Thakuri, S. and Zahnd, A. (2006) *High altitude smokeless metal stove: A research, development and implementation project through the Kathmandu University.* In: National conference on Renewable Energy Technology (RETRUD-06), 12 - 14 October, Kathmandu, Nepal.

High Altitude Smokeless Metal Stove
A Research, Development and Implementation Project through the Kathmandu University

Sujit Thakuri and Alex Zahnd
Kathmandu University, Mechanical Engineering, Dhulikhel, Nepal, sujit@ku.edu.np

Abstract
This paper aims to highlight the importance and need of a Smokeless Metal Stove (SMS) for high altitude rural communities, in order to improve their health condition through better indoor air conditions, and to help in active ways to slow down the fast increasing, wide spread deforestation. It brings close through facts and pictures the living conditions and way of life of people who suffer under open indoor fire places, as well as the improved living conditions and benefits people themselves have identified through the use of a smokeless metal stove in their home. Experiences from actual "Jumla Design" stove installations in the villages in Humla, as well as the latest KU laboratory data and results of the new designed secondary combustion stove prototypes are discussed and presented through pictures, data and graphs.

KEYWORDS: Renewable Energy Resource, Smokeless Metal Stove (SMS), Secondary Combustion, Holistic Community Development, Indoor Air Pollution, Sustainability, Appropriate Technology

1. Introduction:

In Nepal, nation wide more than 85% of the total energy demand is met by traditional solid fuels (firewood, agricultural residues, animal wastes) and almost 98% in remote, rural areas. About 85% of Nepal's ~ 28 million people live in the rural areas where the fuel wood dominates almost 90% of the total energy consumption. The communities living in those rural areas are economically so weak that the energy from refined fuels such as LPG and kerosene is not an option. According to the government's tenth five year plan, the total percentage of people living below the poverty line was 38% in 2002[1]. Therefore the communities living in those remote mountain areas have no other alternative than to rely on their local available firewood resources from their dwindling forest, for their daily energy needs. This heavy dependence on fuel wood for cooking and space heating on open fire places (called "*odhan*") increases the health hazards for the people living in rural areas, especially on women and children.

An open fire place to cook food and a room full of smoke is common in rural villages in the Karnali Anchal. Especially the mothers and children are exposed to the smoky indoor fires, causing several health hazards such as Asthma, respiratory chest diseases, heart diseases, eye infections etc.

Also, According to the Nepal Water and Energy Commission Secretariat (WECS), about 30%, or 42,240 km^2 of Nepal's total landmass of 140,800 km^2 is covered with forest. About 11% is covered with shrubs and bushes. Monitored data shows that the forest areas are annually reduced by 1.7%[2], which leads to the scarcity of local firewood and forces women and children to spend increasingly more hours to collect their daily needed firewood for cooking, heating and lighting.

In the context of the remote and impoverished mountain villages in Nepal, to provide the energy services for cooking and space heating with a clean indoor environment through a Smokeless Metal Stove, with minimal firewood consumption, is of high value and interest to the local people. Since 2001, Kathmandu University Mechanical Engineering Research Centre has started a project on improved High Altitude Smokeless Metal Stove technology for the remote and mountainous areas, based on the experience from the installed Jumla Design Smokeless Metal Stoves.

2. Firewood Consumption and Cooking method and its impact on health in rural areas:

Fuel wood, dominates more than 90% of the total energy consumption in rural areas. It is used for cooking, space heating and lighting. These activities consume 20 kg-40 kg firewood a day[3]. According to the survey carried out by the Water and Energy Commission Secretariat (WECS)**,** about 90% of the total energy consumption in rural villages is met by fuel wood, followed by animal dung and agricultural residues. Out of 90% of fuel wood consumption 65% is used for cooking, 8% for space heating and the remaining for agro processing, lighting and others respectively[4] (see Figure 2).

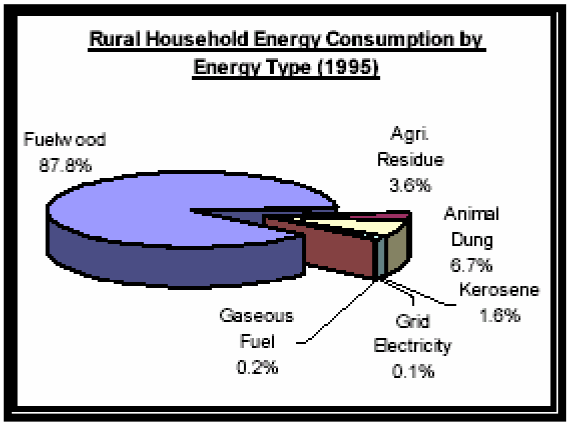


Figure 1: Rural household energy consumption by energy type.

