Vortex-Heater

Design Report

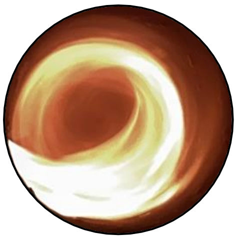

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Table of contents

1 | Introduction

This is a design report concerning a Vortex-Heater. It's a step by step approach, starting with basic elements and resulting to a final personal design. Secondly it describes the making of this Vortex-Heater in real. The building process directly confronted practical issues towards the designed model. At last the execution resulted in some expected vortex principles but not all items were successful. To complete this design report, drawings and additional files are added.

Sander Grummels

2 | Background information

2.1 Rocket-stove basics

Rocket-stoves are more efficient types of woodstoves (which make use of small wood) because of a better burn process (& better insulation) which are used for cooking efficiently. The (L-shape) rocket stove was founded by Dr.Larry Winiarski in the '80s as an efficient solution for people in developing countries who rely heavily on woodfired cooking. The rocket stove is about twice as efficient as open woodfires. Because of the burn process, they reduce smoke and harmful emissions. The stove does also a much better job at transferring heat to cooking pots.

2.1.1 How does a rocket-stove work

The geometry of a rocket stove consists of L-shape tube. (See Figure 1) In the horizontal part of the tube (wood) sticks are placed on a fuel shelve. The sticks are burned behind where the vertical section begins.

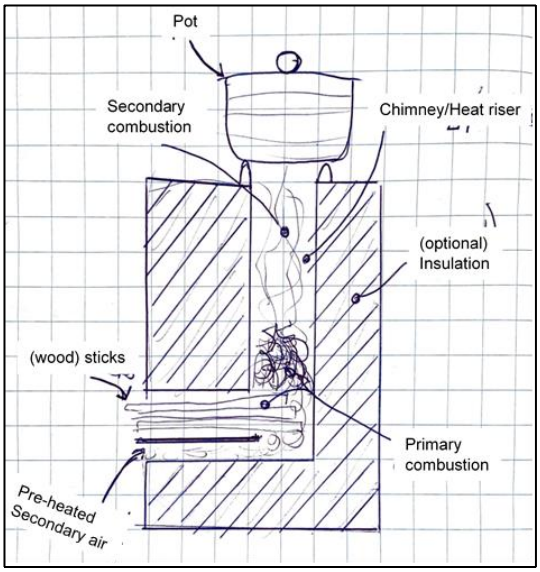

Figure 1 Schematic view of a L-shape rocket-stove

The most important part of a rocket stove is the (insulated) chimney/heat-riser. It produces a very strong draft (hot air wants to rise). Which allows lots of air drawn into the stove. This intensifies the burn (like a blower on fire) and more heat is created. The air is sucked from below the wood and is pre-heated. This limits the amount of cold air that gets in the combustion process.

The L-shape in combination with the insulation is a very important factor in the efficiency of the rocket stove. First, primary combustion takes (at the tips of the sticks) place. This will heat the stove and keep the process going. Due to the abrupt turn from horizontal to vertical flow, a turbulent flow is created. Oxygen gets well mixed with the combustible gases, in combination with the heat concentration in the insulated chimney. Secondary combustion will take place which generates an extra dose of heat.

Another key principle is that the wood is only getting burned at its tips. It is burned bit by bit (in the case of an L-shape, the wood has to be pushed in by hand), it limits the amount of wood that is heated (also due to the draft) and reduces the amount of volatile wood oils being generated. This creates a very constant burn. The burn process will not get overloaded all the wood can be burned cleanly.

2.1.2 Conclusion

All in all, the heat in combination with lots of oxygen drawn into the system is the perfect recipe for an efficient and clean combustion.

(Appropedia, 2021) (Hill, 2017) (Lebel, 2017)

3 | Rocket stove types

3.1 (Outdoor) Cooking rocket-stoves

3.1.1 L-shape

The original rocket stove developed by Larry Winiarski was intended for the use of cooking efficiently. The L-shape featured in rocket-stoves has besides all the other benefits another important function. Due to the insulation in the heat-riser, the heat gets concentrated and if you place a pot or a cooking pan on the heat transfer is very big to the cooking surface.

Important is to keep a gap between the cooking pot and the chimney as small as possible. It forces the exhaust gases to scrape along the sides of the cooking pot which allows high heat transfer.

Figure 2 (L-shape rocket stove)

The L-shaped rocket-stove (See Figure 2) for cooking is intended to use in poorly developed countries to reduce toxic smoke and fuel consumption. This type of stove is mostly made of clay, bricks, or concrete. These materials insulate quite well. Quite often the fuel shelve is not added. This is not such a very big problem sure it will reduce some efficiency but the basic principle is efficient enough and it minimizes the problems of smoke and lots of firewood.

