A portable water extraction plant to generate drinking water for use in times of natural disaster and everyday life using a stand alone system

Project Report
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2013

Abstract

Introduction

Modern society is increasingly reliant on utilities such as drinking water and electricity. This creates a ticking time bomb in the case of natural disaster and perceived natural disaster. In the case of perceived natural disaster people flock to stores to buy supplies such as bottled water. This creates unnecessary panic and drains local resources. Natural disaster in most cases creates the need for reliable drinking water. This need is usually filled by bottled water trucked or flown into the area. Transporting the water usually causes a delay from when the water is needed to when it arrives.

Many people are more aware and prepared in New Zealand for such an even because of the Christchurch earthquake. Some families store drinking water in large 20 liter containers ready for such an event. These containers must be regularly cleaned and water changed to keep them healthy to drink. Furthermore they are heavy and are hard to store. This makes this form of water storage unattractive to the regular person. If a task is too hard and there is only a small risk the vast majority of people will choose not to take steps to mitigate these risks.

There is a gap in the market for a device that can cheaply, safely and effortlessly extract drinking from sources like seawater. This device should be easy enough to use and cheap enough to make people think “why not?” Such a device will attempt to break the reliance on outside aid to keep you and your family alive.

This report will look into the design process and testing of a prototype device along with future developments.

Section 1. Literature Review (Background Research and Design)

Different desalination techniques will be explained and discussed along with the advantages and disadvantages. The relevancy of each method will also be discussed.

1.1 Membrane technologies:

Membrane technologies are essentially filters that separate water molecules from other harmful substances like salts, viruses, bacteria and dirt. They come in many different forms such as course filters for large debris like sand and dirt all the way down to specialty filters that have small enough pores to separate viruses and bacteria. The one that will be looked at is the reverse osmosis membrane which is the only filter that can separate salt and fresh water. This process works by using the difference in osmotic pressure of the fresh and salty water along with a partially permeable membrane. The feed water (seawater) is pumped into the device which has a membrane in it (usually in a spiral configuration). A pressure is then applied to the feed water. The fresh water will travel through the membrane because of this pressure and the difference in osmotic pressure. The fresh water is then collected and the concentrated saline solution is discharged.

There are many advantages and disadvantages to this process. One of the main advantages is that it is very simple and provides relatively high flow rates. A reverse osmosis system is generally a line of filters ending with the osmosis membrane. Although it may appear that this system has a high rate of water production, in actual fact this is not the case. Many of the numbers given run on extremely high pressure that are not possible for home plumbing or for someone trying to create pressure using a pump of some kind.

A membrane system would not be appropriate for this “natural disaster application” because of a number of reasons. The first being cost. A quick look at some house hold membranes shows they are about one hundred US dollars for a five and a half liter per hour membrane (freedrinkingwater.com). Although this may sound cheap but this is only one part of the system, it still requires about three more filters before it. They do however have a relatively good life (5 years in a household). This could be significantly shortened if a person was collecting their water directly from the sea as they would be in a natural disaster. The main two reasons this would not work is that it requires the water to pressurised above the osmotic pressure. This can be done with pressure as small as 40PSI but this yields low flow rates. The second being that the membrane can only filter clean water (no sand or grit). Commercial installations regularly use up to 1200PSI. From a human stand point we cannot create anywhere near this pressure when there is no electricity or running water. Furthermore a person needing this device may be weak because of what has happened and may not be capable of operating a hand or foot pump effectively. This possibly could make them more dehydrated which would be counter productive.

1.2 Ion exchange:

Ion exchange is basically a chemical water softening process. The water doesn't change but certain ions are swapped for other non harmful ones, chemically changing the water. This is done by using a special resin (in a solid form) to swap out the Na- ion (among others) to make the water softer and safe to drink.

This would not work in a disaster situation because aid agencies would have to distribute the resin pellets to people. In my view if you have to do this you may as well hand out bottled water.

It can be shown that pure water is not a good conductor of electricity, it is the ions in that water that make it conductive (salt). Researchers at MIT and in Korea have developed a small desalinator that uses an electric current and a small membrane to separate these ions. They claim that an array of these can produce 3.8L per hour. This process is called ion concentration polarization. Ion concentration polarization is still in the early stages of development and is not yet robust enough to be applied to this application.

1.3 Thermal processes:

These processes use heat to either evaporate water or create steam. This separates the salt from the water. This is also useful because boiling or heating the water kills most bacteria and viruses.

Solar distillation is probably the most widely recognised form of thermal distillation. It works by simply putting a sheet of plastic over a large pond of salt water and through a greenhouse effect the water is heated causing it to evaporate. The fresh water then condenses on the underside of the “cold plastic” and runs off to another storage area. This method works well because there is little energy input, however it produces very little water, bigger pond equals more water produced. Solar distillation in this format is not portable but could be made portable. The size of the device needed to produce enough water for a family would simply be too large. For this reason this method would not work for the desired device.

The basic principal of solar distillation can be used in a “sped up” format. A “pot” of water can be heated (gas, fire, electrical) from the bottom causing vapor to form. The vapor is then condensed in the same way using a cold surface.

Multistage flash is a process where salt water is quickly flashed to steam leaving the brine behind. This is done by exposing the water to high temperature tubes. The steam produced can then be used to preheat the feed water while also being condensed by the feed water. This is a very reliable and robust system that can handle high flow rates and high demands. However this method uses the most energy out of all the methods discussed. This high demand for energy makes this method undesirable for this application.

Other systems involve pressurising the feed water or steam. Some of these include adsorption vapor compression, mechanical vapor compression and thermal vapor compression. Adsorption vapor compression, in simple terms, uses a chemical reaction to preheat the water before it is delivered to the evaporator. This involves additives which make this system unsuitable for a portable system. Mechanical vapor compression works by using mechanical energy to operate a water injector. This injector causes the pressure to rapidly drop and in turn causes the boiling point to drop. This means you need less energy to boil the water. Thermal vapor compression works the same as mechanical vapor compression but with a jet of steam. These systems use pressure so are most likely unsuitable for this application. That does not stop us using a jet (or like device) to cause a pressure drop so less energy is required.

Probably the most promising method of thermal distillation is multiple effect evaporation. This a lower temperature version of multistage flash distillation. Water is first heated to vapor and piped into the device. It then uses multiple stages of condensation to condensate the vapor while using its energy to heat other feed water. This system is very simple and robust. It can handle high flow rates and poor water quality. Because of these reasons this process could be ideal as the main method of distillation. The strength and simplicity of multiple effect distillation makes it portable, paired with the ability to run while dirty/scaly make it desirable. One issue could be the weight. It has many chambers and tubes so material would have to be chosen carefully.

Possibly the concept that would work the best for this application would be a hybrid of a few of the ideas discussed previously. A device that can run on solar heat on a hot day and also can run on a fire or other heat source would be ideal.

Many of the methods discussed require consumables, for example membranes and gas. The ideal device would be able to run on a easily accessible resource like wood or solar energy.

1.4 Design

From the outset this project was approached from a build and test direction rather than a calculated and build one. This is because the ideal device would be one that would work with any fuel and be able to extract water from multiple sources. Furthermore this project had a heavy design for use component. The device would have to be small enough to be easy to store and large enough to function properly. The idea way to determine these parameters was to build a prototype and test the usability.

Many people store their emergency drinking water in 20 liter containers which have a footprint of 280 x 280 mm and 400 mm tall. The initial brief for this device was a device that would take up less room and produce at least as much water as the 20 liter container. The Institute of Medicine (USA) determined that an adequate intake of water for a male is 3 liters per day. This was a good place to start for an approximate capacity.

Initially the design was for a simple container with a fitting to connect a condenser. This is a cheap and easy to build design but could be inefficient with fuel and take time to produce fresh water. The heat exchanger area must be maximised to reduce the boil time and improve efficiency. Many different methods for this were discussed but many conflicted with the design brief: "be able to extract water from multiple sources". Sources could include mud, wet sand, certain types of leaves and even moss. The diagram below shows early designs for increasing heat exchange area (figure 1.4-1). Design 1 features water being heated from the bottom but also from combustion gasses ducted around the mass of water. Option 2 features tubes ducting combustion gasses through the liquid. Inspiration for design 3 was found from a BMETs (Basic Mechanical Engineering Trades) hot water heating project. This design features a large cone separating the combustion gasses from the liquid. After a test with a friends project this design was found to be extremely effective.

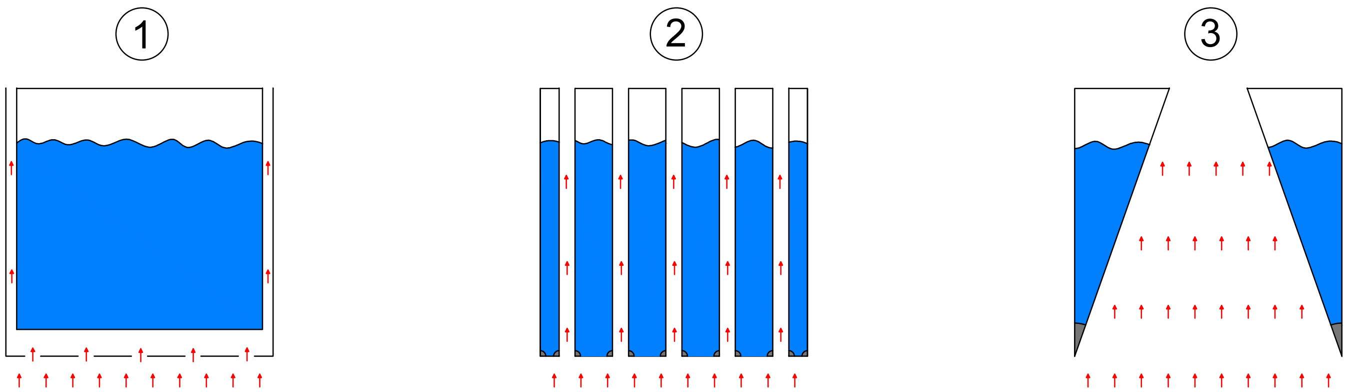


Figure (1.4-1) . Initial design concepts (cross section)

All three designs suffered from a similar problem making them unfit for this device. Small areas and dirt traps shown in the above diagram in grey would be areas sand, dirt and organic material would settle. These areas must be large enough to clean out with basic tools or even a finger or hand. In the worst case scenario of using wet mud as a medium to collect water from these areas would quickly become filled with dehydrated mud that could be impossible to remove.

Modifying design 3 to eliminate the tight dirt trap area promised to be the best way to move forward with the device. After some simple changes the design bellow (design 4) (figure 1.4-2) was developed to maintain the heating area but eliminate the dirt build up areas.

The new design still had the dirt build up areas (shown in grey) but now had a large enough gap so that they could be effectively cleaned out.

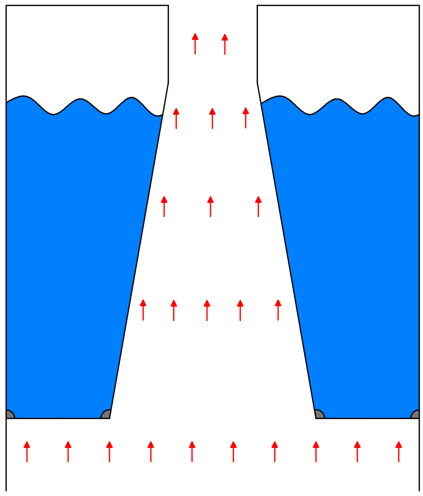


Figure (1.4-2). Revised design

Physical size as explained earlier is constrained to not larger than the size of a 20 liter water container and have a capacity of 3 liters. For test purposes the dimensions decided on were a 150mm high 200mm diameter cylinder with a cone with base diameter of 100mm and a top diameter of 50mm. This left a 50mm gap between the inside of the outer shell and the outside of the central cone (dirt build up area) that is large enough to get a hand, brush or stick in to clean. The device with these dimensions had a capacity of 4 liters.

The condenser was originally designed as a stainless steel tube wrapped around the outer shell of the device similar to the diagram below (figure 1.4-3). This design attempted to use the cold air that would be hitting the outside of the device and use it for the condenser. Therefore pre heating the air before it hit the outside shell of the device (figure 1.4-4). Initially the condenser was tested simply in air to gauge the length and configuration. Furthermore plates or heat syncs were to be added to the central cone to help move heat from the gas to the liquid.

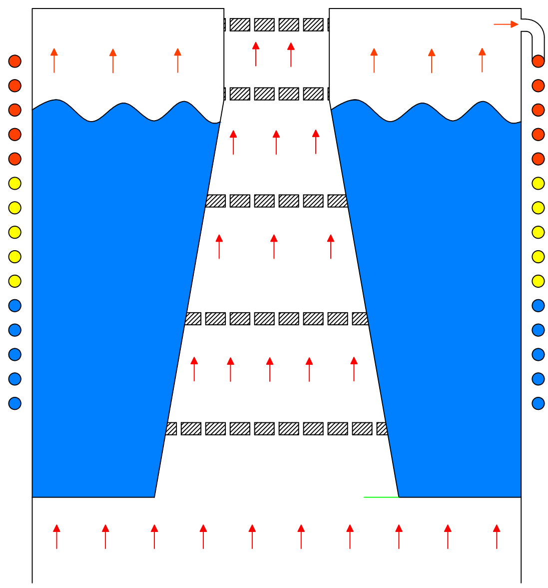


Figure (1.4-3). Wrap around condenser

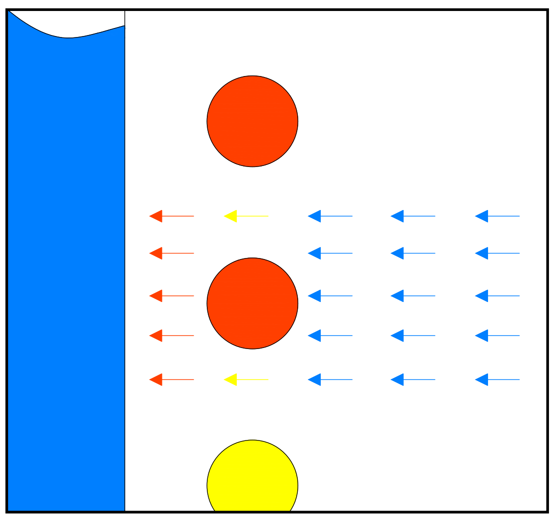


Figure (1.4-4). Condenser detail

After initial design the device was drawn and assembled in Solid Works. Essential extra parts such as fittings, valves, o rings and combustion chamber were added into the model (figure 1.4-5).

Materials considered for this device were steel, aluminium, copper and stainless steel. Steel was not used for the simple reason of corrosion. Salt water coupled with heat would render the device useless very quickly. Aluminium was considered for its light weight, heat conduction properties and malleability. Aluminium does however tend to leach into things especially at high heat. The inside surface of the device would have most likely have had to be painted or enameled for continuous use. Copper has excellent heat conduction and malleability properties but is expensive and dints easily. Stainless steel is usually used for any food grade equipment and would be ideal for this device, at least for the initial testing rig.

In construction the hardness of the stainless steel was slightly underestimated. For this reason the flanges that housed the o rings had to cut out with a water jet machine. These flanges were made from 316 stainless steel and had to have o ring grooves cut into them with a milling machine. Viton o rings along with teflon thread tape were used for fittings and the lid to seal the device. The Viton o rings were rated for 200°C and the thread tape for 327°C. It was also realised in the design phase that the device could potentially generate a small amount of electricity from the combustion gasses rising through the central cone. Pins were added to secure a small computer fan to test this idea. The device in theory could also work off hot gasses from a engine for example. Provisions were made to test this feature in the future. The image below and on the following pages are the final design and working drawings for the testing device.

