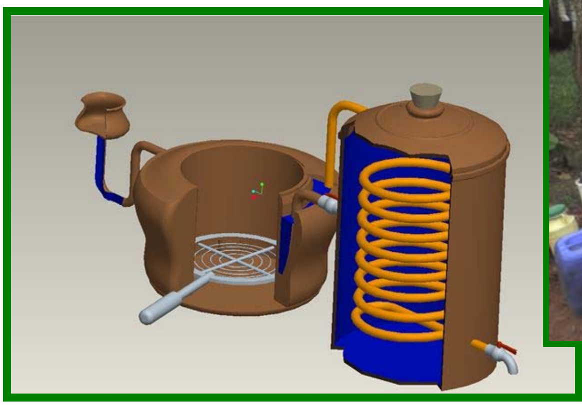
Entry to the Stockholm Junior Water Prize [2008]

Firewood Hearth Distiller For Safe Drinking Water for Vulnerable Rural Populations



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Abstract

The value of water as a finite natural resource is becoming more and more highlighted, due to its depletion and pollution. Although the situation is equally appalling with both ground and surface water, the latter is given prominence merely due to the fact that surface water pollution is more visible. About 60- 70% of Sri Lankan have access to a safe drinking water source, but only a mere 30-40% enjoy the luxury of pipe borne water. Still ground water is the major drinking water source for many rural areas of the country, and more importantly it's the major water-source of the rural-poor.

Issues related to ground water in the dry zone of Sri Lanka range from depletion of deep confined aquifers due to poorly planned Tube Well schemes to pollution of shallow unconfined aquifers due to leaching of chemical fertilizer. Large numbers of fluorosis cases are reported from the North-western and South-eastern areas of the country owing to the geo-chemistry of the area. The ground water issues are not only physical in nature; concerns are being raised by many experts in the country about the water rights of ground water aquifers in the already water stressed areas of the dry zone and possibilities of conflicts in future industrialization of these areas. The market liberalization policies adopted by the Sri Lankan government in the late 70s dramatically changed the resources utilization patterns of the country, little research has been done on the impact of these shift in policy on the dry zone groundwater resources.

This project highlights the present day issues related to the contamination of groundwater in the Dry Zone of Sri Lanka aiming to provide a technique to vulnerable rural poor who do not have access to safe drinking water, having difficulties to get firewood to boil water as proposed by health authorities. The intervention is to provide a total solution while providing an easy to afford, limited maintenance and environmentally friendly (both forests and air) means to meet the drinking water requirement, irrespective of the quality of the water that communities have access to. The system developed is an add-on to a system that they use.

Firewood hearth distiller is a developer of the improved combustion stove called "Anagi Unduna". By using this heat wasted through cooking using "Anagi Unduna" amounting to 73% of the total energy generated through firewood combustion could be used to produce safe drinking water. 1 kg of firewood is producing 1.13 Liters of safe drinking water. A house hold where consumption is about 8 kg of firewood for daily cooking produces 9-10 Liters of safe drinking water which 100% full fills the drinking water requirement of 4-5 people.

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Abbreviations and Acronyms

Al	-	Aluminium
Dry Zone	-	Zone where the annual rainfall is around 500 mm to 1500 mm in Sri Lanka
F	-	Fluoride
ICS	-	Improved Cook Stoves
ISB	-	Industrial Services Bureau
ISB ES	-	ISB Environmental Services
kg	-	Kilogram
kT	-	Kilo Ton
l	-	Litre
min	-	Minutes
ml	-	milliliter
NCP	-	North Central Province
NWP	-	North Western Province

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1.0 Introduction

1.1 Problem Studied

Some 1.1 billion people in the developing world do not have access to minimum quantity of safe drinking water [15]. This is partly due to the high cost of water supply and purification technologies. Even when the systems were provided by donor's communities and governments find it difficult to maintain them. In Sri Lanka only 31% of the total population is covered with pipe borne water supply whereas 10 % of the population is covered with hand pump tube wells [1]. Today around 3 million of people in Sri Lanka are in need of safe drinking water [2].

