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Desalination of Groundwater by Solar Stills - Field Trials in Afghanistan

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Preface

This master thesis is the final assignment in my master degree in Environment and Natural Resources - specialization Sustainable Water and Sanitation, Health and Development, at the Norwegian University of Life and Science (NMBU). The project is implemented in cooperation with Norplan and Norwegian Church Aid (NCA), as a step towards achieving simple and sustainable water technology in Afghanistan, Faryab province. The main vision is to provide poor people in the Faryab province with the option of affordable solutions that produces clean drinking water at a low cost. Due to security reasons the field work was performed in the city of Kabul.

To develop technology that is unfamiliar for the people in Afghanistan is challenging in regards of social acceptance, general understanding and lack of suitable materials. Making use of local materials as well as guiding locals in how to build and use the stills, is an important part of the project, as well as striving to build a robust and mobile unit that provides an "acceptable" volume and is easy to maintain.

The project included the planning and building of solar stills, with a design/construction being as simple as possible. The stills use exclusively solar energy to produce clean drinking water by utilizing the principle of evaporation and condensation to leave salt and pollutants behind. The team consisted of two local carpenters, a student from the University in Kabul, local employees in the NCA, people from Norplan and the Ministry of Rural Rehabilitation and Development (MRRD), and myself. My task in the project has been to review literature and evaluate the technical aspects – prior to and during the building of the stills. I proposed four different designs, and a total of 6 units were built during my stay in Kabul. My work included guidance and supervising in relation to the building process, as well as collecting data in form of temperature, radiation and water quantity produced. Analysis of the quality of the produced water is beyond the range of this thesis, but is recommended in any further/future research.

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Summary

Lack of clean drinking water is amongst the leading problems in Afghanistan, with polluted groundwater, especially in the form of salinity.

As an attempt to find sustainable solutions, low cost solar stills were designed and built in Kabul city. Four different designs and outlines were proposed for this project, with the aim to use solar energy and the principle of evaporation and condensation in the production of distilled water. Of the proposed designs, three were built, in a total of 6 units, ranging from the size 0.1 to 1m^2. The solar stills had different inclination on the glass cover and were built out of a variety of local materials, like plywood, galvanized iron, stainless steel, silicone, paint, insulation and more on.

The experiment was conducted from the 17th to 27th of May, 2014. Hourly measurements of radiation, output and temperatures were registered from 07:00 am to 18:00 pm, and wind- and weather conditions were registered. Individual experiments such as cooling of glass, application of coal and increased salt concentration, were conducted within the research period.

The solar still with the highest efficiency (57 %) was found to be the Plywood single sloped solar still. This and the Wick solar still had an efficiency of 43 % and 31 % respectively. The two solar stills of the smallest size obtained the lowest efficiency, with 12 % and 8 % for Sink double sloped and Plastic single sloped solar still, respectively. The cost estimates ranged from 7 to 70 USD, where the most pricy still was the one with the highest output and the largest size.

Sammendrag

Mangel på rent drikkevann er blant de største utfordringene i Afghanistan, og forurenset grunnvann i form av salt, er blant hovedproblemene.

Med mål om å bidra til bærekraftige løsninger, ble solar stills til en lav kostnad designet og bygget i Kabul by. Arbeidet som ble utført bestod i å bygge solar stills som kunne muliggjøre produksjon av rent drikkevann for de fattigste menneskene i Afghanistan.

Fire ulike design ble foreslått, med mål om å utnytte solenergi, fordampning og kondensasjon i produksjon av rent drikkevann. Tre design ble valgt, og byggingen av seks ulike enheter ble utført, met et areal som varierte fra 0,1 til 1m^2, og en variasjon i vinkling på glass, samt byggematerialer. Materialene ble kjøpt lokalt i Kabul, og bestod i blant annet kryssfiner, galvanisert jern, rustfritt stål, silikon, maling, isolasjon m.m.

Eksperimentet ble utført i tidsrommet mellom 17 og 27 May, 2014. Timelige målinger av radiasjon, utbytte og temperaturer, i tidsrommet 07:00 til 18:00, ble utført, og vind og vær ble også notert. Individuelle tester ble utført under enkelte dager i forsøksperioden, deriblant avkjøling av glass, tilsetting av kull til vannbeholder, og økning av saltkonsentrasjonen, uten at dette gav ønsket effekt.

Solar stillen med den høyeste effektivitet var Plywood single sloped solar still, med en effektivitet på 57 %. Denne og Wick solar still oppnådde en effektivitet på henholdsvis 43 % og 31 %. De to solar stillene med minst areal hadde også lavest effektivitet, 12 % og 8 %, for henholdsvis Sink double sloped og Plastic single sloped solar still. Prisen pr still varierte mellom 7 -70 USD, hvor den dyreste av dem var den som produserer mest destillert vann.

Acronyms and abbreviations

AL	Aluminum
DACAAR	Danish Committee for Aid to Afghan Refugees
EC	Electrical conductivity
GI	Galvanized iron
MRRD	Ministry of Rural Rehabilitation and Development
NCA	Norwegian Church Aid
PE	Polyethylene
PPM	Part per million
SS	Stainless steel
TDS	Total dissolved solids
VPD	Vapour pressure deficit
WHO	World Health Organisation

Ambient temperature – Describes the temperature outside the solar still, in the surroundings.

Basin – Area of the still where the polluted /saline water was contained

Distillation channel – Channels collecting condensed water

Drop backs – Condensed water droplets, dipping down from the glass cover and back to the basin.

Real output – Represents the quantity in ml produced in the real area of the solar still.

Vapour temperature – Temperature of the air inside the solar still.

Wick material – Textile fabric with good capillary forces.

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Introduction

Worldwide, one in nine people lack access to an improved drinking water source, and every year more than 3.4 million people die from a disease related to water, sanitation and hygiene (WHO, 2001.). Access to safe drinking water is important on all levels; global, national, regional and local. Estimates show that investments in water supply and sanitation give economic benefits, increased health effects and reduced health care cost, and thereby outweigh the investment costs (WHO, 2011b).

The Millennium goal 7C of September 2000, aims to "halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation" (UN, 2010). The goal towards improved drinking water sources was met in 2010 (WHO, 2014). From 1990 to 2012, 2.3 billion people worldwide gained access to improved drinking water, either by pipe supply on premises, public tap stand, hand pump or protection of water source (WHO, 2014).

Afghanistan is among the poorest countries in the world, and suffers from the consequences of 30 years of war, underdevelopment, safety issues, corruptive governments and poverty. According to government estimations, 42 % of the population live below the national poverty limit, and 20 % are slightly above (http://www.ruralpovertyportal.org). The poverty is more severe in rural compared to urban areas, and often means lack of safe water sources. Of the Afghan population, 76% live in rural areas (WHO, 2011a), and of these 61 % lack access to safe drinking water (UNICEF, 2011)

The Faryab province is located in the western part of Afghanistan's northern region, and here 89 % of the population live in rural areas. Furthermore 77 % of the people lack access to safe drinking water, where 79 % out of these live in rural areas (www.foodsecurityatlas.org). The primary drinking water source in Faryab is groundwater, which suffers from inadequate monitoring and is of variable quality (DACAAR, 2011). High salinity, bacteria, nitrate, fluoride, sodium, chromium, boron and arsenic are registered (DACAAR, 2011). Natural occurrence of metal elements in the soil, high evaporation rate, dissolution and precipitation of gypsum and halite, excessive groundwater use and anthropogenic sources (Hassan et al., 2013), inadequate waste disposal and poor sanitation (DACAAR, 2011) are the main factors contributing to poor water quality. According to DACAAR, 2011, this may result in birth defects, affect the quality of men’s sperm and the nervous system, and - cause cancer and diarrhoea.

In order to meet the challenges related to drinking water, it is essential to come up with sustainable technical solutions with a potential to produce safe drinking water at a low cost.

Solar stills that function by the principle of evaporation and condensation are able to remove all the pollutants of concern (Velmurugan, 2008) and have the potential for doing this at a low cost. Solar stills were therefore selected for investigation in this project. Aristotle was probably the first one to describe a method to evaporate saline water, and thereby condensing it. In recent years, engineers have conducted experiments on solar stills, trying to enhance the output. Factors of importance are found to be mainly solar radiation, the amount of sunny hours and the design of the still (Abdallah et al., 2009).

This study has focused on the design and the building of six solar stills, which seek the meet the criteria of sustainability while producing safe water for the local peoples.

2.0 Background

2.1 Water Quality

Today, 768 million people live without access to improved drinking water (Unwater, 2014). In the daily life, water is essential to all living beings on earth. The quality can range, but water should be adequate, safe and accessible to everyone. The parameters that influence water quality are divided into three main groups; chemical, physical and biological (Arnell, 2002). Common challenges are the physical properties like colour and sediments. The greatest risk for humans is the microbiological pollution of water, and the main source is faecal contamination from animals and humans. This water can contain pathogenic bacteria, viruses, protozoa and helminths (WHO, 2011b), which will cause health outbreaks in the population.

Exposure to chemical pollution may not cause outbreaks as fast as a biological contamination. Chemical contaminants often cause adverse health effects when exposed over time, like high concentrations of fluoride. Some may also be seasonal, like nitrate/nitrite, as a result of agriculture. Chemicals like arsenic, fluoride, selenium and nitrate are assumed to be present in natural waters, but the concern increases with the concentration (WHO, 2004).

However, all the groups can add taste, colour and odour to the water, without having a direct health effect (WHO, 2011b). Additionally, many chemicals have a natural occurrence in water, most of which are inorganic, originated from rocks and sediments, and these are the cause to most of the health problems (WHO, 2004).

The European Drinking Water Directive (DWD) has published guidelines to improve the quality of drinking water, to ensure satisfying quality in the European Union (http://ec.europa.eu). The United States Environmental Protection Agency (EPA) has their guideline, while other countries, and often developing countries without a legislative framework, follow the World Health Organisation (WHO) guidelines.

2.2 History of solar desalination

In the middle ages, people used solar energy for distillation, to produce wine, perfumes, alcohols and herbs. At the same time, Arabs were using polished Damascus for mirrors, with a concave formation, to enhance the amount of solar radiation to the glass vessels, which contained salt water (Delyannis, 2003). However, Aristotle was probably the first one to describe a method to evaporate saline water, condensing it, and turning it into fresh water (Tiwari et al., 2003).

In 1558 and 1589, Giovani Batista Della Porta published two books, where he presented desalinations systems. From this time, up until the 19^{th} century, there are few important documents on solar distillation discovered. The first patent on solar distillation was granted to the Americans, Wheeler and Evans in 1870. Two years later, Carlos Wilson, a Swedish engineer, established the first large solar plant. This plant was located in Las Salinas, Chile, in 1872, and was a big solar still with 64 basins, made out of wood and sloping glass. The water surface was 4459 m^2, and produced 22, 7 m^3 /day. The purpose was to provide fresh water for the workers who worked on the railway and in mines. The water effluent from the Saltpeter mine, which was applied to the still, had an electrical conductivity (EC) of 2.19×10^5 µS/cm (140 000 ppm) (Delyannis, 2003). The solar plant was in use for more than 40 years; until the first pipeline was established (Talbert et al., 1970).

During the Second World War, the interest on distillations plants grew. This was due to lack of fresh water for soldiers, stationed on isolated places, like North Africa and the Pacific Ocean Islands. Inventions of desalinations devices on lifeboats, for desalination of salt water, were also established during the War, and this saved many lives (Delyannis, 2003). The lack of clean water was a growing concern in the US during the 1940s, and financial support provided further studies. During the 1950s, many solar still programs were founded, due to the establishment of U.S. Office of Saline water, created in 1953 (Talbert et al., 1970).

Other countries also started experimenting with desalination. In Australia, fresh water was produced from saline water in the dessert, using glass cover and a basin enclosed with polyethylene(PE) sheets. Greece constructed solar plants between 1965 and 1970, and it had an output that ranged from 2044 to 8640 m^3 of per day. Plants were also constructed on the Island of Porto Santo, Madeira, Portugal and in India, but no further information on these plants is known (Delyannis, 2003).

From 1940 to 1969, 40 solar plants were established in different parts of the world, most of which are abounded, and no large plants have been constructed in the recent years (Talbert et al., 1970). For villages, small reverse osmosis plants have been established to provide fresh water for small communities, providing a capacity of more than 1 m^3/day (Delyannis, 2003).

2.3 Water quality and supply in Faryab

The groundwater in Faryab is divided into three hydro geological units; Cretaceous-Paleogene fractures (Karst aquifer), Neogene aquifers and aquitards, and Quaternary sediments (Hassan, 2010). The Karst aquifer discharges water as springs in the foot of the mountain, and the yield varies from 1.75 l/s in the Moghito, to 35 l/s, in Char Tut spring. The EC is highest at Moghito, with 3 400 µS/cm (Hassan, 2010).

Figure 1: Map shows the location of the Faryab province and Kabul city in Afghanistan (www.bbc.com).

Salinity is one of the major problems regarding water supply in this province. The salt is natural occurring in the soil, and areas with high ground water table, often have a saline groundwater. When the groundwater is close to the surface, evaporation and irrigation will increase the salinity (Banks, 2001).

Salinity is measured by EC, which is a measurement of the total amount of dissolved solids in the water. The elements of importance are calcium, magnesium, sodium, potassium, bicarbonate, carbonate, chloride and sulphate (Hassan et al., 2013). For the US, guidelines given by EPA, set the upper limit to 750 µS/cm (TDS = 500 mg/l), while WHO rates levels above 1200 mg/l as unacceptable (WHO, 2003). Due to limited access to adequate drinking water, values up to 3000 µS/cm are acceptable in Afghanistan (Hassan et al., 2013).

In the Quaternary sediments, the water is saline and brackish in the downstream area, but fresh in the upstream area. Measurements from 240 water samples show that the salinity

increases from upstream to downstream areas in Faryab. The trend is the same for fluorite, ranging from 10 -62 mg/l in the Astana and Jalaier valley (Hassan, 2010), which exceeds WHO guidelines for fluorine, 1.5 mg/l (Hassan et al., 2013). Samples taken upstream, in Qaysar, Gurziwan and Pashtun Ko, are rich in minerals like Ca, Mg and HCO_3, and they have no salinity problems. In downstream areas, Shirin Tagab, Qurghan, Qarmqol, Andkhoy, Khan Chahar Bagh and Dawlat Abad the minerals Ca, Mg, Na, SO_4 and Cl are present. This water is saline/ brackish due to dissolution of gypsum, anhydrite and halite minerals (Hassan, 2010).
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Throughout most of the year, the evapotranspiration is greater than the precipitation in Faryab. In Maimana, the precipitation exceeds the evapotranspiration from December to March. In regard Andkhoi the precipitation is slightly higher in January to mid-February, which results in limited capacity for recharging the groundwater (Norplan, 2014). This and excessive use is the reason for declination of the groundwater, which has resulted in increased groundwater pollution (Hassan et al., 2013).

In the Shor Darya Valley, both groundwater and surface water is saline. The river has an EC of >6000 µS/cm, due to groundwater discharge. In Astana Valley, EC values above 45 000 µS/cm are registered for both river and groundwater (Norplan, 2014). Here the high evaporation rate leads to an up concentration of the salts, and gypsum and halite minerals (Norplan, 2014). In Shor Darya and Astana Valley, they fetch adequate water from Ateh Khan Khwaja spring, which is assumed to be the freshest water supply in the area. Shirin Tagab River and the springs in Moghaito also contains adequate water do drink. However, Shirin Tagab River is vulnerable for faecal microbial contamination (Norplan, 2014).

In Andkhoi, people travel long distances to fetch water from the Shirin Tagab district. Andkhoi contains dug wells and boreholes, and some purification plants containing reverse osmosis, where the water for the dug wells is desalinated. However, this suffers from high electrical consumption. Recent, a major pipeline was established, ranging from the southern bank of the Amu Darya River, located north-west of Kelif, across the dessert to Andkhoi. This project became unsuccessful due to lack of proper pipe materials and interference with the pipeline (Norplan, 2014).

From March 2004 to December 2011, DACAAR collected water samples in 23800 water points in Afghanistan. Of these, 30 % showed EC levels above 1500 µS/cm. High concentrations was found mainly in the west, north-west, north and north-east, with the highest levels in Shirin Tagab district, Faryab, 52 100 µS/cm. They also recorded high concentrations of sodium, magnesium, chloride and sulphate in the water, which indicate medium to high-polluted water. The cause being mainly high evaporation rate, dissolution and precipitation of gypsum and halite, and anthropogenic sources (Hassan et al., 2013).

According to EPA and WHO, the acceptable concentration of sulphate, is the maximum of 250 mg/l, and levels above this can give a bitter taste and cause diarrhoea. Animals are also sensitive to high concentrations (Hassan et al., 2013). Out of the 23800 water samples, 32 % contained elevated concentrations. Mainly in west, north-west, north and north-east. Levels as high as 11 932 mg/l was recorded in Chel Quduq village, Shirin Tagab district in Faryab. Potential sources are atmospheric deposition and minerals like barite, epsomite and gypsum (Hassan et al., 2013).

Additionally, elevated concentrations of Fluoride and Boron are registered in water supplies. 16 % and 58 % of the total 23 800 water samples showed concentrations above the WHO limit for Fluoride and Boron. The limit for Boron is 0.5 mg/l. There are also elevated levels of Arsenic and bacterial contamination in the Faryab province (Hassan et al., 2013).

In general, the most common elements in the water supply in Afghanistan, which can be a threat to human health is bacteria, nitrate, fluoride, boron, arsenic and salinity (DACAAR, 2011)

Additional water samples can be viewed in Appendix 1.

2.4 The principle of Solar stills - evaporation and condensation

Evaporation of water requires energy. The sun, through direct, diffuse and reflected radiation, supplies this energy to the solar still. Additionally some of the radiation is absorbed and/or reflected back by the glass cover, basin and the water. By using a black basin, most of the solar energy is absorbed, transmitted to the water, and thereby increasing the water and air temperature inside the still. Some energy can be lost throughout the basin and glass cover, by conduction /convection and radiation, making the solar still less effective. Parameters like; latitude, cover slope, orientation, glass thickness, time of the year, amount of diffuse radiation are important factors that have an impact on the total amount of solar radiation received by the solar still (Cooper, 1969). To maximise incoming radiation, the inclination of the glass and latitude should be the same. This will give maximum received radiation in a whole year. In the summer period, the declination angle of the sun is at its highest, due to the tilt of the earth on its axis of rotation. Thereby, having a lower inclination of the glass will increase incoming radiation to the still in the summer period (Al-Hinai el al., 2002a). A still with inclination of 19°, will maximize the incoming radiation from May to the end of August. According to the page www.nrel.gov, the annual global horizontal solar radiation in Faryab is 5.5 kWh/m^2/day (19.8 MJ/m^2/day).

As the water is heated, the bonds that are keeping the water molecules together breaks, making it evaporate. The vapour transfers from the basin, towards the cooling glass by convection, radiation and evaporation. Here the vapour condense, and thus releasing the latent heat (Tripathi et al., 2004).

The total amount of energy required to change the water into vapour, is termed as the latent heat of vaporisation (Λ) and is calculated as followed:

$$\Lambda = 2.501 - 0.0002361\, T \; [\text{MJ kg}^{-1}] \qquad (1) \qquad \text{(Arnell, 2002)}$$

As seen in the equation, the energy required is dependent on temperature, in degrees Celsius. The air above the water surface has to be unsaturated, for the evaporation to occur. There will be no evaporation if the air is saturated. The vapour pressure deficit (VPD) refers to the amount of moisture in the air, and how much moisture the air can hold when it is saturated. This value increase with temperature, and when exceeded, the dewing point is reached. For open water surfaces, the evaporation rate increases with the speed of the wind, there by leading the saturated air away, and bringing new unsaturated air to the surface. Together, the humidity and turbidity controls how the water vapour can diffuse into the surrounding (Arnell, 2002).

For the water vapour to transform into liquid, it has to condensate. This can happen in two ways, cooling the air to its dewing point, or oversaturate the air with vapour making it to condense (education.nationalgeographic.com). The glass cover is the condenser in a solar still, and it is therefore important to have a temperature difference between the air inside and outside the still. To place the still in a windy area or perform outside cooling of the glass can give a higher outcome of the still, due to enhanced condensing.

The salinity of the water also affects the evaporation rate. As the salinity increase, the evaporation rate decrease, because of the salt occupying space in the water, makes fewer molecules available for evaporation. This is why saline water has a higher saturation vapour pressure than fresh water (Arnell, 2002). Ward et al, 2000 however, found this effect to be small, about 2 – 3% lower evaporation rate for saline water over fresh water. Akash et al, 2000 found that increasing the salinity percentage by 10 to 75 %, gave a decrease in output by 1.5 litres /day.

It is important that the still is airtight, due to heat loss to the ambient air. The outcome of a still therefore depends on both weather conditions and the design of the still. Weather conditions such as solar radiation, temperature and wind velocity are important factors that affect the outcome (Murugavel et al., 2008). Radiation, and how it is distributed through the day, is the most important parameter to increase the yield of a solar still (Ray et al., 2011).

To calculate average daily output (Q) for the solar still:

$$Q = \frac{E * G * A}{L}, \qquad (2) \qquad \text{(www.engineeringforchange.org)}$$

Where E = effectivity, L = Latent heat, A = area of still, G= daily/annual global horizontal solar radiation (MJ/m^2), and Q is daily output.

This equation can be used both prior and post experiments, to predict outcome. A solar still normally has an efficiency ranging between 30 – 60 %, depending on materials and design (www.engineeringforchange.org). The efficiency of the still can be calculated after the experiments, but some assumptions can be made to get a prediction on the daily output of the still.

2.5 Literature review

To enhance the productivity of the solar still, the design is essential. There are mainly three factors that have impact; solar radiation, the amount of sunny hours and the design of the still (Abdallah et al., 2009). Design factors of importance includes water depth, surface area, colour of the basin, inclination of the glass, insulation, materials, temperature of the water, air-tightness, wind velocity and temperature differences in the still and ambient air (Velmurugan et al.,2011). In studies conducted on solar stills, the water production has been a major concern. Scientists have therefore looked into how to improve the efficiency, without increasing the costs and complexity.

Several experiments have looked upon how the shape, inclination of the glass and the area of the basin affect the productivity. By trying out different shapes; single slope, double slope and pyramid shape, A.Y. Hashim et al., (2010) found that the highest yield was in the symmetric double sloped still. He also explored which effect the inclination of the glass had, and the area of the basin. The production increased with increasing inclination, but he said that the still with the lowest inclination, here 15°, would be preferable due to smaller size and lower cost, compared to a still with inclination 45°. The highest average daily output was 4.5 l/m^2 day.

Others have stated that the inclination of the glass should be the same as the latitude, to enhance the solar radiation (Velmurugan et al., 2011). Stills with different inclinations, ranging from 15° to 55°, were tested in Amman, Jordan. The still with inclination 35° had the highest outcome, 2.2 $l/day*m^2$ (Akash et al., 2000). This is approximately the same as the latitude of Amman (31°). In the sultanate of Oman, there was recorded an increase in yield with increased inclination of the cover in the winter season, and a decrease in yield when increasing the angle during the summer (Al-Hinai et al., 2002). This is probably due to negative values for the declination angle in the winter and positive in the summer. Nafey et al., 2000, also proposed this. However, Al- Hinai concluded that the inclination should be the same at the latitude, to receive the highest amount of radiation throughout the year.

Nafey et al (2001), when comparing the result to a still without materials, found an increase of 20 % and 19 %, using 10 mm thick black rubber and 20-30 mm black gravel in two separate stills. Others have used black ink and black dye to colour the water. Comparing the results for black ink, black dye and a black rubber matt, there was found an increase of 60 %, 45 % and 38 % (Akash et al., 1998). The highest outcome was 1.2 l/m^2, 1.1 l/m^2, and 1 l/m^2

respectively. However, the most commonly used lining is asphalt or black butyl rubber (Delyannis et al., 1970).

