- **Keystone:** is a block of masonry stone at the top of an arch that holds all other stones in the arch in place, preventing the arch from collapsing. ‘Keystone’ is

used as a metaphor in ecology to denote a species in an ecosystem that plays a vital role in supporting the existence of other species, such an elephant in an African savanna, or beaver in a northern forest. In the same way, 'keystone' is used as a metaphor to describe the char-making function of TLUD gasifiers in supporting a variety of human enterprises that can use the char.

- **Migratory flaming pyrolytic front (MFPF):** is a narrow zone of oxygen-limited, partial combustion in a fuel bed. In the zone, heat is generated by the partial oxidation pyrolytic volatiles. The heat causes pyrolysis of raw biomass fuel particles, releasing more pyrolytic volatiles and leaving behind a solid char residue. The MFPF moves downward in the fuel bed by radiative (mostly) and convective heating of raw fuel below, so that that as it starts to pyrolyse, it also becomes surrounded by flame.
- **Natural draft:** the air intake and gas flow in a stove/furnace is driven by buoyancy of hot gases of combustion; this is contrasted with forced draft, where ambient air is blown into the stove/furnace using a fan.
- **Primary air:** is the ambient air that flows into the bottom of the TLUD reactor to support combustion in the MFPF.
- **Pyrolysis:** is the thermal decomposition of organic compounds by heat in an oxygen free atmosphere, such as inside a particle of fuel. It starts at around 200 °C, becomes rapid around 300 °C, and is largely completed by 450 °C.
- **Pyrolytic volatiles:** are the products of pyrolysis including permanent gases (CO, CO_2, H_2, CH_4, N_2, H_2O), and tars which are composed of condensable gases, suspended droplets of liquid, and fine suspended solids. Pyrolytic volatiles undergo additional chemical reactions, called cracking and gasification, as they exit the fuel particle, and as they move away from the MFPF and up through the char.
- **Riser:** a tall cylindrical space that creates a buoyancy or chimney effect in burning gases that causes secondary air to flow into the natural draft, gas burner. Buoyancy created in the riser by the gas flame acts along with buoyance created by the ignition front in the fuel bed to drive the intake of primary air.
- **Secondary air:** is the ambient air that flows into the gas burner to support the combustion of pyrolytic gases.
- **TLUD (Top-Lit Updraft Gasifier)**: is a type of gasifier that consists of a vertical reaction chamber full of biomass fuel, which is ignited at the top to create a MFPF that moves down through the fuel bed against the flow of primary air rising from below through natural draft, or forced draft. The MFPF pyrolyzes the fuel creating volatiles, and leaving behind residual char.

PRIOR ART

Scientific history: Scientific publications describe TLUDs as laboratory instruments for studying fuel combustion (Nicholls, 1934; Rogers et al., 1972; Starley et al., 1985), chain grate stokers (Marskell and Miller, 1946), or moving grate gasifiers (Stubington and Fenton, 1984). In the years following these early articles, there have been 70 academic papers in English that used forced-draft, laboratory TLUDs to develop the science for designing large, industrial, moving grate gasifiers.

History of the portable, metal, micro-gasifier cookstoves: In the late 1980s, natural draft TLUD cookstoves were independently pioneered by Dr. Tom Reed and colleagues (La Fontaine and Reed, 1993), and Paal Wendelbo (Anderson, 2015). Dr. Paul Anderson (2015) developed natural draft TLUD cookstoves starting in 2001. Over these years, forced draft TLUD cookstoves were also developed (Reed et al., 2000; Varunkumar et al., 2013). All the cookstoves were portable, and made from stainless steel. As the TLUD micro-gasifier cookstoves became known, patents were obtained.