3.1.2 V-shape

Also, a lot of stoves are constructed of steel, and instead of an L-shape it features a V-shape (See Figure 3). This has an advantage because the wood feeds itself when it burns because of the slope. This type of construction is barely seen on stoves made from clay, bricks. First, because it’s quite hard to make a geometry like this with these materials. Secondly, the friction between the wood and the slope is often too high so self-feeding doesn’t work. With the V-shape, the fuel shelve is very important because otherwise the air gets sucked over the wood, and turbulence mixing will not happen. For that reason, fuel is capped off.

Figure 3 (Bardon) V-shape rocket-stove

Earlier in the text is mentioned that insulation is the key for a clean burn. Feeling says that steel is not a very good insulator. That maybe partly true, more heat will dissipate from the fire, but as long the stove is a low mass (mostly the weight is much lower than their concrete counterparts) this will be minimized. The next material where heat is lost is air and is only due to natural convection (and the air is a bad conductor). Still, a relatively clean burn can be maintained only more heat is lost but it is still way more efficient than an open fire or a traditional stove

(Winiarski & Still, 2001)

3.1.3 Apostol rocket-stove

An Apostol rocket-stove (See Figure 4) is a rocket-stove with a bigger fuel stock capacity. More fuel can be loaded into the stove. The feed tube is much bigger than the chimney. The flow is slower and the wood will burn more slowly so the stove will burn much longer before refilling. It also generates more heat for bigger cooking applications where more heat is required. They are mostly constructed of steel. The inventor of this stove variant is Gabriel Apostol.

Figure 4 (Apostol rocket-stove)

Figure 5 (Rocket Stove Shower - Apostol H.E. 850)

There is also an outdoor application of generating hot water for showering off the grid. (See Figure 5)

(Engineer775, 2016)

3.2 Rocket-(mass)-heater

A rocket-mass-heater (See Figure 6) is an extended variant of the basic (L-shape) rocket-stove. Where a standard rocket-stove is very good at efficiently heating a small surface it is not very suitable for space heating because the heat is concentrated at the top of the chimney. When it is used inside it will fill the room with exhaust gases which is not desirable.

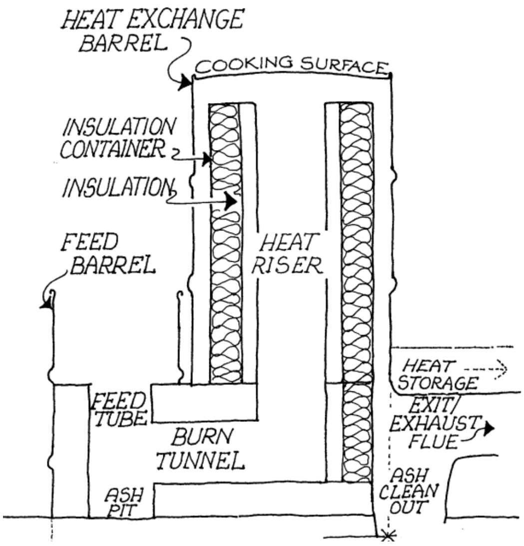

Figure 6 (Evans & Jackson, Rocket Mass Heater cross-section, 2007)

A rocket-mass-heater captures the hot exhaust gases that come out of the heat riser and mostly radiates the heat (into the building). The rocket-mass-heat does this by placing the chimney inside an enclosure (heat-exchanger). This is mostly a steel barrel. The gases are lead tightly along the sides of the enclosure (heat transfer is increased). The barrel cools the exhaust gases down to ±400 °C at the exit. As an option for more efficiency, the exhaust gases can be lead through a masonry mass which acts as a thermal battery. It stores the heat and cools the exhaust gases further down to ±50 °C before exiting the building through a chimney. Only Co2 and water vapor will exit the building. All added up this results in fuel saving of around 80% compared to traditional woodstoves.

What a rocket-mass-heater distinguishes from a standard stove is the J-shape. Instead of placing the wood horizontally, the wood is placed vertically. This allows for self-feeding so the fire doesn't have to be constantly monitored. The J-shape lets the fire burn horizontally in the burn tunnel (this is possible due to the high draft) where primary combustion takes place. Due to the abrupt turn with a gas flow, the gases will mix further and secondary combustion takes place in the heat riser. This is much better than in a standard rocket-stove and it will burn more efficiently. The most important to the rocket-mass-heater is its heavy insulation. The stove burns at around 1000 °C. These temperatures are needed to burn all the volatile compounds and extract all the heat from the wood.

A disadvantage of the rocket-mass-heater is that it is only capable of burning small wood so a lot of wood chopping is needed. Also, it burns very fiercely so it has to be filled quite often.