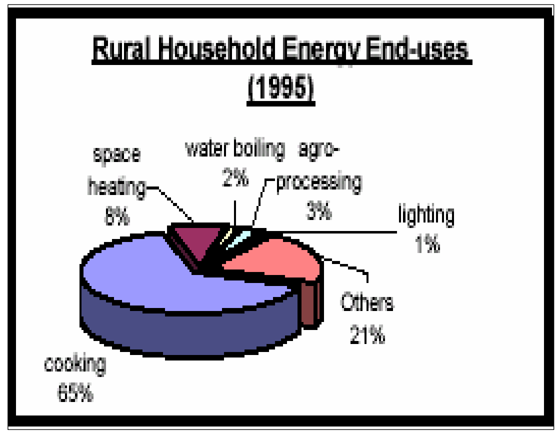


Figure 2: Rural household energy end uses.

In the mountain areas 32% of household energy is used for cooking and 56% is used for space heating. That indicates that the fuel wood demand for space heating is greater than the demand for cooking, compared to 40% for cooking and 36% for heating in hill areas. The remaining 12 % and 24% respectively, is used for lighting, electrical appliances, boiling water and other agro- processing activities[5].

Thus it comes not as a surprise that this high dependence on fuel wood to meet the local populations' daily energy services caused already alarming conditions in regard to the country's deforestation. According to WECS, about 30%, or 42,240 km^2 of Nepal's total landmass of 140,800 km^2 is covered with forests, and about 11% is covered with shrubs and bushes. Monitored data shows that the forest areas are annually reduced by 1.7%, which has be considered as too high for such a fragile and unique hill eco-system as the Himalayas[6].

This wide-spread deforestation leads to an increased scarcity of local fuel wood resources and forces people, mostly women and children, to spend hours and hours to collect fire wood for their daily energy need.

Nation wide annually 7 million metric ton available fuel wood through natural growth, though with 15 million metric ton fuel wood consumption clearly indicates that deforestation is a wide spread, fast growing problem in Nepal.

In rural areas, women are responsible for cooking and other households' works and the increasing deforestation forces especially women and children to spend 7-8 hrs daily to gather fuel wood further a field every second day[7].
Therefore women in particular place a high value on a smokeless metal stove which consumes up to 40% less firewood and provides a clean indoor air environment for the whole family.

Among the four greatest risks leading to death, diseases and injury identified by WHO, smoke from burning of solid fuel kills more than 1.6 million people each year, of which 66% are children aged under five[8]. Children, if exposed to indoor air pollution, are two or three times more likely to contract acute respiratory infections which is the main cause of children's death from indoor air pollution. Women in the remote areas who use firewood for cooking, room heating and light spend about six hours of per day for cooking food on a traditional stove (open fire place with a metal support called "*odhan*" as seen in the picture). The smoke and sod from the open fire generate highly toxic pollutants, resulting in eye infections, heart diseases and irreversible impacts on the respiratory system. These chronic, long-term health impairments are the major reasons for the extremely low life expectancy for women (as women are four times more likely to suffer from chronic bronchitis) and the high death rate of under five years of aged children.
According to the Nepal Demographic Health survey (NDHS) in 2001, the child mortality rate was 50.1 in urban areas and 79.3 in rural areas

Cooking in such an unhealthy, smoke filled environment is one of the key reasons for the low life expectancy of women and the high death rate of children under 5. .

whereas the under 5 mortality rate for urban and rural areas were 65.9 and 111.9 respectively[9]. Illness caused by smoke kills more children annually than malaria or HIV/AIDS[10].

The life expectancy in Nepal, is very low compared to other countries. What is even more astonishing is, that the female life expectancy is about one year lower than for male. The average life expectancy for Nepal was 58.95 years at the end of 2002 (Ninth Five Year Development Plan, 2002) and the Tenth Plan has set the target to increase this upto 65 by 2007[11]. Moving towards a cleaner indoor environment, i.e. "to install and the use of a smokeless metal stove for cooking and space heating" can be one step towards the fulfillment of this target.