Besides the importance of the black basin, the specific surface area is essential to the productivity. Abdallah et al., 2009, achieved an increase of 43 %, 28 % and 60 %, when applying uncoated metallic wiry sponges, coated metallic wiry sponges and black volcanic rocks to the basins. The main drawback was the corrosion of the metallic wiry sponges. However, the volcanic stones did not corrode. The study also showed that coated metallic wiry sponges were less effective than uncoated ones. Abu-Hijleh et al (2003) also experienced an increase in outcome, using black and yellow sponges. However, the colour reduced the capillarity force to the sponges, making it more difficult to attract water. He therefore concluded that the capillarity effect is of greater importance than absorbing capacity. In this experiment, there was achieved an increase of up to 273 % when applying uncoloured sponges to the basin.

Naim et al., 2003 showed that using charcoal increased the productivity by 15 % over a wick-type solar still. In another experiment, wick materials were compared; black cotton cloth, jute cloth, sponge sheet, coir mat and waste of cotton pieces, and some aluminium rectangles fins were included together with black cotton cloth and jute cloth. Black cotton cloth, without fins, gave the highest production for the wicks, with 1.5 l/day*m^2. The basin with black cotton cloths and fins gave a slightly increase in yield over black cotton cloths, 1.55 l/day*m^2 (Murugavel et al., 2011).

In Baghdad, three solar stills where tested. All had black basins, and two of the stills had additionally jute wicks. One wick floated in the basin, the other tilted. For the wintertime, an increase of 77% and 70% was achieved for the tilted and floating wick, respectively, over the still without wick material. For the summer, there was a decrease in output for the tilted wick, of 43 %. This is due to higher evaporation rate than to capillarity properties of the wick, resulting in dry spots. In June, the floating wick still had its highest outcome, 10 l/day*m^2 (Al-Karaghouli et al., 1995). Others have also stated that wick solar stills have a better performance compared to basin type (Moustafa et al., 1979). An increase of 20-50 % output for a tilted wick, compared to basin type can be expected (Tanaka et al., 1981).

Stones can absorb and store heat, hence applying 6.3 mm and 19.0 mm quartzite rock, 6.3 mm naturally washed stones, 38.1 mm cement concrete pieces, 31.7 mm red brick pieces and mild steel scraps to the basins, can enhance the outcome. 19.0 mm quartzite rock was found to give the highest output, 2.0 l/day*m^2 (Murugavel et al, 2010).

Akash et al., 2000, Nafey et al., 2000, Singh et al., 1995, stated that a shallow water depth could increase the daily yield, and tested depths ranging from 2 – 10 centimetres. The experiments showed that the optimum depth was two cm. Akash et al., 2000 discovered that the depths were linearly related to the output, and that an increase in depth would decrease the outcome. Tiwari et al., 2007, performed experiments on water depths ranging from 2 to 18 cm during a whole year. For the summer and winter season, the yield increased 33 % and 32 % respectively, for water depth 2 cm compared to 18 cm. An annual increase of 44 % for a 4 cm depth, compared to 18 cm was also registered. When comparing depths of 8 cm to 18 cm depths, and 16 cm to 18 cm, the outcome was reduced with 9 % and 1 %, respectively. Tiwari et al (2007) concluded that for water depths above 8 – 10 cm, the outcome becomes close to constant. When including water-absorbing materials to the basin, the result can differ. By adding sponges to the basin, the yield increased as the water depth increased. This is true up to the water depth of 7 cm (Abu-Hijleh et al (2003)

Materials used for constructing a solar still have to withstand high temperatures, solar radiation and restrain leakage of water and vapour over a long period. Materials, which are toxic or corrosive, can off-gas, melt or fracture under these conditions is not suitable for this purpose.

A transparent cover, usually glass, transmits the radiation to the basin. 3-4 mm glass is the most frequently used (Gad et al., 2011, Abdallah et al., 2009, Badran., 2007). Some also has applied Plexiglas, however; this is known to reduce the effect of the UV light, by making it less intense (www.ehow.com). The distillation channel attached to the glass cover for collecting the condensed water is usually PVC pipe, a piece of glass, GI sheet, or bend aluminium (AL) (Badran, 2007, Velmurugan et al., 2007, Velmurugan et al., 2008, Ali Samee., et al 2007).

Akash et al., 2000, Akash et al, 1998, and Nafey 2001 used stainless steel (SS) as a basin, enclosed by black rubber or painted black. Galvanized iron (GI) is also common basins in solar stills (Abdallah et al., 2009, Ali Samee et al., 2007, Velmurugan et al., 2008). Another material, which is easily available, is wood, painted black, or enclosed by black PE sheets (Srivastava et al., 2012 and Gad et al., 2011). Wood can also be applied outside the GI or SS to make it easy to insulate. Insulation of the basin will reduce heat loss to the surroundings, and the most common materials used for this purpose are rock wool, foam and glass wool (Badran., 2007, Nafey., 2001, El-Bahi., 1999, Murugavel., 2011). Cheaper materials like sand, cotton, cloths, sawdust, straw etc., will give a similar effect, but may be less effective. To prevent leakage, silicone sealant is often used, but other materials like an rubber gasket, putty, tars and tape are also an option (AliSamee et al., 2007, Akash et al., 1998, Srivastava et al.,2012,). However, this may be less effective, yet it may be cost-efficient. Clamps and rubber gasket are also widespread (Akash et al., 2000). Mirrors inside the basins, can enhance the amount of solar radiation, but may be costly (Al-Hyek et al., 2004).

3. 0 Methodology

The function has been assessed by evaluating the quantity of produced water seen in light of radiation, temperature, design and choice of materials. The main objective has been to perform a pilot project developing solar stills in Kabul, and to try to achieve an acceptable volume at a low cost, and to evaluate the effectiveness of solar stills using different materials and designs.

3.1 Work in Kabul

When choosing materials for the solar stills, the availability and price has been considered. SS, GI, Al sheets and wood were all easy to obtain in Kabul, however butyl rubber and PE was not to be found despite extensive searching. Isogam, a local brand used for sealing roofs, were easily available and therefor revised. After discussions with local carpenters and engineers, the conclusion was that this material was not suitable for this purpose, due to the high temperatures, amount of solar radiation and salt concentration. Paint was however easily available, but fact-sheets were hard to trace. Due to lack of butyl rubber and PE, wood alone was not considered to be a sufficient solution for the basin. For insulation, Glass wool and strands of straw was available in local shops.

Different brands of silicone, glue and tape were easy to find. However, it was difficult to get a hold on fact-sheets and information regarding maximum temperature. On most of the labels, maximum temperature was excluded. Rubber gasket, PVC, garden hose and glass were available in several sizes and thicknesses.

In order to get the total cost down, and to speed up the building process, two pre-manufactured basins were purchased. One plastic box and one sink. An overview over material cost and total cost for the solar stills can be viewed in the result section.

The following chapter describes the design and materials used for each solar still in detail.

3.2 Proposed designs

Four designs were proposed for this project: double sloped solar still, single sloped solar still, double chamber still and wick still. For the double sloped-, single sloped- and wick solar still, two inclinations of the glass is proposed: 36° for maximum radiation throughout the whole year, and 19° for optimal radiation from 1 May to 1 September. For the double chamber still a low inclination is preferable to obtain pressure difference between the chambers. A dark colour and an area of $1m^2$ on the basin are proposed.

3.2.1 Double sloped solar still

Double sloped solar still is a basin type solar still with a triangle shaped glass. The glass is attached to the basin and two distillation pipes-collect the condensed water, on each side of the rectangular glass. These pipes are sloped in order to drain the water to each side and from where it is transported into a bucket.

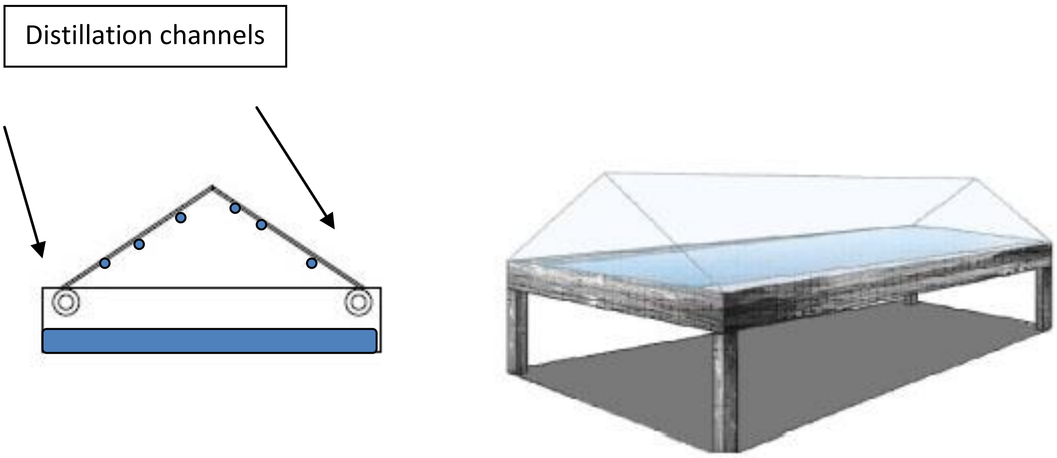

Figure 2: Design of a double sloped solar still (Drawing: Inga Mccarley Potter, Asplan Viak)

3.2.2 Single sloped solar still

A single sloped solar still is a basin type still with a singular sloped glass as cover. A distillation channel is attached in the lower end of the glass, draining the condensed water out to a collecting bucket.

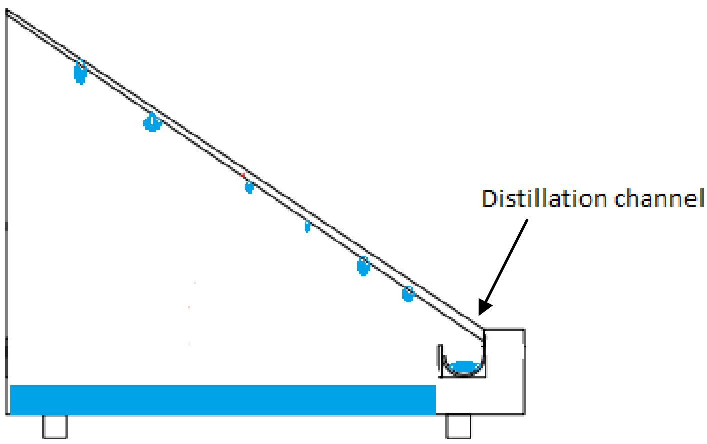

Figure 3 : Design of a single sloped solar still (Drawing: Inga Mccarley Potter, Asplan Viak)

3.2.3 Double chamber still

The double chamber still is a solar still with two chambers — one for the polluted water and one for the distilled water. A barrage to prevent mixing separates the chambers, and a glass cover above the saline water exposes the water to radiation. A low inclination on the glass, obtains a difference in pressure between the two chambers, causing the vapour to transfer into the condensing chamber. Building the condensing chamber out of light reflecting materials is therefore preferable, to achieve a lower temperature inside. Distillation pipes may be connected to both glass cover and condensing chamber, to collect the distilled water. To enhance the radiation to the water surface, a vertical reflecting object may be used on the vertical wall behind the saline water basin. This will additionally contribute to shade the condensing chamber.

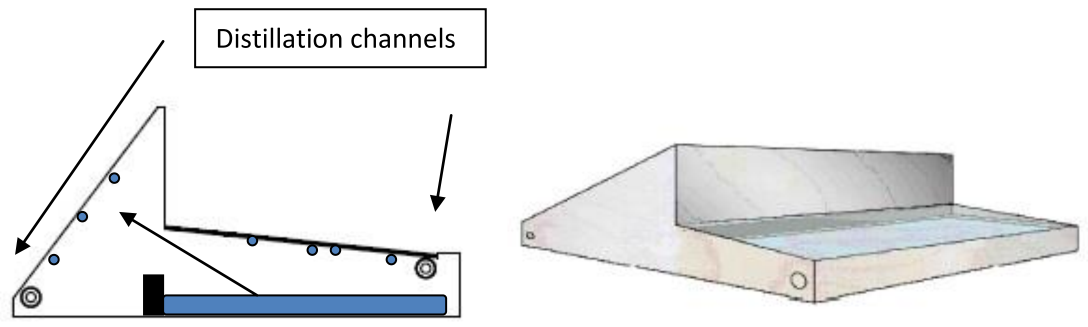

Figure 4: Design of a double chamber solar still (Drawing: Inga McCarley Potter, Asplan Viak)

3.2.4 Wick still

This solar still includes a water basin and a wick, which extracts water from the basin. The wick has to have good capillary forces to fasten the water transport along the wick, preventing dry-spots. The wick or the surface below the wick should have a natural dark colour to increase the evaporation rate. The water basin must always contain a higher pressure than the end-wick, regardless of water level, making the water moving faster down the wick. A shallow water basin will also be preferable to enhance the travel time from the basin to the area of the wick being exposed to the sun. The glass cover is the condenser, and a sloped distillation pipe is draining the water into the bucket.

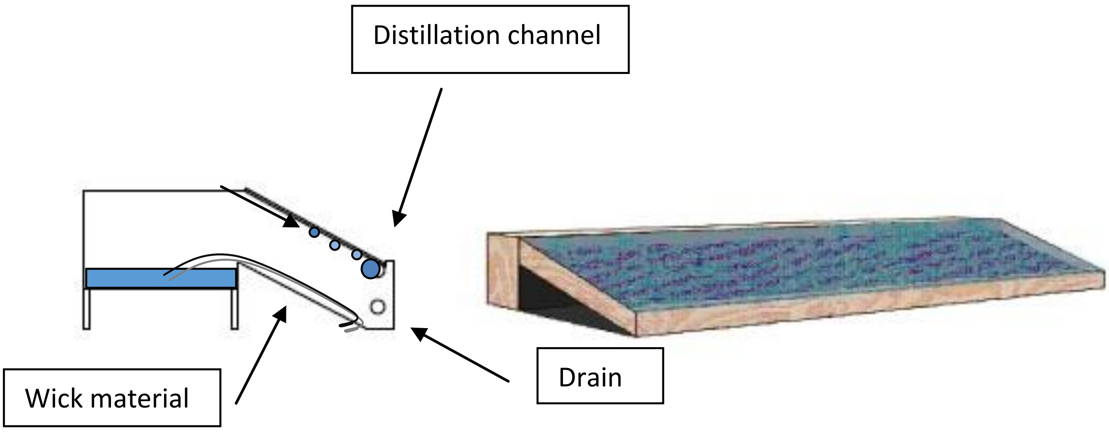

Figure 5: Design of a wick solar still (Drawing: Inga McCarley Potter, Asplan Viak)

3.3 Implemented designs in Kabul city

Of the proposed methods, one unit of the wick solar still, two units of the double sloped solar still and three single sloped solar stills were built. Additionally one prefabricated unit from the US was ordered, but due to delay in customs, this unit arrived some days after my departure from Kabul, and is therefore excluded in this thesis. The double chamber still was excluded due to limited time and the complexity of the design.

3.3.1 Plywood double sloped solar still

The basin area of the still was 1300 mm x 800 mm, with a height of 120 mm and contained 0.5 mm SS sheet and 20 mm plywood as an outside frame. The total height of the still was 390 mm, excluded table frame. The bottom and sides of the SS sheet was polished, painted with corrosion resistant paint and further painted black. The interface between the SS and plywood was lined with 50 mm of glass wool to prevent heat loss. The condensing surface consisted of glass, divided into two rectangular parts with dimensions of 1305 mm x 510 mm and with inclination 36°. The glass was 4 mm thick, protected with a rubber gasket, and directly attached into the distillation channels that consisted of bended SS. The distillation channels were inclined by 20 mm, where the distillate water continuously drained into two water-buckets through a garden hose. The two triangular sides in the cover were made out of SS and wood to protect it from breaking. A hence was installed on one of the triangular sides to ease the access to the basin. A rubber gasket encloses this door to prevent heat loss.

Additionally, one hole for refilling was made in the triangular door — this was plugged when not in use. Silicone was used as sealant between the glasses, the basin and the glass, and the triangular sides to make it airtight. See Annex 1 for technical drawing.

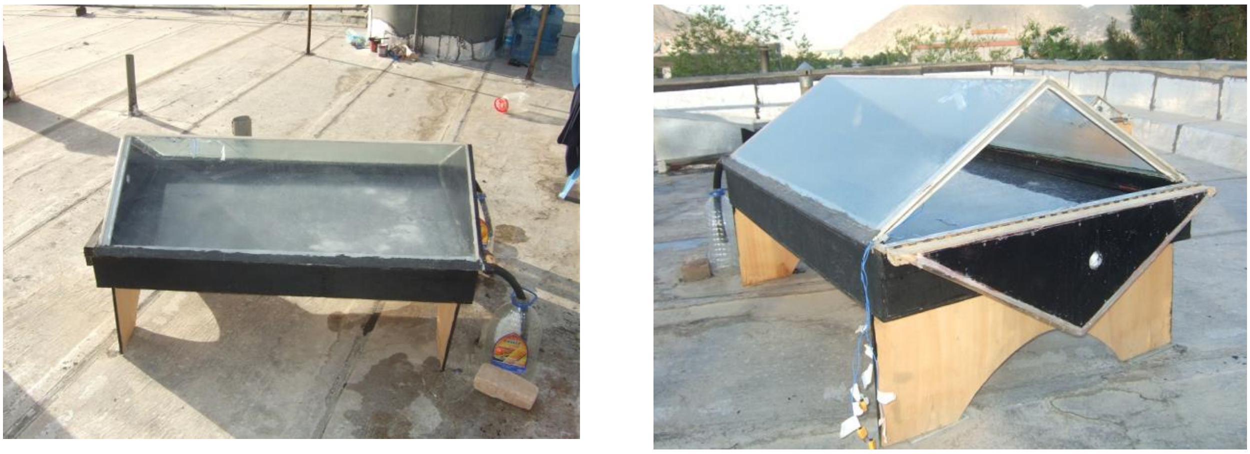

Figure 6: Plywood double sloped solar still.

3.3.2 Sink double sloped solar still

The basin consisted of a prefabricated sink, with a ground area of 410 x 350 mm and with a height of 200 mm. The total height of the still was 330 mm, including the glass cover. The bottom and sides of the basin was polished, painted with corrosion resistant paint and thereby painted black. The glass had double slope and 4 mm thickness with an inclination of 36°. The two rectangular glasses had dimensions of 420 x 220 mm and were enclosed by a rubber gasket and sealed together with silicone. The two triangular sides were made out of SS, where one of which including a refilling hole that was clogged during production. The solar still was kept airtight by the weight of the glass, pressing down a rubber gasket attached to the sink. The glass cover was removable for cleaning. The distillation channel consisted of PVC and had an inclination of 15 mm that continuously drained the water to a water-bucket through a garden hose. For stability and easily drainage, a wooden box consisting of 20 mm plywood was built as an outer frame, lifting the sink above ground level. See Annex 2 for technical drawing.

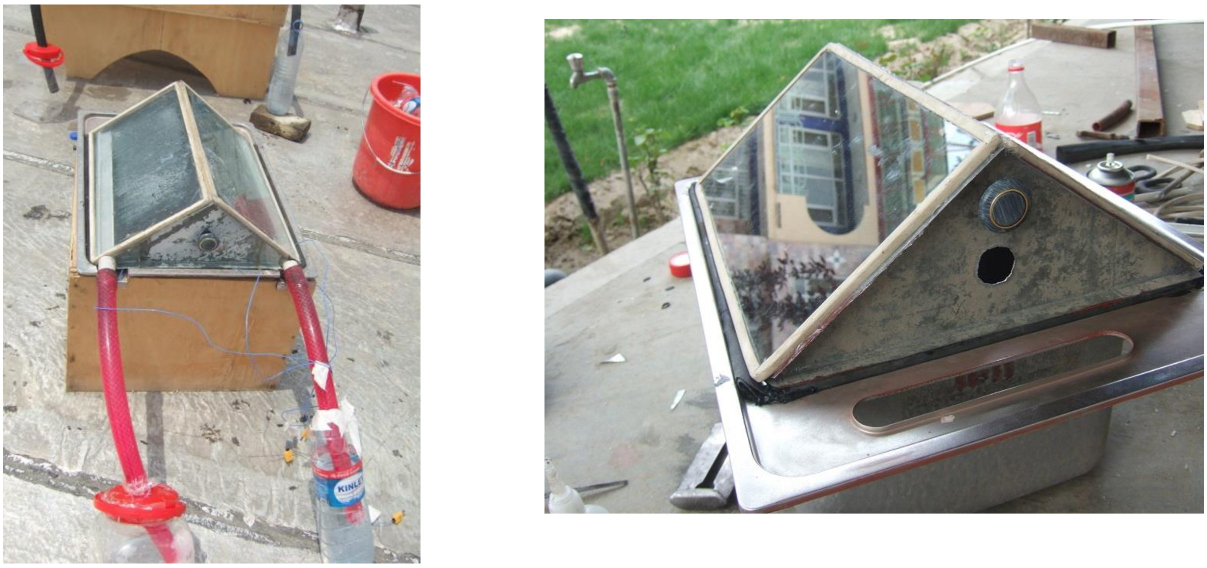

Figure 7: Sink double sloped solar still

3.3.3 Plastic single sloped solar still

A prefabricated red plastic box with an area of 395 x 290 mm was used as a basin. It was painted black and had a total height of 210 mm. The 4mm thick condensing glass had a single slope with rectangular shape, inclination of 19° and an area of 380 x 280 mm. The glass was entered into the original box lid and sealed with silicone. Additionally a rubber gasket was applied in between the basin and the lid, making it air tight. Bended SS sheet, with inclination of 25 mm, collected the condensed water and drained it through a garden hose and into a water-bucket. See Annex 3 for technical drawing.

Figure 8: Plastic single sloped solar still

3.3.4 Plywood single sloped solar still

The basin had an area of 1000 mm x 1000 mm with single sloped glass cover, inclination of 36° and 4 mm thickness. The glass, which was divided into two equal pieces, had a total area of 1040 mm x 1290 mm and was protected with rubber gasket. The total height of the still was 840 mm. The basin consisted of 200 mm plywood and SS sheets and with interface consisting of 50 mm glass wool. The bottom and the sides up to 50 mm were polished, painted with corrosion resistant paint and black paint. The remaining sides of the SS were unpainted, to increase radiation to the basin. The distillation channel had an inclination of 20 mm and was attached below the frame that the glass was resting on. For refilling and drainage, a hole in the north side of the basin was made and this was plugged during production. For cleaning the glasses was removable. See Annex 4 for technical drawing.

Figure 9: Plywood single sloped solar still

3.3.5 GI single sloped solar still

The basin consisted of 1.25 mm GI sheet and had an area of 800 x 1000 mm. The glass cover was 4 mm thick and had inclination 11°. The glass was sealed on to an iron frame with silicone, and the distillation channel attached below consisting of iron, covered with grey paint and with inclination 20 mm. The total height of the still was 350 mm. In the north wall a door with dimensions 315 x 210 mm was located, used for refilling and cleaning. For drainage, a removable bolt was installed in the bottom of the basin. See Annex 5 for technical drawing.

Figure 10: GI single sloped solar still

3.3.6 Wick solar still

The basin, which contained the water, had a volume of 1300 mm x 200 mm x 100 mm. The rectangular surface where the wick material was obtained had an area of 1300 mm x 400 mm. The distance between the wick and the glass cover was 100 mm, where the glass had an inclination of 36° and 4 mm thickness. The solar still was made out of 20 mm plywood and

SS sheet and sealed with silicone sealant. The glass was sealed with a rubber gasket and silicone, and was directly inserted into the distillation channel, which was made out of SS. The inclination of the channel was 30 mm and the water drained to a water-bucket through a garden hose. For refilling and washing, the top of the water basin worked as a lid, build out of wood and SS sheet, and was therefore never directly exposed to sunlight. See Annex 6 for technical drawing.

Figure 11: Wick solar still

3.4 Experimental setup

For this experiment, primary data was collected from 17th to 27th of May. All the solar stills were refilled with water through the refilling hole 18.00 pm, up to a level of 20 mm. Output during 18:00 pm to 07.00 am was measured in total at 07:00 am. Between 07:00 am and 18:00 pm hourly measurements was registered. All the solar stills were facing North-South direction.