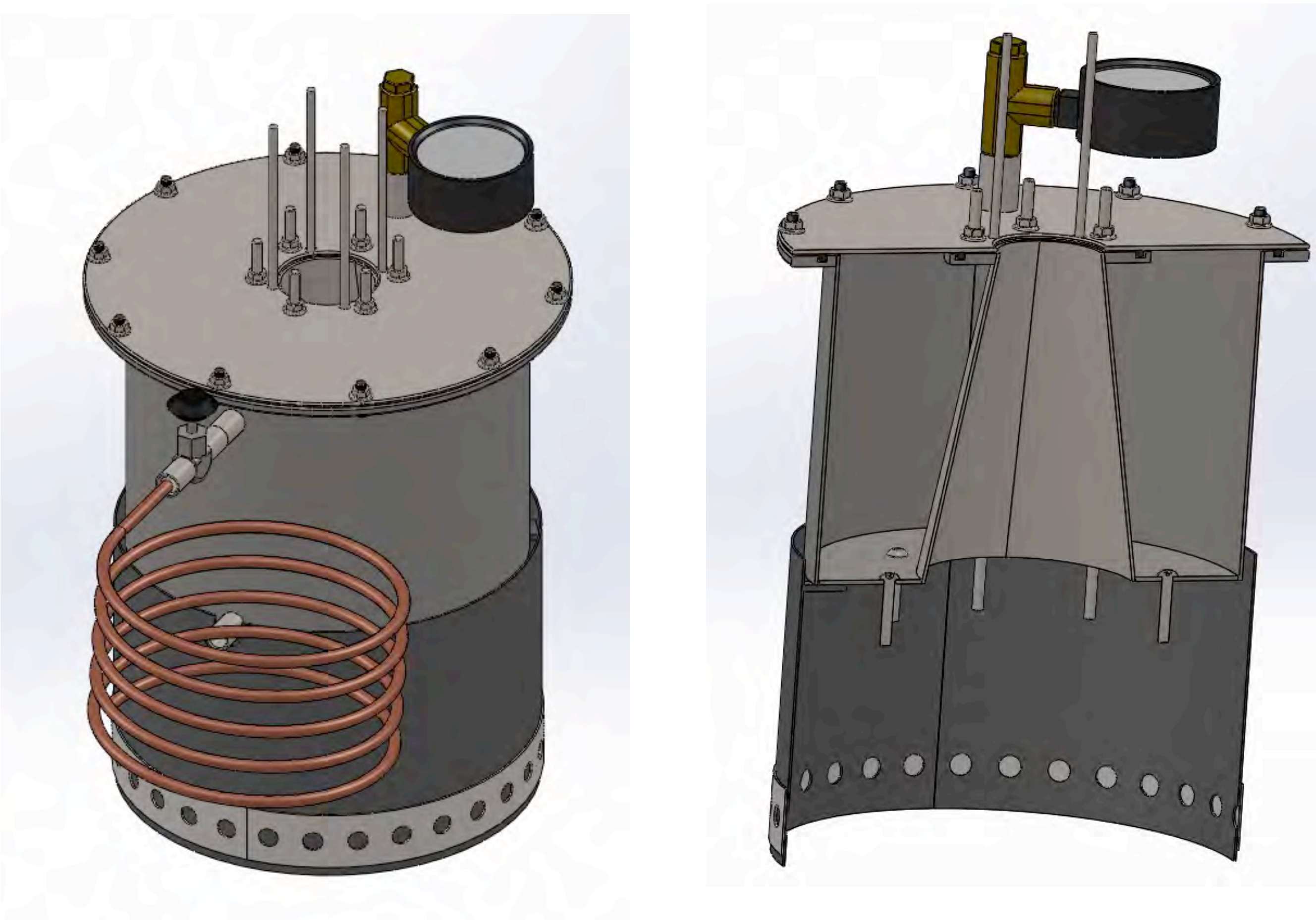
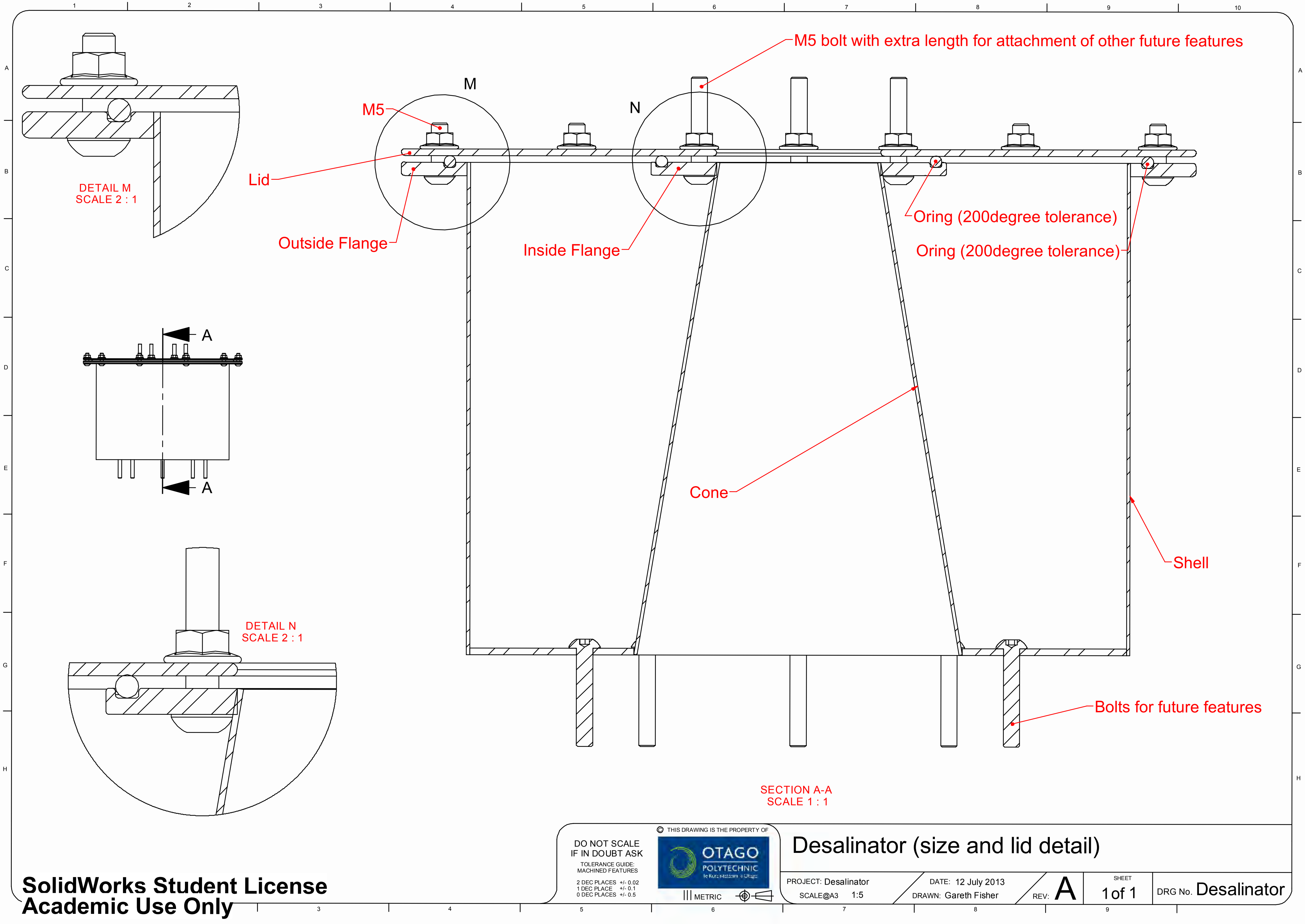


Figure (1.4-5). Desalinator, condenser, combustion chamber (wood burner) and cross section


M5 bolt with extra length for attachment of other future features
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M5
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DATE: 12 July 2013
DRAWN: Gareth Fisher
REV: A
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DRG No. Desalinator
SolidWorks Student License
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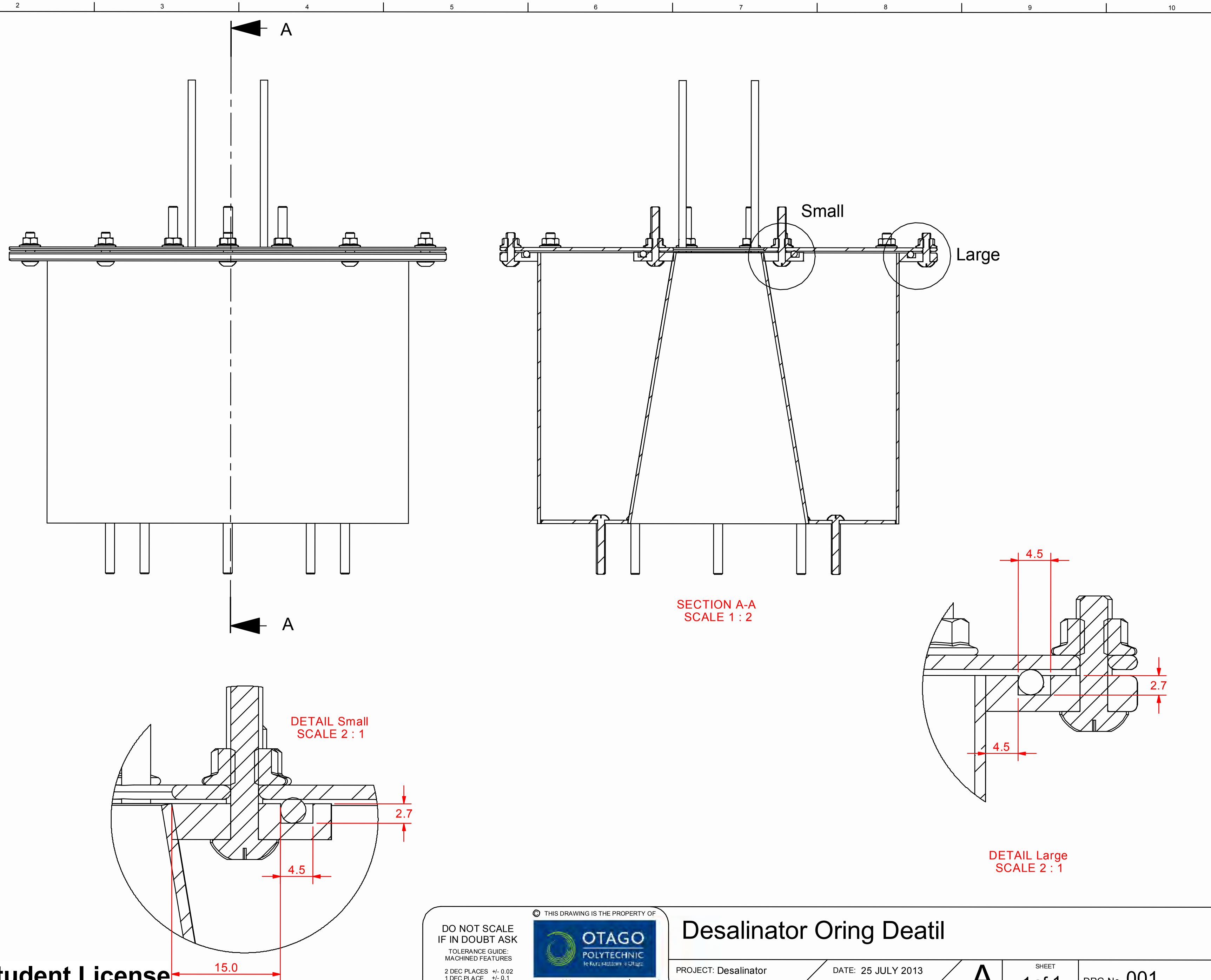