3. High Altitude Smokeless Metal Stove

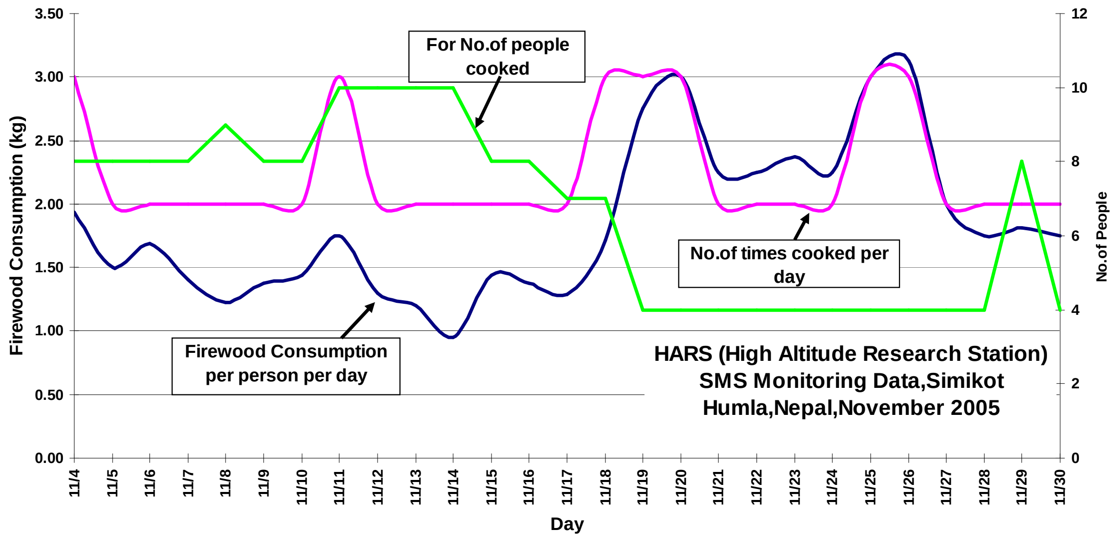
3.1 Jumla Design Smokeless Metal Stove

Mr. Alex Zahnd developed the "Jumla Design Stove" in 1997/98, during his 4 1/2 years living and working in Jumla[12]. This stove has been implemented and installed successfully in different mountain areas through the Karnali Community Skill Training Project, and now through the RIDS-Nepal NGO. Currently, the stove is installed at a subsidized rate of NRP 2500 for farmers in Humla, provided that they first have built an appropriate pit latrine. The stoves are manufactured in Nepalgunj and up to June 2006, a total of 2933 "Jumla design Smokeless Metal Stove" have been installed in Jumla, Mugu and Humla in the Karnali zone. Because of its functionality, reliability and user friendly characteristics, the Jumla design SMS has been gaining great popularity also in the mid-hill regions. According to the manufacturer, about 1500 stoves have been installed in the mid hills north of Pokhara. In October 2005, on the request of a local village community in Dhital VDC first 12, and then 25 in June 2006, Jumla design SMS, have been installed.

Cooking on "Jumla design smokeless metal stove" in Jumla (left) and in Dhital (right).

Jumla design SMS is designed for cooking and space heating for rural mountain areas. It has three pot holes for cooking "*Dal, Bhat and Tarkari"* (Rice, Lentils and Vegetables) at the same time and a stainless steel hot water tank attached to have continuously hot water for other household purposes. In addition to this, a slot is made on which "roti "(the traditional bread) can be baked in a traditional way directly on ambers. In order to

minimise the downside heat loss, the stove has a mud filled double bottom. To transfer the heat more efficiently towards the cooking pots, an air draught allows the regulation of the combustion air through an adjustable air vent in the main door and a damper in the flue pipe. With 1.5 mm thick steel walls and a 4 mm thick cooking surface plate, this stove has 38 Kg of weight.
Properly installed and used, the Jumla design SMS consumes up to 40% less firewood compared to cooking on open fire places. The ongoing monitoring of the firewood consumption in the HARS (High Altitude Research Station) office in Simikot shows that the average firewood consumption per person per day for all food and heating services is 1.8-2.6kg and a field test survey shows that the average cooking efficiency of this stove is 14-22%.



Graph 1: Jumla design Smokeless Metal Stove Daily Firewood Consumption.
The daily firewood consumption per person and no. of times cooked per day plotted in primary Y-axis and No. of people in secondary Y-axis shows the average fire consumption per person is 1.85 kg per day.

Considering wood energy as 100% energy input, 15% is being distributed towards the 3 potholes and 4% towards the 9 liter stainless steel water tank. Laboratory tests showed, that from the remaining 81% an estimated 15%-28% of the energy input can be utilised for space heating.

3.2 KU-1 Secondary Combustion Smokeless Metal Stove Prototype

In 2002, Kathmandu University started a research on high altitude Smokeless Metal Stove project with the aim to improve the Jumla design SMS by introducing a secondary combustion process with improved combustion efficiency. The first prototype built in 2002 named as KU-1 Secondary combustion SMS (see above picture), has two separate

combustion chambers, one primary and one secondary. The primary combustion chamber is provided with two pot holes and a separate air vent to control the air flow. The unburned, from the first combustion chamber escaped volatile gases, are combusted in the secondary combustion chamber with the properly supplied hot air (~ 630°C-650°C) through the separate air passage opening at the bottom of the secondary combustion chamber.
An ashtray placed underneath of primary combustion chamber serves also as air passage for both primary and secondary combustion chamber. A stainless steel water tank for holding up to 8 liters water is attached on a primary combustion chamber to provide hot water for cooking, drinking, washing and other household purposes. 500mm×450mm×320mm KU-1 stove manufacturing costs NRP 3700 (2002 price) and weighs 37 kg.

KU-1 Secondary Combustion Stove

By providing three pot holes and a "roti" grilling slot, it can be said that it is socially and culturally acceptable but this stove lacks in technical performance. The secondary air temperature of >630ºC required to burn the volatile and unburned gases in the secondary combustion chamber could not be reached through the designed air passage. The un-insulated stove walls are one of the main reasons for not obtaining the required air temperature for the secondary combustion chamber. That led to the development of the KU-2 secondary combustion Smokeless Metal Stove.