Sri Lanka is divided into three main climatic zones according to the annual rain fall. Major portion of the land comes under the Dry Zone where the annual rainfall is around 500 mm to 1500 mm. Dry zone of Sri Lanka historically had many water related problems and which were given deferent types of solutions at different times.

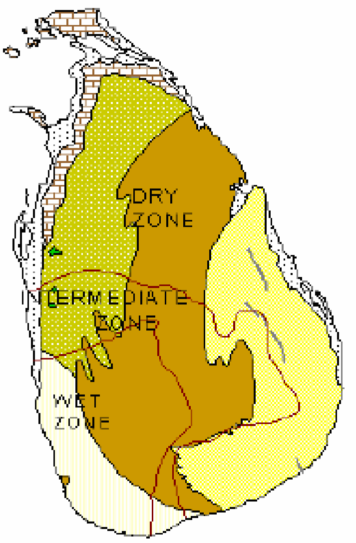


Figure 01: Three zones in Sri Lanka

The main available water resource in the Dry Zone for potable use is ground water. There are many water quality related issues in the Dry Zone of Sri Lanka, some are related to industrial or agricultural pollution of aquifers whereas other are more connected with natural geochemistry of the area.

- The water extraction from ground must not exceed the aquifer's replenishment capacity. But in the dry zone surface water supply is very much lower than the demand. Because of over-extraction of water, the wells dry-out in coastal areas and brackish water enters in to the wells and ended up with high salinity concentrations.
- Usually, the Fluoride level is high in Dry Zone water. The level of Fluoride is more than 1mg/l in many Dry Zone areas [1]. When over-extraction of ground water occurs, the concentration of Fluoride will be increased. In the Dry Zone around 327,000 people are at the risk of fluoride related dental diseases [13].
- Leaching of agro chemicals used by farmers to the ground water causes problems. The nitrate levels in the Kalpitiya peninsula is between 133 – 221 mg/l [14]. The blue baby syndrome is a commonly found disease in Kalpitiya and this is mainly due to use of nitrate contaminated water.

Water bone diseases add pressure to the development budgets, drain resources and affect the quality of lives of affected and their loved ones. People spend hours fetching water daily for drinking. For example, around 3,000 people have registered with kidney diseases in the dry zone in Sri Lanka and due to the fear that kidney diseases are caused by poor quality water the communities tend to consume less water resulting further dehydration of their bodies.

In Sri Lanka and around the world it is necessary to provide these vulnerable communities with affordable tools and techniques to clean contaminate water and build their capacity to use the techniques. Due to the poor education levels prevailing in these communities, the systems provided needs to be easy to operate and with minimum maintenance. Therefore most of the chemical filters provided to communities are not being maintained nor replaced. Energy efficiency is another factor to be concerned as these poor groups have limited access to energy and often depend on firewood which is also a rare commodity.

1.2 Background information.

Out of 71% of the global water resources available in the whole world, only 2.78% is available as fresh water [3]. This amount is used for different types of applications and some activities are shown in the following table;

Type of use	Amount of water (Liters /day)
For drinking (elder person)	2
For washing at toilet (one time)	20
For Washing clothes (one time)	170

Table 01: Water requirement for different activities [3]

Drinking water could be contaminated at the original water source, during treatment, or during distribution to home.

- **If water comes from surface water (river or lake)**, it can be exposed to acid rain, storm water runoff, pesticide runoff, and industrial waste. This water is cleansed somewhat by exposure to sunlight, aeration, and micro-organisms in the water.
- **If water comes from groundwater (private wells)**, it generally takes longer to become contaminated but the natural cleansing process also may take much longer. Groundwater moves slowly and is not exposed to sunlight, aeration, or aerobic (requiring oxygen) micro-organisms. Groundwater can be contaminated by disease-producing pathogens, and septic systems, careless disposal of hazardous household products, agricultural chemicals, and leaking underground storage tanks.

1.2.1 Water quality related issues

The levels of contaminants in drinking water are seldom high enough to cause acute (immediate) health effects. Examples of acute health effects are nausea, lung irritation, skin rash, vomiting, dizziness, and even death. Infants under six months of age are susceptible to nitrate poisoning.

The resulting condition is referred to as methemoglobinemia, commonly called "blue baby syndrome."