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OTAGO POLYTECHNIC

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PROJECT: Desalinator
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DATE: 25 JULY 2013
DRAWN: Gareth Fisher
REV: A
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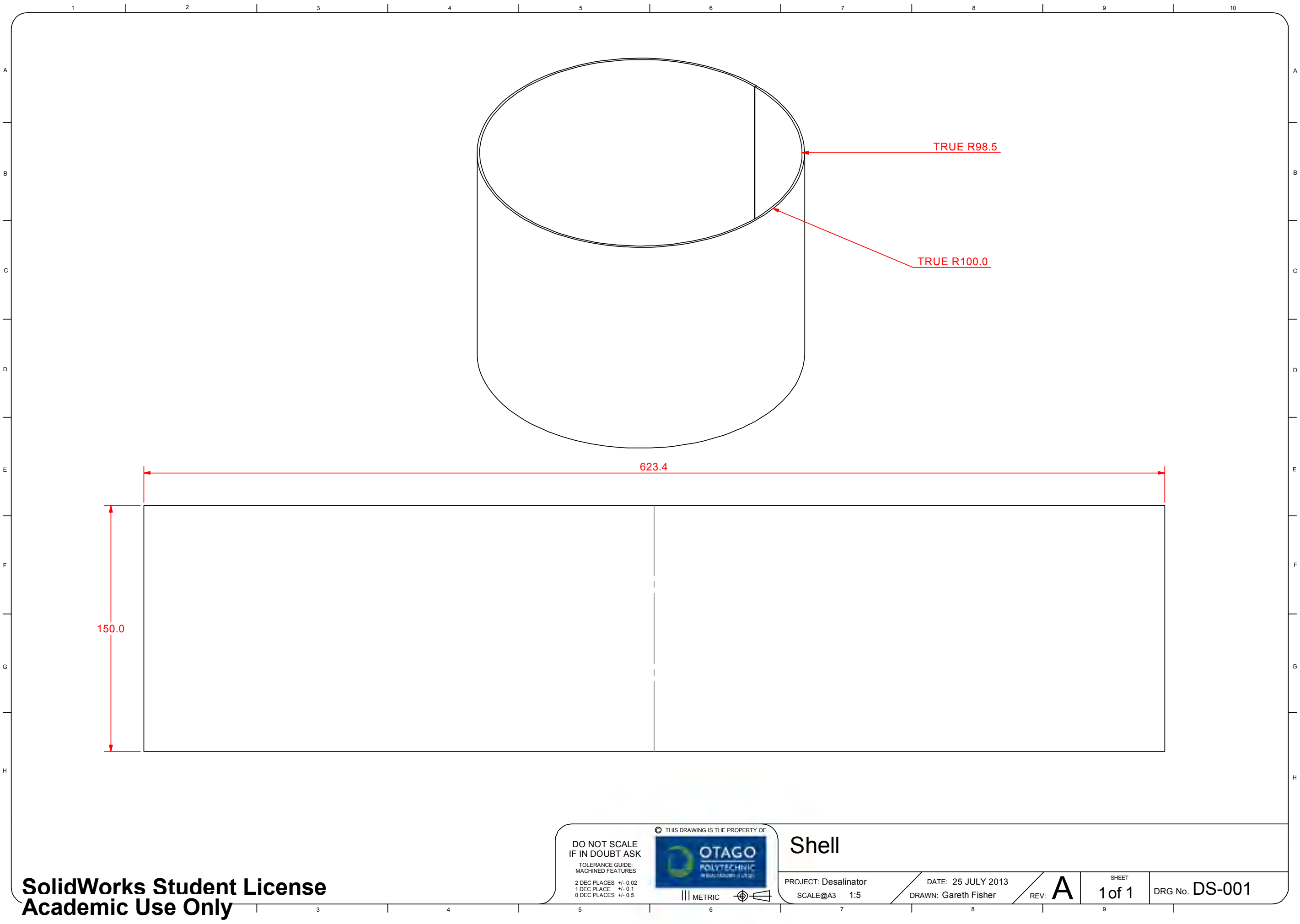
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DATE: 25 JULY 2013
DRAWN: Gareth Fisher
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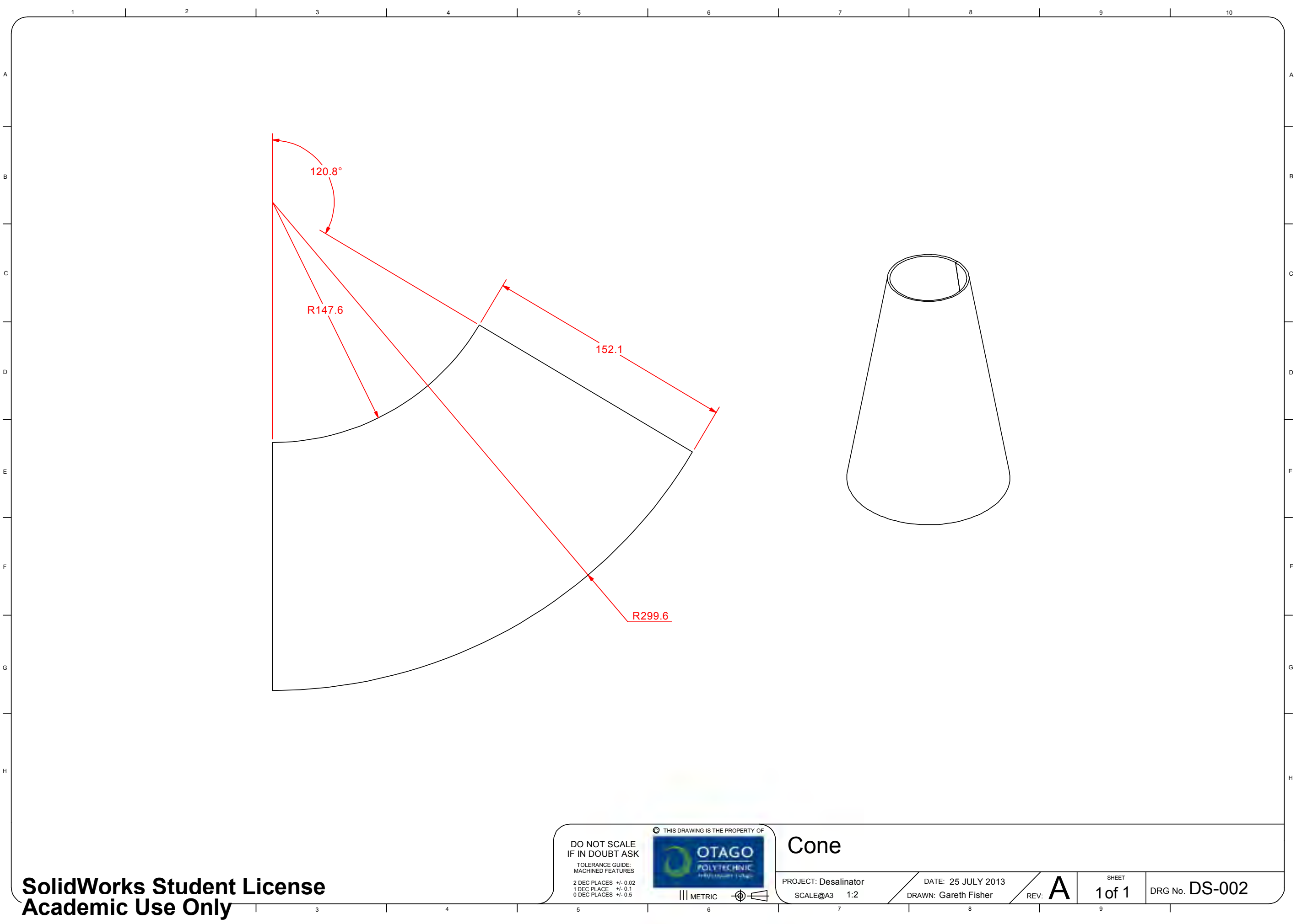
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PROJECT: Desalinator
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DATE: 25 JULY 2013
DRAWN: Gareth Fisher
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SHEET 1 of 1
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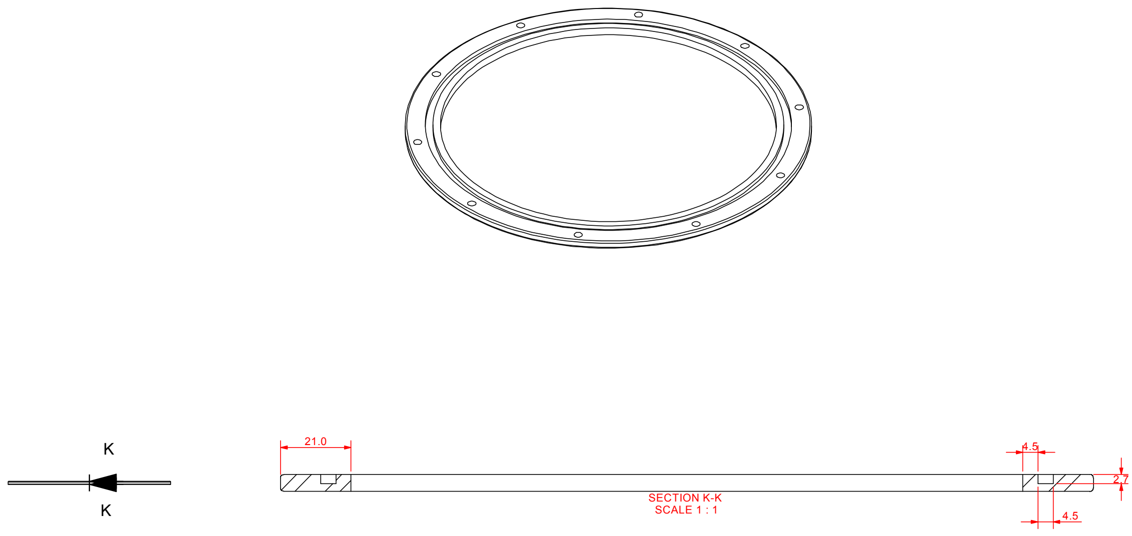

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METRIC

Large Flange

PROJECT: Desalinator	DATE: 26 JULY 2013	REV: A	SHEET 1 of 1	DRG No. DS-003
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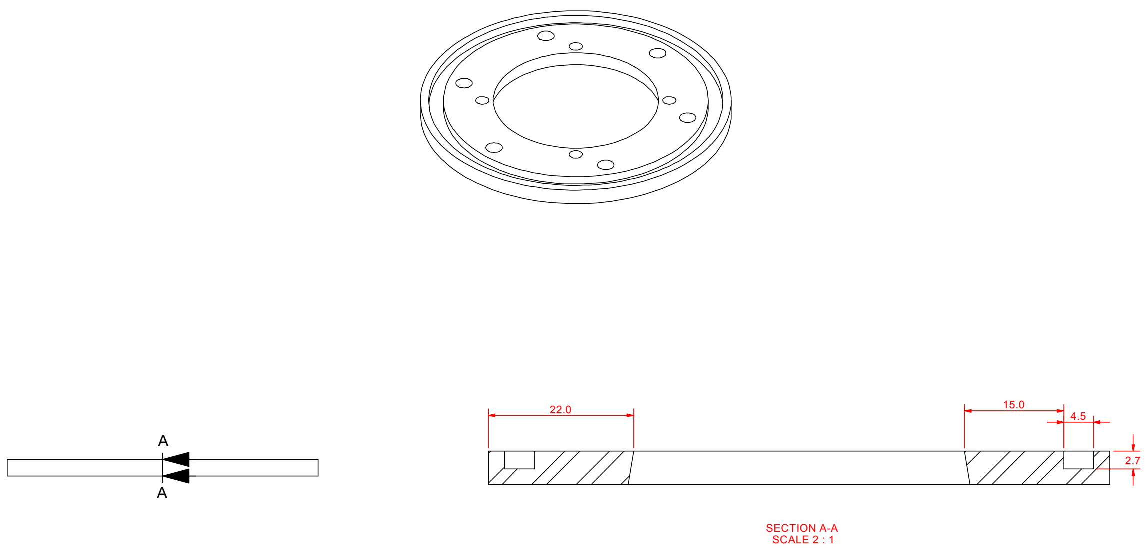

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METRIC

Small Flange

PROJECT: Desalinator	DATE: 26 JULY 2013	REV: A	SHEET 1 of 1	DRG No. DS-006
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Section 2. Methodology

The testing procedure for this device was to test the function of as many as possible of the features and gauge their feasibility. Furthermore the overall efficiency and optimum operating conditions for the device were to be found. In the case of features the testing will show the features that should move onto the next prototype and which features should be abandoned. The optimum operating conditions will show the amount of heat the device can absorb and give a starting point for efficiency improvements. Different heating locations on the device were tested with the aid of an LPG burner with three concentric rings. This will test the effectiveness of the central cone at improving efficiency and speed.

2.1 Desalination

Initially the main feature of desalination was tested. This was carried out by simply placing 2 liters of salt water in the device and heating it to get steam. The water was taken from the beach and placed unfiltered into the device. The water was heated by the LPG burner with only the middle and smallest ring on (figure 2.1-1). At this stage the mass of gas and time it took were irrelevant. This test was simply to test weather the device could remove salt from the water and make it safe to drink. The steam was condensed by a 2.5 meter long ¼ inch (6.35) mm copper tube from a heat pump line (figure 2.1-2). Copper was used because it was easier to form into the coil shape by hand compared to a stainless steel tube. Furthermore the copper tube could be sourced from heat pump installers as free scrap. This condenser was cooled simply by placing it in a PVC tube and water from a garden hose was sprayed slowly over it (figure 2.1-3).

Figure (2.1-1). Desalinator, condenser and LPG burner.

Figure (2.1-2). Device showing condenser

Figure (2.1-3). Condenser cooling

2.2 Generation Fan

Once the base feature of the device was tested (desalinisation) the device was broken into different parts for individual testing of all the different features. The generation fan mounted at the top of the central cone was the first feature to be tested. The heat syncing plates were not added because they would restrict the combustion gasses and slow them down as they rose up the central cone. If the fan turned with a unrestricted airflow from the cone plates could be added to the point where the efficiency and the airflow both could be maximised. A manometer was used to measure the velocity of the air leaving the central cone (figure 2.2-1). The manometer was a home built device with total and static pressure probes (figure 2.2-2). The fan was tested by placing the device on the LPG burner and fitting the fan. The pins are made from 4mm stainless steel threaded rod and are long so more fans could be stacked up as needed (figure 2.2-3).

Figure (2.2-1). Manometer

Figure (2.2-2). Homemade pressure probes

Figure (2.2-3). Generation fan fitted.

2.3 Wood Combustion Chamber

Next the combustion chamber designed for burning wood was tested to see if it could produce more airflow through the central cone (figure 2.3-1). The combustion chamber featured a rotation ring to control airflow.

Figure (2.3-1). Wood combustion chamber.

2.4 Air Cooled Condenser

The original condenser was 2.5 meters long and was tested in many different configurations to gauge which one if any could be looked at for a second condenser prototype. All the condenser tests were done using the LPG burner with only the middle ring on. This is so results can be compared. At the outset the condenser was filled with water and then frozen. This was done to stop the tube collapsing when it was made into a coil. The condenser was turned upside down to ensure there was no pressure build up in the condenser tube. It was then simply attached to the steam valve and left to hang freely off a ledge (figure 2.4-1) to test the condenser in an air cooled situation.

Figure (2.4-1). Air cooled condenser

2.5 Water Cooled Condenser

As described earlier the condenser was also tested in a low flow water cooled condenser as in figure 9. The condenser was upside down compared to figure 9 this prevented pressure build up as the steam was condensed. The flow rate for this was found by measuring the time it took for the condenser to become ineffective. This was done by placing an end cap on the PVC and filling it with 1.5 liters of water. The salt water was bought up to 100°C and then the steam valve was opened. This is when the timer was started. At the moment that steam started to exit the end of the condenser the timer was stopped. From here the minimum flow rate can be calculated.

2.6 Underground Condenser

The final condenser test was the underground test. A new condenser had to be made as the original one had become work hardened and would collapse if bent further. The new condenser was of the same length, material and dimensions but was of a different shape. It was designed in a flat configuration to maximise the area of ground it was touching while minimising the depth at which it would have to be placed (figure 2.6-1). Furthermore it dropped the entire length of the condenser to stop pressure build up. The hole was a simple flat pit with a slightly deeper section at the outlet of the condenser where the collection cup was placed (figure 2.6-2). The device was heated until boiling and the steam valve was opened. The time taken for the first steam and time taken for complete steam was recorded. Complete steam was the point at which no liquid water was coming out of the condenser, only steam.

Figure (2.6-1). Condenser shape

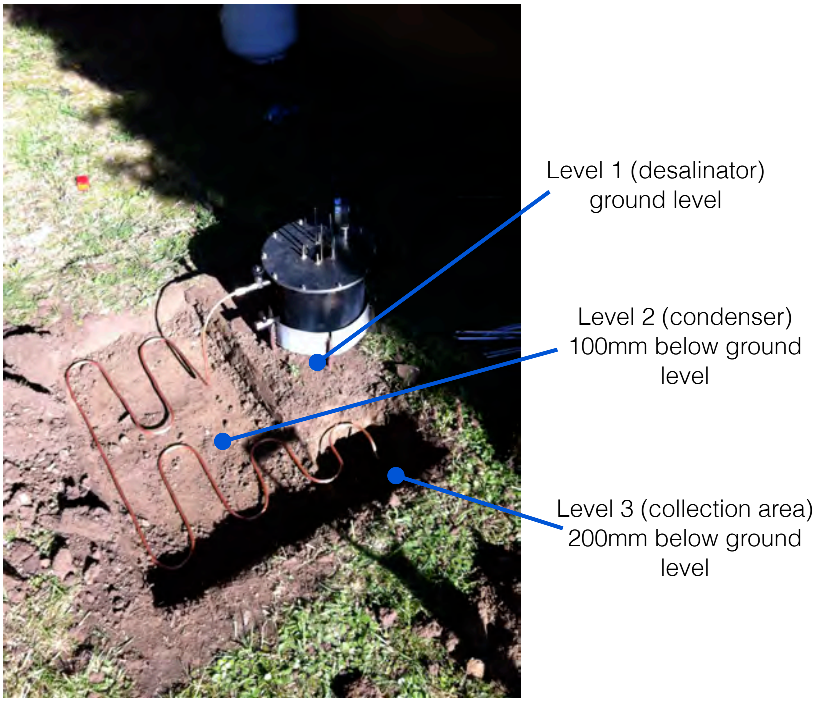

Figure (2.6-2). Pit shape

2.7 Heating, Fuel and Efficiency

The final testing was done on the heating of the water and production of steam. The optimum point at which the maximum amount of steam could be produced in the smallest amount of time and with the smallest amount of fuel could then be found. These tests were all done on the LPG burner because it was highly controllable. Furthermore the fuel and heat output was constant compared to other fuels such as wood. This is important so the results become meaningful and could be compared.