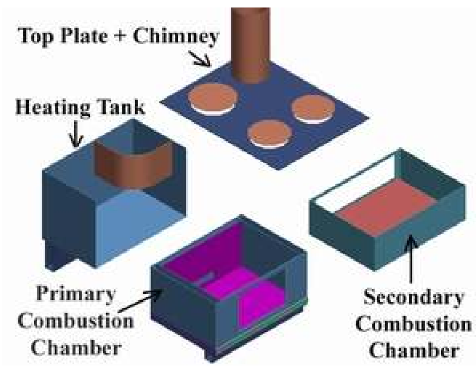
3.3 KU-2 Secondary Combustion Smokeless Metal Stove Prototype

With the sponsorship of SINTEF, Norway, from Nov.2002, a new prototype, KU-2, has been designed and tested in the KU stove laboratory in Dhulikhel. This design consists of a well-insulated primary combustion chamber, a secondary combustion chamber, a better-heated secondary air route and an un-insulated heating tank. Each of the three major parts of the prototype is manufactured as a module, in order to change each part separately for the various laboratory tests and for ease of carrying and transporting.

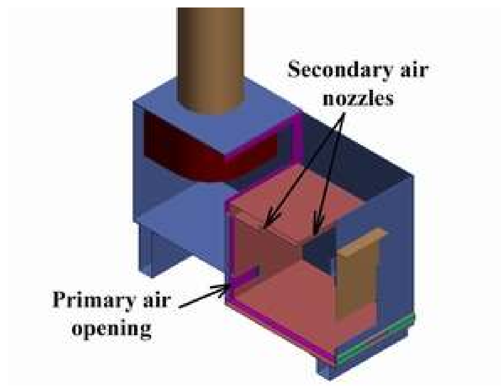
As shown in the following figures, the primary air flowing below the floor is preheated, and the secondary air supply beneath the primary zone floor and up the back of the primary chamber enters the secondary combustion chamber, through two layers of nozzles, well preheated. Both secondary and primary chambers are insulated using mud.
A baffle plate is used below the chimney so that hot flue gases have a slightly longer resident time inside the stove, thus increasing the convective heat transfer. Air flows are controlled by a primary air sliding vent, 2 secondary sliding air vents and a damper in the exhaust pipe.

KU-2 secondary combustion stove with all 3 chambers

KU-2 secondary combustion chamber component



KU-2 secondary combustion stove drawing of each module



KU-2 secondary combustion stove cut through the combustion chambers

KU-2 primary fire zone

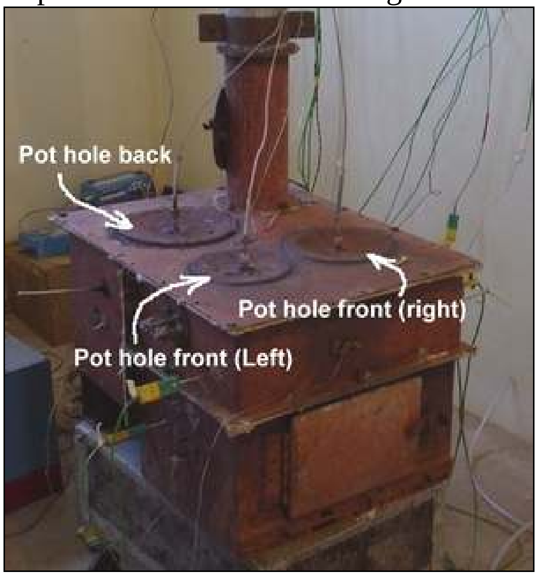
KU-2 Secondary fire zone

4. Comparison between Jumla design SMS and KU-2 Secondary Combustion SMS

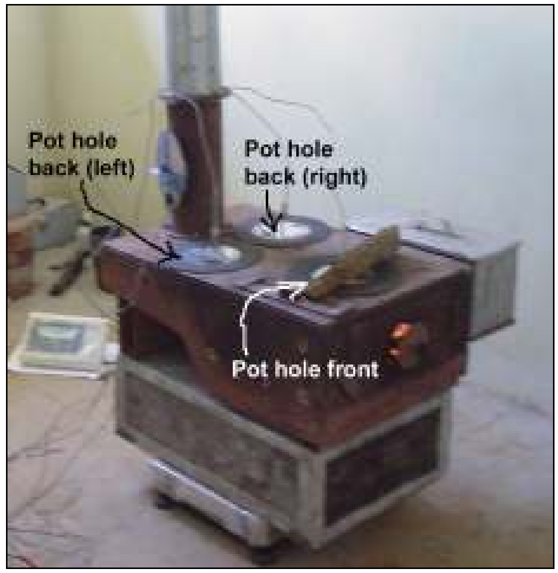
4.1 Firewood consumption and Pot hole Temperatures

The main objective is to develop a stove with secondary combustion, leading to a significant higher efficiency (estimated up to 2-2.5 times). Therefore each part and 'parameter' of the KU-2 stove is compared with that of the "Jumla design" stove. The experiments were carried out after an initial warming up period of the stoves. For the