For a better understanding of a rocket-mass-heater reading the book **"Rocket Mass Heaters"** from Ianto Evans & Leslie Jackson is recommended. (See Appendix E.1)

(Evans & Jackson, Rocket Mass Heaters, 2007)

3.3 Vortex (/Himalayan) rocket-stove

The fundamentals of a vortex rocket-stove are the same as for a normal rocket-stove (Rocket-mass-heater variant or cooking variant). The difference is that the heat-riser is round and a narrowing is made from the burn tunnel to the heat-riser. This narrowing ensures that the gases will flow faster (Bernoulli effect). The narrowing is placed at the left or the right side of the heat-riser (not in the middle). This creates a vortex (See Figure 7). Due to the vortex, the flame path is extended which allows longer heating of the flame and results in better combustion.

Figure 7 (Top view vortex in heat-riser)

The vortex creates an air layer between the fire (which acts as natural insulation) and the heat-riser, what makes insulation not very crucial for maintaining a clean burn.

(Takeshi Ueno, n.d.) (Frequently Asked Questions, n.d.)

3.4 Batch-box rocket-stove

A batch-box rocket-stove is a rocket-mass-heater with a big firebox (See Figure 8) that allows loading more wood for a longer burn. It is intended to burn a pile of wood in one go and store all the heat (in the mass).

Figure 8 (Berg, Open Batch-box rocket-stove)

The batch box rocket-stove uses also the principle of the extended flame path but the narrowing is applied in the middle and no natural insulation is created (See Figure 9). So good insulation is very important. (Berg, Workings, how and why, n.d.)

Figure 9 (Berg, Top view heat-riser)

For a more extensive explanation of the Batch-box rocket-stove is suggest reading Appendix E.2.

3.5 What's not a rocket stove

On the internet, a lot of types of K-shape called rocket-stoves show up (see Figure 10). It has 2 tubes connecting to the chimney, one for the wood supply and one for the air supply.

Figure 10 (sjoerdb, 2019)

It is mostly classified as a rocket-stove but it isn't. Air gets sucked from a separate channel as the wood. So the air will not preheat and an adequate level of turbulence will not be achieved. So secondary combustion will not take place and it will not burn clean. It is a fire at the bottom of the chimney.

(Berg, Rocket stove van stalen koker, 2019)

4 | Concept-phase

4.1 Design intentions

The design idea is to make an efficient woodstove for use in the garden. It should be efficiently easy to construct and easy to demount. Also, it should be easily movable. Further, it is desirable to see as much as possible from the fire.

4.2 Inspiration

The inspiration from the concept design came from different rocket stove ideas from the internet. All the ideas come from YouTube videos.

The first inspiration is a vortex stove design made by Takeshi Ueno. He has made a vortex rocket-stove where the fire can be seen on the top of the heat riser (See Figure 11). That is done by adding tertiary-air at the top of the heat-riser. (secondary-air is added at the bottom of the heat-riser) Further, the vortex rocket-stove is a good option it is easy to construct from only steel which keeps also the weight relatively low. Also, the vortex principle ensures that insulation is not very important for good combustion. Adding insulation is optional the combustion will become better but the steel will slowly corrode away because it can’t handle temperatures above 800° very well.

Figure 11 (ロケットストーブ　アウトドアへ持ち出そう, 2013)

The second inspiration (See Figure 12) is from “Gaetanproductions”. They made a rocket-mass heater from steel but the heat exchanger is made from a gas bottle. It looks sturdy and easy to construct from only steel but it is also movable because there is no masonry mass added.

The last inspiration is by adding glass in the burn tunnel and on top where the flames exit the riser (See Figures 13 & 14). In combination with the vortex stove from Takeshi Ueno, parts of the flames become visible.
All these inspirations meet the design intentions of efficient heating, seeing as much as possible of the burning flames and being movable.

Figure 14 (ROCKET STOVE SIDE VIEW, 2017)

Figure 13 (DIY rocket stove improvement, 2017)

Figure 12 (Rocket stove heater for a workshop or a room, 2015)

4.3 Design concept

Based on the inspiration a first concept was created (See Figure 15). The base of the stove is a vortex rocket-stove. The stove is completely made out of steel, The heat exchanger is made from old (11kg) gas bottles welded together. The heat-exchanger is a 2-piece part for easy assembly. This concept features a window on the top of the heat-exchanger.