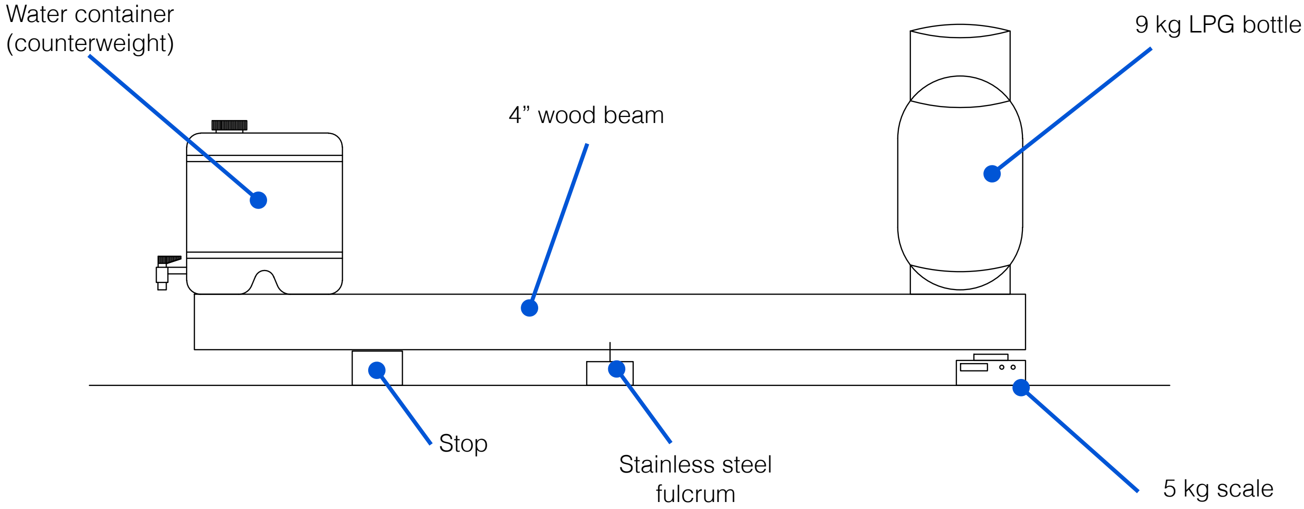

Figure (2.7-1). Counterweight scale

The testing for boil, time and fuel used were conducted by first weighing the LPG bottle. This was done using a counterweighted scale setup (figure 2.7-1). The scale consisted of a rigid beam (4"x4" wood) with a stainless steel blade fixed at the exact center, this acted as the fulcrum. The LPG bottle was placed on the wood beam and a 20 liter container placed at the other as the counterweight. The amount of water in the container could be adjusted via a tap on the side. The reason this setup was done was because the scale used had a maximum of 5 kg and the LPG weighed close to 20 kg. There were problems finding a scale with a small enough accuracy but large enough capacity.

Figure (2.7-2). Thermocouple temperature measurement

Once the initial weight of the LPG was recorded the test was started. The time to heat 2 liters of water from 12°C to 100°C was recorded for all combinations of the 3 burner rings (figure 2.7-2,3).

Figure (2.7-3). Different burner rings

The moment the water arrived at 100°C the LPG was turned off at the bottle valve and re weighed. The difference in the two weights would be the mass of gas used.

Testing for steam was meant to function in the same way except the water would start at 100°C and the time to produce a 83ml of fresh water would be timed. This test could not be entirely completed because of excessive pressure build up because of production rate of steam and the size of the steam valve. Only 3 of the 7 possible combinations of rings could be tested. Furthermore the condenser had constant water cooling through all of these tests.

Once the optimum combination of rings was found tests could be conducted to zero in on the optimum operating flow rate of LPG through that ring. This was tested by simply repeating the water boil and steam production tests described earlier for different positions of the valve controlling that ring. The valve was a brass bodied taper ball valve with a 90° range of motion. In these tests 0° described fully closed and 90° described fully open.

Finally the combined time for the optimum ring at different valve settings was tested. The combined time describes the function of heating 2 liters of water from 12°C through 100°C and condensing 83ml of fresh water. This process better applies to the real world use of the device.

These heating tests were not so much to find the optimum operating point as they were to test why that is the optimum. These tests can tell us a lot about how the shape of the device and the placement of heat effects the efficiency. Furthermore many non measurable observations were conduced and will be talked about in the next sections.

Section 3. Results

The results shown in this section are the raw and processed values along with observations from the previously described tests. These results will help to show what features will work and those that will not. Additionally these tests will help to make changes to the prototype to improve efficiency and usability and to further understand how the device functions.

3.1 Desalination

As described in the previous section the first test to be done was the desalinisation feature. This was conducted and an initial “taste test” was done. No salt was detected but there was a particular taste to the water. This was most likely from the steam valve or condenser as the desalinator body was made from food grade stainless steel. There possibly could be some sort of coating on the copper tube as they were from a HVAC system. Samples of the raw sea water and processed water were sent to Citilab. Citilab is a specialist in analyzing water, wastewater, soil and foods. The samples were subjected to a simple salinity test using a conductivity meter. The results were as follows:

Raw seawater = 32.7 ppt (parts per thousand), 3.27%

Processed water = <0.2 ppt, < 0.02%

It is important to note that the detection limits of the conductivity meter are 0.2ppt therefore the salt content in the processed sample could be anywhere from 0 to 0.02%. From the raw seawater to the processed water a minimum of 99.4% of the salt was successfully removed.

3.2 Generator fan

The speed of the combustion gases coming from the top of the central cone were very slow and had low pressure. A manometer was constructed to measure the speed of these combustion gases. When measured the manometer fluid did not move for the static or total pressure probes. The next option was to simply place the generator fan in place and see if it turned. The fan turned very slightly when placed on the pins but did not spin. There was immense amounts of heat rising through the central cone which melted the fan in a few seconds (figure 3.1-1).

Figure (3.2-1). Melted generator fan

3.3 Condenser

The first condenser configuration that was tested was the one used to generate the water samples to be tested. The condenser was housed in a PVC tube as in figure 3.3-1

Figure (3.3-1). Initial condenser

The coil was situated so seam would enter at the bottom and as it rose it cooled and exited at the top into the collection cup. The output of the condenser behaved in a particular way. It would trickle a small amount of fluid out and then suddenly shoot a large amount out. This usually caused the water to miss the collection cup. The rapid expulsion of the water was put down to pressure build up then overload because of the head difference of the intake and outlet of the condenser. All later condenser tests were conducted with the condenser in the reverse position so there was no rises in the condenser (inlet the highest part).

3.4 Air Cooled Condenser

The first real condenser function test was the simple open air test (figure 3.4-1). The water was heated to boiling then the steam valve was opened. The condenser expelled approximately 3 - 4 drops of water before steam started to gush from the condenser outlet. There was however a few drops coming out with the steam and settling on the end of the condenser tube (figure 3.4-2).

Figure (3.4-1). Steam out of air cooled condenser

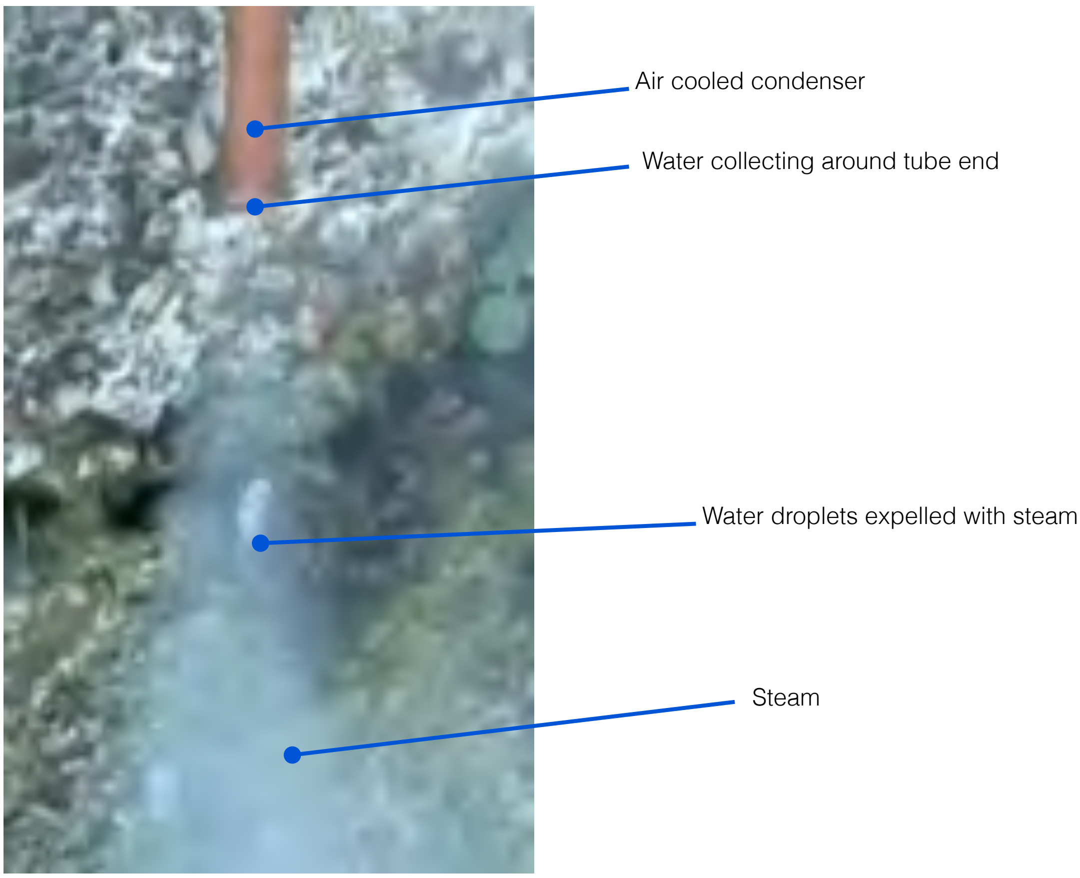

Figure (3.4-2). Water droplets in steam

3.5 Water Cooled Condenser

The water bath and running water tests were the most promising of all the condenser configurations. Running water tests were hard to measure without flow measurement equipment. These values can however be found from testing the condenser in a water bath and timing the length of time it takes for the bath to become ineffective at condensing the steam. Ineffective means the point where steam exits the condenser. In a survival situation this loss of steam is unacceptable, the condenser must have a very good steam efficiency.

Only three of the seven combinations of rings were tested due to pressure issues explained earlier.

Configuration	Number of holes	Time for steam to exit condenser (s)
Ring 1	25	Did not boil
Ring 2	55	375
Ring 3	110	315

Therefore the minimum flow rate for the cooling water when only ring 2 is on:

1.5/375 = 0.004 L/s

Minimum flow rate for the cooling water when only ring 3 is on:

1.5/315 = 0.00476 L/s

3.6 Underground Condenser

Using the ground as a heat sync was the last condenser configuration tested. The condenser was set up as in the previous section. The water was boiled then the condenser was connected ducting the steam underground (figure 3.6-1).

Figure (3.6-1). Steam prior to the condenser being connected.

In the first few second of operating the condenser produced fresh water at what looked like a smoother flow rate compared to the other condenser tests. The first steam to come out of the condenser was only after 101 seconds. This steam however remained constant for a further 615 seconds (figure 3.6-2). After this time the steam gushed out with no visible (very small amount) condensed water.

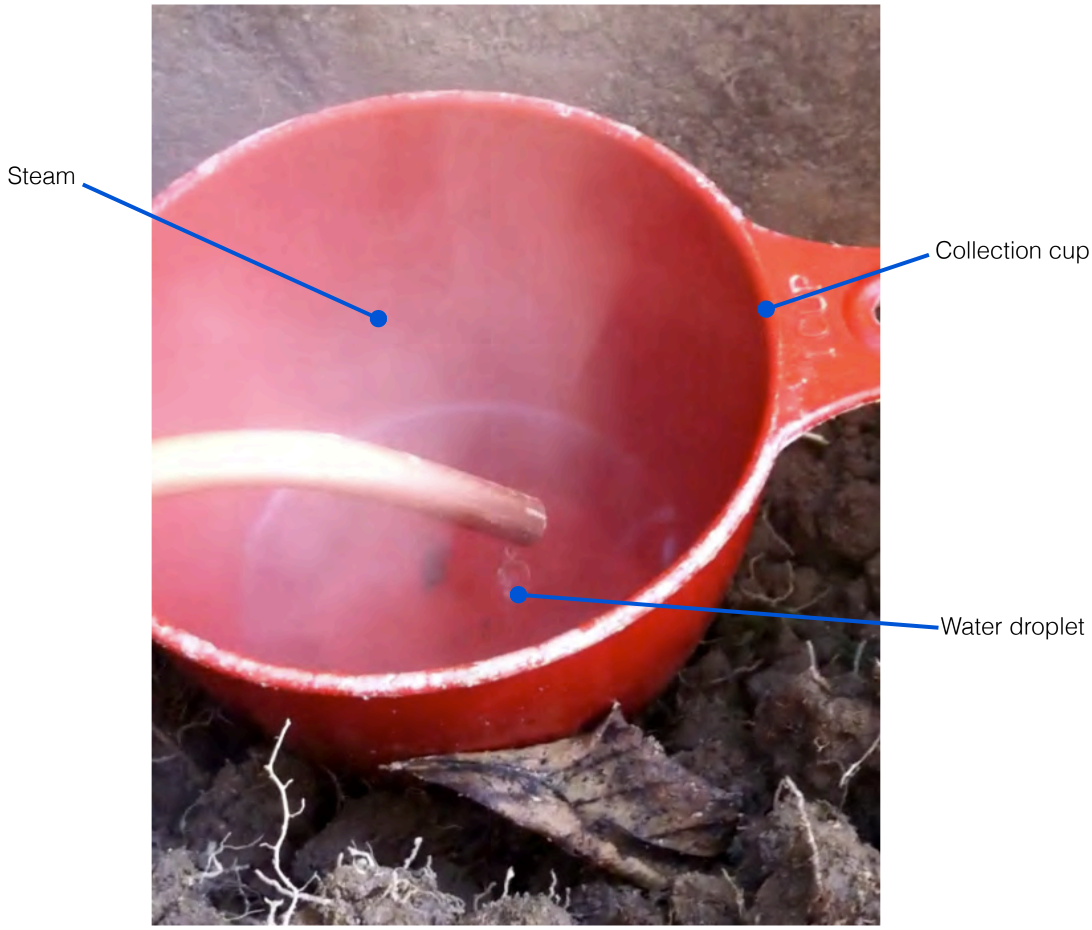

Figure (3.6-2). Underground condenser output

3.7 Heating, Fuel and Efficiency

Heating fuel and time tests were all conducted using the 3 burner LPG apparatus. The first test was designed to show which one of the ring combinations was the most efficient. In the following graphs error ranges are shown by two similar color bands on each side of a dotted line. The dotted line corresponds to the measured experimental values.