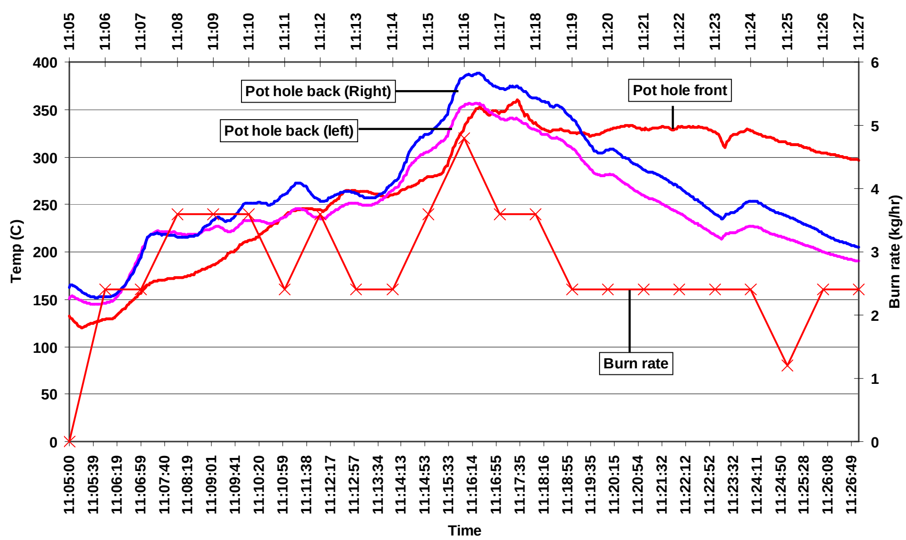
"Jumla design" stove, 1 kg firewood, and for the KU-2 stove, 500 gm firewood was burned during the warm-up period.
Afterwards, the same experiment conditions, equipment (including the same exhaust pipe length), arrangements and measuring equipment were used. The same regular firewood inputs were maintained throughout the tests.



KU-2 Secondary Combustion Stove

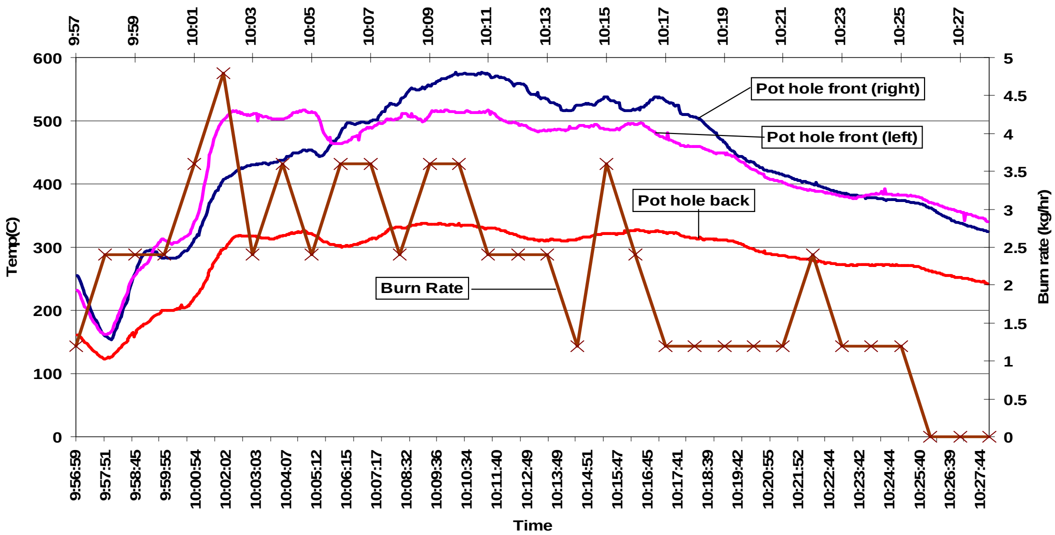


"Jumla Design" Smokeless Metal Stove



Graph 1 : Firewood consumption and pot holes temperatures on Jumla design SMS

It can be seen that the pot hole temperatures vary with burning rate which further depends upon the amount of air supplied for the combustion. During the experiment, with a properly adjusted air vent and chimney damper, it took approximately 21 min to burn 1 kg of pinewood. The pot hole temperatures attained were 250ºC -350ºC for most of the test period and the maximum temperature recorded was 380ºC. for the Jumla design SMS, with properly controlled air draught, it takes 30-40 minutes to cook a traditional meal for an average family with 5 people.



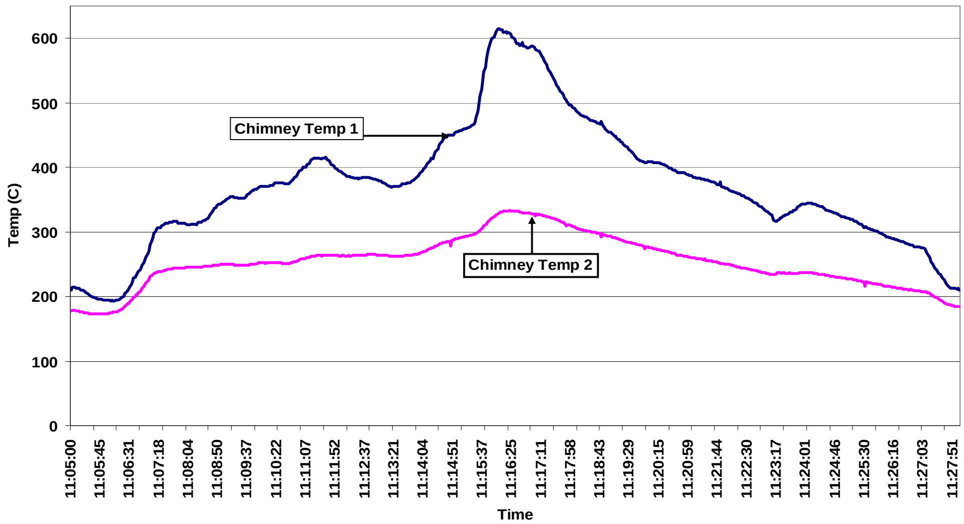
Graph 2 : Firewood consumption and pot holes temperatures on KU-2 Prototype

