Development of Heat Exchangers for Water Pasteurization in Improved Cooking Stove

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ABSTRACT - — In Nepal, drinking unsafe water is attributed for the mortality of 13,000 children. The prevalence of this cause of morbidity and mortality in many poor rural regions has created a need for water quality intervention. These days various household drinking water treatment options are currently available in Nepal. Almost 85% of Nepalese population use cooking stove and more than 70% of the heat energy is wasted through chimney of cooking stove. Three different heat exchangers with different efficiencies were designed for Water Pasteurization by utilizing waste heat of flue gas.

Locally available hollow aluminum pipe (internal diameter 8 mm, length 3.65 m) was coiled into a spiral ovular helix of 12 cm in diameter. Two different heat exchangers with coiled unit placed inside and outside of the chimney were designed. Similarly a jacket type heat exchanger with 0.5m height was also designed for Water Pasteurization.

With 6 hours of average cooking period per day, total water output from three different prototypes was found in the rage of 24 to 28 liters/per day. Water quality test for treated samples from three different prototypes was done and the *E. coli* test result was less than 5 CFU/100ml and thus treated water was safe to drink.

Keywords— Heat exchangers, Pasteurization, Improved cooking stove, *E. coli*, Thermal efficiency, Water boiling test, Carbon trade, Biomass, Flue gas, Distillation, Heat transfer.

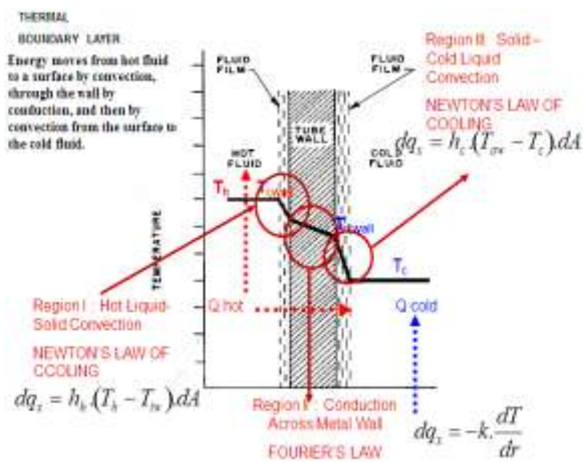
Introduction

Solid biomass fuels such as wood, dung and agriculture residue are used by more than 85% of the Nepali population for daily cooking and heating activities (CBS, 2007). Two major characteristics of energy systems in Nepal are excessive dependence on biomass energy and very low efficiency in its use. Similarly, many household water treatment systems (HWTs) are currently available in Nepal to treat unsafe water. Many household water systems such as solar disinfection (SODIS), Boiling, Chlorination and filtration has been developed and promoted by different NGOs and GOs like Environment and Public Health Organization (ENPHO).

Indoor air pollution and unsafe water are two major environmental risk factors in the developing countries (Corvalán and Üstün, 2006). Globally, 1.8 million people, mostly children, die from waterborne diarrheal disease annually (ITDG, 2004; Smith etal.,2004; WHO 2007a, 2007b). In Nepal, drinking unsafe water is attributed to the mortality of 13,000 children (DWSS and UNICEF, 2006; WHO, 2007; UNICEF, 2005). The occurrence of these major causes of mortality in many poor rural regions of Nepal has created a need for water quality interventions. Thus there is a need to develop an integrated technology that eliminates risk factors at the rural level.

Heat exchangers can be installed in the chimney for water pasteurization in improved cooking stoves making it safe to drink and utilization of heat from the waste flue gas increases the overall efficiency of the stove system. This technology uses pasteurization method for water purification, where water should be maintained at certain temperature for certain period of time in the system. In order to do so, retention time of water in the system plays a critical role for purification. Alike pasteurization, distillation is also a process of water purification. Distillation involves boiling the water and then condensing the steam into a clean container. Water purification, such as distillation, is especially important in regions where water resources or tap water is not suitable for ingestion without boiling or chemical treatment. Use of this distilled water for drinking can contribute a lot in reducing death rate due to water borne disease.