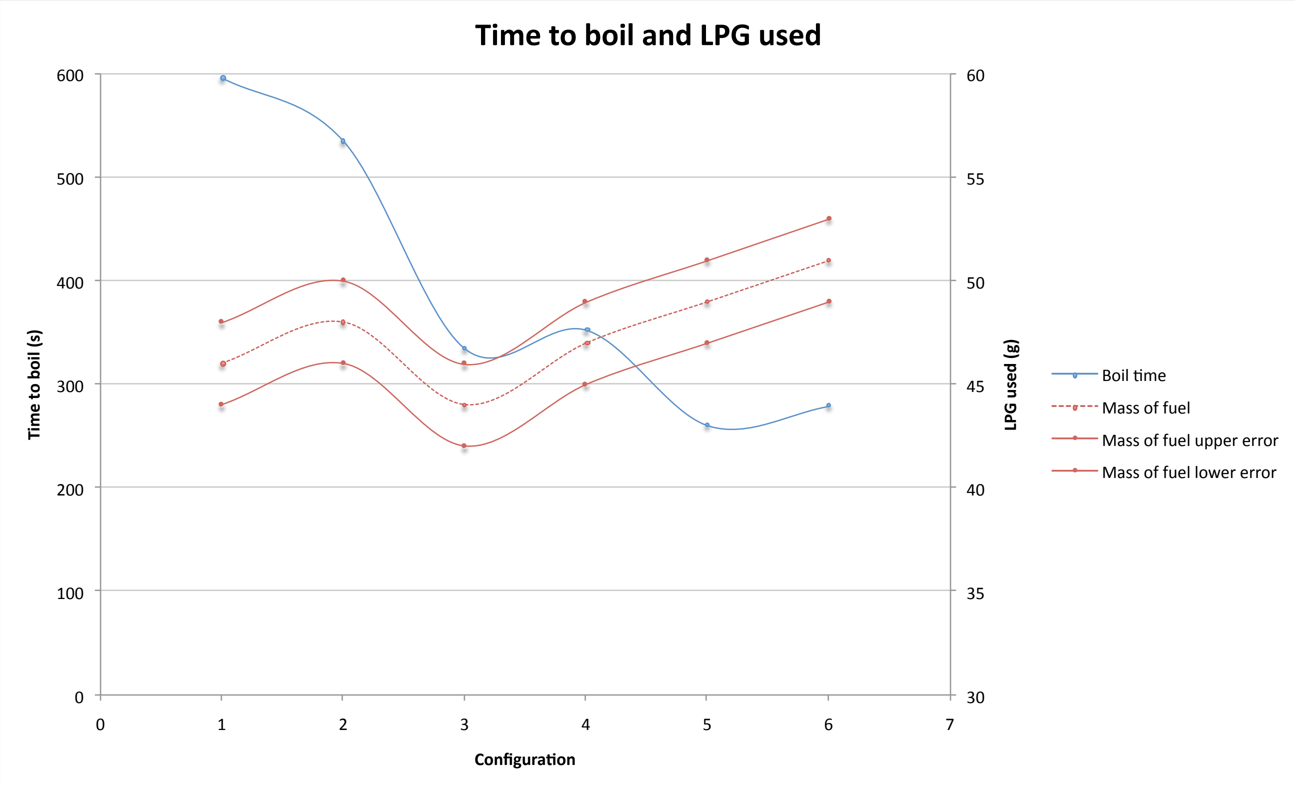

Figure (3.7-1). Configuration, time to boil and mass of fuel used.

Configuration	Rings used	Number of holes
1	2	55
2	1,2	80
3	3	110
4	1,3	130
5	2,3	170
6	1,2,3	190

The above graph (figure 3.7-1) shows the boil time as well as the mass of fuel used for each of the configurations. The graph shows the boil time decreasing as the number of holes increases. This is to be expected as the amount of holes directly relates to the amount of heat being produced by the burner. The mass of fuel relates to the amount of fuel used in the length of time the water took to boil.

The graph shows that the lowest amount of fuel used occurs at the 3rd configuration which is the 3rd ring alone. This low amount of fuel used here can be attributed to the drastic reduction in boil time from the second configuration (first and second ring) to the 3rd. The third ring however is not as fast as the fifth and sixth configurations but uses far less fuel.

If a graph of the amount of fuel used per liter is analysed we can indeed see that the third ring uses the least amount of fuel per liter compared to the other configurations (figure 3.7-2).

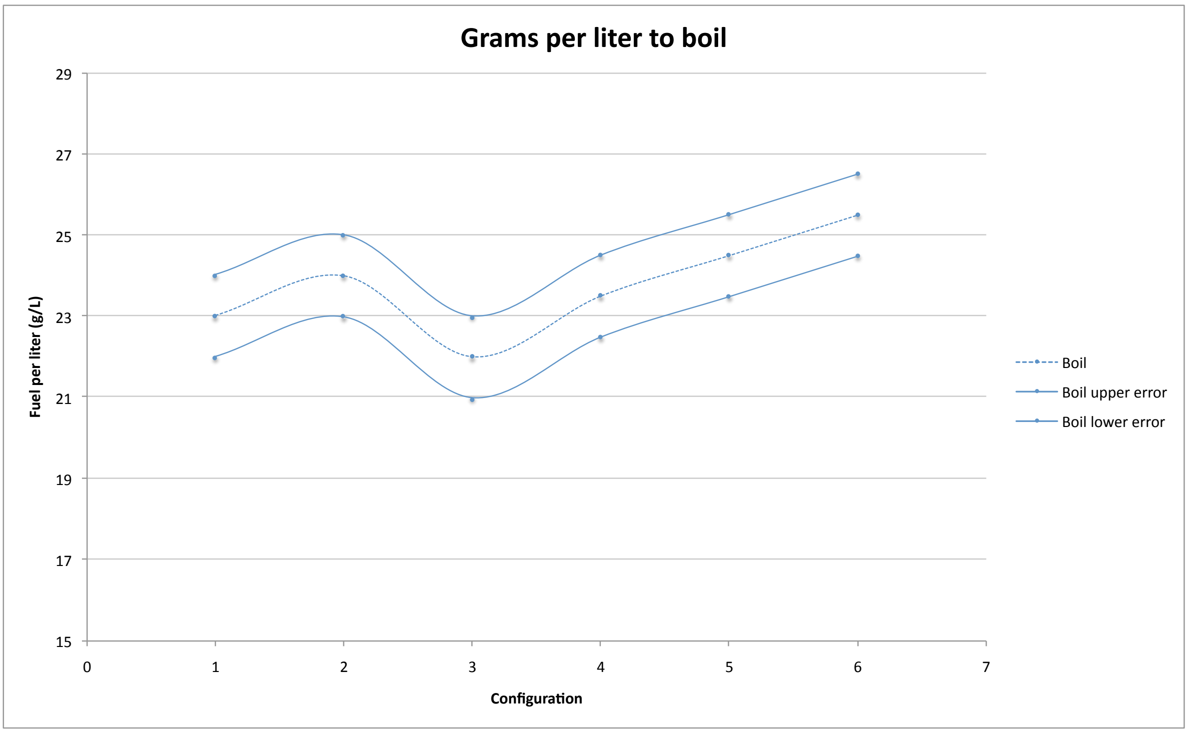

Figure (3.7-2). Fuel per liter to boil

Efficiency calculations also back up this fact. Below is the graph of the efficiency of each configuration (figure 3.7-2). These values were calculated by comparing the theoretical time to boil taken from fuel flow rate to the actual time to boil. This calculation gave the percentage of the heat that is being absorbed by the device. It is shown that the efficiency peaks at 36.16% at the third ring.

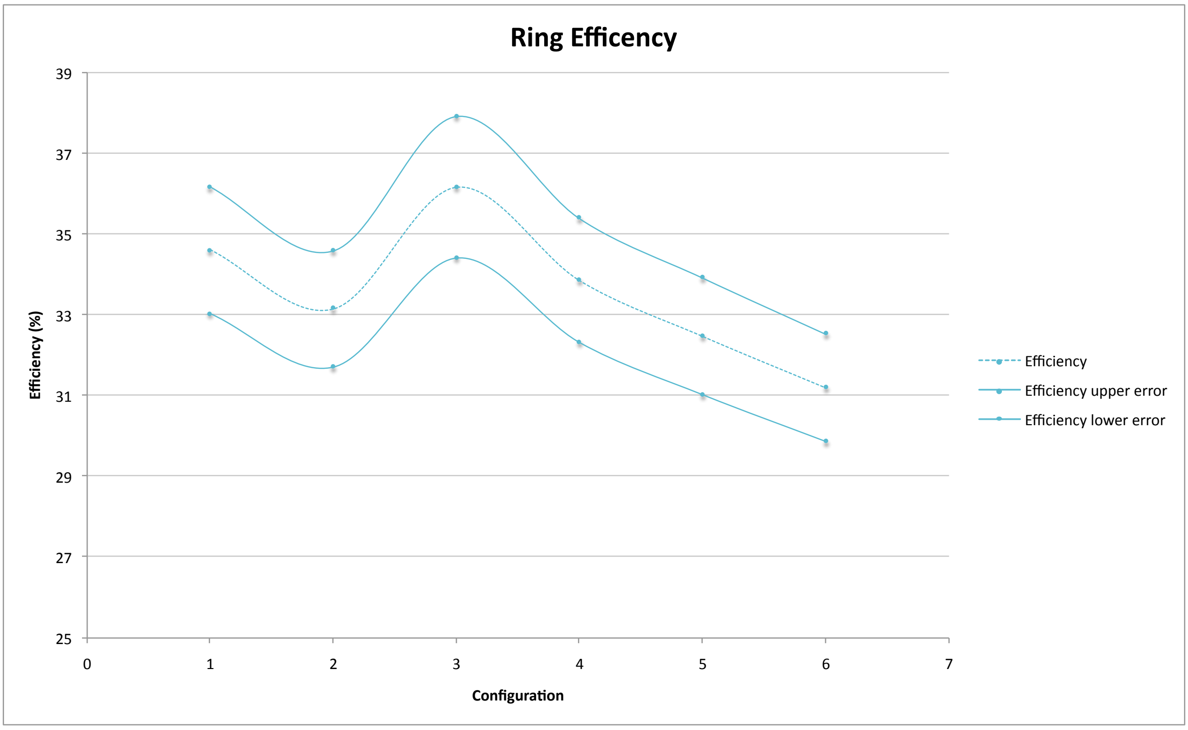

Figure (3.7-3). Configuration efficiency.

Sample efficiency calculation:

Mass of gas used = 44g

Time to boil = 335s

LPG flow rate = (44/1000)/335 = 0.000131 kg/s

Power output at burner = flow rate x calorific value of LPG

= 0.000131 (kg/s) x 46350 KJ/kg

= 6.09 KW

Heat needed to boil 2 liters = $mc\Delta T$

= 2 x 4.19 x (100-12)

= 737.44 KJ

Time to boil (theoretical) = heat needed / power output

= 737.44 / 6.09

= 121 s

Efficiency = theoretical / actual time

= (121 / 335) x 100

= 36.16 %

Once the third ring was found to be the optimum ring it was broken down into smaller portions to find the optimum flow rate for the LPG. The boil test was repeated again for the third ring. Furthermore a steam test was conducted as well. The valve controlling the third ring relates to the angles shown on the graph (3.7-4). This graph shows the steam efficiency being at its peak when the boil efficiency was at its lowest. This provided a conclusion of sorts. The first option is when the device is used it uses two different flow rates for the boil and steam phases. This would involve the operator knowing when the water boiled and changing the flow rate with the valve. A much more likely and user friendly option would be to have a single setting for the valve that would maximise these both. As shown by the graph this is impossible. The method to solve this problem was to model how important each of these efficiencies were in comparison to each other.

As shown in the graph (3.7-5) the amount of fuel needed per liter of water was compared for the steam and boil phases. The amount of fuel per liter for the water to boil is ten times smaller than the amount of fuel required to generate steam. From this we can say that trying to improve the efficiency of the boiling stage will not create a major gain in efficiency. Maximizing the efficiency of the steam phase is what will create better efficiencies. Furthermore the change in the fuel per liter in the boiling phase is negligible. The tests and graphs showed that the optimum operating flow rate was between 65° and 70°.

Tests previously done focused on the boiling and steam phases separately, this is not how the device would operate. Ideally the valve could be set in one orientation for the entire operation of the device. For this reason another third test was done which was the combined boil and steam test. As explained earlier trying to optimise the steam phase was the main focus for this test. The test involved heating the water from 12°C and gaining condensed fresh water from it. This was done by taking measurements at 65°, 67°, 69° and 71°. The graph (3.7-5) shows that the optimum point for the combined fuel per liter is very close to the optimum point for the steam phase. This value is approximately 69°