Above graph shows the front pot hole temperatures are between 400ºC -550ºC for most of the test period and 580ºC maximum, during experiment. In this KU-2 Prototype Secondary combustion stove, it took approximately 31 minutes to burn 1 kg of the same firewood**.** Low firewood consumption and increased pot hole temperatures indicate that the KU-2 stove transfers the combustion energy better (by radiation and convection) to the cooking utensils, and over a longer period, compared to the “Jumla Design” stove”.

4.2 Chimney Temperature

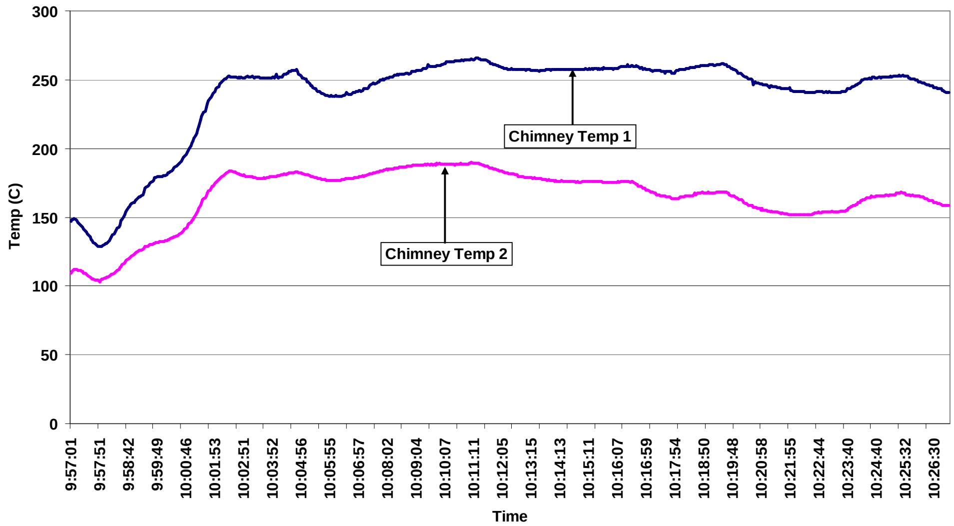
The optimum temperature of the flue gases leaving the chimney should be around 120 °C to insure complete combustion and better heat utilisation of the combustion energy. The greater the chimney temperature, the more of the hot flue gases escape without being used for cooking and space heating. That results in an overall lower stove efficiency. The chimney temperatures were measured in 2 places: one at the bottom of the chimney (chimney temperature 1) and one at the middle of the chimney (chimney temperature 2), as shown in the Figure.

The following graph shows the flue gas temperatures measured over the course of the laboratory test of both, the “Jumla Design SMS” and the KU-2 Secondary combustion stove. .



Graph 3: Flue Gas Temperature in Jumla design stove.

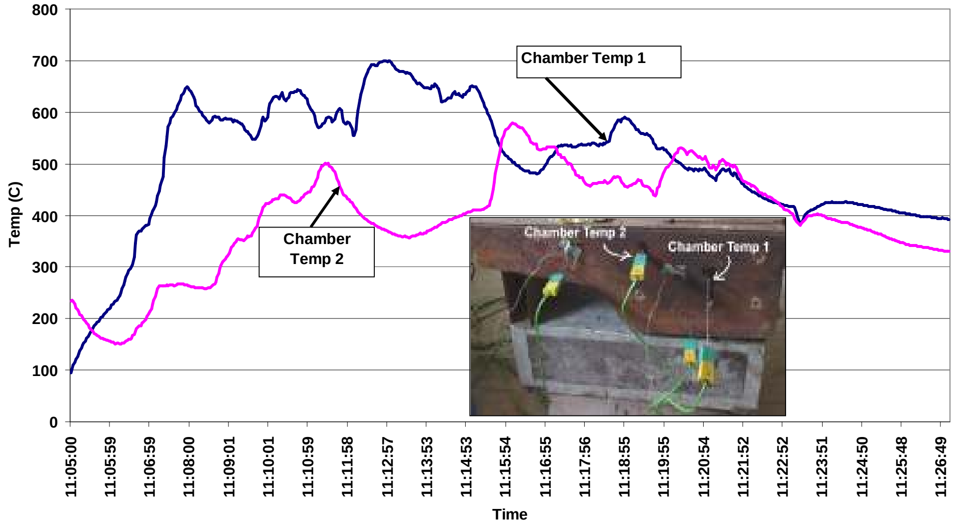
Around 400ºC chimney temperatures at the bottom and 250ºC chimney temperature at the top in Jumla design SMS shows the considerable energy is in the hot air leaving the chimney without being used for cooking and space heating.