Contaminants of water are more likely to cause chronic health effects - effects that occur long after repeated exposure to small amounts of a chemical such as Fluoride, Nitrates, etc. Examples of chronic health effects include Dental Fluorosis, Chronic Renal Failure, cancer, liver and kidney damage, disorders of the nervous system, damage to the immune system, and birth defects.

Area	Total Population	Population served by pipe borne water	Percentage
Dry zone	5,333,612	484,045	9%

Table 02: Pipe born water supply in Dry Zone [1]

1.2.1 Health Concerns

High Salinity Level in drinking water

Brackish water was infiltrated and mixed with fresh groundwater lenses as indicated by the elevated groundwater salinity levels. Long-term consumption of highly saline water designated health impacts under the term "stone disease".

High Nitrate (NO_3) Concentrations in drinking water

Drinking water high in nitrate is potentially harmful to human and animal health. Nitrate (NO_3) is a naturally occurring form of nitrogen (N) which is very mobile in water. It is essential for plant growth and is often added to soil to improve productivity. Water moving down through soil after rainfall or irrigation carries dissolved nitrates with it to ground water. In this way, nitrate enters water supplies of many homeowners who use wells.

The most noticeable symptom of nitrate poisoning is a bluish skin coloring, called cyanosis, particularly around the eyes and mouth. Most reported cases of blue baby syndrome due to contaminated water have occurred when infant formula was prepared using water with greater than 40 mg/L NO_3-N.

High Fluoride concentrations in drinking water

In Sri Lanka, concentrations up to 10 mg l^{-1} are found in groundwater in the Dry Zone, associated with dental and possibly skeletal fluorosis [4]. Fluoride has beneficial effects on teeth at low concentrations in drinking-water, but excessive exposure to fluoride in drinking-water, or in combination with exposure to fluoride from other sources, can give rise to a number of adverse effects. These range from mild dental fluorosis to crippling skeletal fluorosis as the level and period of exposure increases. Crippling skeletal fluorosis is a significant cause of morbidity in a number of regions of the world.

Problems relating to elevated levels of fluoride in drinking-water in Sri Lanka are relatively recent and reflect the increase in the number of tube wells, particularly in the "Dry Zone", where levels of fluoride up to 10 mg l^{-1} have been reported [4]. Defluoridation, using charcoal and charred bone meal, has been introduced in some areas. [4][5].

1. 2 Related Works

There are several projects operated and still doing promotional campaigns along with the awareness creation among the affected communities to introduce different types of treatment methodologies to people living in areas where safe drinking water scarcity prevailed. Given below are the possible treatment methods available in Sri Lanka promoted by several institutions;

- Fluoride filter – using brick pieces [2]
- Rain water harvesting – Tanks [1] to reduce using ground water contaminate with high Nitrate concentrations
- Introducing of Charcoal Filters [2] to reduce salinity level

Figure 02: Fluoride filter

Most people who lack access to safe drinking water are the poor who lack the means to obtain good quality water. Even though there are technologies available such as fluoride filters, charcoal filters etc due to poverty-related issues they cannot afford for such treatments.

1.3 Potential for the recovery of Waste Energy for safe drinking water

Most of the Sri Lankan households in rural areas use firewood using either most inefficient three-stone stove or semi-enclosed mud stove (nearly 50 – 60% of the population) for their daily cooking. Further, this type is also used by nearly half (around 40-45%) of the households in the Dry Zone, where firewood is more abundantly available. [8]

Figure 03: Semi enclosed stove and three stone stoves

Improved cooking stoves (ICS) have been introduced to Sri Lanka by various organizations in late 90s [7] to minimize waste heat reduce air quality problems and improved efficiency. Following figures show two types of ICS;

Figure 04: Improved cook stoves (Anagi 1 & Anagi 2)

Need to use the improved stoves is encouraged due to the scarcity of fuel wood, potential indoor pollution due to smoke from conventional stoves. As the improved stoves are gaining popularity around the world, adding a water purification system on to the improved stove will reduce educational affords and will allow poor vulnerable populations to enjoy the multiple benefits that include health, environment and economic benefits.

Following tables give details on ICS and firewood consumption.