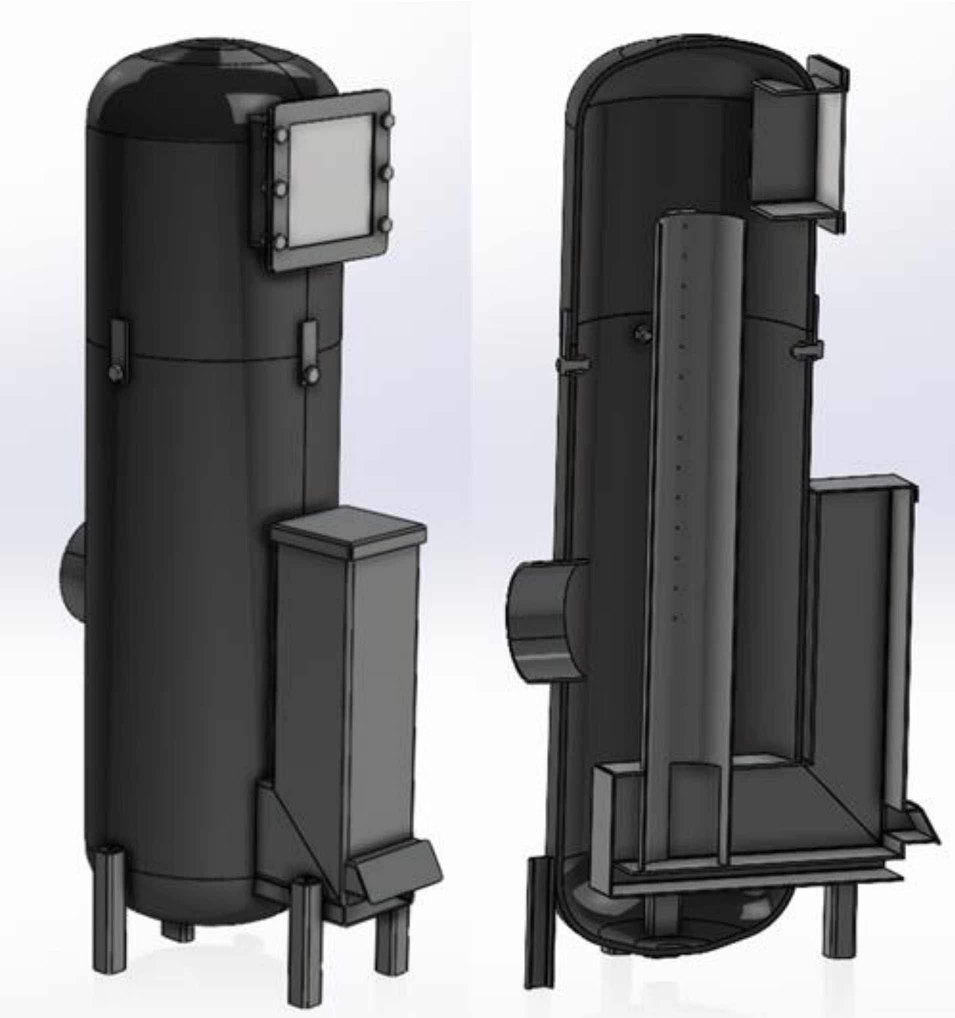

Figure 15 Vortex-Heater concept

See Appendix A.1 for a 3D pdf of the concept design

5 | Detail design

The definitive design (See Figures 16, 17 & 18) will be explained in the following paragraphs. It will describe which choices are made and how the design came about.

5.1 Design substantiation

For the whole stove, there is chosen to make it fully out of steel. As a base, a vortex rocket-stove is used. this paragraph will explain how the design meets the design intentions.

1. Easy construction:
    - Because the stove is made of steel, all parts can be made with a laser cutter & basic metalworking tools (no milling). So no concrete casting of clay molding.
1. Moveability:
    - Because the stove is made of steel the weight stays relatively low (78 kg) so the stove is moveable.
2. Easy to demount:
    - The stove is made of 4 parts so it is demountable.
3. See as much fire as possible:
    - Two viewing windows are included in the design where the flames are perceivable.
4. Efficient burning/heating:
    - As a starting point, a vortex rocket-stove is used. It allows the stove to be made from steel (because the insulation is not very important for explanation see 3.3). However, efficiency will be less, a compromise has to be made for easy construction and moveability. Also, the extra windows will reduce efficiency.
    - The heat-exchanger will radiate a lot of heat which is desirable outside.

Figure 16 Vortex-Heater 3D render

Figure 17 Vortex-Heater section

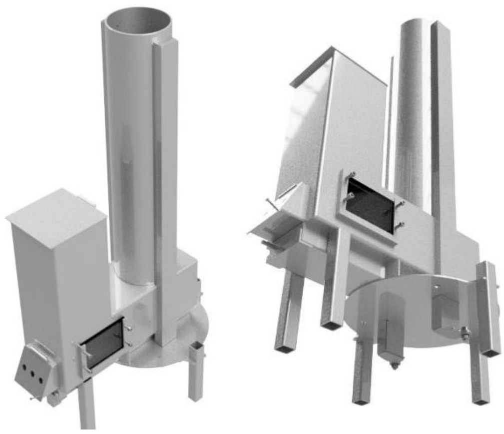

Figure 18 Vortex-Heater stove base 3D render

For a 3D pdf see Appendix A.2. For more 3D renders see Appendix B.1.