Patents for metal, natural draft TLUD stoves were taken out by:

I. Hall (1998; US Patent 5,842,463 A) describes a natural draft TLUD similar in principle to La Fontaine and Reed (1993)
II. Reed (2003; US Patent 2003/0200995 AI) patents the general principles behind natural and forced draft TLUD cookstoves that he, along with Hottenroth, La Fontaine, and Larson, had been developing since 1985 (Anderson, 2015).
III. Doge (2007, German Patent DE 202007010436 U1) describes a natural draft TLUD similar in principle to La Fontaine and Reed (1993)

Patents for metal, forced draft TLUD stoves were taken out by:

I. Reed (2003; US Patent 2003/0200995 AI) patents the general principles behind natural and forced draft TLUD cookstoves that he, along with Hottenroth, La Fontaine, and Larson, had been developing since 1985 (Anderson, 2015).
II. Mukunda, et al. (2007; World IPO patent WO2007036720A1) describes a forced draft TLUD with separate regulators for primary and secondary air. This is the “Oorja Stove”. Research was continued by Varunkumar et al. (2013)
III. Mulcahy (2011; US Patent US2011209698A1) describes a novel vortex burner for a forced draft micro-pyrolyzer cookstove that has design features similar to a TLUD, although it is claimed not to function that way, but as a “top-lit opposing draft” (TLUD) pyrolyzer. This is the “Lucia Stove” and has a natural draft companion called the “Everything Nice Stove.” At present, the TLOD mechanism should be regarded as a hypothesis needing scientific study.

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THE MODULAR TLUD GASIFIER COOKSTOVES/FURNACE

The modular TLUD heater/cooker is composed of three parts stacked on top of each other (Figure 1): (a) the base, (b) the reactor (c) the gas burner on top. Two examples are illustrated below made from (i) concrete, and (ii) bricks and metal.

EXAMPLE ONE — CONCRETE-METAL-CLAY TLUD (Figure 3.)

BASE: The base (Figure 2) has three primary functions:

I. Provide a frame (Fig. 2 #4) that gives stable support for the reactor and burner placed on top.
II. Control the (primary) air flow into the bottom of the reactor. Very little primary air is necessary to sustain gasification in the reactor, so there should be fine control of air flow, so the base should have *air-tight seals* at it joints, doors, the floor below, and the reactor above. Joints may be sealed with clay or mud. Primary air flow may be controlled by closing an aperture(s) with a sliding door (Fig. 2 #5), rotating disk, conical plug, or other means.

III. Allow for removal of fuel, char and/or ash from the reactor without having to move the reactor. The base contains the grate (Fig. 2 #2) that supports the fuel and char inside the reactor, and allows the passage of primary air. The grate must openable (by sliding or hinging) to drop fuel, char and/or ash into the base for collection. (Instead of being part of the base, the grate may be built into the bottom of the reactor.) A door (Fig. 2 #3) provides access for char removal.

REACTOR: A solid-walled container (Figure 3 #8) made of reinforced concrete with a vertical, cylindrical chamber is used to containing the fuel, and the gasification reaction. If the reactor is made of ordinary building concrete (not refractory concrete), the chamber should be lined with clay or mud to protect the concrete from high temperatures that can range from 500 to 1200 °C (depending on the fuel and primary air supply). The reactor may have a chamfer in the top edge of the chamber to transition to from the diameter of reactor to the diameter of the burner mounted on top, which will facilitate gas flow, and expansion of the gas flame below the burner (Fig. 3 #6, #7).

BURNER: The burner (Fig. 3 #6, #7) functions to (i) mix secondary air with the pyrolytic volatiles from the gasifier, (ii) house the gas flame, and (iii) convey radiant heat and hot gases upwards to the object that is to be heated, such as a cooking pot. Like the reactor (Fig. 3 #8), the burner is made of reinforced concrete with a clay lining if necessary. The inner chamber (a "riser", Fig. 3 #6) of the burner is cylindrical, and sufficiently tall to create a buoyant force in the burning gases to drive the draft of secondary air, and partially drive the draft of primary air and pyrolytic volatiles. The burner chamber must also be sufficiently tall so that the flame reaction is completed, and is not quenched by contact with the relatively cool surfaces of a pot. The diameter of the burner chamber is 1.2 times the diameter of the reactor chamber, which allows for horizontal space for the secondary air to mix with the pyrolytic gas and for gas flame to expand (to be contrasted with a tall, conical flame, wherein mixing of air and pyrolytic gas is limited, and combustion of gases is not completed). The top surface of the riser (Fig. 3 #6) can be sculpted to increase the contact of hot exhaust gases with a cooking pot to improve the convective transfer of heat.