Stove type	**% of number of housing units**		**Fuel wood consumption (kT/year)**	**Efficiency (%)**
	Rural	**Urban**		
Traditional three stone units	47	56	5,029.5	8
Semi enclosed stoves	32	31	2,281.6	13 - 18
Improved Cook stoves	21	13	1,015.9	22 – 27
Total			**8,327.0**	

Table 03: Stoves distribution, firewood consumption and efficiencies [8] [9]

In our research, we have been trying to incorporate these two issues and provide a solution to both safe drinking water problem and reduce indoor air pollution levels/wastage of firewood by introducing a new firewood hearth to the community who are mostly affected.

1.4 Objective of the research

The overreaching objective of this research is to improve the health conditions of rural community in Sri Lanka by providing adequate safe drinking water. The specific objective is to develop a firewood hearth distiller to produce safe drinking water by rural communities with minimum cost, improved fuel wood efficiency, reduce air pollution and easy maintenance.

2.0 Materials and Methods

2.1 Materials

2.1.1 <u>Lab experiment</u>

Following items were used for the laboratory experiment

- Liebig Condenser
- Measuring Cylinder (1000 ml capacity which could measure 1 ml min)
- Gas burner
- Gas Cylinder
- Water
    - Sample water
    - Water for condenser
- Stop watch

Figure 05: Liebig Condenser

2.1.2 <u>Field experiment</u>

2.1.2.1 Firewood hearth with mini boiler

- Clay
- Valve (Φ – ½ inch)
- U tube (Φ – ½ inch, length 6 inch)

2.1.2.2 <u>Other materials used,</u>

- Copper tube – to form the steam condenser (Φ – ½ inch, length 3 feet)
- Clay pot – to store feed water and house the condenser
- Tap (½ inch)
- Measuring instruments (ruler, measuring cylinder (1000 ml), beaker (1000 ml), Thermometer 0-200^{0}C)
- Stop watch

2.2 Experimental Method

2.2.1 Lab experiment

To check the efficiency and suitability of distillation methodology to be used in removal of unwanted chemicals dissolved in water, laboratory experiments were carried out using a water boiler whose outlet was connect to a Liebig's condenser. Following steps were carried out in the laboratory;

i. Arranging of samples rich in high Nitrate, fluoride and salinity concentrations.
ii. Apparatus were arranged as in the figure 05 for the experiment
iii. Three water samples were analyzed for raw water quality for following parameters which have high Fluoride concentration, high Nitrate concentration and high Salinity;
    - pH

- Total Dissolved Solids (TDS)
- Nitrates (NO_3)
- Fluoride (F)
- Electrical Conductivity

iii All three samples were evaporated and condensate was collected for 01 hour.

iv Condensate for three samples were analyzed for the above 05 parameters.

Energy released from the burner and rate of collection of distillate was calculated.