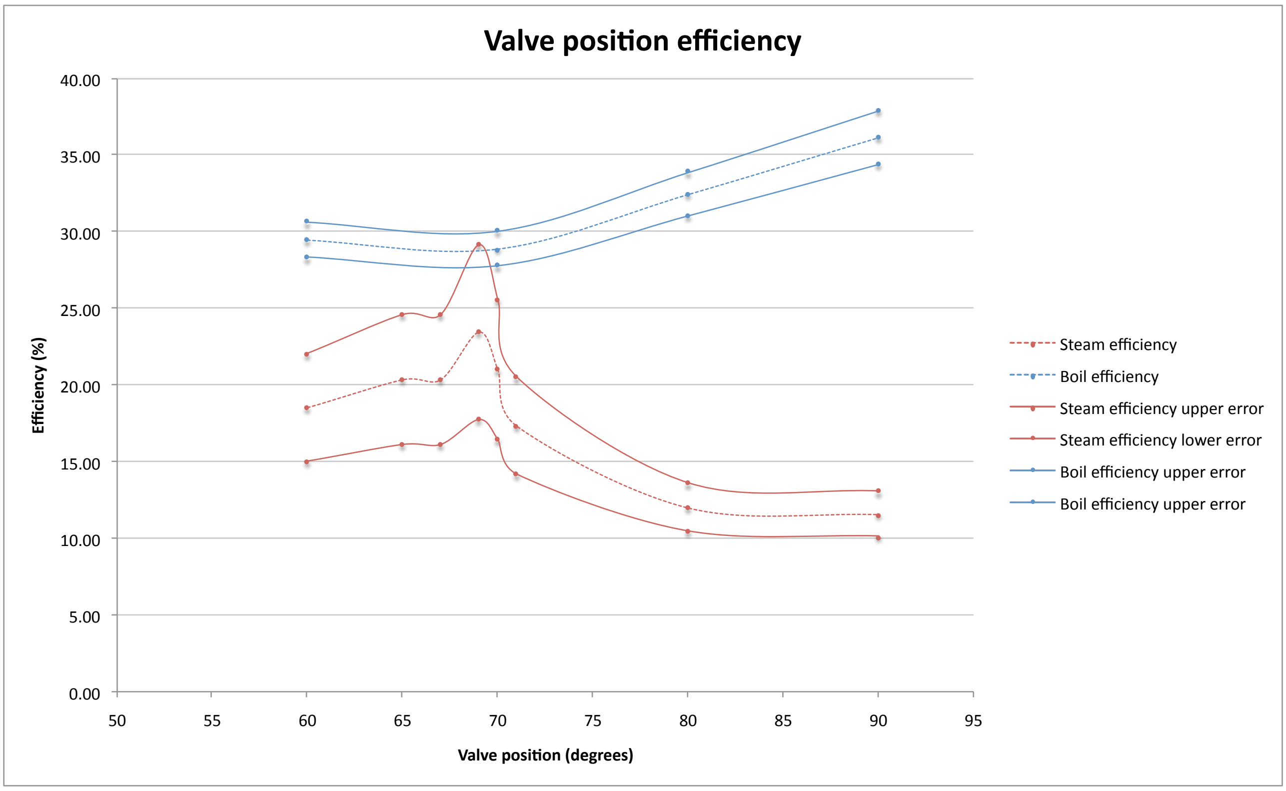

Figure (3.7-4). Valve position efficiency

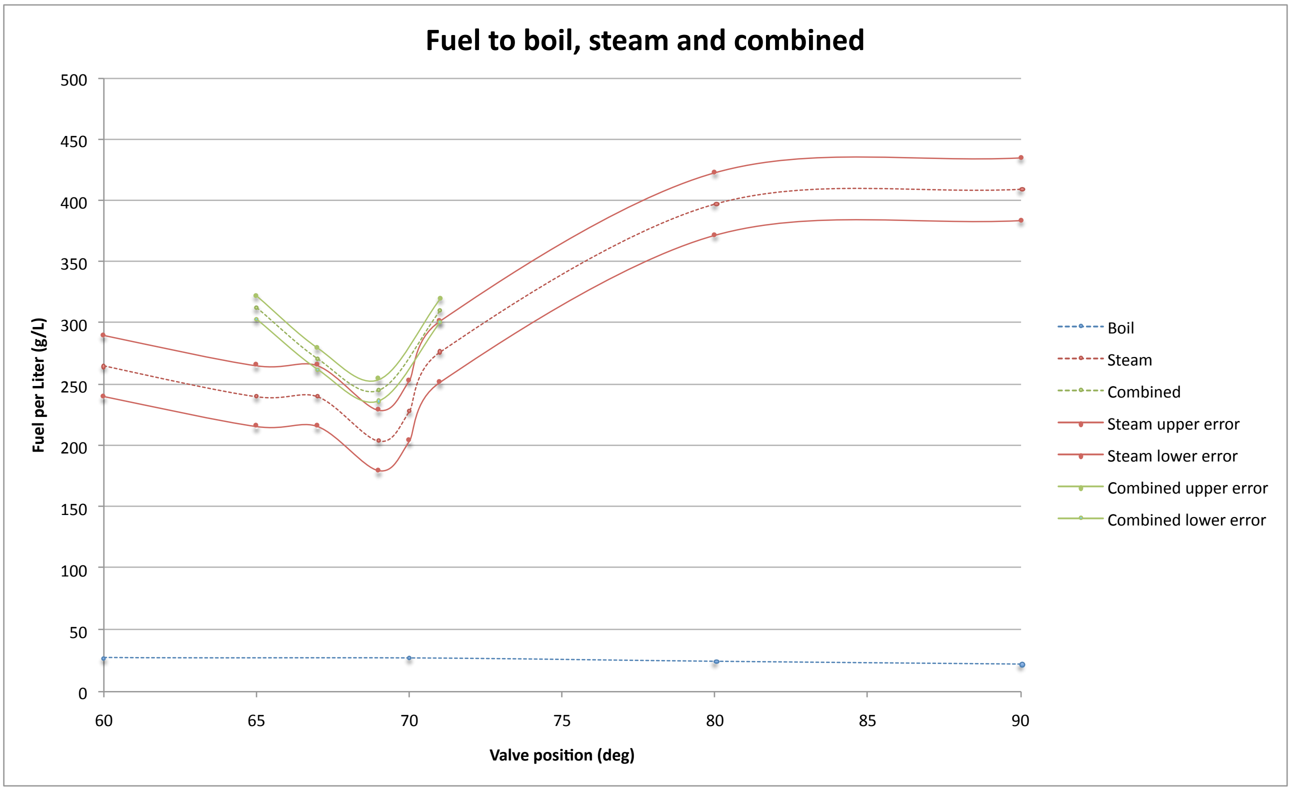

Figure (3.7-5). Fuel per liter to boil, steam and combined.

Section 4. Discussion

In this section the results of all the tests will be interpreted and applied back to the device. These results will give a starting point for improvements and new features.

4.1 Desalination

As described in the results section 99.4% of the salt in the water was removed using this device. We can say that the desalination feature of this device was highly successful.

4.2 Generation fan

The electrical generation feature of this device unfortunately was unsuccessful, this was for a few reasons. The first and most important reason was that there was simply not enough air coming out of the top of the central cone. This is difficult to remedy but could be attempted. The central cone could be made even smaller at the top to further compress the air and gain more speed from it. This could create more problems though like back drafting. Back drafting is a phenomenon where combustion gasses cannot effectively pass out the flue and begin to flow back into the combustion area. In many cases this causes a more inefficient combustion and excessive smoke because the combustion gasses flow against the draw of the combustion. Furthermore the fan used for this test was a cheap plastic computer fan. Ideally the fan would be of a pelton wheel (impulse) type rather than a fan type. Pelton wheels gain energy from the kinetic energy of a flow where as a reaction turbine uses pressure. In this case we have very little pressure but a relatively high speed because of the stack effect or natural draft:

$$\Delta P = C*a*h\ ((1/T_o)-(1/T_i))$$

ΔP = pressure difference

c = 0.0342 (constant)

a = atmospheric pressure

H = height of stack

T_o = Outside air temperature

T_i = Outside air temperature

As shown by the formula the only real variable we can easily modify is the height of the stack. If the stack (cone) was taller then there would be a grater pressure difference and therefore greater speed. Furthermore this could enable the fan to be mounted at the top of a taller cone further away from the extreme heat of the combustion area. A taller cone could be better for the generation feature but could be detrimental to the overall efficiency. A taller stack creates a faster draw which in turn creates a faster burn of fuel. If this burn is too fast it maybe over the devices ability to absorb that heat. This would use large amounts of fuel with a large portion of the heat passing unused up the cone.

The main purpose of the device is to efficiently extract drinking water, the power generation is a side feature. This feature would be useful for charging cellphones etc in times of disaster but not if it caused the device to become extremely inefficient. There will be a point where the cone could be modified so that sufficient speed is generated and an acceptable amount of heat is absorbed by the device. This would be hard to implement though as the device is designed to run on many different fuels. Different fuels generate different amounts of combustion gases for example wood burns at a ratio of approximately 1:5 where as coal burns at 1:12. This in turn creates different flue flow rates per kg of fuel.

4.3 Wood Combustion Chamber

When tested the combustion chamber provided sufficient heat to boil the water and produce steam. It did however cause a lot of back drafting because of inefficient design. The central cone top proved to be to small for the amount of gases being produced by the wood. Furthermore the secondary combustion gap was too small as well (figure 4.3-1).

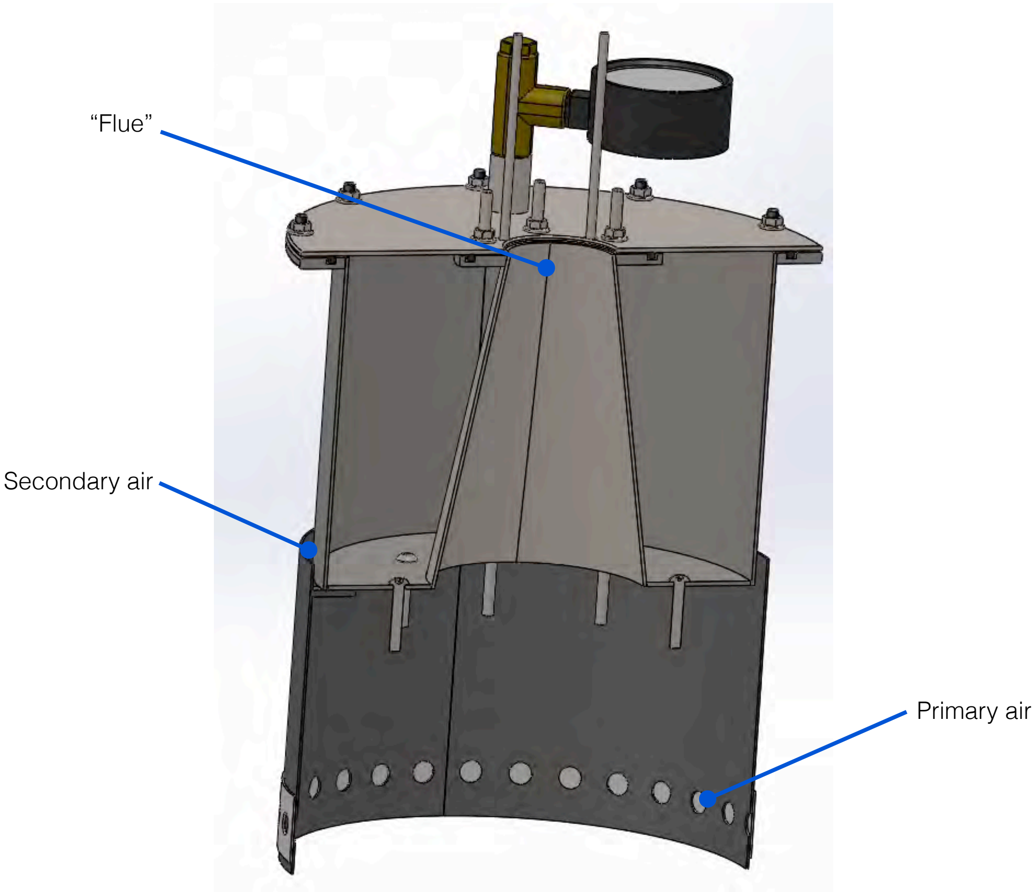

Figure (4.3-1). Cross section showing primary and secondary air

The combustion chamber functioned well with out the desalinator mounted on top of it. This was because the combustion could use the air from the outside easily. When the desalinator was added the fire was chocked and produced excessive amounts of smoke. This is for a few reasons. The main problem was the availability of oxygen to the combusting wood through the primary air holes. The air holes would most likely work if the fire was left to burn to coals as this would align the holes in the correct area. Initially the wood was lit from the top and was expected to burn down. The primary air holes were too low and were covered by unburnt wood causing a serious lack of oxygen. This flaw causes this device to be inadequate in this configuration. A person in need of water does not want to wait for coals to burn down, they want to start heating from the first flame. This chamber does not allow for this. Because the primary air holes were blocked air was sucked in through the flue (central cone) which caused back drafting. The secondary air space was an approximately 5mm gap between the chamber and the desalinator and was designed to only supply the secondary air. When the primary air was not enough the air was sucked through the secondary air gap and was inadequate. Modifying this design to be more like a rocket stove could provide a solution. This will be talked about in the recommendations section.

4.4 Air cooled condenser

The air cooled condenser was unsuccessful at condensing even a small amount of the steam. This was simply because it was too short. Air has a specific heat of approximately 1 kJ/kgK while water is 4.2 kJ/kgK. These two numbers tell us that it is much easier to heat the air than it is to heat the water. The condenser surface area remained constant between the air cooled and water cooled tests. Therefore if the area remains the same the air is simply not able to move enough heat away from the condenser as the water was. This is greatly dependent on the weather, wind would cause a forced convection adding to the natural convection giving better cooling abilities. The air cooled condenser concept is not dead however. The condenser used was a simple copper pipe with no fins or attempt to increase the area. More work needs to be done on designing a more efficient condenser before the air cooled concept is dismissed.

4.5 Water cooled condenser

Water cooling the condenser is the easiest way of getting the desired result while still causing the condenser to be small. The question is how much water do you need? If you are using this device on the coast cooling water is not a problem as you can just get sea water.

Minimum flow of cooling water = 1.5/315 = 0.00476 L/s (3rd ring)

This could be achieved by having a small valve or possibly a hole in the bottom of the condenser housing to release the water at the desired rate. The condenser housing is then simply topped up with cold water from the sea at the same rate. This would actually be more effective than having a water bath for two reasons. The first is with moving water there is a higher rate of heat exchange because of forced convection. Hot water is quickly replaced with cold water keeping the temperature low. The second is the stratifying of the temperature gradient over the height of the condenser (figure 4.5-1).

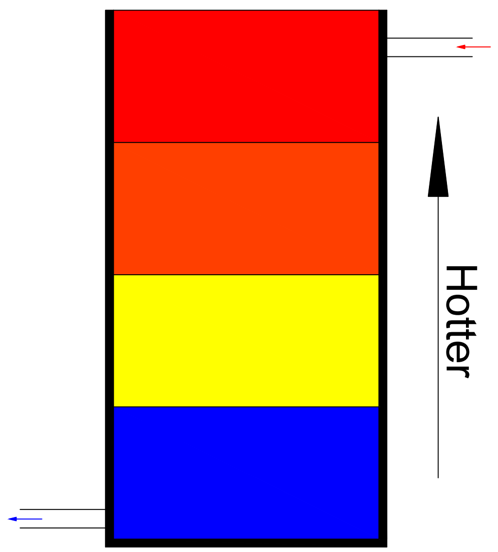

Figure (4.5-1). Temperature gradient

As shown in the diagram the water at the top of the container is significantly hotter than at the bottom. In testing this difference was as great as 60°C. The top up sea water would be added to the top of the housing cooling the top water and reducing the stratifying effect. It was observed however that when this top up water was added there was a stall in the production of water out the end of the condenser compared to the water bath test. It appeared that the more constant the cooling the more constantly the water was being produced.

In terms of cooling water quantity to condensed water the values are as follows:

Minimum flow of cooling water = 1.5/315 = 0.00476 L/s (3rd ring)

Amount of water produced per second = 83 / (1000*192) = 0.000432 L/s

Therefore there is an approximate ratio of cooling water to water produced of 1:11. For the entire capacity of the device (3L) to be desalinated there must be a water source of at least 33L. This is not a problem if the device is used near a body of water or even a puddle containing enough liquid as it doesn't have to be clean. You could use clean water for cooling and then save this water for the next refill of the device as it would already be warm. Furthermore it could be used for bathing etc. At this stage the condenser is a single unit containing a housing (PVC) and the condenser (copper tube). The condenser unit is then simply screwed onto the steam valve for use. Fitting a flexible hose to go from the steam valve to the condenser would be advantageous as it leads to easier use of the device. Furthermore it leads to various other condenser configurations such as placing the condenser on its side. Placing the condenser like this may reduce the stratifying effect and lead to a lower cooling water to water ratio.

4.6 Underground Condenser

It is hard to comment on the underground condenser effectiveness as there are so many different types of soils and ground types that the condenser could be used in. The one tested however was moist soil found underneath a lawn. The temperature that day was 13°C and the ground temperature just 100mm below the surface was only 7°C. The concept behind the underground condenser is that the ground even a few centimeters down is generally colder than the air furthermore it has large thermal mass. The test showed that the first sign of steam was only after 101 seconds after this the steam to water ratio remained roughly the same. After 615 seconds steam only was coming out of the condenser. There is three definite stages in the operation of this condenser. The first being the water only stage (under 101 sec). In this stage the ground was simply heated up as the steam passed through it (figure 4.6-1).

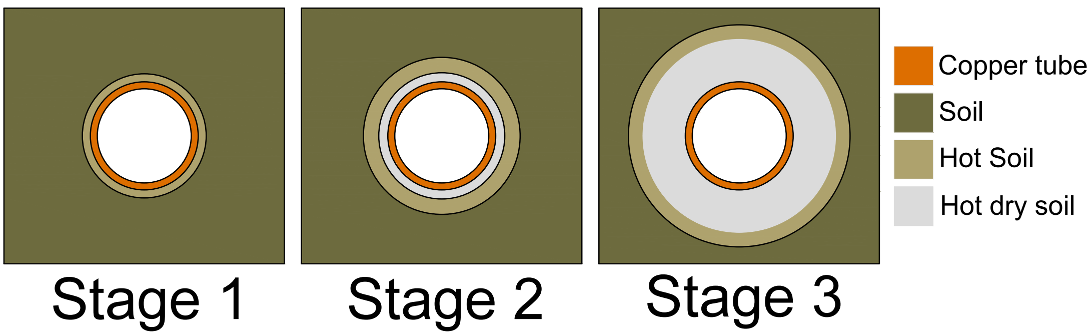

Figure (4.6-1). Underground condenser stages cross section

In stage 2 the hot soil around the tube has turned to a dry hot layer with another layer of hot soil around that. Finally a layer or dried soil thick enough to effectively slow the heat transfer down as if it were not happening forms (stage 3). Dry soil is a very good insulator especially if it contains clay. From the test we can see that it is the water in the soil that pulls the heat away from the tube. The soil can store this heat because of large thermal mass. Keeping even a small portion of water around the tubes is essential for operation. If there is dry soil that is too thick then the heat transfer effectively stops. This could be done by simply moistening the ground every couple of minutes depending on the type of soil, sand etc. If water was not available to do this the condenser could be moved even a small amount to get away from the dried soil. This however, according to this test, needs to be done every 101 seconds if steam to water efficiency must remain high.