5.2 Design description

The Vortex-Heater consists of 4 main parts:

- Stove base (vortex rocket-stove)
- Bottom part heat-exchanger
- Top part heat-exchanger
- Chimney

For an overview of all characteristic parts of the stove see Figure 19

On the stove base, the bottom part heat-exchanger gets mounted. On top of the bottom part heat-exchanger, the top part heat-exchanger gets mounted. At the exit-port of the bottom part heat-exchanger the chimney gets mounted.
Secondly, in the design two windows are included. One is mounted in the burn-tunnel and one in the top of the heat-exchanger. The windows are attached with bolts and are pressed against a heat-resistant seal cord. Also between all the 4 main parts heat resistant seal cords are added for a good air-tight sealing.
Besides, the top part of the heat-exchanger is removable, this makes it possible to add insulation around the heat-riser (vermiculite for example). Take into account that insulation will result in a better burn, but because the temperature will rise it goes to temperatures where the steel can corrode away slowly and the life expectancy of the stove will be shorter.
Further, the whole stove is made from standard mild steel (S235) except for the heat exchanger that is made from stainless steel (SS316). (In contradiction to the concept there are no gas bottles used for the heat-exchanger.

Finally, all the main parts are coated with heat-resistant paint for corrosion resistance related to outside weather conditions.

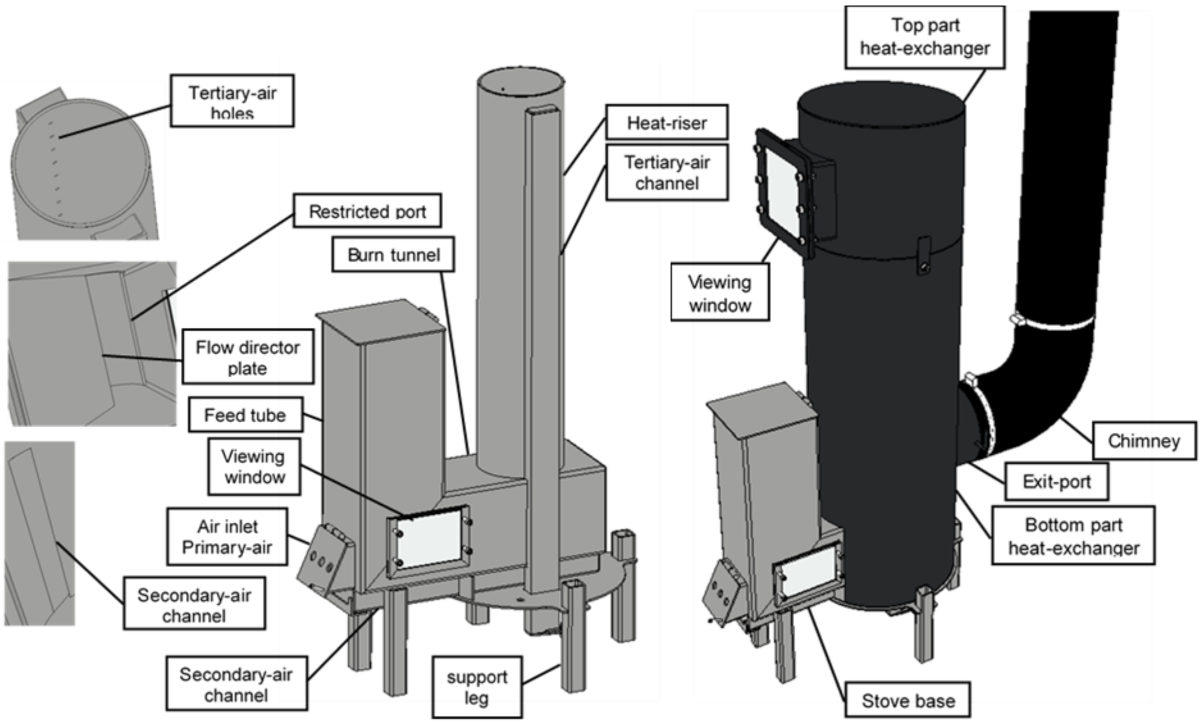

Figure 19 Vortex-Heater distinctive parts

5.2.1 Accessories

2 accessories are included in the design. An ash remover (See Figure 20) and a pellet burner (See Figure 21). It is easy to clean the ashes out with the ash remover. And with the pellet burner, it is also possible to burn pellets. In the pellet burner, a recess is made so it doesn't block the view in the burn tunnel.