2.2.2 <u>Field experiment</u>

2.2.2.1 Firewood hearth distiller

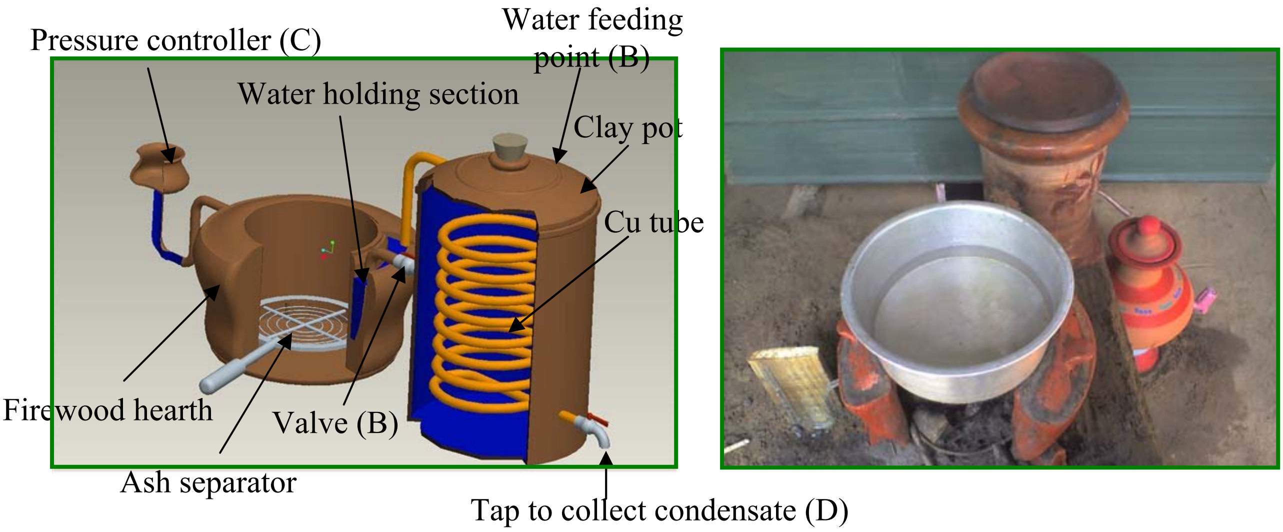


Figure 06: Firewood hearth distiller Front view and field experiment

Figure 07: Collecting required data

Three samples were collected from three locations in the Dry Zone, in cities Eppawala, and two locations in Kalpitiya where high nitrate concentration available and high salinity concentration available.

Following table shows the basic details of samples;

Location in Dry Zone	Reason
Eppawala	high Fluoride concentration
Kalpitiya Location 01	high Nitrate concentration
Kalpitiya Location 02	high Salinity

Table 04: Details of samples

At the time of cooking, using waste heat recovered from side walls of the firewood hearth produced with mini boiler (water jacket) boiled contaminated water in the water jacket and produce steam. Impurities such as inorganic compounds and large non-volatile organic compounds are not vaporized and are left behind in the water jacket of the firewood hearth. The heat inactivates bacteria, viruses and protozoan cysts. The steam rises and enters the Cu tube through the clay tube provided in the water jacket which is a cooling section containing condensing Copper (Cu) coil. The steam cools, condenses back to a liquid, and the water flows in to a storage container through the pipe D.

A firewood hearth, water jacket is connected to the water supply line coming from the pot which installed Cu tube coil thus recovering the heat released when condensing. A continuous flow of the water going in to the water jacket is allowed by regulating the flow using a valve at point B. The water and impurities remaining in the boiling chamber are periodically removed through a discharge line water jacket. Pressure developed will be released if any emergency occurred through point C where the small pot filled with water and U tube connected to the steam side of the water jacket. Raw water is fed through point A as required.(Cross refer to figure 6)

This collected water can have up to 99.5% of impurities removed. The water remaining in the water jacket has a much higher concentration of impurities. This water is removed by a drain and discarded.

All three samples were analyzed for raw water quality and allowed all three samples pass through the water jacket and distillate for all three samples collected separately.

2.2.3 Measurements

2.2.3.1 General measurements;

Measurement	Remarks
Volume of water in the pot which was boiled	To calculate the useful energy of the hearth
Initial temperatures of water	
Final volume of water in the pot	
Weight and the moisture content of the firewood used	To calculate the total energy produced through combustion
Amount of water distilled	To calculate the rapidity of the mini boiler
Time taken	

Table 05: General measurements taken and its relevance

2.2.3.2 Scientific measurements;

Raw water samples and distilled water samples were analyzed for following parameters;

- pH
- Electrical Conductivity (Instead of salinity, if EC high salinity is at higher level)
- Electrical Conductivity
- Nitrate
- Fluoride

3.0 Results

3.1 Lab experiment

3.1.1 General measurements

Distillate recovery : 1 Liter

Time taken : around 01 hour

3.1.2 Chemical analysis

Chemical analysis was done using spectrophotometer and pH meter for raw and distillate waste samples.