Graph 4: Flue Gas temperature in KU-2 Prototype.

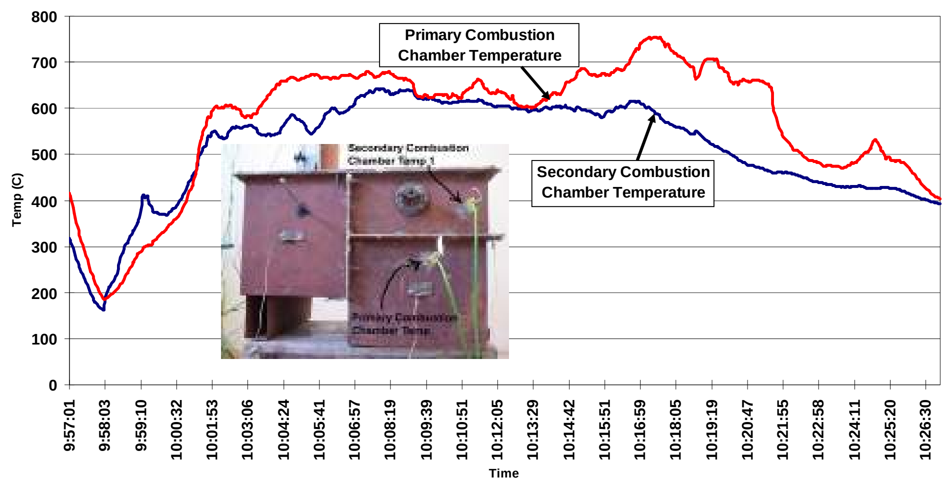
The KU-2 stove has a chimney temperature 1 of about 250°C with an almost constant value throughout the test period. Its chimney temperature 2 is just between 150°C to 200°C. These are much lower chimney temperatures compared to the Jumla design stove. That indicates that more energy is utilized to cook or heat the kitchen, which in turn results in an overall higher stove efficiency.

4.3 Combustion Chamber Temperature:



Graph 5: Combustion chamber temperature in Jumla design SMS

The chamber Temp. 1 is around 600 °C, with maximum values of up to 700 °C over a short time period. The chamber Temp. 2 is lower for the first half of the test period and then reaches about the same temperature during the second half of the test period. It can be concluded that the combustion process is less efficient in the Jumla design stove, compared to that in KU-2 Prototype stove.

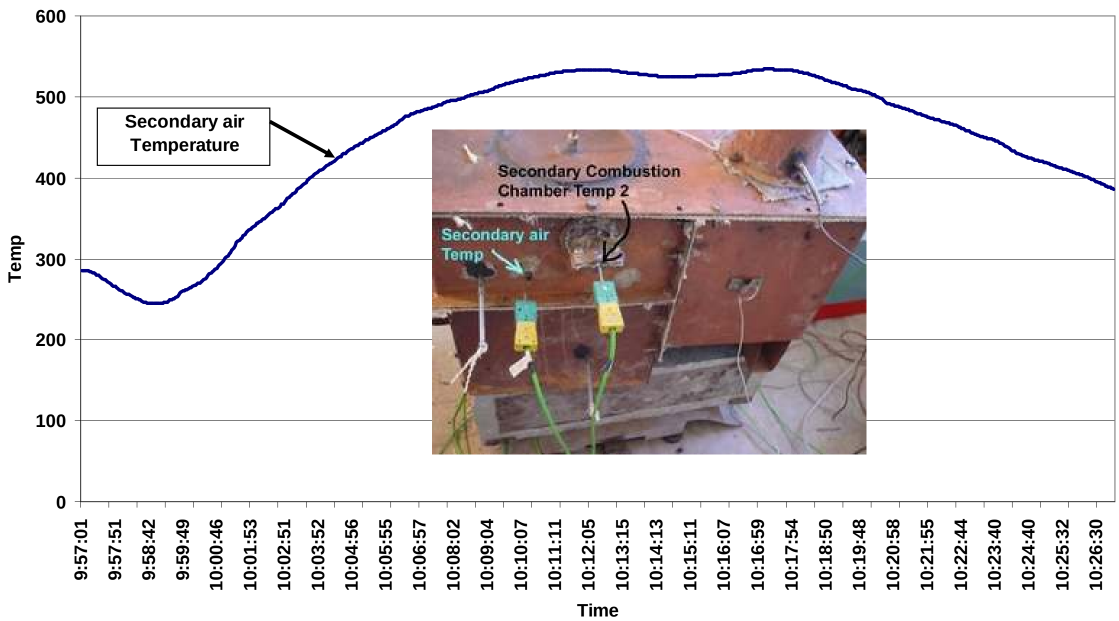


Graph 6: Combustion chamber temperature in KU-2 Prototype SMS

The burning of volatile gases in the secondary combustion chamber should have higher temperature than in the primary combustion chamber. The primary combustion chamber is the hottest zone, measuring a temperature between 600ºC -700ºC and 400ºC -600ºC in secondary chamber. The sudden increase in secondary combustion temperature and pot hole temperature between 10:05 - 10:10, indicate that the secondary combustion occurred, though only over a short time.