The following parameters were measured:

1. Temperatures of south and north glass cover (˚C)
2. Water temperature (˚C)
3. Vapour temperature (˚C)
4. Ambient temperature (˚C)
5. Incoming solar radiation (north and south glass cover) (W/m^2)
6. Output from north and south distillation channel (ml)
7. EC level
8. Registrations on wind and weather

Temperature wires were attached to the glass cover by tape, and the wire for the water was attached to the basin. A rubber gasket prevents damage to the wire recording water temperature. The wire sensors are named TP01, had a length of 1m and were continually in the solar still during the experiment. These wires were connected to a data logger thermometer, Elma718, which measured the temperature. Hourly manually recordings were noted during the day.

The solar radiation was measured using a Solar Power meter, HT204, with units W/m^2. The sensor was positioned on the glass cover to get the same inclination as the glass. A digital thermometer was placed in the sun for measuring the outside temperature, which in this thesis is referred to as the ambient temperature. VWR International CO30 measured EC levels. Water bottles collected the distilled water and the hourly output was measured in 100 ml and 500 ml cups.

Plywood double sloped solar still was filled in the evening at 18:00 pm on the 16th of May. In the morning of 17th of May, the Sink double sloped solar still was filled at 08:00 am and the Plastic single sloped still was filled later the same day at 18:00 pm. Measurements on the GI single sloped solar still started at 18:00 pm on the 18th of May, and the day after, 18:00 pm, the Plywood single sloped still was filled. The last still finished on the 22nd of May, the Wick solar still, and this was filled 08.30 am.

From the 16th to 21st of May the stills was filled with tap water with EC 1395 µS/m. On the 21st of May, 18:00 pm, the water was drained out and the stills were washed, and thereby refiled with water containing a concentration of 50 ml salt into 19 litres buckets, resulting in an EC of 6.95mS/m. This was in regard Plywood double sloped still, GI single sloped still and Plywood single sloped still. The Wick solar still was added the salty water on the start-up day, 24th of May.

On the 20th of May 18:00 pm, black coals was added to the Sink double sloped and Plastic single sloped solar still, to try to achieve an increased output by increasing the specific area, and increase the capacity for storing heat. On the 21st of May 18:00 pm no further experiments was conducted on these two units.

During the hottest hours of the day on 24th and 25th of May, a wet blanket was added onto one of the two glass covers in the Plywood double sloped still. From 10:00 am to 14:00 pm the blanket covered the north glass, and between 14.00 and 15.00 pm, it covered the south glass. At 15.00 pm, the blanket was removed. Water was applied to the blanket every full hour, after recorded measurements.

On the 23nd and 24th of May the wick material in the Wick solar still consisted of three different parts. One third was a thin black sweater, the other third was a thin brown textile tablecloth and the last third part was a white thin bed sheet. On the morning on the 25th of May the wick material was changed to a thin black shawl.

The efficiency is calculated by using an annual global horizontal solar radiation value estimated by U.S Department of Energy, Office of Energy Efficiency and Renewable Energy for Kabul city (http://www.nrel.gov/). Presuming that this estimate will give a more accurate prediction of the efficiency of the solar still, due to the low correlation related to radiation values in this thesis, and that manual recording may not be an adequate impression of the reality due to change in weather during the hour. The efficiency is calculated for the day with the highest and lowest output, excluded the rainy days.

3.4.1 Possible errors in technical investigations

When recording manually it is likely to assume that the maximum and minimum recordings are excluded from the readings, for both temperatures and solar radiation. During partly clouded days, radiation differs a lot during the hour, when the weather is shifting from sunny to cloudy. However, the sunny days are probably the most accurate recordings.

After some days in the stills, the sensors began to give some inaccurate values. When correcting/shaking on the wire from outside of the still, the values corrected itself to the assumed correct value. This was discovered happening from the 22nd of May on the south glass sensor in the Plywood double sloped still and on the 25th of May for the water temperature sensor in the Plywood single sloped and Plywood double sloped solar still.

3.5 Statistical analyses

Illustrations and blueprint is designed in AutoCAD.

The collected data is analysed with Minitab 17, using the Linear regression model to estimate expected output (response) when increasing the water and vapour temperature with 1˚C in the various solar stills.

Additionally Excel is used for correlation analyses for the different parameters/for several parameters within each solar still, in order to/as an attempt to obtain knowledge about the properties of the stills.

4.0 Results and discussion

The days selected for illustration in regard hourly temperatures and output in this section is chosen in belief that they give the most accurate representation of the processes in the solar still during sunny days. Additionally some special observations and test are shown in figures.

Figure 13 show the 24 hours output for all the solar stills during the experiment. In general, the Plywood double sloped still is found to have the highest output, followed by the Plywood single sloped still, Wick still, GI single sloped still, Sink double sloped and Plastic single sloped still. Figure 12 excludes the night production, and shows the output from 07:00 am to 18:00 pm.

The output from the Plywood double sloped still during the day ranges from 1658 to 4945 ml/m^2 over the period, while the Sink double sloped still has the lowest maximum output, with a production of 288 ml/m^2 (Fig 12). The high output on the 17th and 18th of May in the Plywood double sloped still (Fig 13) is caused by heavy rain entering the distillation channel by night.

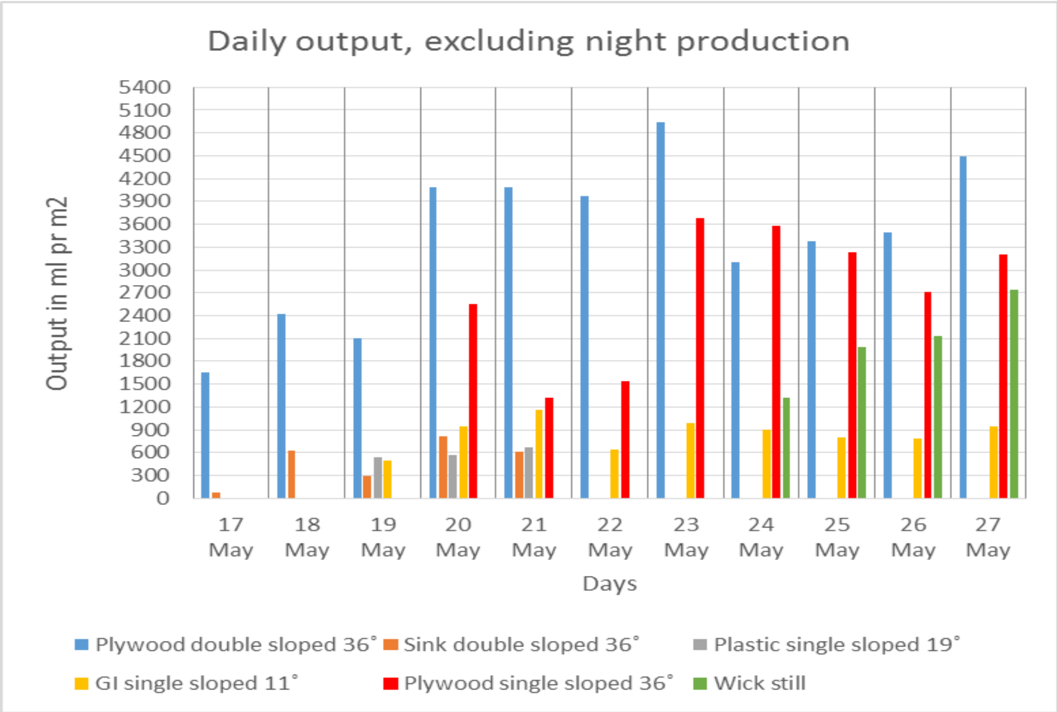

Figure 12: Daily output in the time frame 17th to 27th of May, excluding night production, in ml per m^2 regarding the Plywood double sloped still, Plastic single sloped still, GI single sloped still, Sink double sloped still, Plywood single sloped still and Wick still, 07:00 am to 18:00 pm.

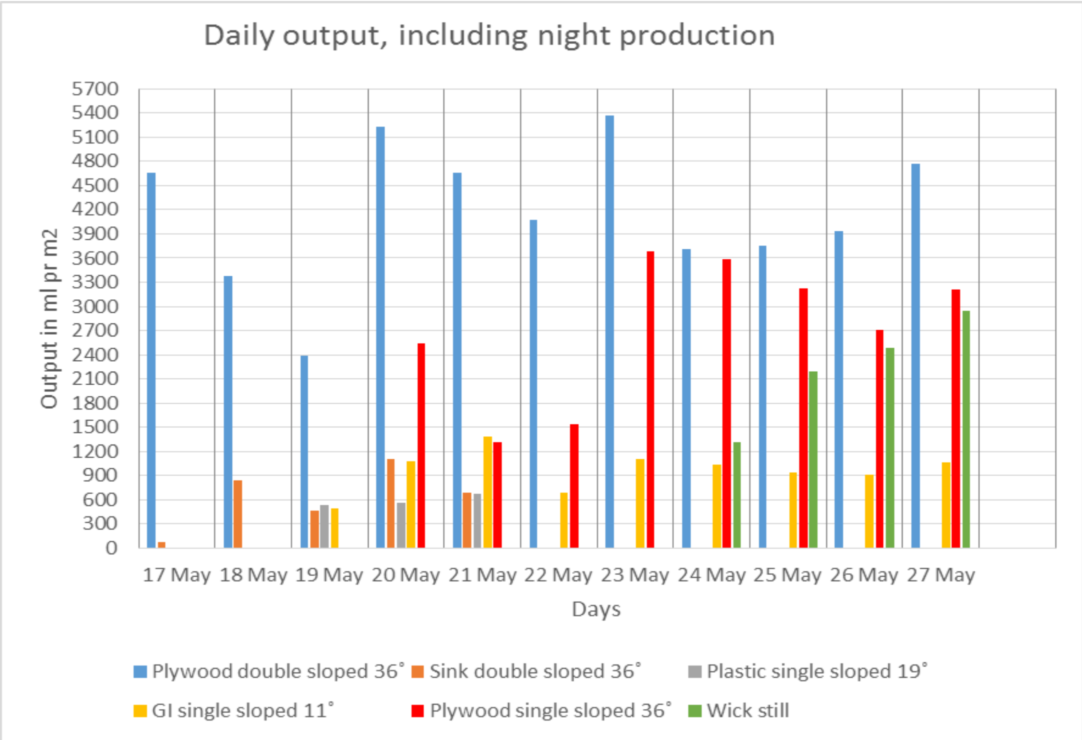

Figure 13: Daily output in ml per m^2 in the Plywood double sloped still, Plastic single sloped still, GI single sloped still, Sink double sloped still, Plywood single sloped still and Wick still from the 17th to 27th of May, 24hours duration.

Over the time period the weather conditions were mostly sunny, with occasionally shifting conditions. From the 17th to 20th of May, the weather was cloudy and occasionally raining where most of the rain came during the night. An overview over the weather conditions can be viewed in Table 1.

Table 1: Hourly weather conditions from the 17th to 27th of May in Kabul city, 2014

Time | Days	17May	18May	19May	20May	21May	22May
1800-0700	Raining	Raining	Cloudy	Thunder and rain	Clear	Clear
07:00	Cloudy - low wind	Cloudy - low wind	Cloudy - low wind	Sunny	Sunny - low wind	Sunny - low wind
08:00	Cloudy	Cloudy	Cloudy	Sunny - low wind	Sunny	Sunny
09:00	Cloudy	Cloudy	Cloudy	Sunny	Sunny	Sunny
10:00	Cloudy	Shifting - sun/clouds	Cloudy	Sunny	Sunny	Sunny
11:00	Cloudy - wind increasing	Shifting - sun/clouds	Shifting - sun/clouds	Sunny	Sunny	Shifting - sun/clouds
12:00	Cloudy	Shifting - sun/clouds	Shifting - sun/clouds	Sunny	Sunny	Shifting - sun/clouds
13:00	Thunder	Shifting - sun/clouds	Cloudy	Sunny	Sunny	Shifting - sun/clouds
14:00	Raining	Shifting - sun/clouds	Cloudy	Sunny	Sunny	Sunny - strong wind
15:00	Cloudy	Raining	Shifting - sun/clouds	Sunny	Shifting - sun/clouds	Sunny
16:00	Raining	Cloudy - windy	Cloudy	Sunny	Shifting - sun/clouds	Sunny
17:00	Cloudy	Cloudy	Cloudy	Sunny	Shifting - sun/clouds - windy	Sunny
18:00	Cloudy	Cloudy	Cloudy	Sunny	Shifting - sun/clouds	Sunny

Time | Days	23May	24May	25May	26May	27May
1800-0700	Clear	Clear	Clear	Clear	Clear
07:00	Sunny - no wind	Sunny - low wind	Sunny - no wind	Sunny - no wind	Sunny - no wind
08:00	Sunny	Sunny	Sunny	Sunny	Sunny
09:00	Sunny	Sunny	Sunny	Sunny	Sunny - wind increasing
10:00	Sunny	Sunny	Sunny	Sunny	Sunny
11:00	Sunny	Sunny	Sunny	Sunny	Sunny
12:00	Sunny	Sunny	Sunny	Sunny	Sunny
13:00	Sunny	Sunny	Cloudy	Shifting - sun/clouds	Sunny
14:00	Sunny	Sunny - wind increasing	Cloudy	Shifting - sun/clouds	Sunny
15:00	Sunny	Cloudy	Shifting - sun/clouds	Cloudy	Sunny
16:00	Sunny	Cloudy	Cloudy	Cloudy - windy	Shifting - sun/clouds
17:00	Sunny	Cloudy	Cloudy	Cloudy	Sunny
18:00	Sunny	Cloudy	Cloudy	Cloudy	Sunny

4.1 Plywood double sloped solar still

4.1.1 Correlation

There is found a 73 % correlation between output and vapour temperature over the period from 19th to 27th of May (Fig.14). When including the rainy days 17th and 18th of May, the correlation is lowered by 6% (Table 2). The R-sq. value between water temperature and output is 79 % in the period 19th to 27th of May (Fig.15). When including results for 17th and 18th of May the value is decreased by 4 % (Table 2). Output vs. ambient temperature show an R-sq. value of 58 %, excluding 17th and 18th of May (Table 2).

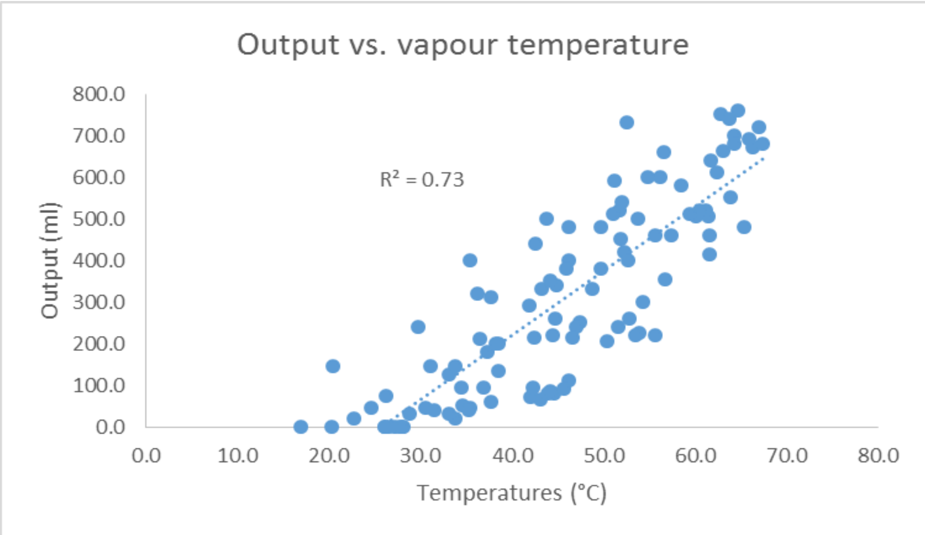

Figure 14: : Regression fit for output vs. vapour temperature inside the Plywood double sloped solar still, from the 19th to 27th of May, with a R-sq. value of 73 %

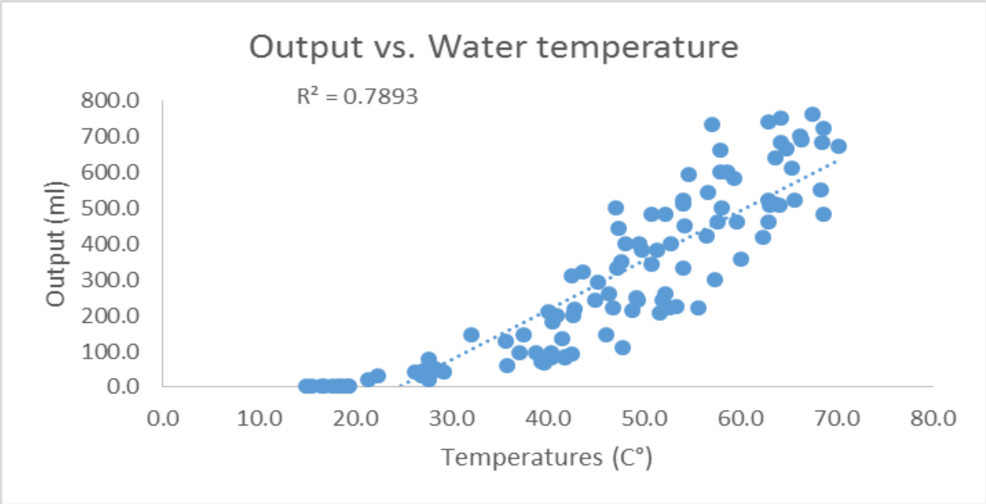

Figure 15: Regression fit for output vs. water temperature in the Plywood double sloped solar still, with an R-sq. value of 79 %, 19th to 27th of May.

A correlation of 93 % is found between vapour and water temperature (Table 2). In regard of radiation the highest registered R-sq. value is found with vapour temperature, and registered to 51 %. Water and ambient temperature both have a correlation of 40 % with the radiation. However, the highest R-sq. value towards ambient temperature is vapour, being 67 %. Values marked with * show correlation when excluding 24th and 25th of May, when a wet blanket was applied onto one of the two glass covers, trying to increase the condensation rate. Temperatures and output in this regard can be viewed in Figure 18.

Table 2: R-sq. values from the 17th to 27th of May in the Plywood double sloped solar still. () excludes 17th and 18th of May. * excludes 24th and 25th of May

Correlation (%)				
vs.	**Water (°C)**	**Vapour (°C)**	**Output**	**Radiation**
Ambient (˚C)	53	67	48(58)	40*
Output	75 (79)	67 (73)		20*(22*)
Vapour (˚C)	93			
Radiation	40*	51*		

4.1.2 Mean temperatures and output

An overview over mean temperatures and output during the daytime is shown in Table 3. The highest output is registered on the 23rd of May, which is the same day vapour and water temperature has its maximum mean value, of 53˚C and 52˚C respectively. The highest mean ambient temperature is on the 27th of May, with 37˚C, where the output recorded is 4490 ml. Estimates suggest that the output will increase with 13 ml when the temperatures increase 1˚C for water, - as well as vapour.

From the 16th to 21st of May an increase in EC level was registrated, 1395 μS/m to 2.65 mS/m. Towards the end of 21st, at 18:00 pm, water with an EC of 6.95 mS/m was added to the still, which lead to an increase of 16.05 mS/m on the evening of 27th of May.

On the 22nd and 26th of May a decrease in water and vapour temperature is found, comparing ambient temperatures with respective days. A decrease in output is also achieved. A decrease in temperatures on the 24th and 25th of May is due to a cooling blanket on the glass cover. There can be seen that on the day with the highest salt concentration, 27th of May, is also reaching the second highest temperatures inside the still. However, higher ambient temperature is also recorded this day.

Table 3: Mean daily temperatures in the Plywood double sloped solar still, 07:00 am to 18:00 pm from the 17th to 27th of May. Real output is excluded night production, and is in ml per 1m². Red colour indicates improper estimates due to error within the temperature sensor.

May	South glass (˚C)	North glass (˚C)	Vapour (˚C)	Water (˚C)	Ambient (˚C)	Output (ml/d/m²)
17	21	21	25	27	16	1658
18	32	31	36	38	22	2422
19	33	33	37	39	24	2103
20	43	43	49	49	31	4085
21	42	43	49	50	30	4080
22	29	39	45	46	30	3970
23	46	46	53	52	30	4945
24	38	37	43	44	30	3105
25	40	40	44	46	32	3380
26	40	39	43	45	32	3490
27	45	46	50	52	37	4490

Figure 16 shows an overview over the temperatures and output during the rainy days on the 17th, 18th and 19th of May in the Plywood double sloped solar still. In general, all the temperatures follow the same tendency as the ambient temperature, having the water temperature as the highest from the mid-day and to until evening. Output increase as the temperatures increase, with deviation on the 17th May, at 14:00 pm and 17:00 pm. Deviation is also seen on the 18th May at 16:00 pm. The temperatures inside the still is generally lower on the 17th of May, having the highest maximum temperatures on 18th of May, being 59˚C in regarding water temperature at 12:00 pm. There are low deviation between the temperatures of north and south glass cover all three days.

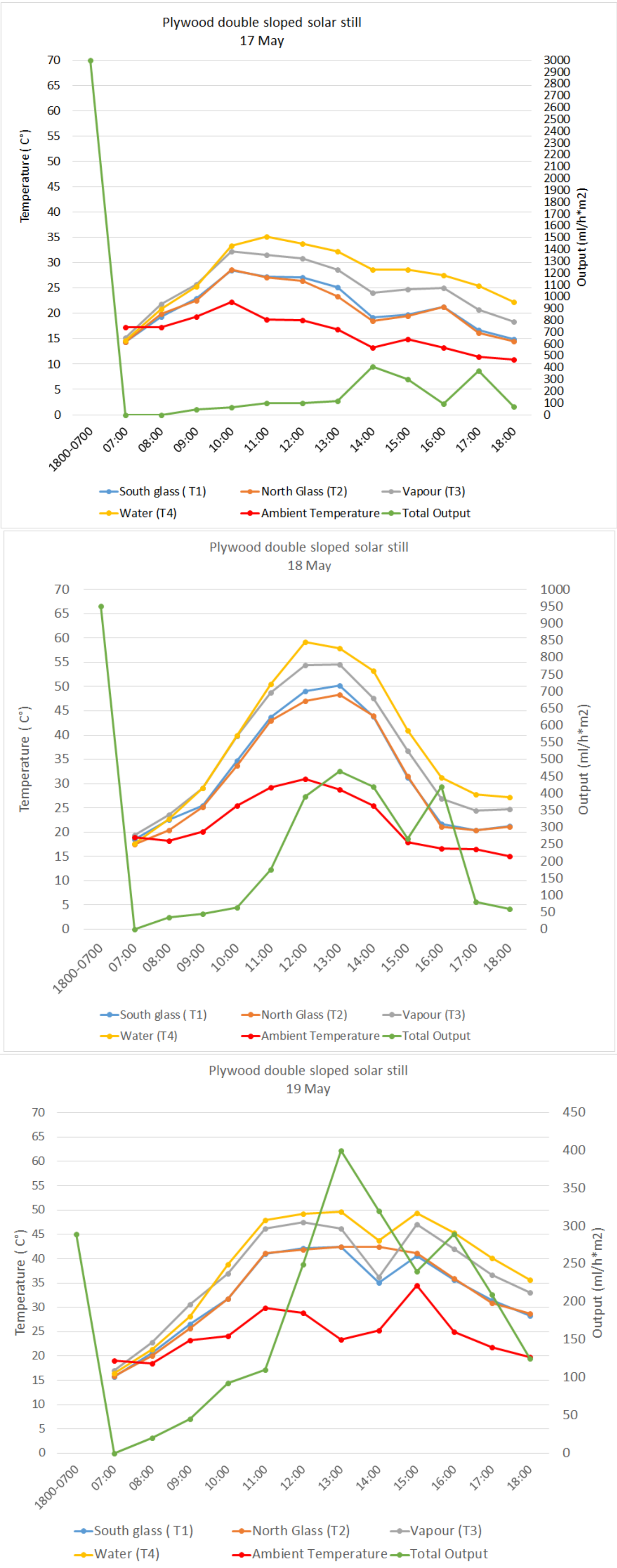

Figure 16: Temperatures and real output inside the Plywood double sloped solar still on the 17th, 18th and 19th of May, at 07:00 am to 18:00 pm.