Figure 20 Ash remover 3D render

Figure 21 Pellet burner 3D render

5.3 Operation

5.3.1 Stove base

In the feed tube, wood sticks are loaded and ignited. The fire starts burning sideways in the burn tunnel. With the flow director plate, the flames are directed to a restricted port. The flow accelerates into the (round) heat riser and a vortex arises. Through a small port at the bottom of the heat-riser, preheated secondary air is introduced into the vortex. It will mix and secondary combustion takes place. The gases rise and tertiary air is introduced at the end/top of the heat riser with a pattern of small holes. The tertiary burn will take place at the top of the heat riser. For an overview see figure 22.

In contradiction to standard rocket-mass-heaters the primary air is sucked from a separate air inlet than the feed tube. This is because the stove is made from steel. Steel is quite a good conductor of heat. When burning, the whole stove heats up. The feed tube gets hot and it will act as a counteracting heat riser. (Siepmann, 2017) This appearance is not desirable. It disturbs the proper functioning of the stove. To eliminate this appearance the feed tube is capped off and the air inlet is placed at the bottom.

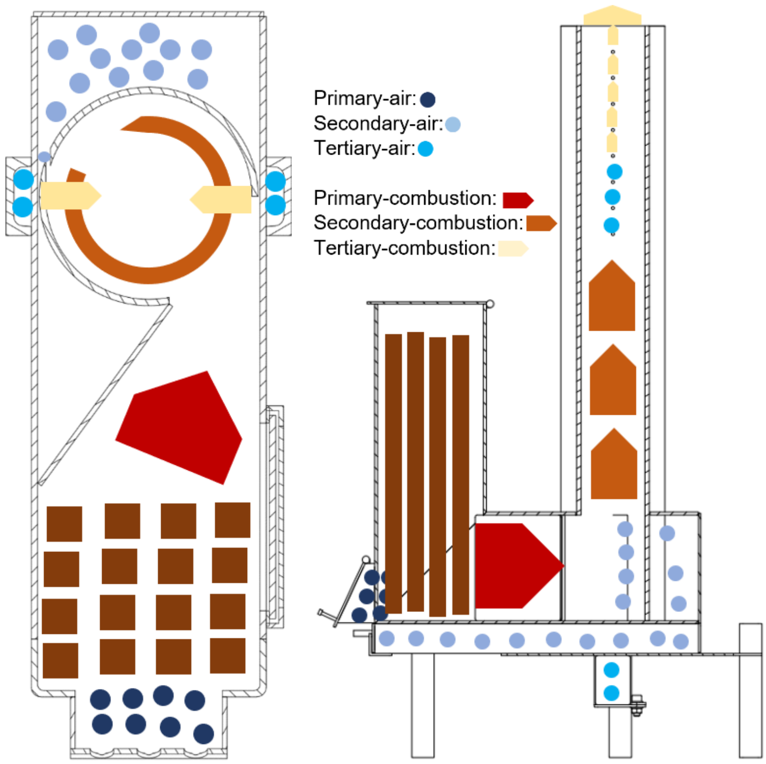

Figure 22 Schematic operation overview

The secondary-air that is introduced into the vortex is lead through a channel below the burn tunnel. When flowing through the channel the air gets preheated.

Also, tertiary-air is supplied through two channels that are attached to the sides of the heat-riser. The tertiary-air will be preheated by the heat-riser. For the secondary & the tertiary-air applies that the spinning gases (vortex) create an under pressure at the place where they are introduced (venturi-effect). It will suck the air into the vortex (See Figure 23). Furthermore, these flows can be regulated with the valves that cover the channels.

Figure 23 (Tertiary combustion vortex rocket-stove, 2015)

This stove has the basic principle of a vortex rocket-stove, but with added features copied/inspired from Takeshi Ueno's designs.

5.3.2 Heat-exchanger

When the hot gases (& flames) exit the heat riser into the heat exchanger, they flow up where the flames can be seen through the glass. The vertical flow of gases will be cooled by the heat-exchanger, and a lot of radiation heat is created. Thereafter, the gases escape into the exit-port into the chimney. See Figure 24 for an overview of how the gases will flow.