Heat exchangers are devices that facilitate the exchange of heat between two fluids that are at different temperatures while keeping them from mixing with other. Heat transfer in a heat exchanger usually involves convection in each fluid and conduction through the wall separating the two fluids. During the analysis of heat exchangers, it is convenient to work with an overall heat transfer coefficient U that accounts for the contribution of all these effects on heat transfer. The rate of heat transfer between the two fluids at a location in a heat exchanger depends on the magnitude of the temperature difference at that location, which varies along the heat exchanger. In the analysis of heat exchangers, it is usually convenient to work with the *logarithmic mean temperature difference LMTD*, which is an equivalent mean temperature difference between the two fluids for the entire heat exchanger.



Principle of Heat Exchanger (parallel flow)

Methodology

The range of method includes both primary and secondary analyses, with activities ranging from direct field investigation to elaborate desk works. The methods along with the detail procedures followed are described below.

Literature review

It is essential for the development of theoretical foundation as well as to gain current knowledge on related topic including substantive findings. Also, some required secondary data can be extracted through literature review.

Experimental activity

The experiment was performed to measure the mass flow rate of flue gas as well as average temperature of the flue gas in chimney. To design the heat exchanger we need to find the design parameters. The major design parameters are temperature profile of the chimney, flow rate of the water to be obtained, mass flow rate of the flue gas, thermo physical properties of water, flue gas and materials.

In order to find out these design parameters some primary lab testing were carried out and the thermo physical properties were determined from different literature. After some primary lab testing, the temperature profile of the chimney was known by using thermocouples. To determine the mass flow rate we used excel sheet based software and determined the velocity of flue gas in the chimney. After determining the velocity of the flue gas, discharge and hence mass flow rate of flue gas using continuity equation was determined.

$$Q_D = V.A$$

Then, total heat transfer rate of chimney section was calculated.

$$q_s = \dot{m}.\dot{C}_{p.}dt$$

Design of heat exchangers

The design of heat exchangers was done by writing a program in MS-Excel. Heat exchanger was designed using concept of parallel flow heat exchanger. Different assumptions were made before designing the heat exchanger which is mentioned below:

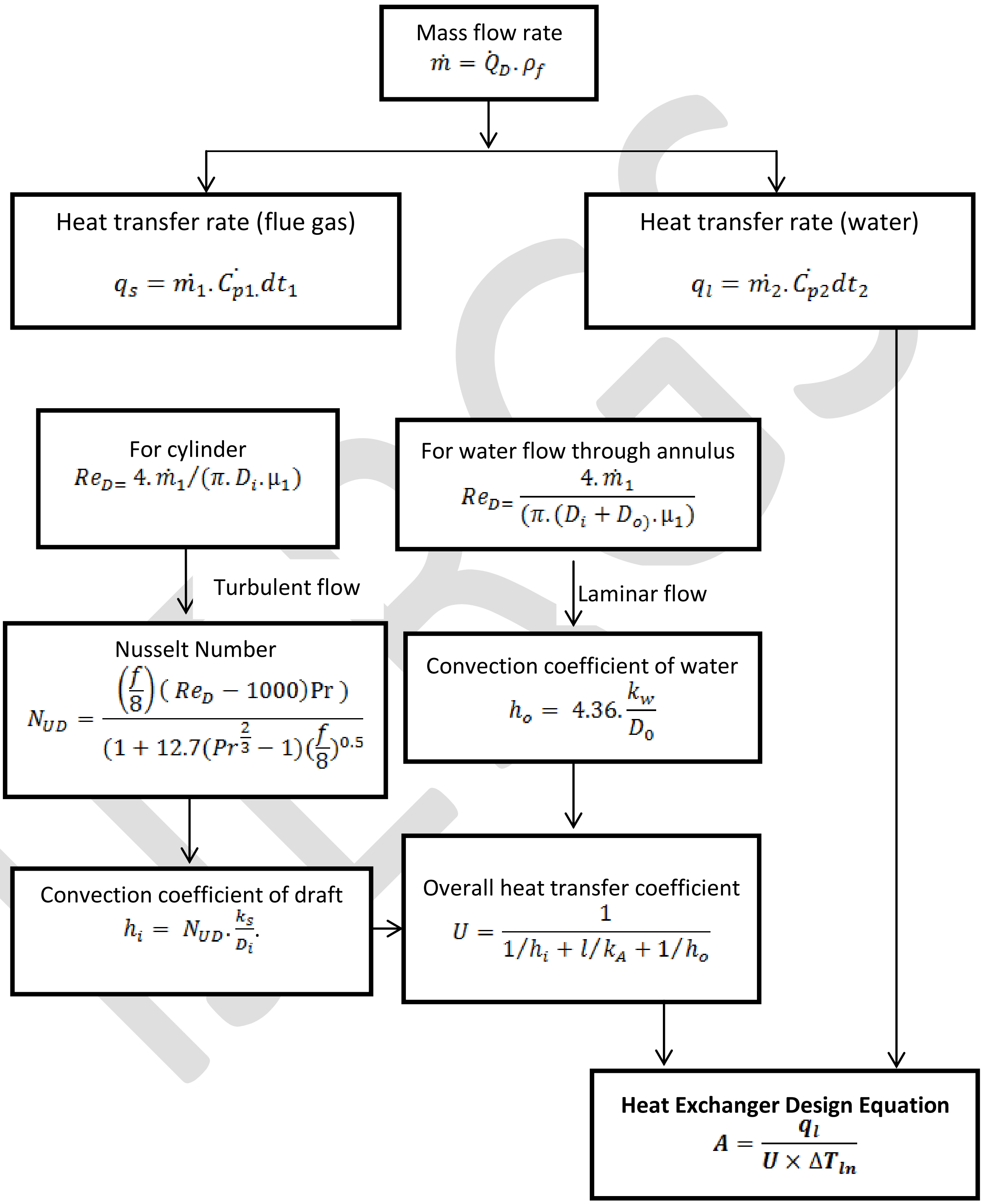
i. Negligible heat loss to surroundings.