During sunny conditions on the 21st, 23rd and 26th of May, the water temperature exceeds the vapour temperature around 10:00 - 11:00 am, and is at its highest during mid-day, 12:00 – 13:00 pm (Fig.17). All the temperatures inside the still follow the same trend, by having water temperature as the highest from the mid-day to the evening at 18:00 pm. All three days show a low difference in temperature between the south- and north facing glass. The output increases as the inside temperature increases, with an up to two hour delay between the maximum temperature and the maximum output.

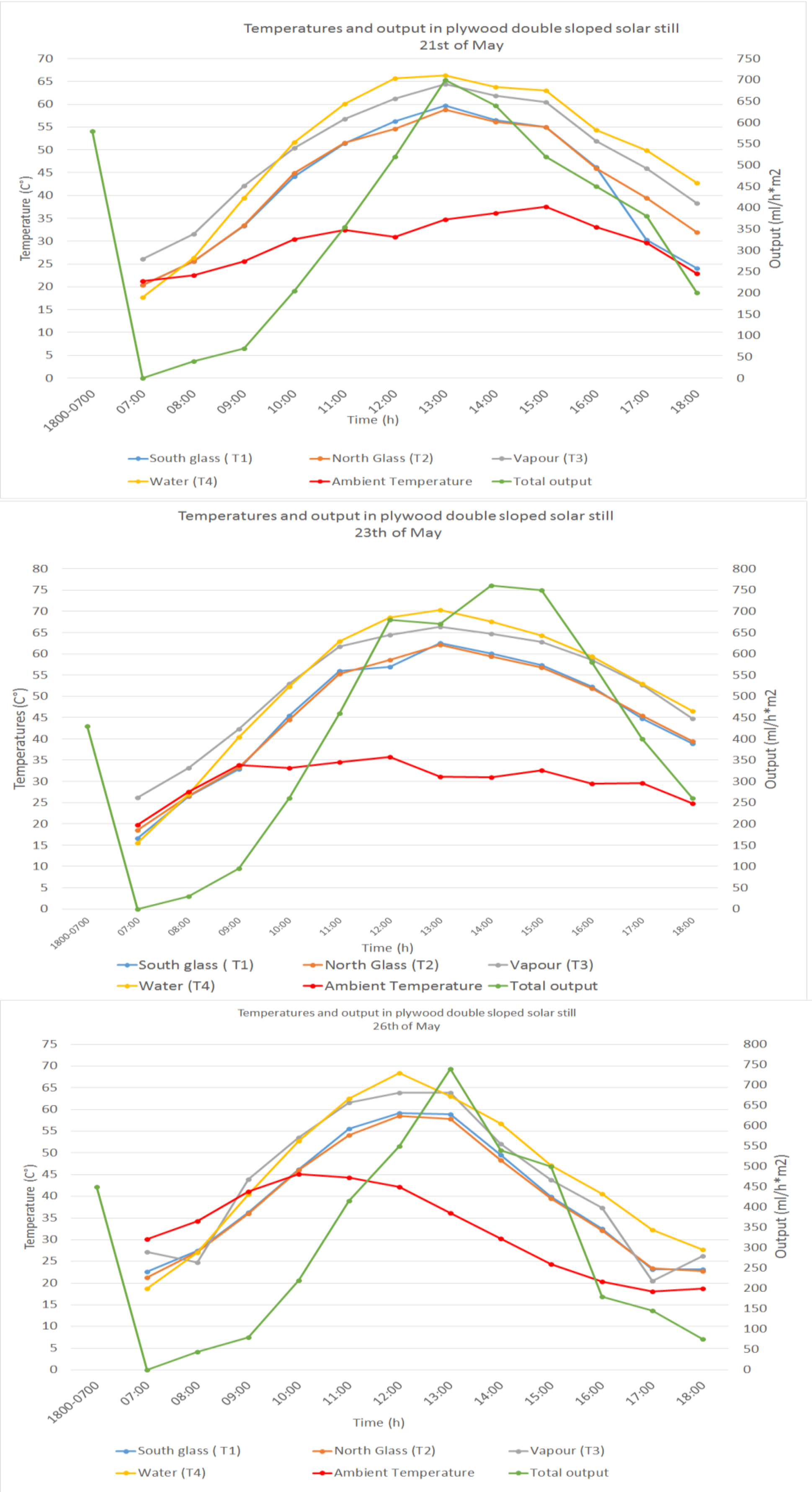

Figure 17: Temperatures and real output in the Plywood double sloped solar still on the 21st, 23rd and 26th of May, 07:00 am to 18:00 pm.

Figure 18 shows little variance between the temperatures of south and north glass cover under normal conditions on 23rd and 26th of May. Applying a wet blanket onto the north glass cover at 10:05 am, on the 24th and 25th of May, the temperature difference is increased by 0.1˚C and up to 7˚C, in-between 11:00 am and 15:00 pm. However, maximum deviation between the glasses is on the 25th of May at 16:00 pm having an difference of 9˚C.The wet blanket was changed to the south glass at 14:05 pm due to the sun position, and thereby removed fully at 15:05 pm.

Figure 18: Showing the effect on the glass temperature when preforming outside cooling by a wet blanket, on the 24th and 25th of May. 23rd and 26th is days with normal conditions. Real output (ml/m^2) in is shown for the north and south distillation channel.

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4.1.3Efficiency

The efficiency is calculated for the day with the highest and lowest output, excluded the rainy days. The annual global horizontal radiation is set to be 5.5 kWh/m^2/day (19.8 MJ/m^2/day), area 1 m^2 and latent heat of evaporation is 2.3 MJ/kg.

For this experiment, the Plywood double sloped solar still has efficiency that range between 24 % and 57 %. Keep in mind that on the 19th of May the weather was cloudy with occasionally sun gaps, and is therefore in reality is receiving reduced amount of radiation.

E = efficiency, L = Latent heat, A = area of still, G= daily/annual global horizontal solar radiation (MJ/m^2), and Q is daily output.

23 May:

$$Q = \frac{E * G * A}{L}, \qquad (2) \qquad \text{(www.engineeringforchange.org)}$$

$$E = \frac{\frac{2.3MJ}{kg} * 4.9l}{\frac{19.8MJ}{(m^2 * day)} * 1m^2}$$

E = 57 %

19 May:

$$Q = \frac{E * G * A}{L} \qquad (2) \qquad \text{(www.engineeringforchange.org)}$$

$$E = \frac{\frac{2.3MJ}{kg} * 2.1l}{\frac{19.8MJ}{(m^2 * day)} * 1m^2}$$

E = 24%

4.1.4 Discussion – Plywood double sloped solar still

An increase in correlation is found when excluding rainy days, 17th and 18th of May. An increase in output is due to rainy periods, where water droplets entered the distillation channel via small gaps in-between channel and glass cover, contributing to a lower correlation with temperatures. Output and water temperature are correlated, which is to be expected, as evaporation rate increases with an increase in water temperature. This, and high vapour temperature can probably explain why the highest output is on the 23rd of May. High correlation between vapour and water temperature is expected since an increase in vapour temperature contributes to an increase in water temperature.

That 22nd and 26th of May has a small decrease in temperatures inside the still is likely due to shifting weather conditions in the evening, and an increased wind speed. There is no clear trend that the temperatures inside, nor the output decrease with increased salt concentration, however, few days of recording may not give an accurate estimate of the reality.

An increased difference in temperature is seen between south and north glass cover during the hours when a wet blanket is covering one of the glass covers. Since the glass temperature was recorded a few minutes before wetting the blanket, it is expected that the difference in glass temperatures was higher the first period of the hour. It was expected that a decrease in glass temperature would increase the productivity by increasing the condensation; however, blocking one glass cover resulted in lower temperatures and a decrease in output, this especially applies to the south distillation pipe.

During the first days of testing the output gave off a light smell and taste. This was reduced during the experiment, but was however never fully removed. It is assumed that the taste and smell is due to off-gassing from the paint, glue and silicone. However, exposing the basin in the sun for some period of time, without attaching the glass cover, will probably decrease this problem, by having the paint off-gas to the surroundings before making the still airtight. Occasionally drops backs were observed during the day, usually in context with change in weather, when the ambient temperature decreased or the wind increased, which again increased the condensation resulting in drop backs.

4.2 Sink double sloped solar still

4.2.1 Correlation

An R-sq. value of 8 % and 12 % for respectively output vs. vapour temperature and output vs. water temperature is found (Fig.19, Fig.20). Output and ambient temperature have a correlation of 4% (Table 4).

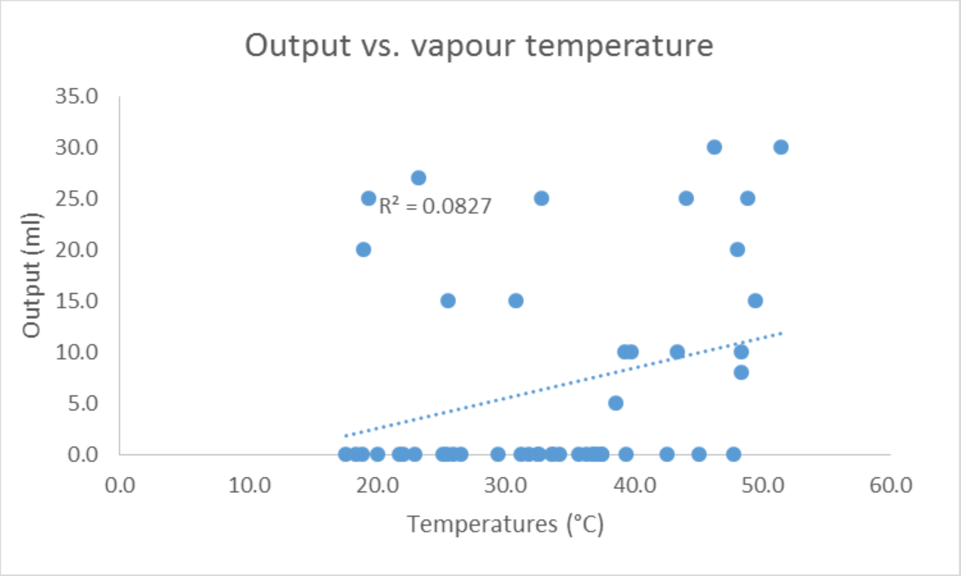

Figure 19: Regression fit for output vs. vapour temperature inside the Sink double sloped solar still, from the 18th to 21st of May, with an R-sq. of 8 %

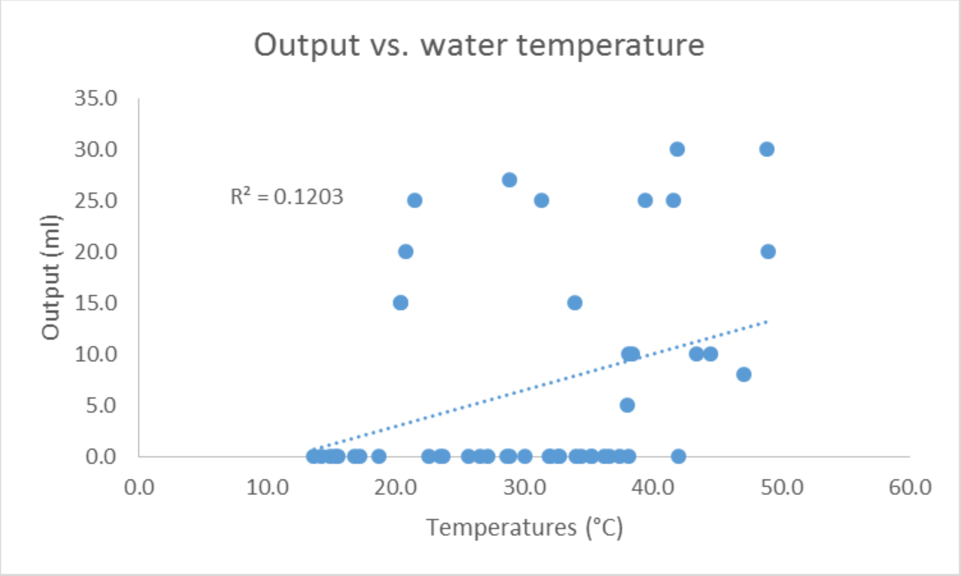

Figure 20: Regression fit for output vs. water temperature inside the Sink double sloped solar still, with an R-sq. of 12 %, from the 18th to 21st of May.

The highest correlation is found between ambient temperature and vapour temperature, with a correlation of 88 % (Table 4). Water and vapour temperature have a correlation of 69 %. Regarding radiation, the highest R-sq. value is towards vapour temperature being 66 %, and with the lowest towards output, of 1%

Table 4: R-sq. values in the Sink double sloped solar still from the 18th to 21st of May regarding real output. R-sq. values regarding temperatures are from 17th to 21st of May.

Correlation (%)				
vs.	**Water(°C)**	**Vapour (°C)**	**Output**	**Radiation**
Ambient (°C)	72	88	4	56
Output	12	8		1
Vapour (°C)	69			
Radiation	28	66		

4.2.2 Mean temperatures and output

The mean water temperature and output is highest on the 20th of May, being 36 °C and 113 ml respectively. Mean maximum vapour temperature is 41°C on the 21st of May, with an output of 85 ml. The lowest output is on the 17th of May, where the weather was cloudy and occasionally raining (Table 1). Estimates suggest that the output will increase with 0.3 ml when the temperatures increase 1˚C for water, - as well as vapour.

Table 5: Mean daily temperatures in the Sink double sloped solar still, 07:00am to 18:00pm from the 17th to 21st of May. Real output is excluded night production, and is in ml per 0.14m²

May	South glass (˚C)	North glass (˚C)	Vapour (˚C)	Water (˚C)	Ambient (˚C)	Output (ml)
17	17	17	20	20	16	10
18	24	24	27	26	22	87
19	26	26	30	28	24	40
20	33	34	38	36	31	113
21	35	35	41	33	30	85

The vapour temperature is the highest of the temperatures inside the still from the morning and up to 12:00 am, from where water temperature and vapour temperature is shifting on being the maximum (Fig. 21). All the temperatures are lower on 18th and 19th of May, compared to 20th and 21st of May. The highest maximum temperature concerning vapour is on the 21st of May. A decrease in water temperature is also observed the same day, comparing it to 20th of May, which had the same weather conditions. On the 20th and 21st the maximum output is in the same timeframe as maximum temperatures inside solar still.

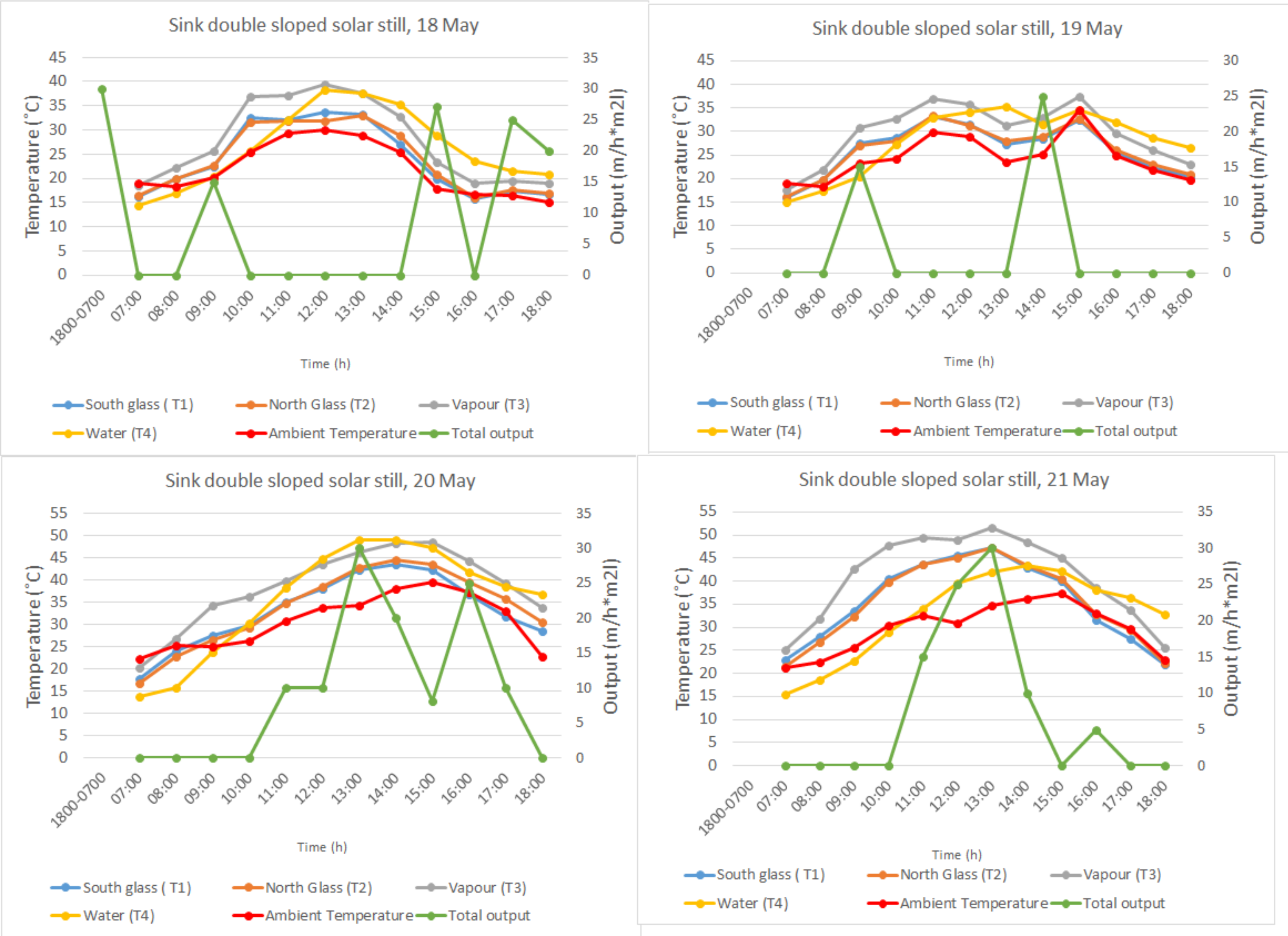

Figure 21: Hourly temperatures and real output inside the Sink double sloped solar still from the 18th to 21st of May, 07:00 am to 18:00 pm.

4.2.3 Efficiency

The annual global horizontal radiation is set to be 5.5 kWh/m^2/day (19.8 MJ/m^2/day), area 0.14 m^2 and latent heat of evaporation is 2.3 MJ/kg.

For this experiment, the Sink double sloped solar still has efficiency that range between 5 % and 13 %. Keep in mind that on the 19th of May the weather was cloudy with occasionally sun gaps, and is therefore in reality is receiving reduced amount of radiation.

E = efficiency, L = Latent heat, A = area of still, G= daily/annual global horizontal solar radiation (MJ/m^2), and Q is daily output.

<u>20 May:</u>

$$Q = \frac{E * G * A}{L}, \qquad (2) \qquad \text{(www.engineeringforchange.org)}$$

$$E = \frac{\frac{2.3MJ}{kg} * 0.153l}{\frac{19.8MJ}{(m^2 * day)} * 0.14m^2}$$

<u>E= 13 %</u>

<u>19 May:</u>

$$Q = \frac{E * G * A}{L} \qquad (2) \qquad \text{(www.engineeringforchange.org)}$$

$$E = \frac{\frac{2.3MJ}{kg} * 0.065l}{\frac{19.8MJ}{(m^2 * day)} * 0.14m^2}$$

<u>E = 5%</u>

4.2.4 Discussion – Sink double sloped solar still

The high correlation between ambient temperature and vapour temperature is probably due to the low volume of vapour inside the solar still, making it easily affectable by the ambient temperature. The low correlation found between radiation and water temperature, may be explained by the height of the basin, causing partly shadowing of the water during the day. This may also explain the correlation between water and vapour, and also the generally lower mean water temperature, compared to the other solar stills. Low correlation with output may be due to the low quantity of produced water, and also the high variation in produced water within relatively short time. There is also no clear trend within output and mean temperatures. The high scale effect on the small area of the basin and the low size of the glass cover, together with low temperatures is probably the reason for low output during the experiment.

The low difference in temperatures between the southern and northern glass, suggests there to be little increased capacity for condensation on the north glass compared to the southern glass during the day. The overall lower temperatures in the solar still on the 18th and 19th of May are most likely due to cloudy weather.

The application of coal to the basin on the 21st of May is likely to have contributed to the increase in vapour temperature, and the decrease in water temperature, compared to the 20th of May, which had almost identical weather conditions. The decrease in water temperature is probably due to the added water, followed by an increase in water depth when applying the coal.

There is not found indications of increased heat storing capacity as a result of the coal application. This may partly be due to a decrease in ambient temperature and shifting weather conditions at 15:00 pm on the 21st compared to 20th of May. However, a decrease in output is also registered, having the same amount of output as on the 18th of May, which have a temperature differences up to 13˚C (Table 5). However, only comparing estimates based on five days, and where one of these were containing coal, may not give an accurate picture of the reality.

4.3 Plastic single sloped solar still

4.3.1 Correlation

Figure 22 show low correlation between output and vapour temperature, with 26 %. There is found a slightly higher correlation between output and water temperature of 38 % as seen in Figure 23. The parameter with the highest correlation with output is ambient temperature, with a correlation of 40 % (Table 6).

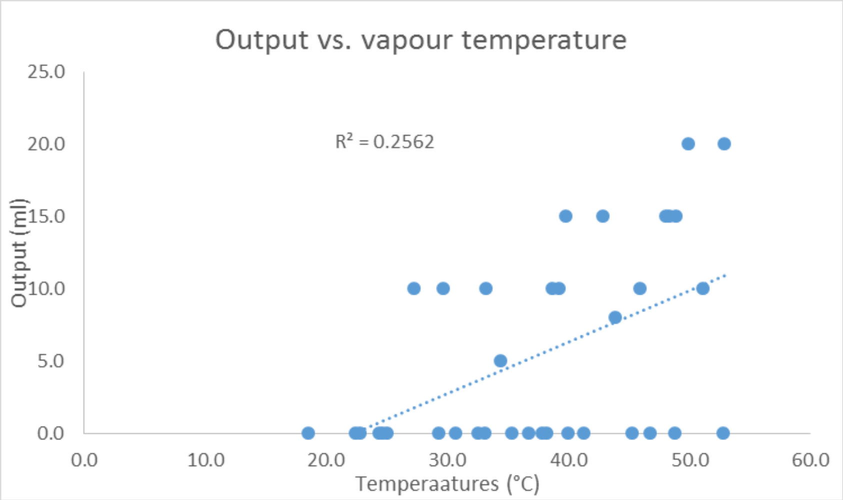

Figure 22: Regression fit for output vs. vapour temperature in the Plastic single sloped solar still, from the 19th to 21st of May, with a R-sq. of 26 %.

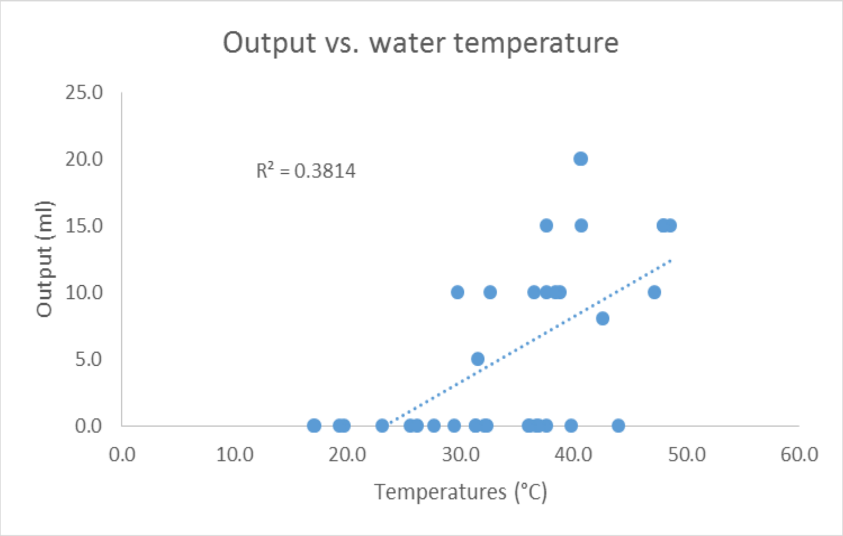

Figure 23: : Regression fit for output vs. water temperature in the Plastic single sloped solar still, with an R-sq. of 38 % from the 19th to 21th of May.