Sample	Raw water	Distillate
Saline water (S1)	RW1	D 1
Water rich in Fluoride (S2)	RW2	D 2
Water rich in Nitrate (S3)	RW3	D 3

Table 06: Sample categorization

Parameter	Units	Analysis						Permissible Level*
		RW1	D1	RW2	D2	RW3	D3	
pH	-	7.97	7.2	7.38	7.0	6.64	7.1	6.5 – 9.0
EC	µc/cm	4,290	231	387	05	436	17	3,500
Nitrate	mg/l	1.3	0.0	0.6	0.0	14.5	0.04	10.0
Fluoride	mg/l	0.01	00	3.96	00	0.32	00	1.5

Table 07: Water quality analysis data

* - Permissible level gazette by the Sri Lanka Standards Institute for drinking water standards under SLS 614 : 1985 Part 1 & 2

3.2 Field Experiment

3.2.1 General measurements

Ambient Temperature : 30^0C

Specific heat capacity of firewood : 12,500 kJ/kg @ 20% moisture [8]

Specific heat capacity of water : 4.2 kJ/kg

Weight of Aluminum (Al) pot : 0.16 kg

Specific heat capacity of Al : 0.9 kJ/kg

Measurement	Units	Normal Hearth	Hearth with Distiller
Initial volume of water in the Al pot	ml	3,000	3,000
Final volume of water in the Al pot	ml	2,200	2,785
Initial weight of firewood	kg	1	1
Final weight of firewood	kg	0	0
Volume of distillate	ml	NA	1,290
Time taken	min	60	60

Table 08: Measurements data

Note: NA – Not applicable

Assumptions made;

- No leakages in the system.
- Combustion is at highest efficiency.
- Energy waste to the environment as body losses and other all losses are considered as constant and make it to minimum.
- Water in the water jacket, evaporated as steam, 100% condensed and collects as distillate.

3.2.2 Quality analysis of Distillate

Quality of water collected through condensate pipe is measured for all three parameters and raw water quality was tested and tabulated as follows;

Parameter	Units	Analysis						Permissible level [15]
		RW 1	D1	RW 2	D2	RW 3	D3	
pH	-	7.97	7.5	7.38	7.5	6.64	7.5	6.5 – 9.0
EC	µc/cm	4,290	320	387	08	436	22	3,500
Nitrate	mg/l	1.3	0.0	0.6	0.0	14.5	0.03	10.0
Fluoride	mg/l	0.01	00	3.96	00	0.32	00	1.5

Table 09: Quality of raw sample and distillate

4.0 Discussion.

There is an increasing awareness about health problems associated with drinking contaminated water. This is common to most under-developed and developing countries in the world.

The contaminants present in water vary mainly due to demography, industrial and agricultural pollution. For example, presence of nitrates, phosphates etc may be attributed to industrial effluents, poor sewerage systems and excessive use of fertilizers in agricultural land. Also high salinity levels experienced in most coastal areas due to over extraction of water from wells and intrusion of sea water in to the ground water table.

The commonly used treatment methods tend to be non-affordable to most societies in Sri Lanka. We have such problems prevalent in most areas in dry zone – hence the need for looking at an innovative way of providing drinking water of acceptable quality.

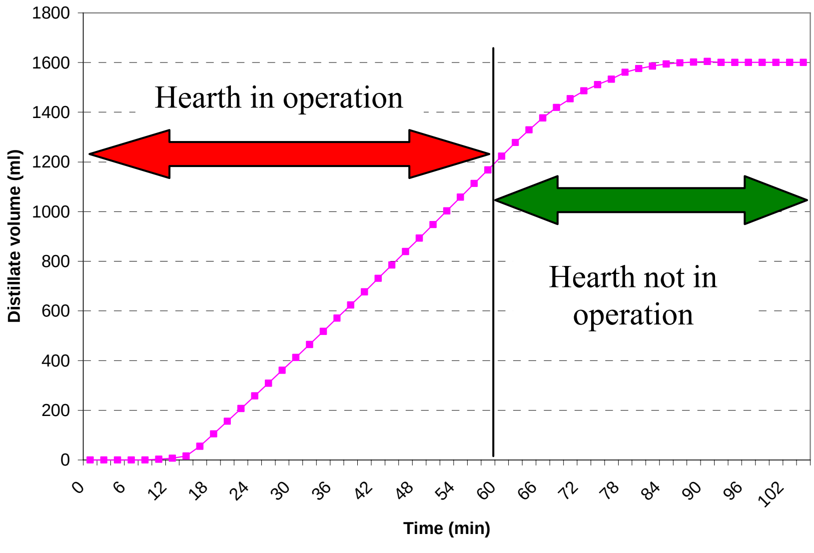
It is commonly accepted that most of these impurities (except volatile organics) can be removed effectively by distillation. However, distillation processes are quite expensive and continue to escalate due to ever increasing prices of energy. In general, this method of producing drinking water would be considered as one of the most expensive processes.