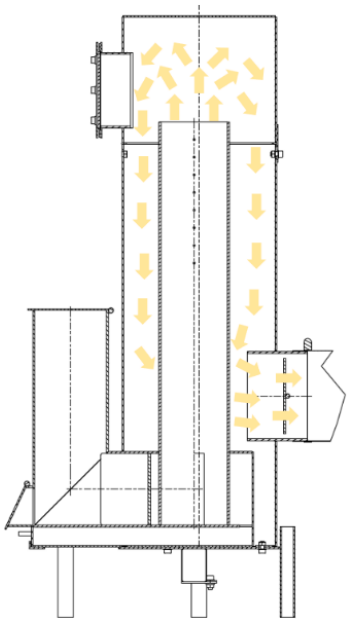

Figure 24 Schematic overview Vortex-Heater

5.4 Dimensioning

For vortex rocket-stoves there are no clear design rules how to dimension a kind of stove. The inspiration from this stove came from Takeshi Ueno. By analyzing his stoves dimension estimations have been done and applied on this design.

As a starting point, a round tube Ø139,7x4mm is used for the heat-riser. Based on these dimensions all the other dimensions are determined.

Ianto Evans describes in his book "Rocket Mass Heaters" page 35 & 36: (See Appendix E.1) some key dimensions and proportions for dimensioning. When dimensioning these basic rocket-stove these design principles were taken into account.

(Evans & Jackson, Rocket Mass Heaters, 2007)

5.4.1 Dimensioning explanation

J-shape dimensions
The basic length proportions for a J-shape should be as followed designed, 1:2:4 (feed-tube:burn-tunnel:heat-riser). These proportions are relative to the system size[1] and are measured from center to center. This is just a rule of thumb.

Important is that the length of the heat riser is at least twice as long (longer = better) as the burn tunnel to provide a good draft. Also, the heat-riser should be at least 4 times the length of the feed tube to prevent a counter draft from the feed tube. This last rule doesn't apply to this design because the feed tube is capped off and the primary air gets sucked from a separate inlet.

Air-inlet
The dimensions of the air-inlet are important because the right amount of air has to be introduced. Too much air and the fire cools too much and not all the volatile gases will burn, too little air won't provide enough oxygen for a clean burn. For a calculation of the sizing of the air-inlet see Appendix C.

Burn tunnel
A design principle is that in the whole system the burn tunnel needs to have the smallest cross-section. For this design, this doesn't count because the restricted port replaces this function (of mixing). The restriction has the smallest cross-section area in the system. Further is stated that the burn tunnel should be as short as possible but a horizontal part is needed for the mixing.

Restricted port
The restricted port is a restriction from the burn tunnel into the heat-riser. It accelerates the gases into the heat-riser and spins into a vortex. There are no clear rules for the width of the restriction but mostly the width varies between 30% to 50% of the internal diameter of the

[1] Diameter or square dimension of the cross section of the (heat riser) J-shape. No distinction is made between square and round tube. A square tube has a larger surface than a round tube, but it's skin surface is larger, which provides more resistance. So this equals each other out.

heat-riser. In this design width of 40% of the total internal diameter is applied (estimated from the design of Takeshi Ueno).

Secondary- and tertiary-air inlets

The secondary and tertiary-air port/holes are dimensioned also by an estimation.

Exit-port

For a good flow in the stove and to ensure that no accumulation of gases takes place, the cross-sectional area of the exit port needs to be bigger than that of the cross-sectional area of the heat riser.

5.4.2 Conclusion

All these dimensioning rules are taken into account. They are applied to the definitive design of the Vortex-Heater. For an overview of the dimensions of the stove see Figure 25.
(For a better view see Appendix A.3)