Table 6 show R-sq. values in Plastic standard still from 19th to 21st of May. The highest correlation is found between ambient temperature and water, and ambient temperature and vapour, both with a correlation of 66 %. Water, ambient temperature and output all show little correlation with radiation, with 16 %, 23 % and 9 % respectively. Vapour temperature and total radiation is found to have an R-sq. value of 56 %.

Table 6: R-sq. values in the Plastic standard solar still from 19th to 21st of May.

Correlation (%)				
vs.	**Water (°C)**	**Vapour (°C)**	**Output**	**Radiation**
Ambient (˚C)	66	66	40	23
Output	38	26		9
Vapour (˚C)	51			
Total radiation	16	56		

4.3.2 Mean temperatures and output

An overview over mean temperatures inside the solar still and ambient temperature is shown in Table 7. The mean water temperature is at its highest on the 20th of May, with temperature of 39˚C respectively. The mean vapour temperature is at its highest with 41 ˚C on the 20th and 21st of May. The 21st of May is also the day with the highest measured output, of 75 ml. An increase of 12 ml in output was found when applying coals to the basin of the solar still. A decrease in water temperature was also achieved. Estimates suggest that by increasing the water and vapour temperature by 1˚C, the output increases with 0.5 ml and 0.4 ml respectively.

Table 7: Mean daily temperatures in the Plastic single sloped solar still at 07:00 am to 18:00 pm from the 18th to 21st of May. Real output is excluded night production, and is in ml per 0.1m^2

May	Glass (˚C)	Vapour (˚C)	Water (˚C)	Ambient (˚C)	Output
19	28	32	30	24	60
20	37	41	39	31	63
21	37	41	35	30	75

Vapour temperature is higher compared to water temperature up to 12:00 am on the 19th and 20th of May, which from there the highest temperature changes between water and vapour (Fig.24). From 12:00 am there is found close to no deviation between vapour and water temperature on the 20th of May. However, all three days follows the same trend as ambient temperature. 20th and 21st of May has almost the same weather conditions, but the figure show a decrease in water temperature on the 21st. There is no measured output up to 11:00 am, and the highest output is recorded in the middle of the day, when the still has its highest temperatures.

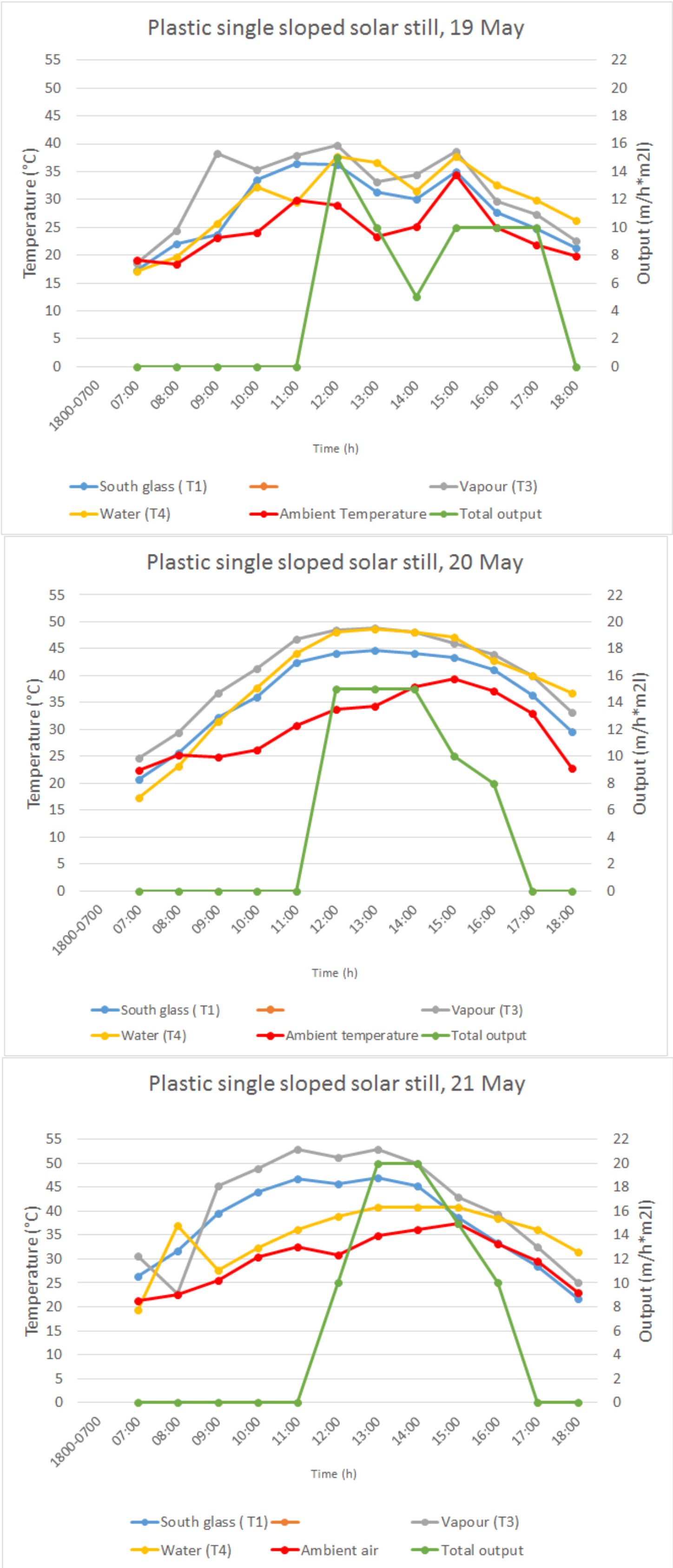

Figure 24: Temperatures and real output in the Plastic single sloped solar still from the 19th to 21st of May, 07:00 am to 18:00 pm.

4.3.3 Efficiency

The annual global horizontal radiation is set to be 5.5 kWh/m^2/day (19.8 MJ/m^2/day), area 0.11 m^2 and latent heat of evaporation is 2.3 MJ/kg.

For this experiment, the Plastic single sloped solar still has efficiency that range between 6 % and 8 %. Keep in mind that on the 19th of May the weather was cloudy with occasionally sun gaps, and is therefore in reality is receiving reduced amount of radiation.

E = efficiency, L = Latent heat, A = area of still, G= daily/annual global horizontal solar radiation (MJ/m^2), and Q is daily output.

<u>21 May:</u>

$$Q = \frac{E * G * A}{L}, \qquad (2) \qquad \text{(www.engineeringforchange.org)}$$

$$E = \frac{\frac{2.3MJ}{kg} * 0.075l}{\frac{19.8MJ}{(m^2 * day)} * 0.11m^2}$$

<u>E= 8%</u>

<u>19 May:</u>

$$Q = \frac{E * G * A}{L} \qquad (2) \qquad \text{(www.engineeringforchange.org)}$$

$$E = \frac{\frac{2.3MJ}{kg} * 0.06l}{\frac{19.8MJ}{(m^2 * day)} * 0.11m^2}$$

<u>E= 6%</u>

4.3.4Discussion – Plastic single sloped solar still

A higher correlation between vapour and water temperature would be expected. At the first day of testing, condensed water was dripping back and into the basin, 10 mm before the distillation channel, resulting in a lower output. It was therefore replaced further up towards the middle of the glass. On the 21st of May the distillation channel started to detach, resulting in water droplets going in-between the glass and distillation channel, dripping back to the basin. This, and a generally low output, is probably the reason for a low correlation with output. Low output is also affected by the small size of the glass cover and the basin. The low correlation values are based on the result from three days of experiment, giving single measurements high credibility, and increasing the impact of any errors in the measurements. Increased correlation in regard ambient temperature and temperatures inside the solar may therefore increase, with increased recordings.

The decrease in water temperature on the 21st of May is probably due to an increase in water depth when applying coals. As a result of intense solar heat, after three days – on the 21st of May, there was observed a vapour leakage between the lid and basin of the plastic box.

4.4 Plywood single sloped solar still

4.4.1 Correlation

Figure 25 and 26 shows the correlation for the 20th and the 23rd to 27th of May, between output and vapour temperature, and output and water temperature, with R-sq. values of 71 % and 75 % respectively. Output shows low correlation with ambient temperature and radiation, with 19 % and 28 % respectively.

Results from the 21st and 22nd of May in regard output was decided to be excluded due to leakage from the distillation channel. In the morning on the 22nd of May, the leakage was stopped and measurements started at 11:00 am.

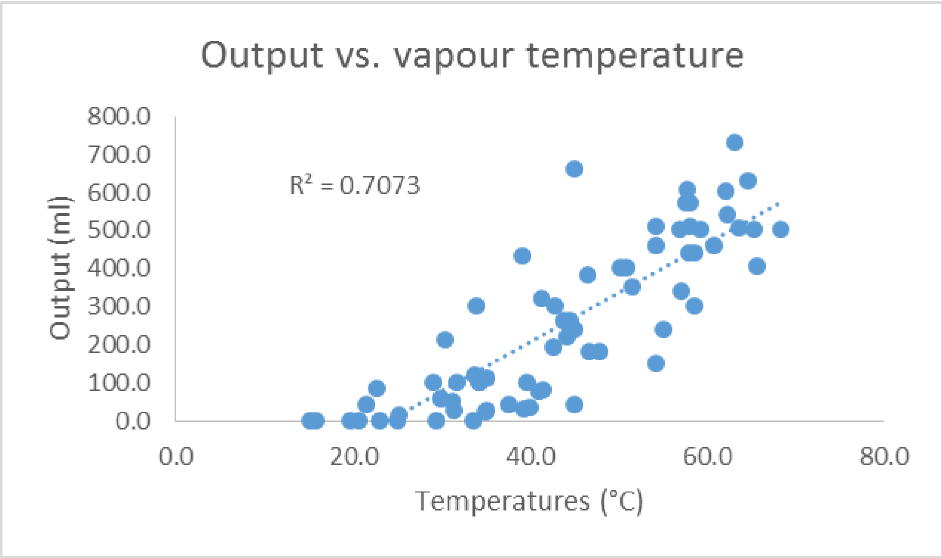

Figure 25: Regression fit for output vs. vapour in the Plywood single sloped solar still, on the 20th and 23rd to 27th of May, with an R-sq. of 71 %

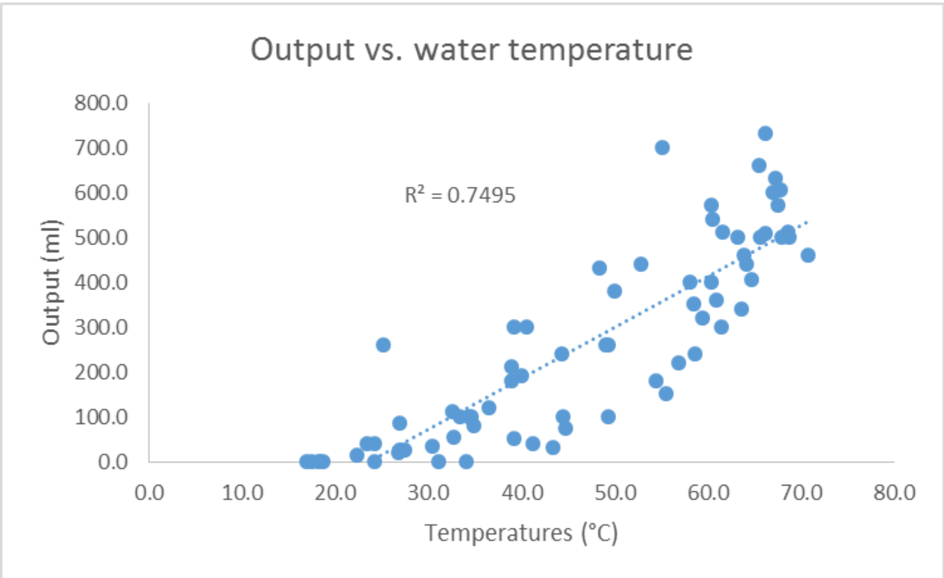

Figure 26: Regression fit for output vs. water temperature in the Plywood single sloped solar still, with an R-sq. of 75 % on the 20th and from 23rd to 27th of May.

An R-sq. value of 85 % between vapour temperature and water temperature is shown in Table 8. Radiation is found to have the highest correlation with water temperature and vapour temperature, with a 51 % for both. Ambient temperature has an R-sq. value of 41 %, 40 % and 34 % towards water, vapour and radiation, respectively. Towards output, ambient temperature has a 19 % correlation.

Table 8: R-sq. values in the Plywood single sloped solar still regarding real output are excluded on the 21st and 22nd due to leakage from the distillation channel. Other R-sq. values are based on data collected on the 20th and 21st, and 23rd to 27th of May. Regarding vapour temperature, 13:00 pm to 15:00 pm on the 25th of May is excluded due to detachment of the vapour temperature sensor. 22nd of May is excluded due to work/construction on the solar still.

Correlation (%)				
vs.	**Water (°C)**	**Vapour (°C)**	**Output**	**Radiation**
Ambient (˚C)	41	40	19	34
Output	75	71		28
Vapour (˚C)	85			
Radiation	51	51		

4.4.2 Mean temperatures and output

The highest temperatures inside the solar still are registered on the 23rd of May, which coincides with the day of highest output, where 3687 ml water was produced (Table 9). Estimates suggest that by increasing the water and vapour temperature by 1˚C, the output increases with 11 ml and 13 ml respectively.

On May 21st, at 18:00 pm, water with an EC of 6.95 mS/m was added to the still. The EC level was not measured in the evening on the 27th of May due to practical problems in accessing the water in the basin.

Table 9: Mean daily temperatures in the Plywood single sloped solar still are measured from 07:00 am to 18:00 pm on the 20th - 21st, 23rd to 24th, and 26th – 27th of May. Mean daily temperature on the 22nd is recorded from 11:00 am to 18:00 pm, and on the 25th of May regarding glass and vapour temperature, 07:00 am – 12:00 am, and 16:00 pm to 18:00 pm due to detachment of the temperature sensors. Real output is excluded night production, and is in ml per 1 m^2.

May	Glass (˚C)	Vapour (˚C)	Water (˚C)	Ambient (˚C)	Output
20	38	40	47	31	2545
21	40	43	48	30	1320
22	36	41	42	31	1535
23	43	49	51	30	3687
24	40	44	47	30	3580
25	38	43	45	32	3435
26	38	41	43	32	2710
27	44	45	47	37	3285

Water -, air and glass temperatures follow the same trend over the period, with water temperature being the highest (Fig.27). On the 21st and 23rd of May the output measurements follows the same fluctuations as glass and vapour temperature. The output increases with temperature, and appear to have an up to a 2 hour delay in the registered maximum output, compared to maximum water temperature.

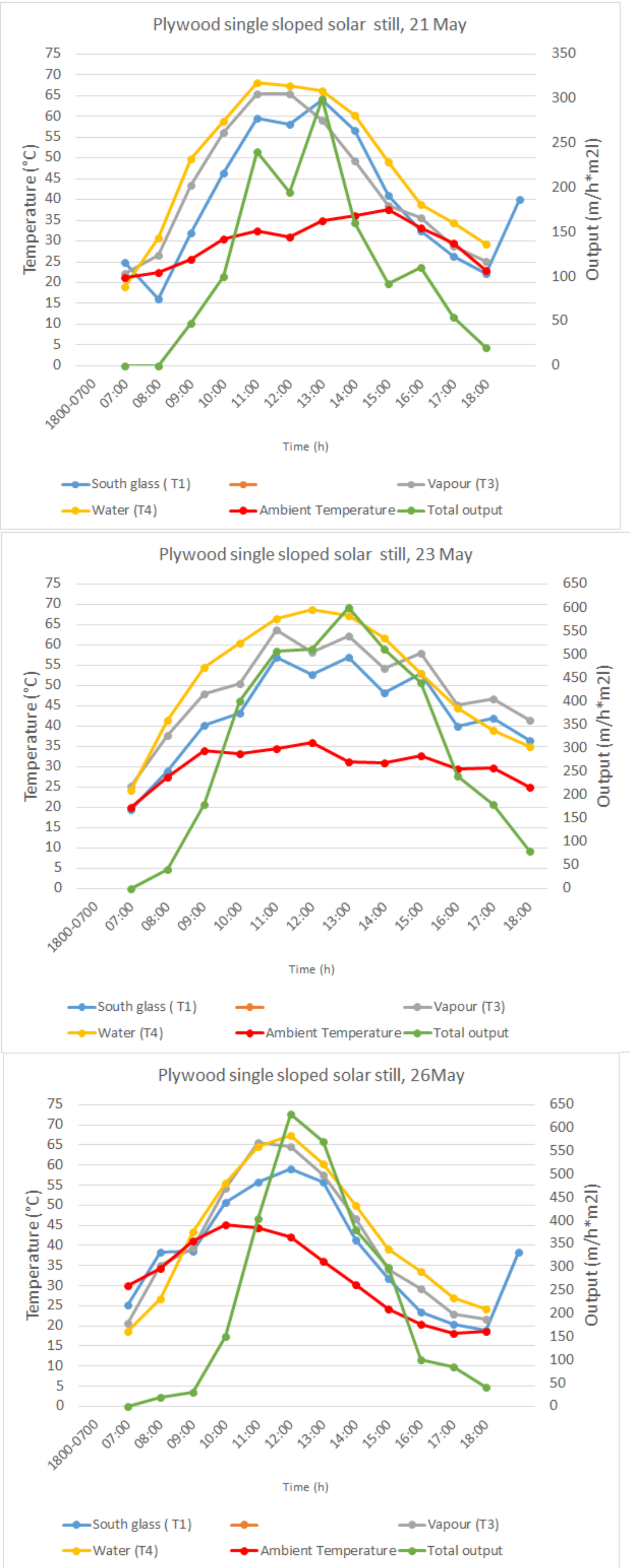

Figure 27: Temperatures and real output in the Plywood single sloped solar still on the 21st, 23rd and 26th of May, 07:00 am to 18:00 pm.

4.4.3 Efficiency

The annual global horizontal radiation is set to be 5.5 kWh/m^2/day (19.8 MJ/m^2/day), area 1m^2 and latent heat of evaporation is 2.3 MJ/kg.

For this experiment, the Plywood single sloped still has efficiency that range between 29 % and 43 %.

E = efficiency, L = Latent heat, A = area of still, G= daily/annual global horizontal solar radiation (MJ/m^2), and Q is daily output.

<u>23 May:</u>

$$Q = \frac{E * G * A}{L},$$ (2) (www.engineeringforchange.org)

$$E = \frac{\frac{2.3MJ}{kg} * 3.7l}{\frac{19.8MJ}{(m^2 * day)} * 1m^2}$$

<u>E= 43%</u>

<u>20 May:</u>

$$Q = \frac{E * G * A}{L}$$ (2) (www.engineeringforchange.org

$$E = \frac{\frac{2.3MJ}{kg} * 2.5l}{\frac{19.8MJ}{(m^2 * day)} * 1m^2}$$

<u>E = 29%</u>

4.4.4 Discussion – Plywood single sloped solar still

There was expected to find correlation between vapour temperature and water temperature as the two will influence each other via convection. A low correlation between vapour and ambient temperature is probably due to the height of the solar still and the big volume of air, which is likely to make it less sensitive to ambient temperature.

The output increase with increased temperatures as expected, since evaporation rate increase with temperature. On the 27th of May the ambient temperature and glass temperature is at its highest, additionally low deviation between vapour and glass temperature is seen, which may indicate the reason for the slightly lower output this day, compared to other days having the same temperatures inside the solar still. It may also presume a low decrease in output, when increasing salt concentration.

The glass cover was cut in two equal sizes due to breakage of the glass cover when trying to fit it as one. The high elevation of the solar still made the mobility difficult. The inside of the basin, which partly remained unpainted to increase incoming radiation to the basin by reflection, started to corrode the first day of the experiment. This happened as a result of misunderstandings during the building process, leading to brushing of the SS sheet and thereby increasing exposure to corrosion.

4.5 GI single sloped solar still

4.5.1 Correlation

The R-sq. values regarding output vs. vapour temperature, and output vs. water temperature for the GI single sloped solar still are 62 % and 74 % respectively (Fig 28, Fig. 29). Output has a correlation of 38 % and 24% regarding ambient temperature and radiation, respectively (Table 10).

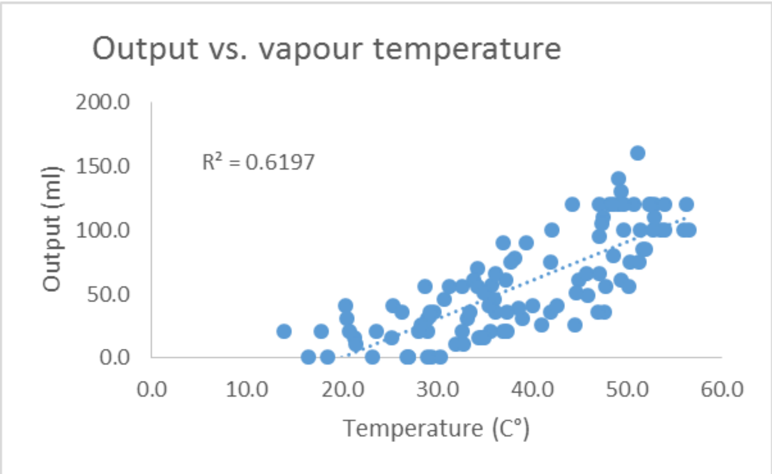

Figure 28: Regression fit for output vs. vapour temperature for the GI single sloped solar still from the 19th to 27th of May, with an R-sq. value of 62 %

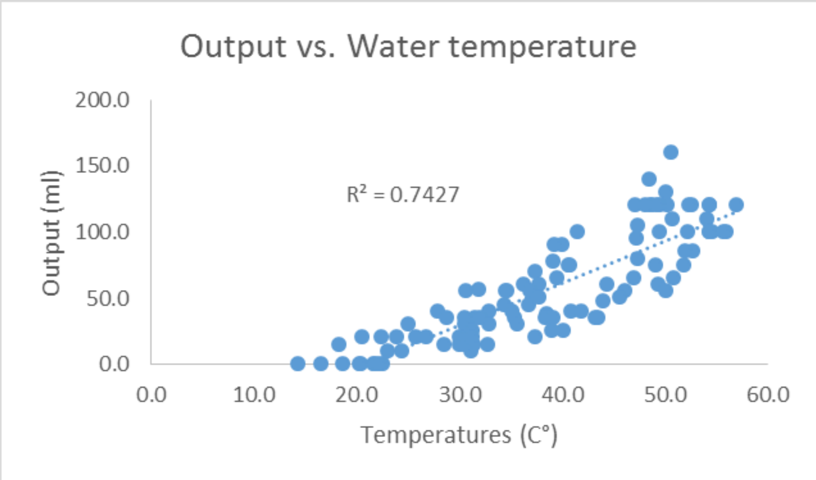

Figure 29: Regression fit for output vs. water temperature in the GI single sloped solar still, with a R-sq. value of 74 % from the 19th to 27th of May.

The R-sq. value between water temperature and vapour temperature is 90 % (Table 10). Radiation has the lowest correlation with output and ambient temperature, of 24 % and 42 % respectively. Increased correlation is found regarding water temperature and vapour temperature, of 47 % and 61 % respectively. Ambient temperature shows the highest correlation with vapour temperature and water temperature, of 66 % and 64 %.

Table 10: R-sq. values in the GI single sloped solar still, from the 19th to 27th of May.

Correlation (%)				
vs.	**Water(°C)**	**Vapour (°C)**	**Output**	**Radiation**
Ambient (°C)	64	66	38	42
Output	74	62		24
Vapour (°C)	90			
Radiation	47	61		

4.5.2 Mean temperatures and output

In the 27th of May, water temperature and vapour temperature has its maximum mean temperature, of 43˚C (Table 11). Ambient temperature is also at its highest the same day. The highest output is measured on the 21st of May, of 925 ml. 19th of May is the day with both lowest mean temperatures and output. It can be seen that there are low deviation between mean vapour temperature and mean water temperature in all days, except on the 26th of May, where the difference in temperature is at its highest, 3˚C. Additionally there are two days, 21st and 27th of May, where the glass temperature exceed the vapour temperature. Estimates suggest that the output will increase with 3 ml when the temperatures increase 1˚C for water, -as well as vapour.