The intension of this research project is to introduce a firewood hearth distiller to produce safe drinking water and thereby to improve the health conditions where safe drinking water scarcity is prevailed to minimize the risk of kidney and other water-borne diseases distiller locally, nationally and even globally.

From the theory we learn from our school and based on the theory on water cycle, we search for a new method to distill water in an economical way. Through our survey, we realize that the waste heat released from the firewood hearth could be used to produce safe drinking water. We tested for the firewood hearth available in the market to assess the amount of waste heat and there by we learn that about 73% of energy is wasted during the cooking.

In Sri Lanka, main source of energy for cooking in domestic sector is fuel wood. Nearly 80% of the population of Sri Lanka depends on firewood and other forms of biomass for their daily cooking purposes [6]. As discussed in the section 1.3 less than half (around 40-45%) of the households in the Dry Zone use either three-stone stove or semi-enclosed mud stove for their daily cooking. Energy efficient “Anagi” stove is not much popular and uses about 13% of house holds in Sri Lanka due to various reasons. But, improving the “Anagi” stove to produce steam will have a higher demand and benefits of it are discussed below;

Distillate collection pattern for one hour is as follows;



Graph 01: Cumulative produce of distillate for operation of 01 hour of firewood hearth distiller

About 10 minutes after starting the cooking the distiller starts producing steam and the rate goes up to 28 ml/min after about 40 minutes and it continues till firewood remove from the hearth after finishing the cooking. Even though the combustion is not taken place heat in the hearth remains for some time and produce steam and distillate. Without any combustion of wood, with the energy remains in the hearth produce about 323 ml of distillate with in about 40 minutes. Total firewood consumed for one hour is 1.15 kg. Per 1 kg of firewood 1.13 L of distillate could be collected.

Total cooking cycle of a house hold consumes about 8 kg of firewood for three main meals and for tea. By using a firewood hearth distiller 9 - 10 Liters of safe drinking water could be collected. For a house hold where 4 – 5 people living required about 9 - 10 Liters of water for drinking [1]

There are about 8,327 kTons [9] of firewood is used in Sri Lanka for cooking. Total thermal energy generation is about 1.04 x 10^{14} kJ. Total wasted energy can be calculated as 0.76 x 10^{14} kJ. To produce 1 L of distillate it required 11 x 10^{3} kJ of energy from the firewood hearth distiller. By using firewood hearth distiller it could be produce 7,000 m^3 of water per annum.. By this methodology about 2,000 families (house holds) could be provide safe drinking water.

The innovation proposed in this process has the distinct advantage of

(1) Utilization of waste heat generated during normal cooking processes;
(2) Improvement of utilization of heat for cooking, from 27% to 42%.

Type of calculation	Units	Normal hearth	Firewood hearth distiller
Heat released from firewood combustion	kJ	12,500	12,500
Waste heat (heat losses due to body losses)	kJ	9,664	7,392
Useful heat	kJ	2,835	5,187
Efficiency of hearth	%	23	43

Table 10: Efficiency of Firewood hearth Distiller

As water is boiled in the water jacket, minerals and other solids can be accumulated within the boiling chamber. If scale and sediment are not periodically removed, the mini boiler may become less efficient and require more energy to distill a given amount of water. A 50% solution of vinegar, which contains a weak organic acid, can be used as the cleaning agent.

Draw backs of the system;

- No one piece of treatment equipment manages all contaminants. All treatment methods have limitations and often situations require a combination of treatment processes to effectively treat the water. Distilled water may still contain trace amounts of the original water impurities after distillation as the steam leaving the boiler (distiller) is not superheated. However, based on the results, these trace amounts are well within the potable water standards.

- Removal of organic compounds by distillation can vary depending on chemical properties of the contaminant. Certain pesticides, volatile solvents and volatile organic compounds (VOCs) such as benzene and toluene, with boiling points close to or below that of water, will vaporize along with the water as it is boiled in the boiler (distiller). Such compounds will not be completely removed unless another process is used prior to condensation.