The burner is mounted on top of clay mini-brick spacers (Fig. 3 #7) that are placed radially on the top surface of the reactor (Fig. 3 #8). The spacers create gaps between the reactor and the burner which allow entry of secondary air to support the combustion of pyrolytic volatiles. The height and number of spacers has to be determined experimentally, so as to minimize CO and particulate soot in the exhaust gases, whilst maximizing the efficiency of heat transfer from the fuel to the cooking pot.

An alternative to mini-brick spacers is to make round holes — tunnels — in the sidewalls of the burner (not illustrated). These tunnels may be conical, with a taper that narrows inwardly. The tunnels can be used to direct secondary air downward as well as inward, and/or induce rotation in the flame. This design of secondary air flow, and burner radius 1.2 x reactor radius is unique to this patent.

EXAMPLE TWO — CONCRETE-METAL-BRICK-CLAY TLUD (Figure 4)

BASE: Same as in Example One (Figure 2).

REACTOR: The reactor has two main components: an inner, metal reactor cylinder (Fig. 4 #13) in which the fuel is gasified, and an outer enclosure made of clay bricks (Fig. 4 #12). Secondary air enters the brick enclosure at or near the bottom through holes in the bricks, and is warmed as it passes upwards in the cavity between the reactor cylinder and the brick box. Both the brick box and the reactor cylinder sit on top of the Base (Fig. 2). The joint between the reactor cylinder and the top plate of the Base (Fig. 2 #1) is sealed with a gasket made of sand and clay (or mud) (Fig. 4 # 14). The gasket is needed so that primary air flow can be controlled in the Base without uncontrolled primary air leaking in at the joint. Since secondary air enters thought holes in the bricks or between bricks, the brick enclosure doesn't need to be air tight. The height of the brick enclosure and the reaction cylinder can be changed to adjust the duration of gasification for a full bed of fuel.

BURNER: The burner is modeled after the principle invented independently by Dr. Paul Anderson (USA) and Paal Wendelbo (Norway) (Anderson, 2015). The principle: secondary air enters over the top lip of the metal reactor cylinder (Fig. 4 #13), through a gap between the top of the reactor cylinder and a horizontal metal plate above (the "concentrator") (Fig. 4 #11). Pyrolytic gases rising from the fuel bed mix with secondary air and ignite (piloted by a gas flame that was established when the stove was first lit). The burning mixture rises through a round hole in a horizontal concentrator plate (Fig. 4 #11). The diameter of the concentrator hole should be at least 75% of the diameter of the reactor cylinder. The concentrator hole forces secondary air and pyrolytic gases together to improve mixing and increase the stability of the gas flame, especially at moderate to low gasification rates. This design of secondary air intake makes the pyrogas flame less vulnerable to being blown out by ambient cross drafts than the burner in TLUD Example 1.

On top of the concentrator plate is placed a vertical cylinder (riser) (Fig. 4 #10) that is sufficiently tall to create a buoyant force in the burning gases to drive the draft of secondary air, and partially drive the draft of primary air and pyrolytic volatiles. The burner chamber must also be sufficiently tall so that the flame reaction is completed, and is not quenched by contact with the relatively cool surfaces of a pot. The diameter of the riser cylinder is roughly the same as the diameter of the reactor cylinder. The top surface of the burner can be sculpted (not shown) to increase the contact of hot exhaust gases with a cooking pot to improve the convective transfer of heat. The riser can be made of metal, or crack resistant concrete or ceramics. In the present example, a simple pot holder is shown (Fig. 4 #9) on top of the riser (Fig. 4 #10).