From 19th to 21st of May an increase in EC, from 1395uS/m to 2.0mS/m was registered. Towards the end of 21st, at 18:00 pm, water with an EC of 6.95mS/m was supplied to the still, which lead to an increase of 13.5mS/m, registered on the evening of 27th of May.

Table 11: Mean daily temperatures in the GI single sloped solar still, from the 19th to 27th of May, 07:00 am to 18:00 pm. Real output is excluded night production, and is in ml per 0.8 m^2.

May	Glass (˚C)	Vapour (˚C)	Water (˚C)	Ambient (˚C)	Output
19	27	30	29	24	396
20	33	39	38	31	753
21	43	41	41	30	925
22	36	36	35	30	510
23	42	43	42	30	790
24	41	41	41	30	718
25	40	41	40	32	645
26	34	34	37	32	623
27	45	43	43	37	755

Figure 30 shows temperatures and output on the 21st, 23rd and 26th of May. The glass temperature is the highest temperature on the 21st of May between 09:00 am and 16:00 pm, and 10:00 am - 14:00 pm on the 23rd. There is low deviation between vapour and water temperature, having highest deviation on the 26th of May. The output increase with temperatures, with up to 2 hours delay compared to maximum temperatures.

Figure 30: Temperatures and real output inside the GI single sloped solar still on the 21st, 23rd and 26th of May, 07:00 am to 18:00 pm.

4.5.3 Efficiency

The annual global horizontal radiation is set to be 5.5 kWh/m^2/day (19.8 MJ/m^2/day), area 0.8 m^2 and latent heat of evaporation is 2.3 MJ/kg.

For this experiment, the GI single sloped still has an efficiency that range between 6 % and 13 %. Keep in mind that on the 19th of May the weather was cloudy with occasionally sun gaps, and is therefore in reality is receiving reduced amount of radiation.

E = efficiency, L = Latent heat, A = area of still, G= daily/annual global horizontal solar radiation (MJ/m^2), and Q is daily output.

<u>21 May:</u>

$$Q = \frac{E * G * A}{L}, \qquad (2) \qquad \text{(www.engineeringforchange.org)}$$

$$E = \frac{\frac{2.3MJ}{kg} 0.925l}{\frac{19.8MJ}{(m^2 * day)} * 0.8m^2}$$

<u>E = 13%</u>

<u>19 May:</u>

$$Q = \frac{E * G * A}{L} \qquad (2) \qquad \text{(www.engineeringforchange.org)}$$

$$E = \frac{\frac{2.3MJ}{kg} 0.396l}{\frac{19.8MJ}{(m^2 * day)} * 0.8m^2}$$

<u>E = 6%</u>

4.5.4 Discussion – GI single sloped solar still

Correlation regarding vapour temperature and water temperature is expected due to a change in vapour temperature affects water temperature.

There are no clear indications that an increased salt concentration decreases the water and vapour temperature, nor the output, since the deviations in this regard are so low within the days. There is assumed that the shifting weather and an increased wind speed are affecting the temperatures inside the solar still on the 22nd and 26th. That glass temperature exceeds vapour temperature is assumed to have an effect on the condensation rate, decreasing the output. This effect is however not clearly observed, due to low range in output.

Low output is probably due to having lower mean temperatures inside the still, compared to Plywood double sloped still and Plywood single sloped still. One reason probably being the lack of black basin.

The distillation channel and the iron frame which was made out of iron, started to show corrosion the same day as the experiment started, contributing to a light brown colour and a taste of iron on the output. Occasionally leakage from the bolt was also observed, but to a negligible amount. Small drop backs was occasionally seen, probably due to low inclination of the glass cover. A change in dimensions, having a shorter distance from the top glass to the end glass where the distillation channel is attached, will also contribute to a decrease in drop backs, preventing them to become too large as they glide down the glass cover.

4.6 Wick solar still

4.6.1 Correlation

An R-sq. value of 61 % and 17 % regarding output vs. vapour temperature, and output vs. water temperature is found (Fig.31, Fig.32). Ambient temperature vs. output, and radiation vs. output shows correlations of 52 % and 33 % respectively (Table 12).

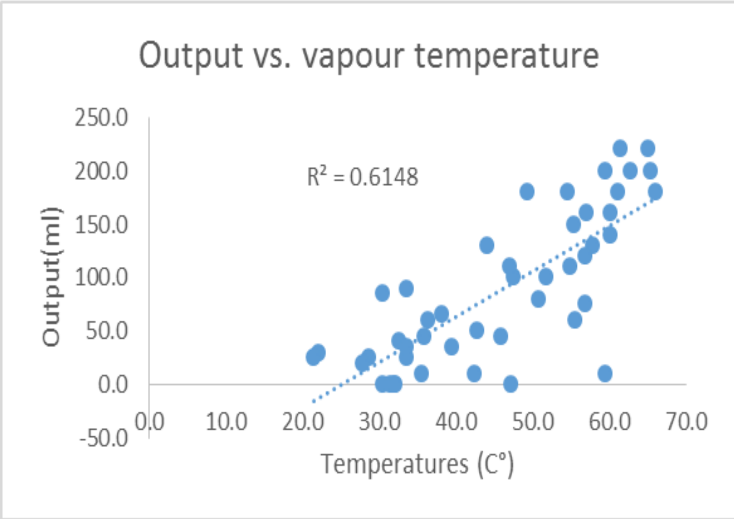

Figure 31: Regression fit for output vs. vapour temperature in the Wick solar still, from the 24th to 27th of May, with an R-sq. value of 61 %

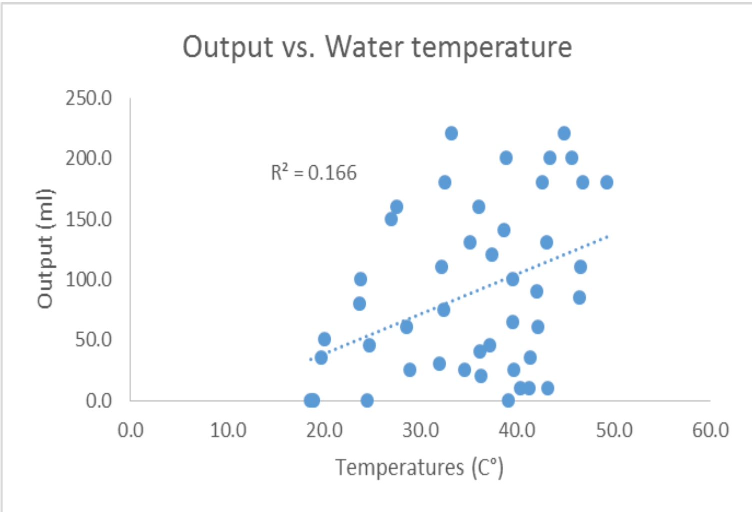

Figure 32: Regression fit for output vs. water temperature in the Wick solar still, with R-sq. value of 17% from the 24th to 27th of May.

The R-sq. value regarding vapour temperature and radiation is 78 % (Table 12). Radiation and ambient temperature have a correlation of 53 %. Water temperature has R-sq. value of 2 %, 6 % and 3 % in regard of ambient temperature, radiation and vapour temperature. Vapour temperature and water temperature have a regression fit of 3 %.

Table 12: R-sq. values regarding output in the Wick solar still from the 24th to 27th of May. Other R-sq. values are based on measurements from 23rd to 27th of May.

Correlation (%)				
vs.	**Water (°C)**	**Vapour (°C)**	**Output**	**Radiation**
Ambient (°C)	2	71	52	53
Output	17	61		33
Vapour (°C)	3			
Radiation	6	78		

4.6.2 Mean temperatures and output

Table 13 shows an overview of mean temperatures in the Wick solar still. Mean vapour temperature is ranging as the highest of the temperatures, having the maximum temperature on the 25th and 27th of May, 48 ˚C. The highest measured output and mean ambient temperature is both on the same day, 27th of May, producing an output of 1370 ml. Total output on 23rd of May is 0 due to leakage from the distillation channel. Estimates suggest that by increasing the water and vapour temperature by 1˚C, the output increases with 3 and 4 ml respectively.

An increase in the salinity of the water was performed on the 24th of May, containing an EC of 6.95 mS/m. The EC had increased to 8.5mS/m on the 27th of May.

Table 13: Mean daily temperatures in the Wick solar still from the 23rd to 27th of May, 07:00 am to 18:00 pm. Real output is excluded night production, and is in ml per 0.5 m^2

May	Glass (˚C)	Vapour (˚C)	Water (˚C)	Ambient (˚C)	Output (ml)
23	40	45	30	30	0
24	42	46	34	30	660
25	44	48	38	32	995
26	38	42	32	32	1065
27	48	48	35	37	1370

Figure 33 showing temperatures and output in Wick solar still on 25th to 27th of May. Vapour temperature is followed closely by the temperature of the glass, and is achieving the highest temperature up to 15:00 pm. From there the water temperature exceeds the vapour temperature, mostly due to a decrease in vapour temperature.

The water temperature has a slow growth, but remaining rising up to 4 hours after a decline in ambient temperature. However, it never ranges as high as vapour temperature. Ambient temperature and temperatures regarding glass and vapour follows the same trend, as well as output increases with temperatures, and has a maximum output up to 2 hours earlier than maximum vapour temperature.

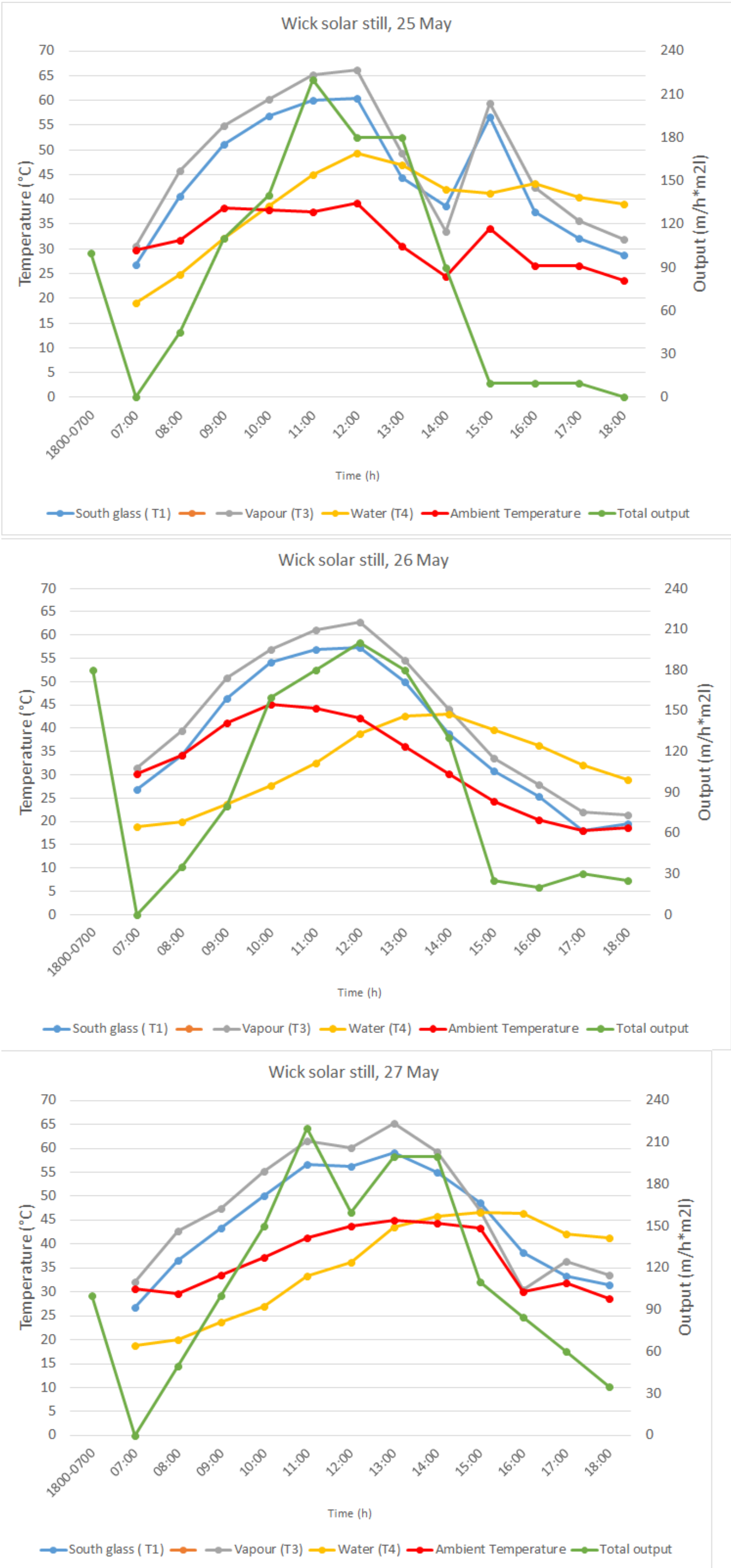

Figure 33: Temperatures and real output in the Wick solar still from the 25th to 27th of May, 07:00 am to 18:00

4.6.3 Efficiency

The annual global horizontal radiation is set to be 5.5 kWh/m^2/day(19.8MJ/m^2/day), area exposed to radiation is 0.52 m^2 and latent heat of evaporation is 2.3 MJ/kg.

For this experiment, the Wick still has efficiency that range between 15% and 31%.

E = efficiency, L = Latent heat, A = area of still, G= daily/annual global horizontal solar radiation (MJ/m^2), and Q is daily output.

<u>27 May:</u>

$$Q = \frac{E*G*A}{L}, \qquad (2) \qquad \text{(www.engineeringforchange.org)}$$

$$E = \frac{\frac{2.3MJ}{kg}*1.37l}{\frac{19.8MJ}{(m^2*day)}*0.52m^2}$$

<u>E = 31 %</u>

<u>24 May:</u>

$$Q = \frac{E*G*A}{L} \qquad (2) \qquad \text{(www.engineeringforchange.org)}$$

$$E = \frac{\frac{2.3MJ}{kg}*0.66l}{\frac{19.8MJ}{(m^2*day)}*0.52m^2}$$

<u>E = 15 %</u>

4.6.4 Discussion- Wick solar still

Low correlation between water and ambient temperature is assumed to be due to a high water level, making it less affected by the ambient. The lid, covering the water basin, is probably the reason for low correlation regarding radiation and water temperature, by not being directly exposed to sunlight. Together, it is assumed to be the reason for the slow rise in water temperature. Having the lid made out of glass is likely to increase the water temperature, but also increase the risk for breaching.

There is assumed that output is more dependent on the evaporation from the wick material, over evaporation of the water basin, contributing to a low correlation regarding water temperature. However, some evaporation is also assumed occurring directly from the water basin. Radiation shows correlation regarding vapour temperature, probably due to the low volume of air inside the solar still. This also is probably contributing to the correlation between ambient and vapours temperature.

The increase in output is assumed to be due to the change in Wick material in the morning of 25th of May, due to increased evaporation. The wick materials used had higher capillarity forces than evaporation rate, resulting in water collecting underneath the distillation channel. This is assumed to be due to the design, constructing it to have a difference in pressure between water basin and end wick, un-dependent on water level. It can therefore be advised and presumed that constructing a Wick still with a wider area (increasing the distance from water basin to end wick material) will increase the output. The highest output measured, 27th of May, is probably a result of higher ambient temperature in the evening, increasing the temperatures inside the still, which resulted in an increased output during the evening.

Due to few days of measurement it’s hard to see how the salt affects the wick material. However an increased salt concentration is measured in the water basin, even though it is likely to assume that most of the salt is absorbed in the wick material. It is therefore expected that using a wick material some maintenance has to be performed to maintain the capillary forces.

4.7 Inclination of the glass cover

There is low deviation between the amount of incoming radiation from 07:00 am and up 10:00 am. From here and out the still with the highest inclination (36˚) is the still that receives the lowest amount of radiation, up to 18:00 pm when they becomes close to equal. The trend is the same during the whole experiment, except from the evening on the 24th to 26th of May, in regard of Plywood single sloped still and GI single sloped solar still. Here the radiation becomes close to equal, due to cloudy weather.

Figure 34: : Received radiation in W/m^2 on the glass cover of the GI single sloped solar still (11˚), Plywood single sloped solar still (36˚), and Plastic single sloped solar still (19˚), on the 20th and 21st of May.

4.7.1Discussion - Inclination

The GI single sloped solar still with the lowest inclination, 11˚, is receiving a slightly higher amount of radiation over Plastic single sloped solar still. This is probably due to the positive declination angle of the sun in the summer months, giving the surface that is closest to horizontal the most incoming radiation. The high height of the Plywood single sloped solar still may also be a contributor for a lower amount of measured radiation. However, the measurement equipment was located on the highest end of the solar still, neglecting this effect. Even if the GI single sloped solar still is receiving higher hourly values of Watt, the Plywood single sloped solar still is receiving a higher amount, due to a bigger area of the solar still.

4.9 Cost estimations

In the Tables below the material cost for each solar still is given separate. The total cost range from 7$ to 70$, where the Plywood double sloped still is the most pricy. The cost estimation of the GI single sloped solar stills is missing due to lack of information from the office in Kabul. However it is assumed that the price is in same range as the Plywood double sloped solar still, due to purchasing materials in the week-end, and that GI is more pricy than SS. www.xe.com is used as a currency converter to convert from AFN to USD, on the 29.07.2014, where 1AFN is estimated to be 0.0177810USD.

Table 14: Cost estimation for the Plywood double sloped solar still in AFN and USD.

Sl. No.	Material	AFN(؋)	USD ($)
1	Plywood	1200	21.3
2	Nail 1", 2"	80	1.4
3	Glass	400	7.1
5	Fiber belt	130	2.2
6	Glass wool	300	5.3
7	Paint	180	3.2
8	Glue and silicone	250	4.4
9	SS	384	6.8
10	Iron distillation channels	200	3.5
11	Solder	500	8.9
12	Plastic cane	100	1.8
13	Garden hose	140	2.5
14	Hinges	40	0.7
Total		**3 904**	**69.10**

Table 15: Cost estimation for the Sink double sloped solar still in AFN and USD

Sl. No.	Materials	AFN(؋)	USD ($)
1	Plywood	60	1.1
2	Sink / Wash basin	1250	22.2
3	Charcoal	150	2.7
4	Glass	160	2.8
5	Fiber belt	80	1.4
6	Garden hoose and PVC	50	0.9
7	Glue and silicone	40	0.7
Total		**1 790**	**31.8**

Table 16: Cost estimation for the Plastic singled sloped solar still in AFN and USD

Sl. No.	Materials	AFN(؋)	USD ($)
1	Plastic box	250	4.4
2	Glass	70	1.2
3	Fiber belt	50	0.5
4	Garden hoose	30	0.9
6	Glue and silicone	10	0.2
7	PVC	10	0.2
Total		**420**	**7.40**

Table 17: Cost estimation for the Plywood single sloped solar still in AFN and USD

Sl. No.	Material	AFN(؋)	USD ($)
1	Plywood	1300	23.1
2	Nail 1", 2"	50	0.8
3	Glass	430	7.6
4	Fiber belt	130	2.2
5	Hole in Glass	20	0.3
6	Handles	20	0.3
7	Paint	50	0.8
8	Glue and Silicone	200	3.5
9	SS	875	15.5
10	Iron distillation channels	100	1.8
11	Solder	400	7.1
12	Plastic cane	50	0.8
13	Garden hoose	70	1.2
Total		**3695**	**65.00**

Table 18: Cost estimation for the Wick solar still in AFN and USD

Sl. No.	Materials	AFN(؋)	USD ($)
1	Plywood	1200	21.3
2	Nail 1", 2"	80	1.4
3	Wooden stick	40	0.7
4	Glass	160	2.8
5	Fiber belt	100	1.8
6	Paint	130	2.3
7	Glue and silicone	215	3.8
8	SS	390	6.9
9	Iron distillation channel	100	1.8
10	Solder	400	7.1
11	Plastic cane	50	0.9
12	Wick	150	2.7
13	Garden hoose	70	1.2
14	Hinges	40	0.7
Total		**3125**	**55.40**

4.9.1 Discussion - Cost

Variance in price for the same material is due to difference in price in different shops and also depending on which day of the week it was bought. Materials purchased in the weekend (Thursday and Friday) had usually an increased price compared to weekdays. Some material was also purchased base on bargaining. However, price difference within the stills is also due to different quantity used. Some of the materials were used on more than one solar still, such as the can of paint, box of nails, the garden hose, glue and silicone. The cost is therefore somewhat approximated, based on the amount used, where the total cost of the material is divided within the solar stills. There is expected that the cost decreases as the number of produced solar stills increase. The material used was chosen based on availability, in Kabul and Faryab, price, and previous experiments.

4.10 Overall discussion

That there is not found a higher correlation between output and temperatures is probably due to other factors affecting both parameters, such as water depth, color and area of the basin, insulation, wind velocity, vapour leakage and drop backs. Additionally the results are likely to be affected by the relatively short duration of the experiment.

The observed tendency is that the solar stills with the lowest air volume have the higher correlation between vapour temperature and radiation. These solar stills being; Plastic single sloped, Sink double sloped, Wick still and GI single sloped, which are also the stills lacking insulation. However, Sink double sloped, Plastic single sloped and Wick solar still have a lower number of measurements, making them more dependent on one single measurement, and possibly more prone to be effected by error measurements.

Radiation which is a contributor for evaporation is generally found to have low correlation estimates, which is unexpected. One of the reasons is likely to be changes in weather within the hour, where clouds occasionally effect the measurements during manual readings. More frequent recordings or use of a data logger could possibly increase the R-square value in regards of radiation.

Water temperature and vapour temperature is expected to show high correlation, as it does in the GI single sloped still, Wood single sloped still and Plywood double sloped still. With more frequent measurements it is likely that this correlation also increases in the Plastic single sloped still and sink double sloped still, however vapour leakage from the solar still is likely to decrease the correlation, and increase it towards ambient temperature. The registrations of water temperature being lower than vapour temperature during the first hours of the day, is believed to be due to the higher specific heat capacity of water compared to vapour, hence water needing more energy before increasing in temperature. The reason is the same during the evening, with water having a higher ability to store heat than vapour, resulting in a slower decrease in temperature.

Overall, the Plywood double sloped solar still produces the most distillate water per m^2 however when covering one of the two glass covers, the Plywood single sloped still produces the most.

The Plywood double sloped solar still has the highest efficiency of 57 % in this experiment, followed by the Plywood single sloped still and wick still with 43 % and 31 % respectively. The Plywood single sloped still has a higher area directly exposed to sun, since the whole area of the glass is directly exposed towards south direction, and thereby producing more output in some of the hours during the day, over Plywood double sloped still. However, in the evening, the high height of the still starts partly shadowing the basin, which is decreasing the output, and therefore the efficiency. Yet, the height of this solar still increases the volume of vapour, contributing to increased area for cooling. Sink double sloped and Plastic single sloped solar still is the two solar stills with the lowest area, and are also obtaining the lowest efficiency of 12 % and 8 % respectively. However, the scale affect must also be taken into consideration, since it has a higher influence on smaller areas over bigger, and thereby losing more energy per surface. That the GI single sloped solar still only obtain 13 % in efficiency is probably due to the lack of black basin.

There is no clear indication that increased salt concentration is decreasing the output in this thesis. Only the Plywood single sloped solar still may indicate a output decrease on the 27th of May, when comparing mean temperatures inside the solar still to previous days.

However, the salt concentration appear to result in increased corrosion in the Plywood double sloped, GI single sloped and Plywood single sloped solar still after increasing the salt concentration, which may result in a lower life-time of the solar still, and contribute to an decrease in both output and quality if it becomes to comprehensive.