- The boiling process during distillation generally inactivates microorganisms. However, if the distiller is idle for an extended period, bacteria can be re-introduced from the outlet spigot and may re-contaminate the water.

Comparison of available drinking water treatment methodologies in Sri Lanka;

Methodology	**Advantages**	**Disadvantages**
Filter with Brick pieces	• Easy to use • Medium cost	• Need regeneration • People do not know when the brick pieces are saturated • Only remove F ions • Made out of SS or Glass
Firewood hearth with Distiller	• Low cost and easy maintenance • Removes most impurities including F, NO_3 and salinity, could be tested for Arsenic • No special treatment needed • Made out of locally available material • Energy efficient • House hold centered solution	• Limited purification volume

Table 07: Advantages and disadvantages of two methodologies available

Cost of the unit;

Total cost for this unit is US$ 28 (1 US$ =1 SLRs).
Cost of water per house hold per day is US$ 0.027 (1 Liter = US$ 0.003/ Liter)
Cost to boil water is US$ 0.17
Payback period is 4.7 months.

The lifespan of the proposed mini boiler with firewood hearth depends on several factors, including the quality of the water supply, safe handling and proper maintenance. With proper maintenance and care, this should last 2-3 years.

5.0 Conclusion

1. Firewood hearth distiller is a highly successful method to produce safe drinking water.
2. Using firewood hearth distiller, Fluoride, Nitrate and Salinity concentrations could be completely removed from drinking water. Could be tested for Arsenic.
3. Thermal energy wasted through firewood hearth is successfully used to produce safe drinking water.
4. Low initial and operational cost of this method make people more comfortable who suffer from drinking water scarcity in Dry Zone in Sri Lanka.
5. Unit could be manufactured with locally available materials by village level local potters.
6. Total time saved of people living in those areas from fetching water is also having a positive impact on income generation.
7. The contribution to the supply of labour provided by those communities living in these areas is on a decline due to the negative effects of polluted water. By improving their health the labour contribution will be more to the economy.
8. This efficient and scientific device could achieve following environmental and social benefits;
    - Less firewood usage is a solution to energy crisis
    - Minimizing of indoor air pollution

6.0 Suggestions for further research

- To add some minerals to distilled water to give a better taste, $CaCO_3$ and brick pieces should be added to the distillate collector. This should be quantified with further research
- Further research is suggested to use gas burners instead of firewood to promote this system for urban residencies
- Further improvements to increase the efficiency and effectiveness of the firewood hearth distiller (automatic level controlling, auto feeding etc)

7.0 References

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Annexure 01

Calculations

	Firewood Hearth Distiller		Anagi Stove	
Readings				
Initial weight of fire wood sample	1	kg	1	kg
Final weight of fire wood	0	kg	0	kg
Specific heat capacity of water	4.2	kJ/kg	4.2	kJ/kg
Specific Heat capacity of Al	0.9	kJ/kg	0.9	kJ/kg
Specific heat capacity of fire wood	12500	kJ/kg	12500	kJ/kg
Initial water volume of the pot	3	l	3	l
Final water volume of the pot	2.785	l	2.2	l
Volume of distillate	1.29	l	NA	
Initial surface temperature of the vessel	30	C	30	C
Final temperature of the vessel	110	C	110	C
Weight of the vessel	0.16	kg	0.16	kg
Calculations				
Total Energy released	12500	kJ	12500	kJ
Energy absorbed by the vessel	11.52	kJ	11.52	kJ
Energy absorbed by water	1008	kJ	1008	kJ
Latent Heat	488.05	kJ	1816	kJ
Energy absorbed by water in the water jacket	672	kJ	NA	
latent heat	2928.3	kJ	NA	
Heat Balance				
Total energy				
Waste heat	7392.13	kJ	9664.48	kJ
Useful Energy	5107.87	kJ	2835.52	kJ
Efficiency of the hearth	40	%	23	%

Note:

D: Latent heat of Distillate

DW: Energy absorbed by Distiller water in the water jacket

V: Heat absorbed by Al vessel

VW: Heat absorbed by water in the vessel

VWLH: Latent heat of water in the Al vessel

WH: Waste heat