ii. Negligible kinetic and potential energy changes.

iii. Constant Properties

iv. Negligible fouling factors.

v. Fully developed conditions for the water and flue gas.



Schematic Representation of Methods Applied for designing Heat Exchangers

Fabrication of heat exchangers

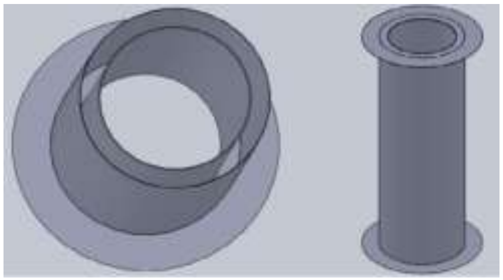
First model of heat exchanger i.e. aluminum coil inbuilt inside the chimney was made by coiling the aluminum coil in the inner wall of the chimney. The total length of the aluminum coil that was calculated to obtain the predefined quantity of distilled water i.e. 3 l/hr was found to be 3.8 m i.e. 11 no of turns but extra 2 no of turns was added for factor of safety and uncertainties. But the length of the aluminum coil that is normally available in the market was only 3.65 m i.e. 9.7 no of turns. The inlet hole was made at the bottom of the chimney where the temperature is very high about 600 °C. The outlet hole was made at a location where the chimney temperature was about 400 °C.

Fabricating first Prototype (Aluminum Coil Inside)

Second model of heat exchanger i.e. aluminum coil winded outside the chimney system was fabricated to overcome the problem of tar deposition in the first model. Length of aluminum coil calculated was 3.65m. Both the concentric cylinders were made up of cast iron of 1mm thickness. The aluminum coil was then winded on the outer surface of the inner cylinder. . Concentric cylinders were bonded together on both the ends with cylindrical cast iron metal sheet, welded finely along the perimeter of the cylinder to avoid the leakage of flue gas two holes were made in the system one for the inlet and the other for the outlet pipe for the water flow. This inbuilt system has to be placed in the chimney system to be fitted with nut and bolts

Second prototype (Coil and Jacket combination)