4.10.1 Maintenance and user friendliness

Local materials were available for building the solar stills, however some side effects were related to them, like of-gassing and corrosion. The Plywood double sloped solar still was the most time consuming to build, due to the double slope of the glass, and that it was the first solar still constructed. There is limited access to advanced tools, and purchasing materials is time consuming, because the materials is sorted by streets, having wood in one part of the town, and nails, glass and silicone in other parts of the city. It is therefore recommended to keep the total amount of different materials to a minimum. Using prefabricated basins is cost efficient, and speeds up the building process, however no such basin was found in an acceptable size. Some challenges in regard a prefabricated basin may occur, like challenging attaching the glass cover, and also obtain a slope on the distillation channel.

Concerning the mobility and robustness of the solar stills, the GI single sloped still is found to be the most suitable. The Wick and Plastic single sloped still also had satisfying mobility, however, the plastic basin showed signs of deterioration caused by heat, and the plywood enclosing the Wick still showed cracks early in the experiment. These observations suggest that these two materials are not suitable for a long-term solution.

The Plywood double sloped- and Plywood single sloped solar stills were found to be too heavy for proper mobility. The material on the GI single sloped still, however, was robust, with a stable glass cover and iron frame, which decreased the chance for rupturing. This solar still was also easily drained. However, the door used for refilling and maintenance is recommended to upscale, to fit cleaning equipment.

The maintenance of the Plywood double sloped solar still was easily performed by a broom; however, draining the water was done using a water mug. The big entrance made it easily accessible; however there may be a risk of leaking of vapour over time due to the influence of high temperatures on the rubber gasket in between the door and the frame. The maintenance of the Plywood single sloped still was also performed by a broom, however removal of the big glass cover for each time, increased the risk of breaking. This was not considered as a challenge in the Plastic single sloped and Sink double sloped still, due to the small size of the glass cover. The Wick solar still was easily maintained and entered through the lid.

The plywood was not of the same quality as the Norwegian standard, and there was also some concern about the paint, not obtaining a detailed fact-sheet. Extensive searching for PE was unsuccessful; however, it is reason to believe that a basin made from PE, enclosed with GI would increase the lifetime and mobility of the solar still. Excluding the black paint from the inner basin will also minimize the risk of off-gassing and the further influence on the quality of the produced water. Further studies regarding water quality, as well as search for more suitable materials are recommended. Remaining the technical drawings simple is likely to contribute to an increased understanding and acceptance by the locals, and is therefore recommended in further studies.

5.0 Conclusion

The Faryab province in Afghanistan is largely dependent on groundwater as the main source of water supply. However, pollution, mainly in form of salt, is deteriorating an already scarce resource, and there is a need of sustainable and manageable solutions for production of drinking water to a low cost, to ensure a safe future for local inhabitants.

The results reveal that the solar still with an area of $1m^2$ can produce a water quantity of up to 4.9 l/m^2*day, and has potential to increase further, during increased temperatures in the later summer season.

Findings reveal that a double sloped solar still produces more than a single sloped still and wick solar still. Estimates suggest that the Plywood double sloped still and Plywood single sloped still is the most efficient when it comes to making use of temperature rises, with an increased production of 13 ml distilled water for each increased temperature unit (˚C). There was found no decrease in output when increasing salt concentration, however increased degradation of the materials was observed. The solar still with the lowest inclination, 11˚, is receiving the highest amount of radiation (W/m^2), compared to the inclinations of 19˚ and 36˚. The two solar stills of biggest size, Plywood double sloped and Plywood single sloped still, had the highest output. Mainly due to scale effects, larger area, higher temperatures inside the still, obtaining a black basin and has a bigger area for condensation. Cooling of the glass cover appear to lower, rather than increasing, the output. Experiments of application of coal to the basins also failed to increase the output.

Cost estimations range from 7$ to 70$ where the Plywood double sloped still was the most pricy. However, this was the first solar still built, and it is assumed that the cost will reduce with increased production.

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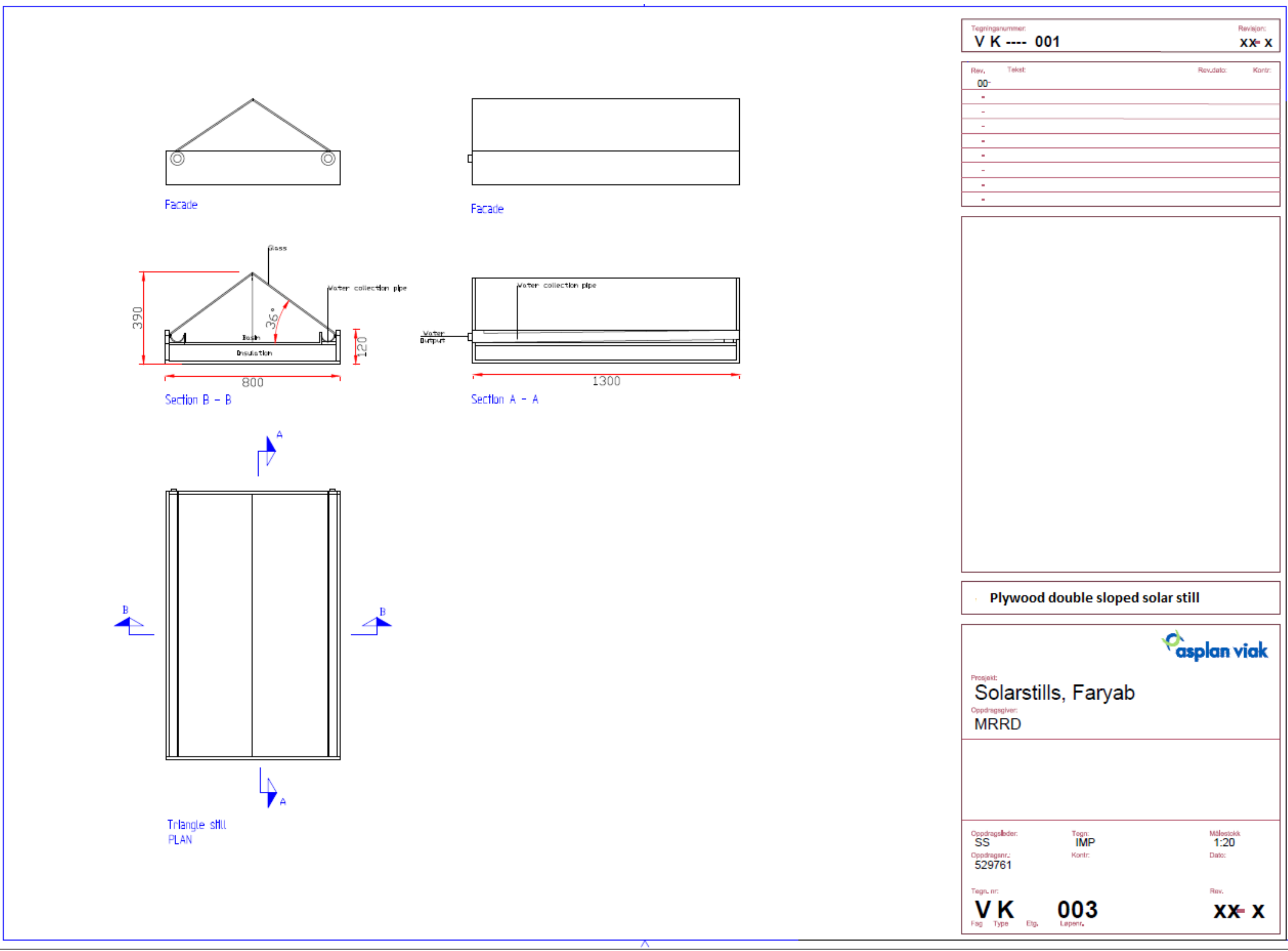
Appendix 1 – Water analysis from the Faryab province (Hassan et al., 2013)

Province	District	Sample Date	Analysis Date	Longitude	Latitude	EC (µS/cm)	pH	Chloride (mg/L)	Sulphate (mg/L)	Fluoride (mg/L)	Nitrate NO3 (mg/L)	Nitrite NO2 (mg/L)	Boron (mg/L)	Sodi-um (mg/L)	Chro-mium (mg/L)	Arse-nic (mg/L)	Faecal Coliforms (Col/100 ml)
Faryab	Khwaja Sabz Posh	13/06/05	14/06/05	64.96935	36.21174	2422	7.7	23	675	2.30	6.00	0.013	0.70	256	0.00	0.000	7
Faryab	Khwaja Sabz Posh	19/08/06	19/08/06	64.76291	35.90353	2060	7.2	23	320	1.10	1.08	0.004	0.65	232	0.00	0.000	22
Faryab	Khwaja Sabz Posh	23/08/05	24/08/05	65.09676	36.11281	2270	7.8	25	720	1.50	2.26	0.005	0.60	227	0.00	0.000	95
Faryab	Khwaja Sabz Posh	25/06/05	25/06/05	64.77049	36.17609	2022	7.6	21	622	2.30	6.28	0.020	0.60	324	0.00	0.000	6
Faryab	Khwaja Sabz Posh	17/05/06	17/05/06	64.77440	35.92225	481	7.9	8	95	1.20	2.38	1.130	0.55	155	0.00	0.000	7
Faryab	Khwaja Sabz Posh	02/05/09	02/06/09	69.20972	34.04400	12780	7.3	440	83	0.30	77.00	3.700	0.50	1751	0.00	0.000	3
Faryab	Khwaja Sabz Posh	04/04/09	04/05/09	69.76063	34.08727	12780	7.3	440	480	0.30	54.00	3.700	0.50	1751	0.00	0.000	7
Faryab	Khwaja Sabz Posh	22/11/08	12/01/08	70.08273	34.76348	1522	7.3	13	252	0.70	0.64	0.008	0.50	195	0.00	0.000	1
Faryab	Khwaja Sabz Posh	15/05/06	15/05/06	64.77521	35.93623	1620	7.2	16	260	1.20	2.08	0.001	0.50	114	0.00	0.000	3
Faryab	Khwaja Sabz Posh	16/05/06	16/05/06	64.77521	35.93623	1620	7.2	16	260	1.20	2.08	0.001	0.50	114	0.00	0.000	7
Faryab	Khwaja Sabz Posh	14/11/05	14/11/05	64.85755	36.06753	1620	7.5	16	270	1.30	2.20	0.007	0.50	50	0.00	0.000	3
Faryab	Khwaja Sabz Posh	13/08/06	13/08/06	64.79699	35.91831	1495	7.4	15	440	1.20	2.60	0.009	0.45	169	0.00	0.000	6
Faryab	Khwaja Sabz Posh	10/08/06	11/08/06	64.77625	35.91973	1684	7.5	22	320	1.20	4.98	0.001	0.45	90	0.00	0.000	5
Faryab	Khwaja Sabz Posh	14/05/06	14/05/06	64.71228	35.98653	1512	7.6	17	380	1.20	2.40	0.004	0.40	163	0.00	0.000	2
Faryab	Khwaja Sabz Posh	14/08/06	14/08/06	64.77408	35.91743	1655	7.6	22	322	1.20	5.40	0.002	0.40	137	0.00	0.000	5
Faryab	Khwaja Sabz Posh	14/11/05	14/11/05	64.66339	36.06780	1822	7.6	18	400	1.30	3.46	0.015	0.40	142	0.00	0.000	2
Faryab	Khwaja Sabz Posh	18/08/06	18/08/06	64.78460	35.91064	3650	7.8	44	790	1.10	5.34	0.006	0.35	515	0.00	0.000	0
Faryab	Khwaja Sabz Posh	21/05/06	21/05/06	64.73795	35.92570	3422	7.5	44	750	1.20	6.22	0.004	0.35	808	0.00	0.000	8
Faryab	Khwaja Sabz Posh	24/03/05	24/03/05	64.93383	36.39977	2660	8.2	40	83	4.20	2.42	0.011	0.35	273	0.00	0.000	8
Faryab	Khwaja Sabz Posh	26/08/08	26/08/08	66.18020	34.57056	1380	7.8	13	255	0.60	2.62	0.003	0.30	169	0.00	0.000	0
Faryab	Khwaja Sabz Posh	06/09/08	16/06/08	69.17068	34.58370	1554	7.5	17	360	0.70	4.24	0.002	0.30	126	0.00	0.000	7
Faryab	Khwaja Sabz Posh	09/04/08	09/04/08	69.18466	34.58554	1570	7.4	18	360	0.70	3.31	0.001	0.30	151	0.00	0.000	2

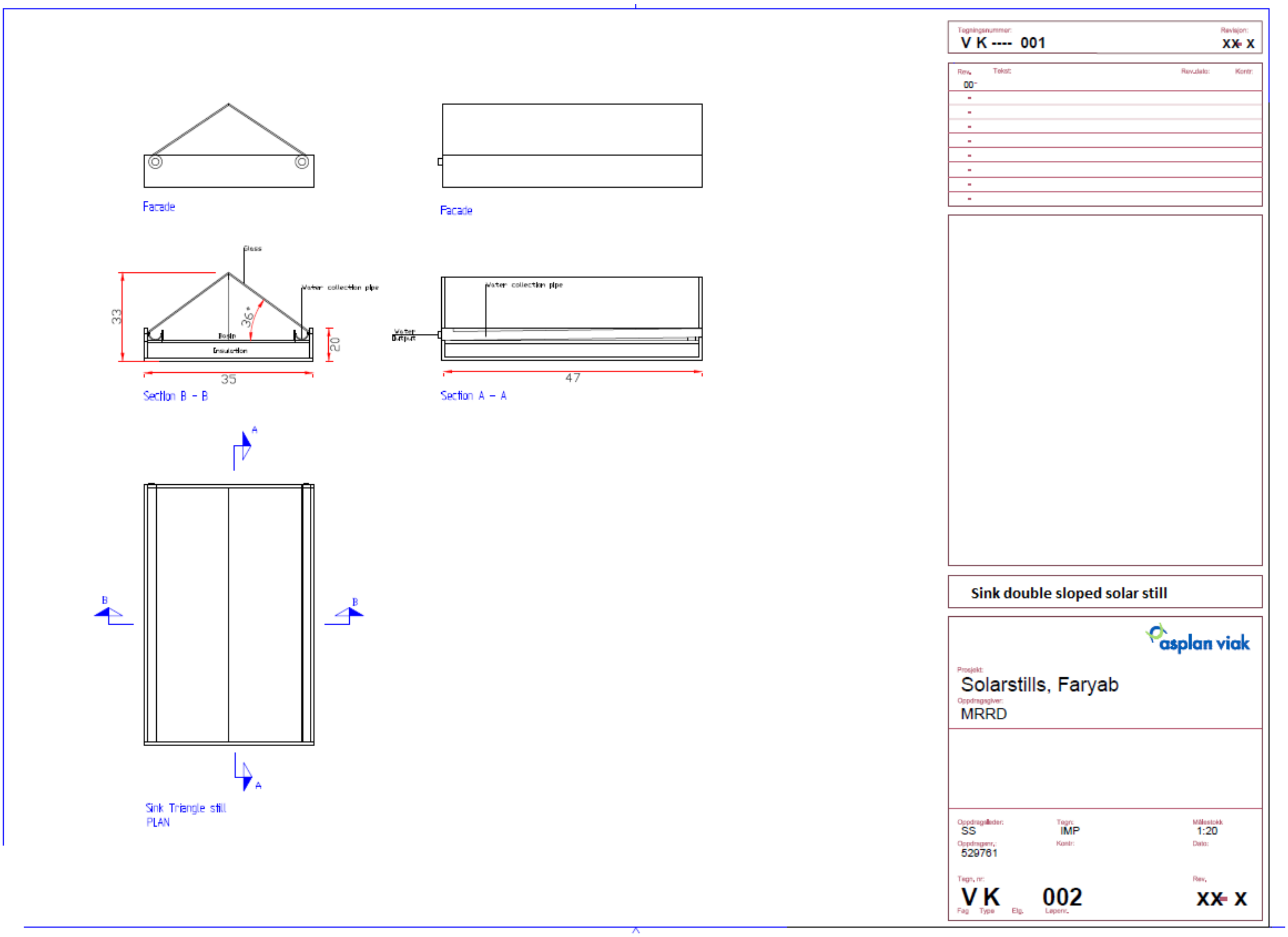
Province	District	Sample Date	Analysis Date	Longitude	Latitude	EC (µS/cm)	pH	Chloride (mg/L)	Sulphate (mg/L)	Fluoride (mg/L)	Nitrate NO3 (mg/L)	Nitrite NO2 (mg/L)	Boron (mg/L)	Sodi-um (mg/L)	Chro-mium (mg/L)	Arse-nic (mg/L)	Faecal Coliforms (Col/100 ml)
Faryab	Khwaja Sabz Posh	14/01/07	16/01/07	64.86603	35.82238	1241	8.5	9	255	1.10	2.12	0.016	0.30	124	0.01	0.000	20
Faryab	Khwaja Sabz Posh	13/08/06	13/08/06	64.77408	35.91743	1237	7.7	16	260	1.20	1.98	0.001	0.30	86	0.00	0.000	7
Faryab	Khwaja Sabz Posh	14/08/06	14/08/06	64.77408	35.91743	1422	7.6	18	253	1.20	5.70	0.001	0.30	101	0.00	0.000	11
Faryab	Khwaja Sabz Posh	12/05/06	12/05/06	64.77422	35.99886	1347	7.4	13	296	1.30	2.64	0.001	0.30	148	0.00	0.000	4
Faryab	Khwaja Sabz Posh	18/05/06	19/05/06	64.77954	35.92853	1275	7.3	13	252	1.20	2.22	0.007	0.25	108	0.00	0.000	3
Faryab	Khwaja Sabz Posh	23/08/05	24/08/05	65.09676	36.11281	1285	7.5	12	253	1.50	2.86	0.001	0.25	74	0.00	0.000	26
Faryab	Khwaja Sabz Posh	19/07/09	20/07/09	68.41833	33.55324	1216	7.7	11	48	0.20	3.38	0.003	0.20	151	0.00	0.000	7
Faryab	Khwaja Sabz Posh	02/02/09	02/02/09	61.78894	34.39420	800	8.7	11	83	0.50	1.22	0.013	0.20	32	0.00	0.000	3
Faryab	Khwaja Sabz Posh	07/01/09	07/01/09	68.86560	34.40553	800	8.7	11	150	0.50	1.22	0.013	0.20	32	0.01	0.000	5
Faryab	Khwaja Sabz Posh	05/09/06	05/09/06	64.82450	35.88859	1094	7.7	13	134	1.10	2.20	0.030	0.20	90	0.00	0.000	8
Faryab	Khwaja Sabz Posh	15/07/06	16/08/06	64.78392	35.91341	1191	7.5	14	280	1.10	1.90	0.007	0.20	72	0.00	0.000	22
Faryab	Khwaja Sabz Posh	27/11/05	27/11/05	64.66920	36.06519	1857	7.5	15	310	1.30	5.60	0.003	0.20	68	0.00	0.000	7
Faryab	Khwaja Sabz Posh	18/04/06	20/04/06	64.47458	36.02216	1510	7.9	16	58	1.30	1.28	0.004	0.20	129	0.00	0.000	3
Faryab	Khwaja Sabz Posh	20/04/06	20/04/06	64.67029	36.02277	1510	7.9	16	58	1.30	1.28	0.004	0.20	129	0.00	0.000	3
Faryab	Khwaja Sabz Posh	03/08/05	04/08/05	64.88157	36.14429	1226	7.4	10	288	1.60	2.18	0.001	0.20	168	0.00	0.000	16
Faryab	Khwaja Sabz Posh	27/03/05	24/03/05	64.93383	36.39977	2660	8.2	40	83	4.20	2.42	0.011	0.20	273	0.00	0.000	8
Faryab	Khwaja Sabz Posh	20/05/07	20/05/07	63.98873	35.71387	1440	7.6	19	260	1.00	2.22	0.002	0.15	80	0.00	0.000	41
Faryab	Khwaja Sabz Posh	27/08/07	27/08/07	64.74400	35.03570	1517	7.5	16	290	0.90	4.14	0.002	0.10	169	0.01	0.000	0
Faryab	Khwaja Sabz Posh	29/08/06	29/08/06	64.82450	35.88859	1228	8.6	10	270	1.10	2.48	0.014	0.10	147	0.01	0.000	15
Faryab	Khwaja Sabz Posh	11/04/07	11/04/07	65.28516	35.75345	1259	8.5	15	265	1.10	1.90	0.016	0.10	122	0.02	0.000	18
Faryab	Khwaja Sabz Posh	31/07/05	31/07/05	64.96008	36.15363	2590	7.5	46	640	1.70	3.54	1.360	0.10	336	0.01	0.000	6
Faryab	Khwaja Sabz Posh	05/08/05	29/08/05	65.09676	36.11281	1441	7.6	15	270	1.50	3.92	0.004	0.02	116	0.00	0.000	38