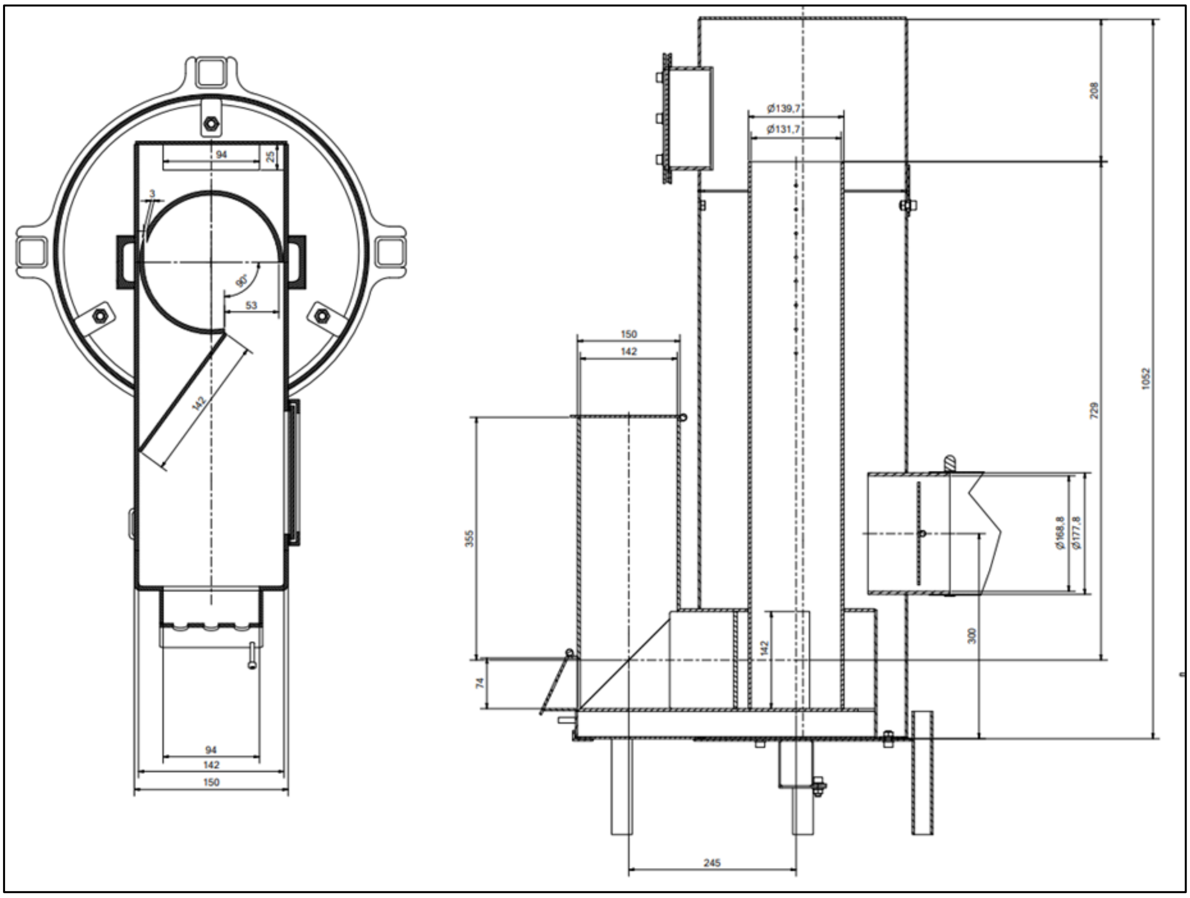

Figure 25 Overview of dimensions of the Vortex-Heater

6 | Execution

From the 3d model design, full detailed 2D drawings are made to make the Vortex-Heater. The stove is build based on the 2D drawings (See Appendix D.1). During building, mistakes in the drawings have been adjusted. In the following paragraphs, the building of the stove is shortly explained. For building a full part list & cut list are added to build the stove (See Appendix D.2 & D.3). Also, production files (STEP and DXF) are added of every part and weldment (See Appendix D.4 & D.5).

6.1 Parts

Before welding and construction, all the parts have to be created. The whole stove consists of 3mm sheet metal and tube steel (S235). Sheetmetal has to be laser-cut (See Figure 26) and the tube steel has to be cut to length.

Figure 26 Laser-cut 3mm sheetmetal parts

6.2 Building

After the parts were made, welding is done. For an overview see Figure 27

Figure 27 Welding process

After welding, every part or weldment is coated with heat-resistant paint (See Figure 28). After painting, all the parts are assembled (See Figure 29). At last, windows and heat-resistant seals are installed.

Figure 28 Stove base coated with heat resistant paint

Figure 29 Vortex-Heater assembled

For more building pictures see Appendix B.2

7 | Final result

After the building, the Vortex-Heater is ready for use and can be fired up. The stove creates a nice vortex as intended. See Figure 30 for the final result. For more burning photo's/video's see Appendix

Figure 30 Vortex-Heater burning

8 | Conclusion & Recommendation

8.1 Conclusion

The stove burns quite well, It produces enough heat for under a veranda outside. The stove is moveable and is easy to demount. It largely satisfies to the expectations of the design.

8.1.1 Setbacks

1. The tertiary air on top does not work, So no flames are coming out of the heat-riser. so the fire cannot be perceived. This is unfortunate but it is hard to explain why it does not work. as a result, the window is no longer useful and its function lapses.
2. The construction of the stove was harder than expected because of the internal geometry of the stove. A lot of places were hard to reach using the welding torch.
3. Unless the heat-resistant coating rust is very present so corrosion protection is quite bad.

8.2 Recommendations

1. Because the tertiary air does not work is it is a better idea to use a J-shape rocket-stove as a base (out of steel).
2. A J-shape rocket stove is a lot easier to construct from only a square tube and the viewing window at the burn tunnel is still possible option. Also the principle of a J-shape is a lot more proven design that works and has a low chance to not fail.
3. When using the stove outside it is still a better option to make it fully from stainless steel it offers a lot better protection than standard mild steel with a protective coating.

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In appendix F source files are attached

9.1.1 List of figures