Third model of heat exchanger i.e. sealed concentric cylinders was made of Galvanized Iron sheet because they avoid the problem of rusting. The height of the heat exchanger was 0.5 m, with gap between the concentric cylinders to be maintained at 15 mm on both the sides. Since, the water is contained in between the cylinders the system should be free from rusting to maintain the quality of water for drinking purpose. Two concentric cylinders were attached together properly by sheet bending and pressing technique as arc welding on GI sheet was not possible. To ensure the leakage problem, M-Seal and Silicon Gel were used all around the joints. Two holes for inlet and outlet water similar to that of the previous system was also made using hand drill



Third Prototype (Jacket type)

Testing of heat exchangers

Before starting the test, both qualitative and quantitative information about the stove, fuel and the test conditions was recorded. These include:

a) Air temperature,

b) Average dimensions of wood (length x width x height)

c) Wood moisture content (%-wet basis)

d) Dry weight of standard pots

e) Local boiling point of water was determined by using the same digital thermometer and sensor that was used in the testing.

These parameters were recorded in the WBT data sheet along with the weight of the fuel wood that was used. Once these parameters had been measured and recorded and the fuel was prepared, the test was started.Three different models of heat exchangers were tested independently. Bucket was filled with 20 L of water and placed in a place maintaining the height for water pressure. Blocker was used so as to maintain the water flow rate entering the system. Then, stove was run in normal condition. Ten minutes after running the stove, the outflow of water from the bucket was started. The amount of distilled water collected in ten minutes was noted. The condensation of the steam was done by bending the outlet pipe. But, complete condensation was not found to occur. Condensation of steam was carried out by introducing the stem directly into beaker containing 3 liters of water. Gradual temperature increase in water was also noted. The temperature rise of the raw water was noted in different time. Once the water reached Pasteurization temperature, steam was introduced in the container containing 3 liters of water for another ten minutes. Then, sample was taken for *Escherichia coli* (E.coli) test. Final amount of water condensed in the beaker was noted.

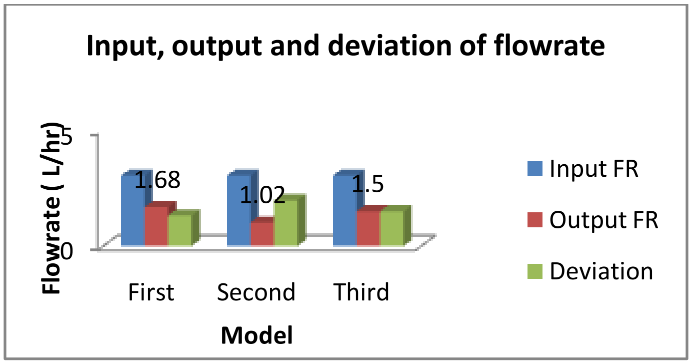
Result and discussion

The effectiveness of three different models of heat exchanger was different from one another. The effectiveness of heat exchanger is based on the amount of heat transferred from the hot fluid to the cold fluid. During our project we conducted numbers of tests. Results based on those experiments are discussed below.

First model of heat exchanger had the maximum ability of heat transfer from the flue gas to the water. With 9 no of turns of aluminum coil, the amount of distilled water collected in the beaker was found to be 280 ml in 10 minutes. This implies the flow rate to be 1.68 L/hr. This model of heat exchanger being more efficient than other models in terms of heat transfer was failed in long run use because of the tar deposition. The flue gas in the chimney contains tar, which is a complex organic compound gets deposited in the aluminum coil. The tar behaves as an insulating material and reduces the amount of heat transferred to the aluminum coil hence reducing the efficiency of the coil and ultimately the heat exchanger system. Another big problem of this model is cleaning of the system. To overcome this problem other two models of heat exchanger were proposed.