4.7 Heating, Fuel and Efficiency

Heating fuel and efficiency tests were done to gauge the level of effectiveness of the device. These tests determined the peak efficiency. From this peak efficiency we can draw conclusions on why this is the peak point and what can be done to improve this.

The first test conducted for the heating system as described previously was the configuration efficiency (figure 4.7-1). Each configuration involved a different number of holes (burner holes) positioned at different locations on the underside of the device.

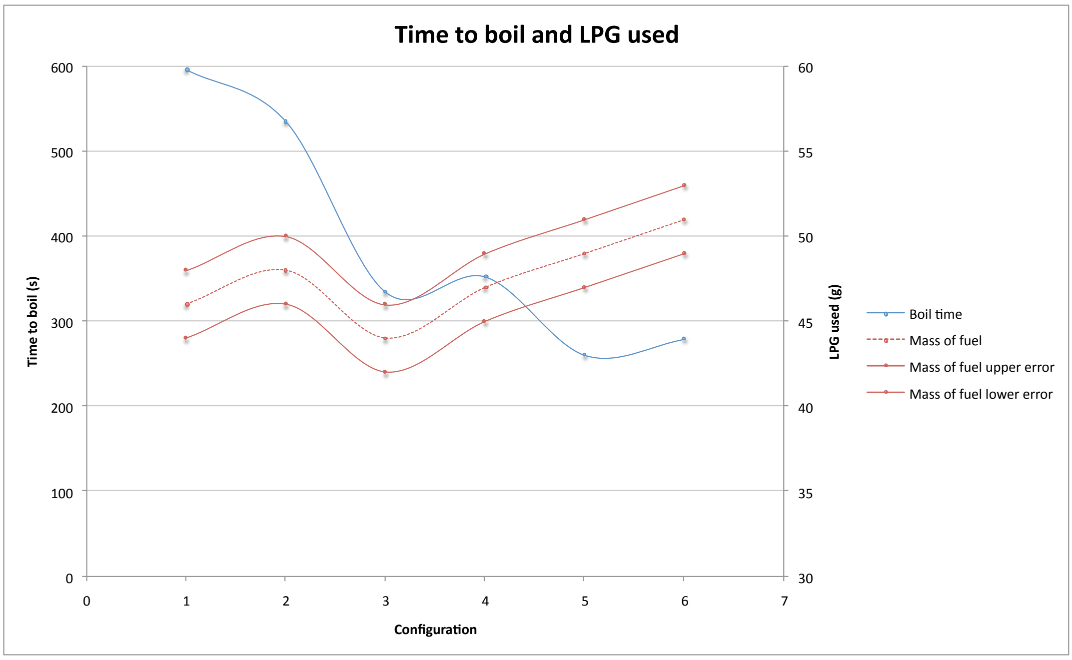

Figure (4.7-1). Time to boil and LPG used

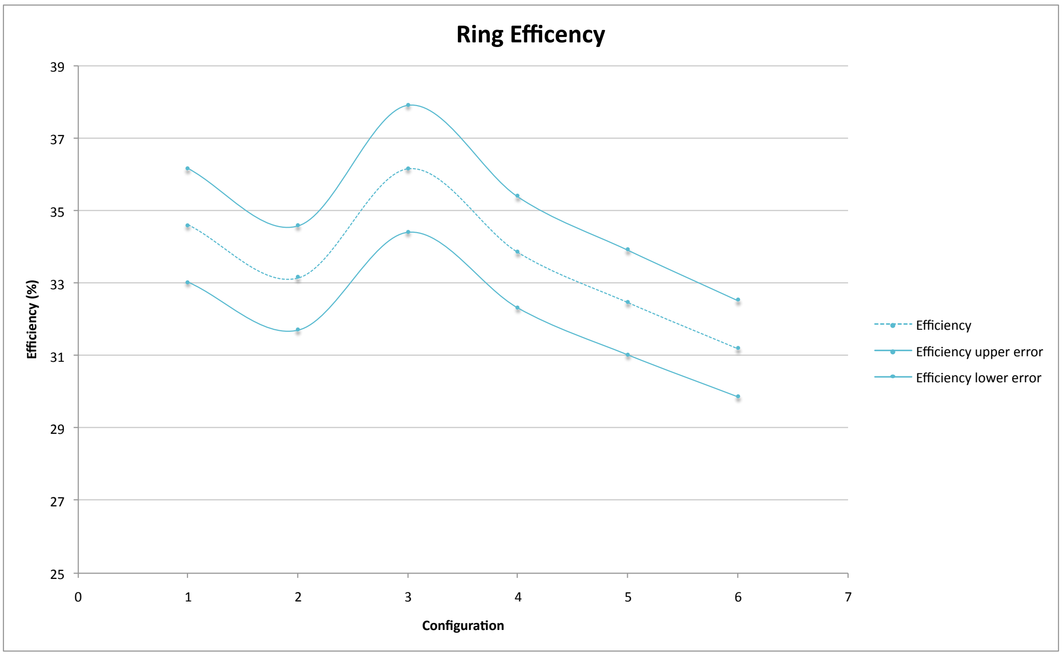

Figure (4.7-2). Configuration efficiency

If the graph (4.7-1) is examined we can explain why the curve looks the way it does. Starting from configuration 1 we can see a long boil time and a relatively small amount of fuel used. Configuration 1 corresponds to ring 2 only (55 holes). The device sits on the burner so that ring 2 is approximately half way between the cone and the outside shell. In this configuration much of the heat rose up through the central cone creating a burning area inside the cone (figure 4.7-3). Very little of the heat appeared to be hitting the flat bottom of the device. This would possibly be from the draw of the combustion. The air would be sucked in from the outside then exhausted through the cone (figure 4.7-4). The flames protruding from the top of the device can be put down to secondary combustion. The graph shows that the amount of fuel used in configuration 1 is actually quite low compared to the time it took. This leads to the conclusion that combustion inside the cone should be encouraged. Having flames inside the cone rather than hot combustion gasses appears to be a more efficient use of the energy in the LPG. This is backed up by the efficiency graph (4.7-2). Configuration 2 is actually the second highest efficiency after configuration 3.

Figure (4.7-3). Central cone combustion

Figure (4.7-4). Draw through central cone.

Configuration 2 was the first and second rings burning simultaneously. At this point there is a slight drop in time taken but a slight increase in fuel used. The rise in fuel use is simply down to more holes burning (80). This is a 30% increase in the amount of holes available to provide heat to the device. There is not however a 30% drop in the time taken to boil there is only a 10% drop. There is an obvious loss in efficiency here and this is down to one main reason. The smallest ring is located in the centre of the cone and is approximately 50mm wide. The heat from this ring never touched the flat bottom of the device because of its size. The smallest ring also did not cause secondary combustion in the cone. Heat from the small ring simply passed as hot gasses through the central cone. This could be due to small amounts of gas coming out of the ring. The ring experiences near complete combustion close to the exit of the burner hole rather than incomplete combustion as with the second ring. This could be improved by increasing the flow rate of the small ring so that there is not enough air for complete combustion. In turn this would force volatile gasses into the central cone where they could experience secondary combustion. This is also shown on the configuration efficiency graph. It is worth noting that there is always a drop in efficiency when the small ring is on further concluding that hot air rising through the cone is less efficient than flames. In theory this could be explained by the difference in temperatures of the flame and the hot air. If we assume the same water temperatures for two hypothetical tests and a higher flame temperature compared to hot air temperature it can be shown that temperature difference creates higher rates of heat transfer. The flame is hotter and therefore transfers more heat to the water in a given amount of time compared to the hot air. Flames and air pass through the cone at approximately the same rate but because the flames are hotter more heat is absorbed from them. The cone could have plates as described in earlier sections to stall this hot air so the same amount of heat could be absorbed.

Configuration 3 consisted of the 3rd ring (largest) running alone. This ring proved to be the most efficient configuration as shown by the fuel consumption in the graph (4.7-1) and the efficiency in the graph (4.7-2). The third ring consisted of 110 holes spread over two concentric lines. These lines were located near the outside of the device when it was placed on the burner. The inside line fell slightly in from the outside of the device while the outside one fell on the device edge (half on half off). Visually the flames protruded mostly from the outside of the device burning up its sides (figure 4.7-5). There was however still a small amount of flame coming through the central cone (figure 4.7-6). The bulk of the flames hit the bottom of the device and were drawn up the sides.

Figure (4.7-5). Side flames

Figure (4.7-6). Central cone flames

This configuration was most was the most efficient because it used all of the possible heating surfaces, cone, bottom and side. It did appear as well that the flange used to house the o ring and secure the lid acted as a plate to stall the hot gasses rising up the sides.

Configuration 4 consisted of the 3rd and 1st rings burning simultaneously. As explained earlier there is always an efficiency drop when the 1st ring is on compared to when it is not (3 alone vs 3,1 together). There is a max flow rate set by the regulator on the LPG bottle therefore the flow rate must must be shared between the two rings. The 3rd ring has a higher flow rate because it has more outlet holes than the smaller inside ring. Essentially when the 1st ring is on it is taking heat from the other rings because of the flow rates. In this case the boil time increased from when just the third ring was on to when they were both on because heat previously used for heating at the third ring was passing from the 1st ring up the cone.

Configuration 5 is when both ring 2 and ring 3 were on (170 holes). This configuration shows a increase in fuel consumption and a decrease in boil time which is good. There is however a drop in efficiency from the 4th configuration. This is due to the device being at or near its heat absorption maximum. At this point and beyond fuel is being burnt but a fairly fixed amount of heat is being absorbed. At this point and beyond adding more fuel will not significantly increase the efficiency.

Configuration 6 is all three rings on (190 holes). There is a drop in efficiency for two reasons. The first being that the 1st ring is on, as explained previously this always lowers the efficiency. Secondly this is most likely past the devices heat absorption maximum point. Fuel is being burnt with no real gain in efficiency (figure 4.7-7) .

Figure (4.7-7). All three rings on

Once the 3rd ring was found to be the most efficient it was broken down into smaller bits to find the optimum flow rate for the LPG.

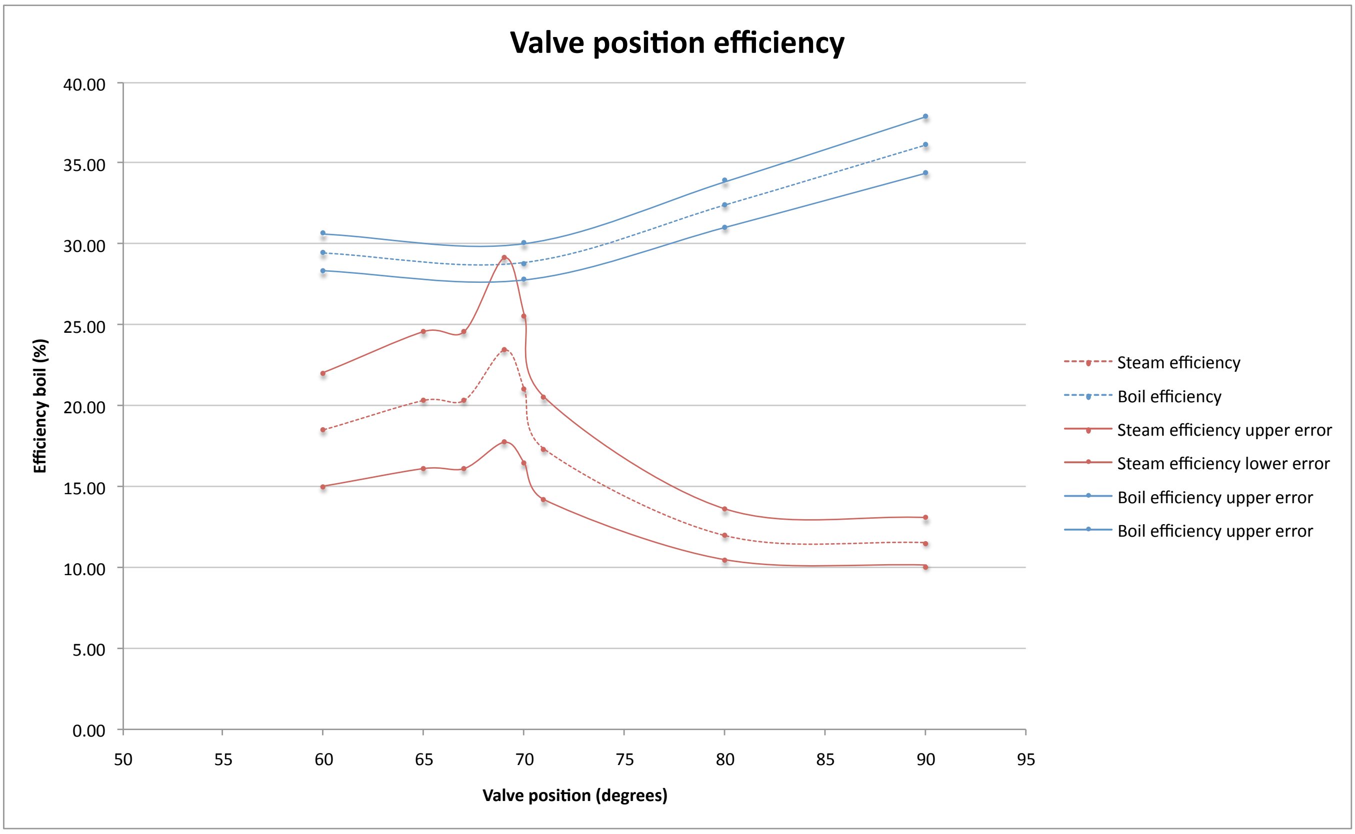

Figure (4.7-8). Valve position efficiency

The graph (4.7-8) shows the efficiency for different positions of the valve controlling the third ring for the boil and steam phases. As shown on the graph the optimum point for the steam phase falls very close to the minimum point for the boil phase. This is most likely due to the specific heats in the two phases. As we know water boils at approximately 100°C at atmospheric pressure. As the water heats up though it expands and pushes up the pressure. This in turn pushes up the boiling point and the amount of energy needed to boil. Steam works in the opposite direction. At atmospheric pressure it takes more energy to create 1kg of steam then it does at a higher pressure. From the graph we can see that it is not possible to run this device on one setting for the entire process of desalination. This brings up a major usability issue, should these run at different flow rates (LPG)? It is my opinion that to improve the ease of use and attractiveness of the device the flow rate should remain the same over the two stages. So what should this flow rate be? This needs to be determined from the significance of the two stages in relation to each other. As explained in the previous section the steam phase uses approximately 10 times the fuel that the boil phase does. Therefore maximising the steam phase is the priority (figure 4.7-9).

Note: error bands on the boil stage in the graph bellow are too small to see.