Figures

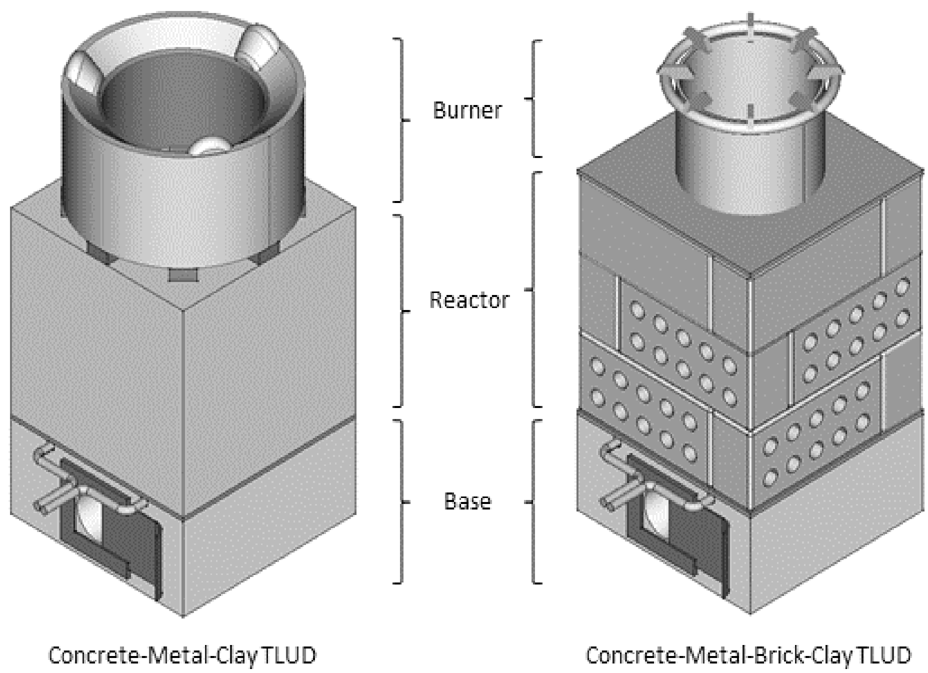


Figure 1. Two examples of modular, natural draft, top-lit updraft (TLUD) gasifiers. The innovation is an integrated, modular design system for TLUD gasifiers used for pyrolyzing biomass fuels to create pyrolytic volatiles and residual char. The modules are: (A) a base for regulating primary air intake and removing char, (B) a gasifier reactor in the middle, and (C) a gas burner on top. The three modules stack on each other, C on B on A, to produce a systematically working stove/furnace. The purpose of the modular design is to offer flexibility to makers and users, so that stoves/furnaces can be made for various income levels, can be adapted to particular applications, and are easy to repair or modify. Two important features are: (i) that it is possible to use materials that are locally available including metal, concrete, clay, and mud; but because bulky materials can reduce portability, (ii) it should be easy to remove char from the gasifier without having to move the installation. (Char is an automatic by-product of TLUD gasification with useful many useful applications.)

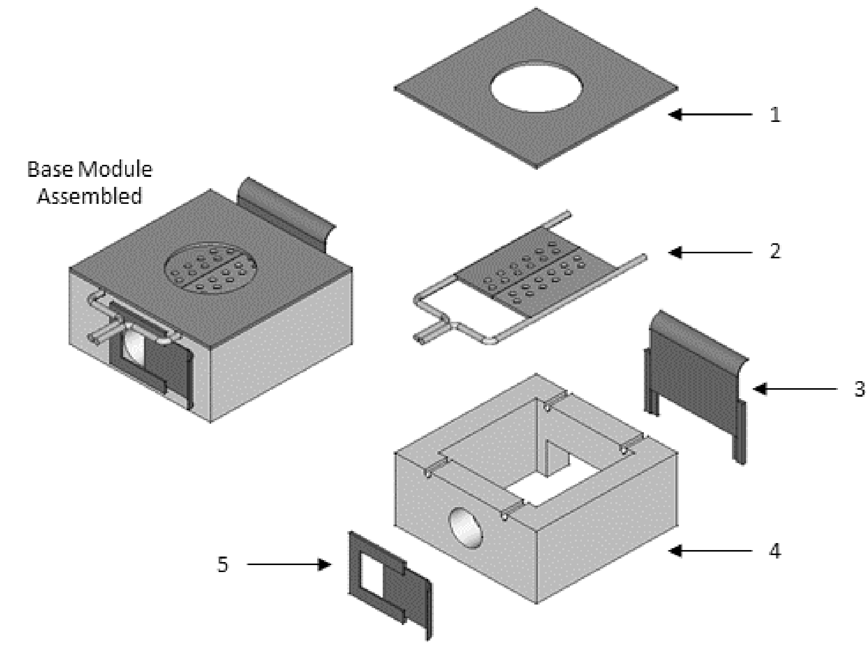


Figure 2. Concrete and metal base module: (1) metal top plate; (2) two halves of the hinged metal grate (handle locking clips not shown); (3) sliding metal door for char removal; (4) concrete frame; (5) sliding metal door for regulating primary air.