The **second model** of heat exchanger had lesser efficiency than that of the first model. That was because the heat from the flue gas is not directly transferred to the aluminum coil rather it is first transferred to the cast iron cylinder and then to the aluminum coil. This system overcomes the tar deposition problem on the aluminum coil which helps in increasing the life time of the system. Thus, on the long run use this system is efficient and the temperature resistivity of cast iron is also more than that of the aluminum which increases the proximity of the system. However, the fabrication of this heat exchanger is more difficult and time consuming than the previous one. This is also more expensive than the previous one as the cost of the cast iron is also included along with the aluminum coil. Total amount of distilled water collected was 1.02 L/hr

The **third module** of heat exchanger was efficient in terms of heat transfer but was very difficult to fabricate. Joints were sealed by bending and pressing technique which is very difficult to perform and time consuming. The joints were not completely leak proof and M-seal was used to counter it. But due high temperature about 600 ºC the life of M-seal is shortened and after few hours, the system was suffered from the leakage problem. The amount of distilled water collected was found to be 1.5 L/hr.



Output flow rates of the system.

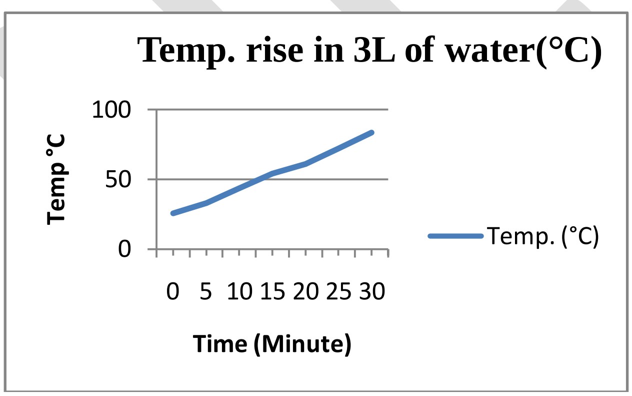
Water collected through Pasteurization

Distilled water was collected by condensing the vapor directly into container containing 3 liters of water.

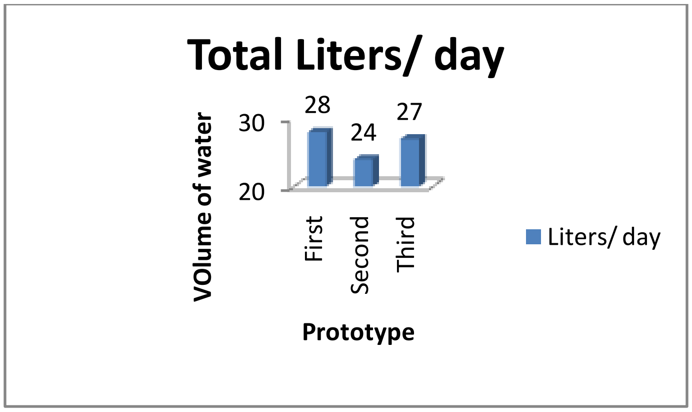
Heat exchangers	Initial volume of water (L)	Final Volume of water (L)	Amt. of Distilled water (L)	Total vol. of water pasteurized. (L)
First Model	3	4.68	1.68	4.68
Second Model	3	4.02	1.02	4.02
Third Model	3	4.5	1.5	4.5

Final amount of water pasteurized in one hour.

The steam was condensed in a beaker containing 3 liter of raw water of temperature 25.3°C. During condensation, steam was introduced directly into the raw water and gradually the temperature of the water which was at 25.3°C started to rise and reached 83.7 °C in 30 minutes. Further maintaining the water for ten minutes, the water can be expected to get pasteurized. As we know the water at 80 °C when heated for ten minutes gets pasteurized.