Province	District	Sample Date	Analysis Date	Longitude	Latitude	EC (µS/cm)	pH	Chloride (mg/L)	Sulphate (mg/L)	Fluoride (mg/L)	Nitrate NO3 (mg/L)	Nitrite NO2 (mg/L)	Boron (mg/L)	Sodi-um (mg/L)	Chro-mium (mg/L)	Arse-nic (mg/L)	Faecal Coliforms (Col/100 ml)
Faryab	Khani Chahar Bagh	04/01/05	04/01/05	65.22091	37.00222	4500	7.7	52	1460	12.00	51.00	1.117	2.55	424	0.00	0.000	0
Faryab	Khani Chahar Bagh	10/01/05	10/01/05	65.16219	36.99045	4800	7.5	52	1280	44.00	51.00	0.030	2.55	466	0.00	0.000	0
Faryab	Khani Chahar Bagh	10/10/05	10/01/05	65.16219	36.99045	4800	7.5	52	1280	44.00	51.00	0.030	2.55	466	0.00	0.000	3
Faryab	Khani Chahar Bagh	13/01/05	31/01/05	65.08032	36.91496	7670	7.4	52	2200	12.70	7.80	1.160	1.80	157	0.00	0.012	6
Faryab	Khani Chahar Bagh	31/01/05	31/01/05	65.08032	36.91496	7670	7.4	52	2200	12.70	7.80	1.160	1.80	157	0.00	0.012	3
Faryab	Khani Chahar Bagh	11/01/05	11/01/05	65.21907	36.96560	6200	8.0	54	3280	23.60	3.03	0.009	1.50	552	0.00	0.000	10
Faryab	Khani Chahar Bagh	11/10/05	11/01/05	65.11962	36.96402	6200	8.0	54	3280	23.60	3.03	0.009	1.50	552	0.00	0.000	3
Faryab	Khani Chahar Bagh	01/10/09	01/10/09	62.26257	33.35330	4070	7.8	48	1440	1.45	4.70	0.010	0.90	92	0.00	0.000	0
Faryab	Khani Chahar Bagh	03/08/09	03/10/09	62.25480	33.34745	4070	7.8	48	1440	1.45	4.70	0.010	0.90	92	0.00	0.000	3
Faryab	Khani Chahar Bagh	26/03/05	27/03/05	65.21885	36.34382	3250	7.6	44	1220	3.70	2.80	1.150	0.80	109	0.00	0.000	0
Faryab	Khani Chahar Bagh	26/03/05	27/03/05	64.89626	36.32240	3250	7.6	44	1220	3.70	2.80	0.050	0.80	109	0.00	0.000	3
Faryab	Khani Chahar Bagh	31/03/05	31/03/05	64.88933	36.28982	2800	7.9	44	910	2.80	4.00	0.020	0.70	15	0.00	0.000	0
Faryab	Khani Chahar Bagh	01/04/05	01/04/05	64.88803	36.28669	2800	7.9	44	910	2.80	4.00	0.020	0.70	15	0.00	0.000	3
Faryab	Khani Chahar Bagh	25/05/11	28/05/11	65.22091	37.00222	11240	6.8	57	4080	14.30	7.66	0.285	0.70	219	0.00	0.000	40
Faryab	Khani Chahar Bagh	22/03/05	22/03/05	64.87269	36.29333	2950	7.7	36	880	3.00	8.80	0.010	0.60	276	0.00	0.000	0
Faryab	Khani Chahar Bagh	22/03/05	22/03/05	64.87269	36.29333	2950	7.7	36	880	3.00	8.80	0.010	0.60	276	0.00	0.000	3
Faryab	Khani Chahar Bagh	03/03/05	04/03/05	67.70137	36.55800	2560	7.8	46	750	6.80	4.60	0.008	0.35	1197	0.00	0.000	6
Faryab	Khwaja Sabz Posh	22/01/05	22/01/05	65.17838	36.93344	2510	7.8	32	440	14.30	0.46	1.230	8.00	293	0.00	0.000	0
Faryab	Khwaja Sabz Posh	22/01/05	22/01/05	65.17838	36.93344	2510	7.8	32	440	14.30	0.46	1.230	8.00	293	0.00	0.000	0
Faryab	Khwaja Sabz Posh	22/01/05	22/01/05	65.10069	36.92699	2510	7.8	32	440	14.30	0.46	1.230	8.00	293	0.02	0.000	0
Faryab	Khwaja Sabz Posh	14/09/05	14/09/05	64.84572	36.10773	5010	7.8	100	1650	1.50	5.34	0.009	3.50	714	0.00	0.000	7
Faryab	Khwaja Sabz Posh	22/07/05	22/07/05	64.93157	36.15664	2020	7.5	29	322	1.80	3.68	0.013	3.50	192	0.00	0.000	6
Faryab	Khwaja Sabz Posh	16/06/05	16/06/05	64.86400	36.20352	3290	7.6	42	700	2.30	5.26	0.005	3.00	216	0.00	0.000	1
Faryab	Khwaja Sabz Posh	04/03/05	04/03/05	66.79360	36.65803	2010	7.2	25	710	7.50	0.88	0.000	3.00	167	0.00	0.000	1
Faryab	Khwaja Sabz Posh	04/03/05	04/03/05	66.79360	36.65803	2010	7.2	25	710	7.50	0.88	0.000	3.00	167	0.00	0.000	1
Faryab	Khwaja Sabz Posh	01/08/07	01/08/07	69.65229	35.08959	2210	7.3	15	650	0.90	0.92	0.008	2.50	390	0.00	0.000	7
Faryab	Khwaja Sabz Posh	14/12/05	14/12/05	64.84865	36.04337	1372	7.2	18	255	1.30	1.02	0.000	2.40	154	0.00	0.000	2
Faryab	Khwaja Sabz Posh	14/12/05	14/12/05	64.85559	36.04106	1372	7.2	18	255	1.30	1.02	0.000	2.40	154	0.00	0.000	7
Faryab	Khwaja Sabz Posh	24/10/05	24/10/05	64.84037	36.08114	1681	7.4	20	270	1.40	3.90	0.004	1.50	149	0.00	0.000	7
Faryab	Khwaja Sabz Posh	18/05/06	18/05/06	64.77762	35.92854	1870	7.5	16	440	1.20	4.64	0.002	1.00	140	0.00	0.000	15
Faryab	Khwaja Sabz Posh	18/03/06	19/03/06	64.67029	36.02277	1510	7.9	16	58	1.30	1.28	0.004	0.90	129	0.00	0.000	5
Faryab	Khwaja Sabz Posh	24/03/05	25/03/05	64.78998	36.37610	2660	8.2	40	83	4.20	2.42	0.011	0.80	273	0.00	0.008	3
Faryab	Khwaja Sabz Posh	24/03/05	25/03/05	64.78998	36.37659	2660	8.2	40	83	4.20	2.42	0.011	0.80	273	0.00	0.008	3
Faryab	Khwaja Sabz Posh	25/02/05	26/02/05	68.86592	36.79553	2880	7.4	40	252	8.70	0.00	1.100	0.80	102	0.00	0.000	1
Faryab	Khwaja Sabz Posh	12/05/06	12/05/06	68.68722	35.99419	1509	7.6	15	260	1.30	1.58	0.003	0.75	135	0.00	0.000	4
Faryab	Khwaja Sabz Posh	13/05/06	13/05/06	64.81625	35.99365	1509	7.6	15	260	1.30	1.58	0.003	0.75	135	0.00	0.000	7
Faryab	Khwaja Sabz Posh	14/05/05	14/05/06	64.73227	35.96491	1387	7.5	13	255	1.20	1.44	0.001	0.70	136	0.00	0.000	3
Faryab	Khwaja Sabz Posh	14/05/06	14/05/06	64.73227	35.96491	1387	7.5	13	255	1.20	1.44	0.001	0.70	136	0.00	0.000	7

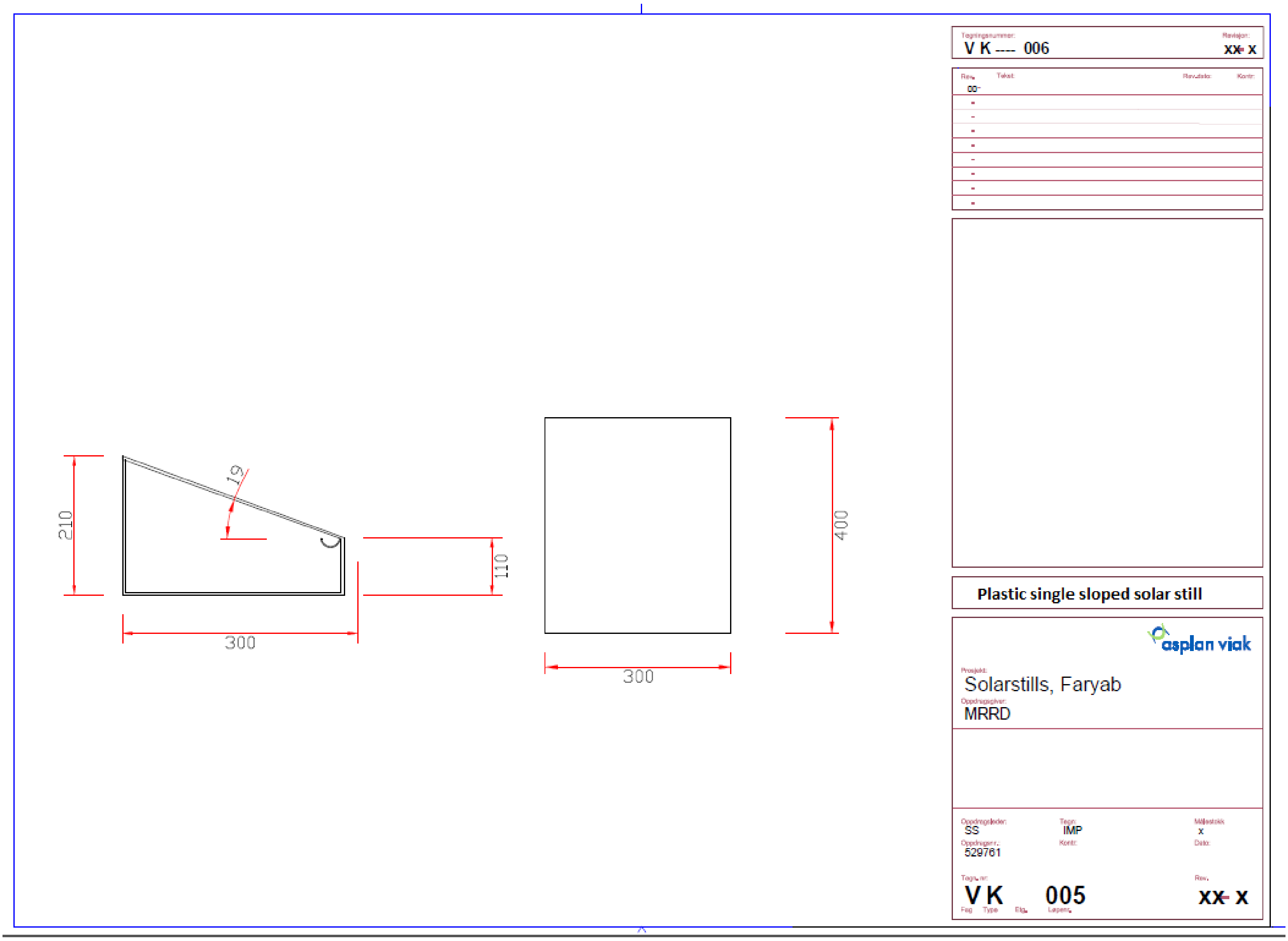
Annex 1: Technical drawing of the Plywood double sloped solar still



Annex 2: Technical drawing of the Sink double sloped solar still

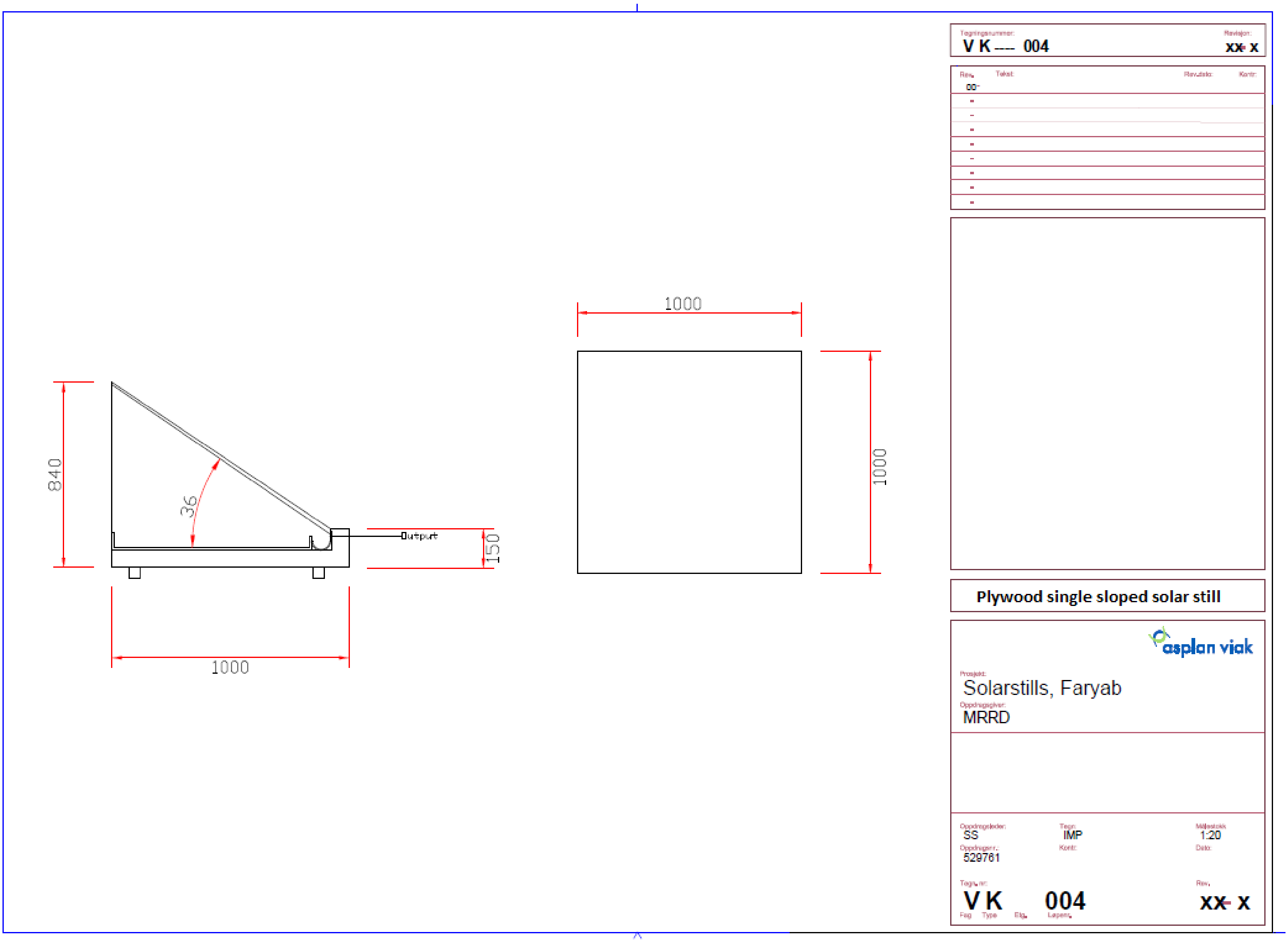


Annex 3: Technical drawing of the Plastic single sloped solar

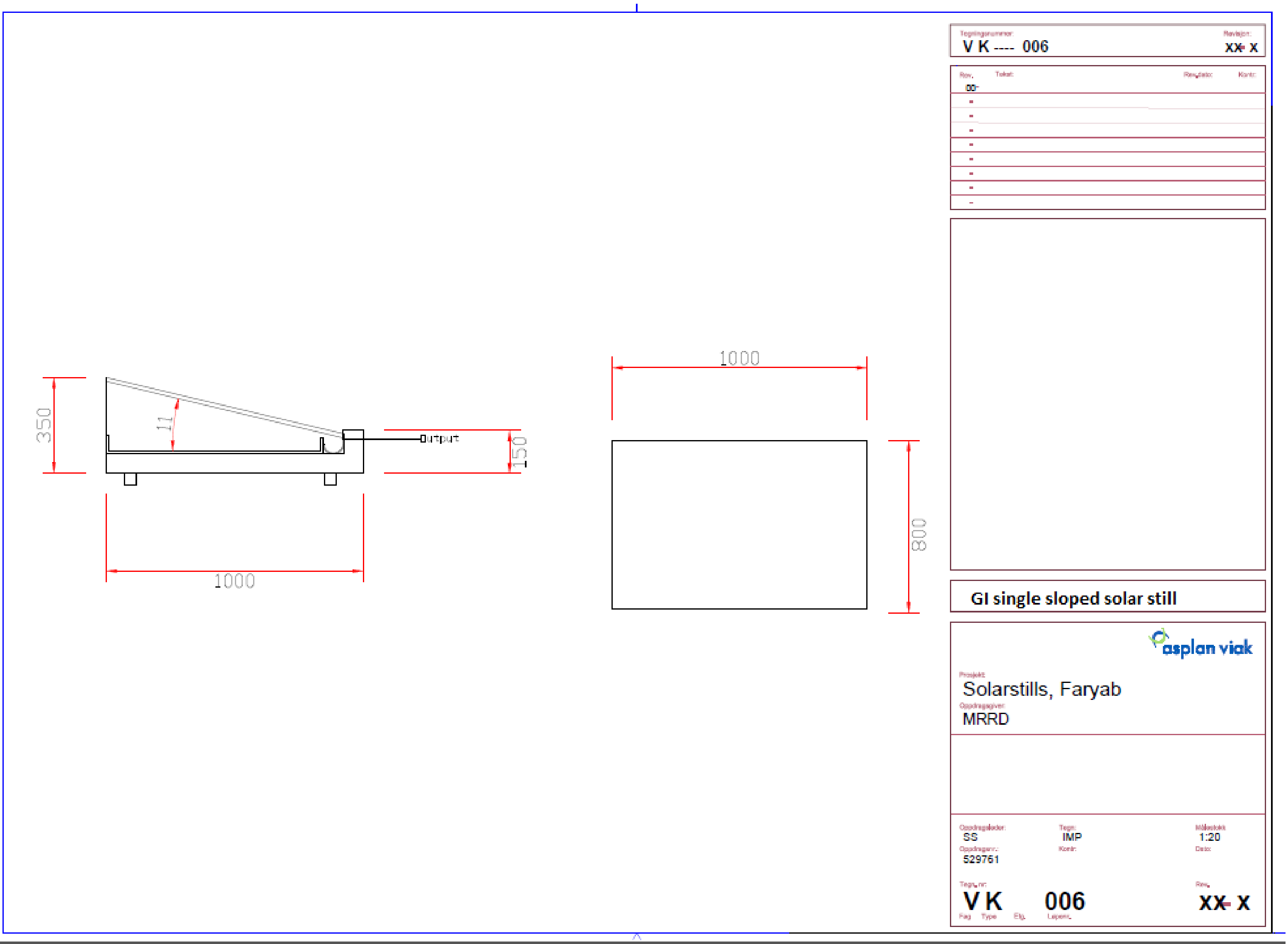


still

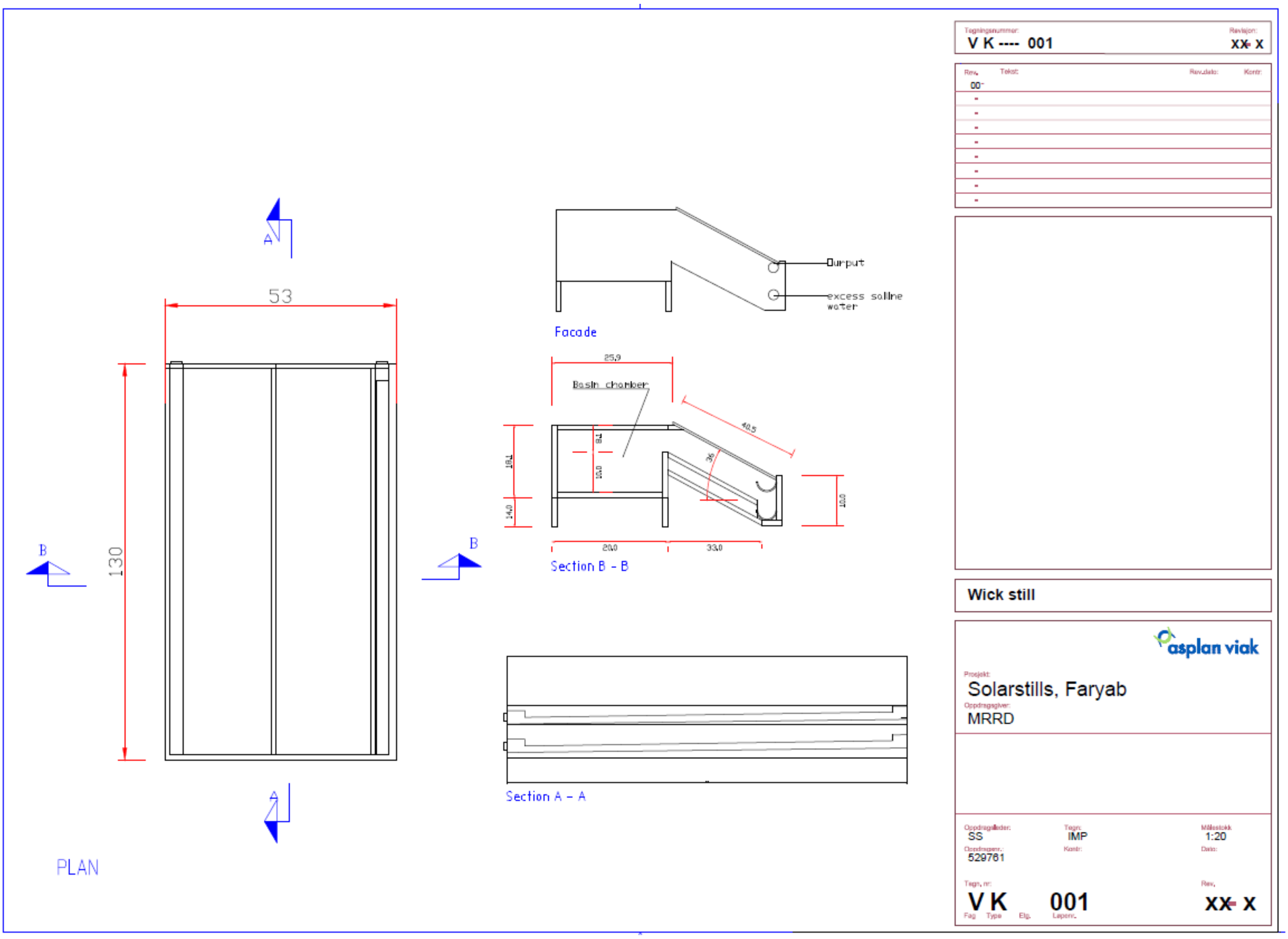
Annex 4: Technical drawing of the Plywood single sloped solar still



Annex 5: Technical drawing of the GI single sloped solar still



Annex 6: Technical drawing of the Wick solar still



Annex 7: Pictures

Picture 1:The solar stills

Picture 2: The team at NCA

Picture 3: The plywood single sloped and the plywood double sloped solar still

Picture 4: Shogofa recording temperatures

Picture 5: Cooling of the glass cover by at wet blanket on the Plywood double sloped solar still.

Picture 6: Plastic single sloped, GI single sloped, Wick still, Plywood double sloped and Plywood single sloped solar still

PICTURE 7: BRUSHING OF THE SS SHEET.

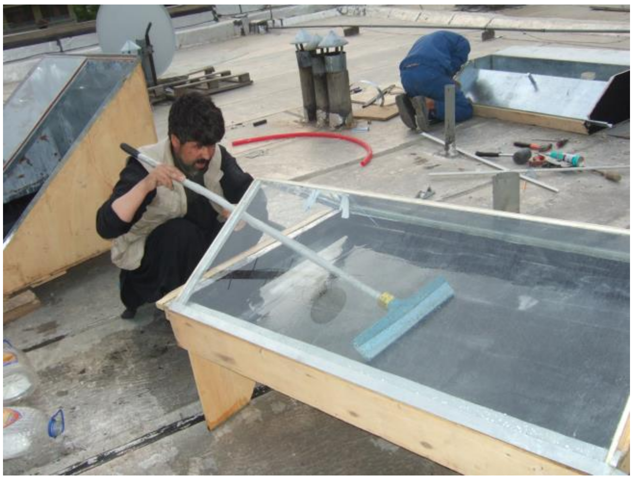
PICTURE 8 : PURCHASING GLASS AND RUBBER GASKET

PICTURE 9: PAINTING THE BASIN OF THE SINK DOUBLE SLOPED SOLAR STILL

PICTURE 10: PAINTING THE PLYWOOD ON THE PLYWOOD SINGLE SLOPED SOLAR STILL

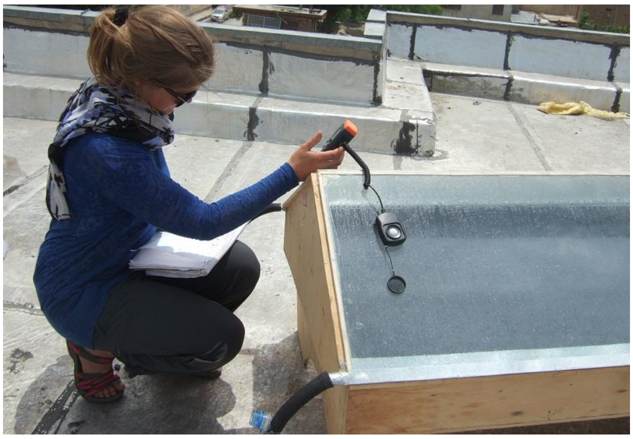
PICTURE 11: FIXING THE DISTILLATION CHANNEL ON THE PLASTIC SINGLE SLOPED SOLAR STILL

PICTURE 12: CARPENTERS INSTALLING THE GLASS COVER ON THE SINK DOUBLE SLOPED SOLAR STILL



Picture 13: Maintenance on the Plywood double sloped solar still

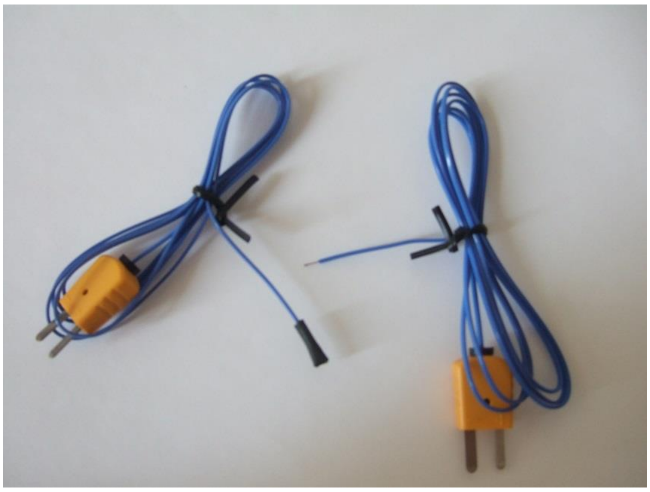
Picture 14: Maintenance on the Plywood single sloped solar still



Picture 15: Measuring radiation

Picture 16: Measuring output

Picture 17: Recording temperatures



Picture 18; Temperature sensors (TP01)

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