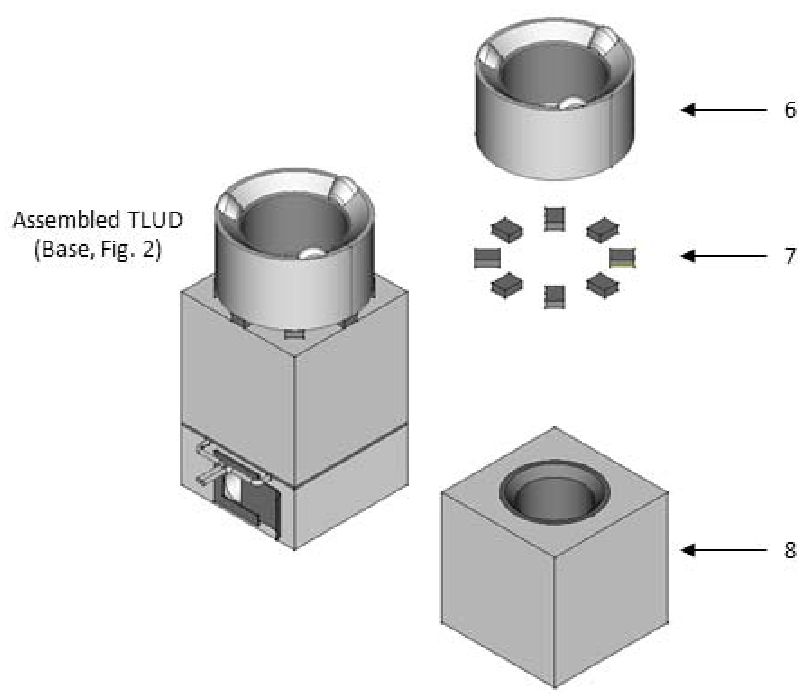


Figure 3. Example One — Concrete-Metal-Clay- Mud TLUD: Burner module: (6) concrete riser, with a clay-lined hole through the middle, and (7) clay spacers for secondary air. Reactor module: (8) concrete block with a clay-lined hole through the middle.