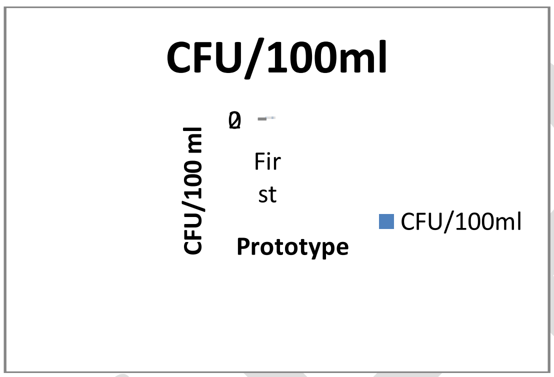
Temperature rise in 3 liters of water



Volume of water pasteurized per day

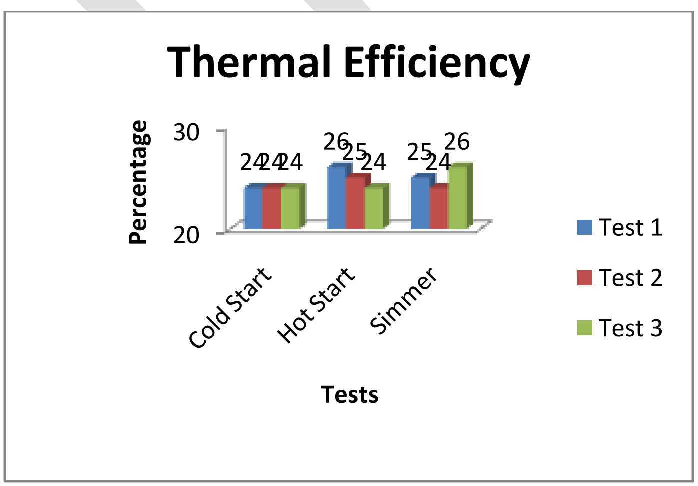
Considering the stove to be used in an average of 6 hr/day, the total amount of pasteurized water including the distilled water collected per day was found to be 28 L/day, 24 L/day and 27 L/day for first, second and third model respectively. For a normal family in Nepal this quantity of drinking water is sufficient for a day.

E. coli testing



Three samples of three different prototypes were taken for lab test. The colony counting for the raw water was TMTC (too many to count). Colony counting for treated was within the WHO guideline for Drinking Water, which is less than 5 CFU per 100ml. This result shows that the treated water is safe to drink.

Thermal Efficiency:



Results from WBT

This result shows that the overall efficiency of the system (ICS) is not disturbed by embedding heat exchangers in chimney but it definitely increases the overall efficiency of the system. However, overall efficiency calculation was not done.

Cost and Energy saved by implementing the system:

Heat Exchanger	Vol. of Pas. Water (ltr/hr)	Daily production (ltr/day)	Fuel wood saved (tons/year)	Total cost saved per year. (Nrs)	Amount of carbon reduction (Ton/yr.)	Amount earned by carbon trade (USD/yr)
First Module	4.68	28	10.074	60444	4.28	128.4
Second Module	4.02	24	8.803	52818	3.68	110.4
Third Module	4.5	27	9.855	59130	4.12	123.6

Total amount of cost and fuel wood saved by Heat exchangers and amount earned by carbon trade

The heat energy contained in flue gas is wasted to the atmosphere. Heat Exchangers use the waste heat and helps in producing Pasteurized Water which can be used for drinking purpose. This means we had saved the significant quantity of firewood that would have been needed to generate drinking water. It is estimated that 1 kilogram of wood is needed to boil 1 liter of water and make it drinkable (WHO, Water sanitation health). The local firewood cost in Dhulikhel is Nrs. 6/kg.1kg fuel Wood generates 418 gm carbon equivalent of carbon emission in ICS (Bajracharya, 2010). Nordhaus has suggested, based on the social cost of carbon emissions, that an optimal price of carbon is around $30(US) per ton carbon equivalent of carbon emission and will need to increase with inflation(Nordhaus, carbon credit).

CONCLUSION

All the heat exchangers were able to recover the wasted heat to some extent. The wasted heat was recovered by pasteurizing the water which is finally used for drinking purpose. The blending of the heat exchanger to the chimney system didn't decrease the overall efficiency of the Stove. Thus we can say that by blending the heat exchanger with the chimney system will certainly increase the overall efficiency of the stove system but further research should be carried out. The collected pasteurized water was safe for drinking meeting the WHO standards. Installing the heat exchanger helps to reduce the quantity and cost of firewood that would have been needed to generate drinking water resulting to carbon emission reduction and carbon trading. The installation of heat exchanger in the chimney system is very easy and simple which can be installed in any stove either traditional or improved cooking stove having chimney system.

Finally, we would like to conclude that by installing these heat exchangers in the chimney system helps to generate pure drinking water economically recovering the wasted heat from the chimney and reducing the carbon emission.

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