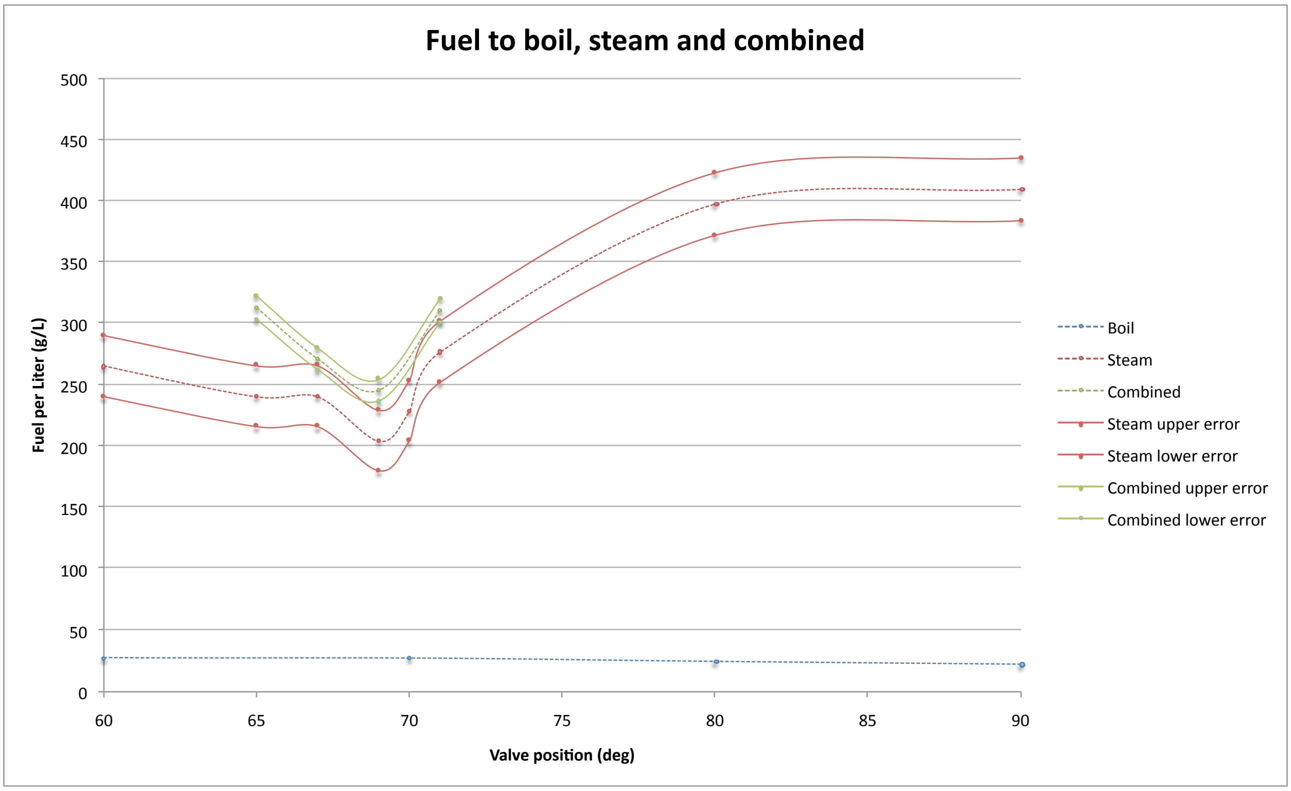

Figure (4.7-9). Fuel consumption for boil, steam and combined

The optimum point falls at approximately 68°-69°. This point is where the device absorbs the most heat for the least amount of fuel.

From these results it can be concluded that as many of the surfaces of the device should be touching flames as possible. Placing the device on a heat source would be less effective than if it had the heat source inside it. This would provide more flame contact and would be easier to use and transport.

4.8 Price comparison

At the optimum point the flow rate is approximately 0.0926 grams of LPG per second. If it takes 446 seconds to boil the water and a further 202 seconds per 83ml for condensed water we can work out how much it would cost to produce that 1l of water compared to buying bottled water.

446sec per 2liters = 223 sec per 1liter

223 x 0.0926 = 20.65g (to boil)

1000/83 = 12.05

202 x 12.05 = 2434sec

2434 x 0.0926 = 225.4g (to produce 1000g of steam)

225.4 + 20.65 = 246.05 (total)

LPG costs approximately $30 per refill (9kg). Therefore it costs $0.003 per gram.

246.05 x 0.003 = $0.82 per liter.

Therefore a full 9kg LPG bottle would produce 36.6L of drinking water. This is of corse assuming that you are only filling it with 1 liter of water, boiling it, condensing it, then starting again. This also assumes that the device is cold before you start heating each liter of water.

If a “Super pump 1.25liter spring water” is taken as an example as bought bottled water we can see that it is much more expensive.

1.25L = $3.30

1liter = $2.64

Bottled water is approximately 3.2 times more expensive than water produced from this device. Remembering that this price comparison is done with bought LPG not free firewood etc.

If we assume a family of 4 each requiring 3liters of water for drinking alone the device along with 1 LPG bottle will last for 3.05 days. This is within the 3 days that civil defense recommends being prepared for.

4.9 Design and Usability

This device from the outset was designed as a replacement for bottled or stored water. The concept behind this was to make a device that was so easy and stress free to use that people simply though “why shouldn't I get one”. It is hard to say weather we have been successful at developing this device from a usability standpoint as this is simply a prototype designed to simply test concepts. If pursued later devices will incorporate handles, pressure relief valves etc. Furthermore the nesting of the device has not been investigated fully. We can however learn valuable lessons from the prototype when it comes to constructing the device.

First of all the material the device is made of could be looked at. The prototype at this stage is made from various different grades of stainless steel:

Top (lid) = 304

Bottom = 304

Shell (cylinder) = 304

Central cone = 304

O ring flanges = 316

This section will briefly go over the lessons learnt for each of these components and future improvements for easier and cheaper construction.

Top (lid): This component was water jet cut from a piece 2mm thick scrap bought from W. Rietvelt Ltd. In hindsight this component should have been made from a thicker piece of plate for 2 reasons. The first is the problem that plagued the construction phase of the device, weld warp. When welding on the fill/pressure fitting the previously flat part buckled as the welds cooled. This resulted in some small gaps forming between the lid and the o ring (figure 4.9-1).

Figure (4.9-1). Weld warp causing pressure leeks

Bottom: the bottom plate was cut from the same 2mm thick piece as the top was. This component buckled extreme amounts when welded. Different areas of it were heated and cooled to flatten it out. The bottom had the most welding of any of the parts in the device. Other components were pickled to counteract the chromium depletion in the metal after the welding process. Because this part had so much welding on it it should have been pickled for longer. The bottom was the only part to show any form of corrosion (figure 4.9-2).

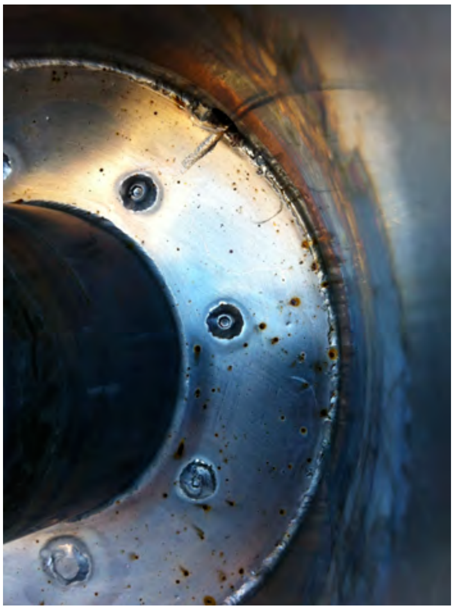

Figure (4.9-2). Bottom plate corrosion.

Shell and cone: The shell and cone were relatively easy to construct and performed exactly as expected.

O ring flanges: The o ring flanges were made of 316 stainless steel which turned out to be overkill for this project. Initially the o ring grooves were cut on a lathe with HSS cutting tools. This proved to be unsuccessful the material was too hard to be cut with HSS. Next a tungsten carbide tool was used. Even this tool chipped slightly with the material. The last option was to cut it on a milling machine with a rotary table. The groove size had to be exactly right or there would have been leeks. The milling machine cut a very accurate and smooth grove for the o rings. The o ring groves were made from 5mm plate cut out with a water jet cutter. Because of this thickness weld warp was not as much of an issue.

Other parts: Valves and o rings performed perfectly. The drain valve was rated for 200°C and so wee the o rings. The steam valve was designed for air at high pressure. After dismantling the valve I found that it had PTFE seals and would work at high temperatures. The steam valve still functions fine and closes completely.

The pressure gauge was also only designed for air. It was uncertain weather it would last for all of the tests. The pressure gauge was initially mounted in a horizontal orientation (figure). In this orientation the steam was entering the valve and condensing then collecting in the body. It was moved to a vertical position so it could drain this condensation. The valve ended up lasting perfectly for all the tests.

Section 5. Conclusion and Recommendations.

Through this research many things were learnt mainly about the feasibility of this project. At the outset the device was meant to be a small easy and safe to use water purifier. This turned out to not be the case. The device essentially had to have three parts to function properly, desalinator, condenser and heat source. This heat source could consist of an LPG burner with a LPG bottle or a wood combustion chamber. The central device is small but the accompanying parts make it much larger. For this reason much more work needs to be done on the look and usability of the device before it is ready for people to use.

There were many many questions to be answered in this research. The initial proposal outlined stages for the design and testing:

Stage 1: The design and development of the central machine (boiler and condenser).

Stage 2: Research and testing of different placements for the condenser (how can I more affectively use the latent heat given off when the steam is condensed).

Stage 3: Developing a system to use the rising heated air and the draw from combustion to turn a fan to generate power.

Stage 4: Calculate and test different heating techniques. For example a lens mounted on top of the boiler or incorporating a water dissociation system powered by the fan mentioned before.

Stage 5: Once I am happy with the design, move onto refining it further and making it more user friendly (stackable, easy storage etc).

From this list we can see that stages 1-3 and part of 4 were completed and tested. Stages 1 and 2 were central to the devices operation and had to be tested. Provisions were made with the central device so stage 4 could be tested. For example there is mounting points for ducting hot exhaust gasses or liquid through the cone. Furthermore there is the ability to mount a clear lens in place of the stainless steel lid fitted on the device. Stage 4 and 5 were not tested because of scope and budget.

The weaknesses of the study were that the device was not tested in different environments, hot, cold, humid and dry. The device could behave differently in these extremes. It can not be said that this device will function as it did in the tests in a different environment. This of course is due to the limitations of budget and scope for this project.

5.1 Recommendations and future developments.

Condenser: Tests could be done on minimising the stratification effect in the water cooled condenser. This could possibly be done by having some form of mixer or changing the shape of the condenser. A flatter wider shape would reduce the stratification effect but would this have a positive effect?

The water cooled condenser body could be finned and use some form of thermosyphon to cool the water in the condenser. This could lead to lower ratios of cooling water to condensed water.

More tests need to be performed on the underground condenser. Testing with different ratios of soil to water and different soil types needs to be performed.

The air cooled condenser used in these tests was obviously not long enough for this application. Testing a longer condenser (the correct length) and determining how it could be fitted into the overall device would be beneficial. Furthermore trying to create a smaller condenser with designs like fins needs to be looked at to make this device more attractive to the customer.

Generator fan: The fan used for testing was inadequate for this application. More testing needs to be done to ensure that the concept has been fully tested. I feel this is a very useful feature that needs to investigated further.

Device heating: As found in the research having flames inside and around the device proved to be more efficient. Having a device that is a combustion chamber and desalinator would beneficial. Modeling on a rocket mass heater could be the next step in evolution. The rocket stove generates the heat for desalination and heating.

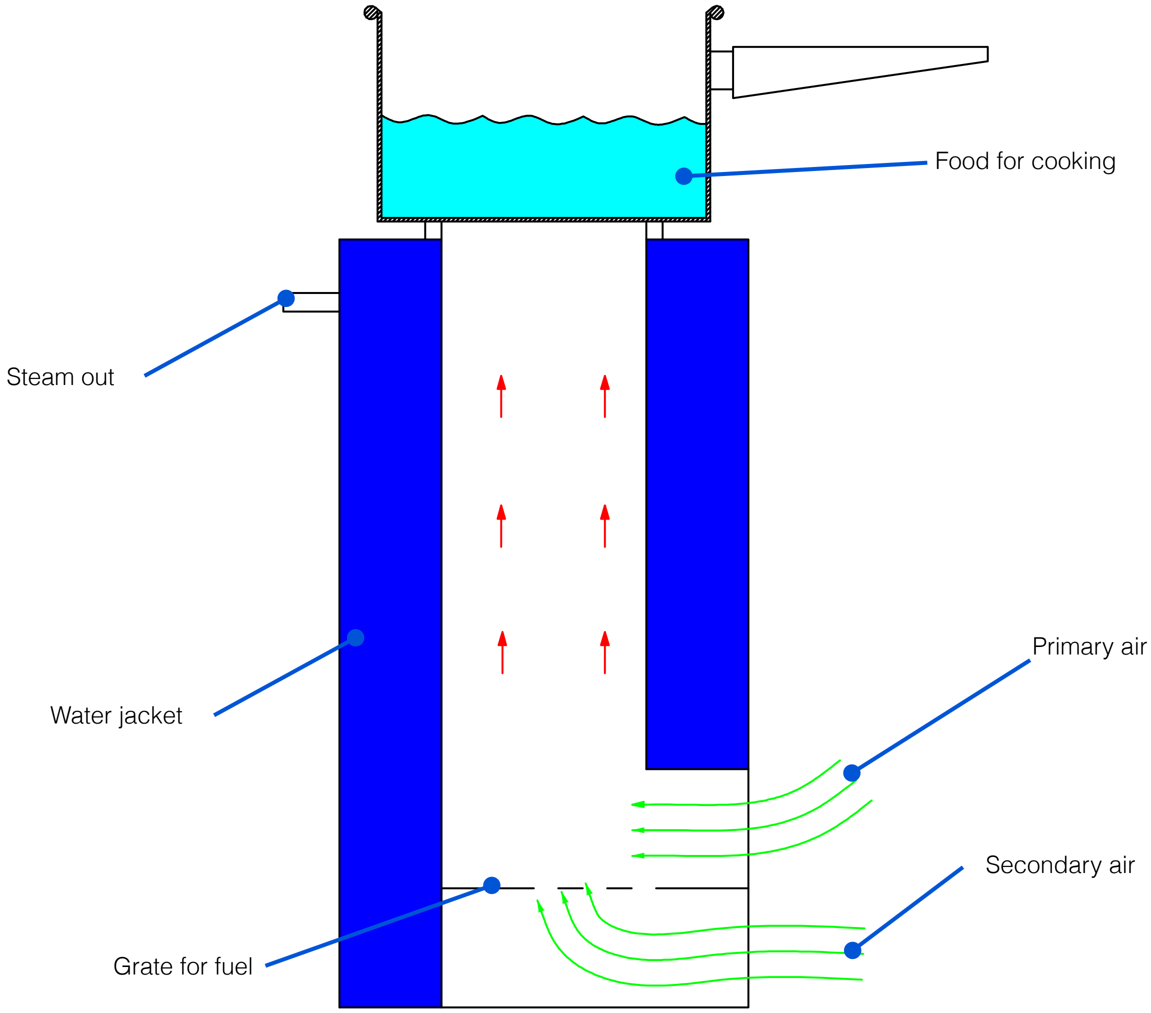

Figure (5.1-1). Rocket stove concept.

Overall the project was successful. We were able to remove almost all of the salt from sea water and make it safe to drink. Many many more changes have to occur before the device is ready for sale to a customer.

Appendix

Glossary

References