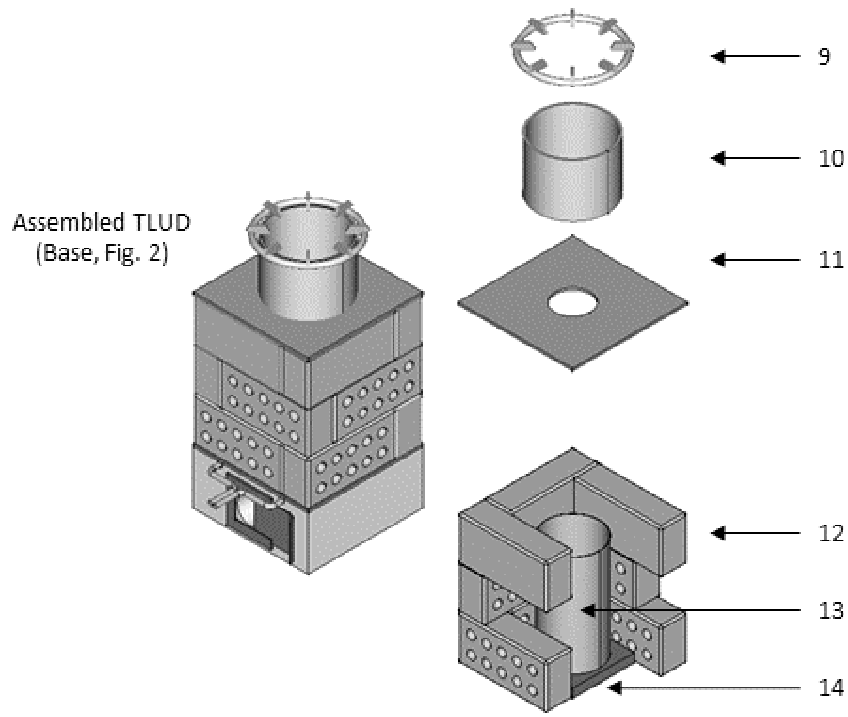


Figure 4. Example Two — Concrete-Metal-Brick-Clay-Mud TLUD: (A) Burner module: (9) cooking pot support ring; (10) metal riser; (11) burner module top plate with concentrator hole. (B) Reactor module: (12) reactor outer wall made with bricks, with holes for secondary air intake; (13) reactor inner metal cylinder (shorter than outer wall so secondary air can pass over the top of #13); (14) sand and clay gasket to seal #13 to Fig. 2 #1.

CLAIMS

We claim that the integrated modular design system is for building a fixed or semi-portable installation of a biomass stove/furnace, that can be made from metal and/or various dense, heavy materials (such as concrete, ceramics, clay, mud) such that:

I. It gasifies solid biomass fuel to produce pyrolytic volatiles

II. It automatically makes char as a by-product of producing volatiles

III. It is assembled in three modules comprising:

- a. A base that
  - i. regulates primary air flow entering the bottom of the reactor
  - ii. has a hinged grate, and a door for removing char from the reactor
- b. A gasifier reactor chamber
- c. A gas burner appropriate to the reactor that
  - i. mixes and burns pyrolytic volatiles in secondary air
  - ii. conveys hot exhaust gases and radiant heat to the object of work

IV. The base module allows for the removal of char from the reactor without having to move the installation.

V. The modular design allows flexibility to make changes to an installation in terms of mechanism, dimensions, and material composition according to:

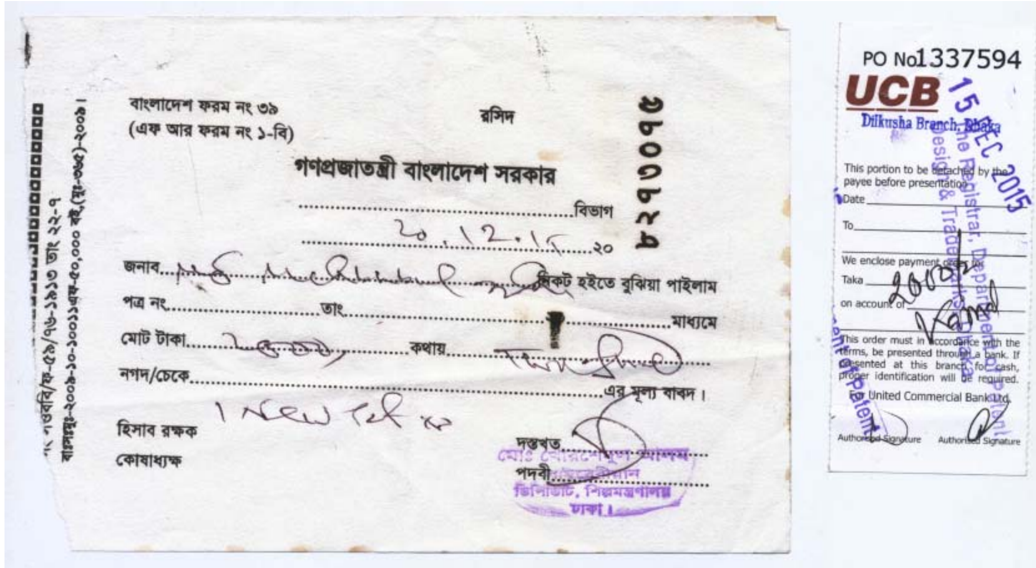
- a. different types of fuel
- b. different heat generation requirements
- c. different modes of fuel loading (batch or continuous)
- d. different modes of air supply (forced or natural draft)
- e. improvements in base, reactor or gas burner technology
- f. availability of materials for manufacture and repair (such as metal, concrete, ceramics, clay, mud)

Notably, the operator can alter the type of fuel (according to bulk density, reactivity, etc.) and dimensions of the installation (e.g., height and diameter of the reactor) according to particular heating tasks. Stove makers can use locally sourced materials.

Md. Mahbubul Islam

Julien Peter Winter

Dated the 17^{th} day of December, 2015



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