5. Secondary Combustion in KU-2 Prototype

The product of primary combustion (aromatic compounds, methane etc.) can ignite when they are mixed with adequate hot air. For the KU-2 prototype it can be said that the primary combustion chamber is the hottest zone, reaching temperatures of 600ºC -700ºC (the right temperature conditions for the occurrence of a secondary combustion). Ideally the secondary zone should have even higher temperatures, but with the present KU-2 design the secondary air can not be preheated hot enough (> 630°C) to ignite the volatile gases. The secondary air temperature was recorded only between 400ºC -500ºC with a maximum of 540ºC. But the sudden rises in temperature of the combustion product in the secondary zone indicate that there is frequently partial secondary combustion occurring but intermittently and not on an ongoing basis.



Graph 7: Secondary air Temperature in KU-2 Prototype

The secondary air temperature, recorded with K-type thermocouple and an ADAM module, is between 400ºC -500ºC during most of the experiment period. The highest temperature recorded is 540ºC for a short period. To obtain complete secondary combustion, a temperature of >630ºC is required.

If secondary combustion can be sustained for longer periods of time, then temperatures up to 800°C will certainly occur. That depends on the presence of combustible aromatics, methane etc, in the primary products of combustion, which in turn depends on the quality and conditions of the available firewood (dhaura). Such high temperatures are only of value when they can be kept for longer periods, to achieve some heating, either of the metal surfaces or of the pots in which the food is being cooked. If secondary combustion can be extended then by slower initial burning, higher temperatures will be available at the pot holes for cooking as well as for heat transfer from the stove's surfaces into the room. That will substantially increase the efficiency of the stove.

BUT even if secondary combustion proves elusive (due to heat losses from the stove, as one must remember that its purpose is to radiate and convect heat externally) the architecture and engineering of the secondary combustion system still increases the temperature of, and the energy delivered to, the cooking area and the upper plates. The insulated primary combustion energy zone heats the secondary combustion chamber air, passing through it in a designated canal, to a high temperature air. This has proven to be an appropriate mechanisms to transfer primary zone energy to the secondary zone. The results shown in Graph 1 and 2 show much higher upper plate temperatures in the KU-2 stove than in the Jumla stove for a comparable firewood burning rate, and that is the principal effect of the design for secondary combustion (as well as measures taken to reduce air leaks).

6. KU-3 Secondary Combustion Stove Prototype

The experience gained from the KU-2 Prototype stove leads to the development of yet another, new secondary combustion stove, “KU-3 prototype”, with the main improvements/modifications based on the learned lessons:

- The chimney position at the center in the back end of the stove to promote a more uniform temperature/energy field at the cooking surface.
- Baffle sheet (before the smoke leaves through the chimney) and cooking surface are redesigned to ensure more heat transfer towards the cooking surfaces.
- The secondary air passage is modified to prevent hot air leakage between adjacent joints.
- The heating tank area is reduced to minimise the manufacturing cost and weight of the stove.

7. Lesson Learned:

The three years experience in designing, manufacturing and data monitoring of secondary combustion Smokeless Metal Stoves formed the basis for the design and manufacturing of the KU-3 secondary combustion SMS, which is at the moment in the testing phase at the KU laboratory. The increased secondary air flow, improved baffle sheet, chimney position and cooking surface for uniform heat energy distribution to the cooking surface is hoped to enable a more stable and longer term secondary combustion process, providing one day even better services than the “Jumla Design” SMS does today, to the local communities in the remote high altitude mountain areas.

But a SMS is just one of various parameters and projects, which have to be implemented alongside each other as part of a sustainable, long-term holistic community development project with the local community as project partner. Other projects such as light inside the home, a pit latrine for each family and access to clean drinking water build some of the other key pillars beside the SMS for a holistic community development project. Alongside planned, implemented and followed-up they bring forth synergetic benefits beyond results and achievements individual implemented project could ever attain.

8. Conclusion:

Due to the low income and few resources of the people living in the harsh environments of high altitude mountain areas, firewood will continue to be their main energy source for the coming decades. But their fragile environments, including their sustainable timber supplies and their vulnerable hillside slopes without trees, as well as their health, must be protected and sustained. Therefore they must have the means to burn fire wood far more efficiently, and at affordable cost. Further, through solar energy and pico-hydro power generated energy services need to be made available to reduce the local people's dependence on fire wood. But first and foremost an improved smokeless metal stove is needed to minimise the excessive use of fire wood (and help actively to overcome deforestation), to improve the overall health condition of the people and to reduce the drudgery of collecting the daily need fire wood for the women and children.

It is widely recognised that the SMS project should not be considered just as an individual project, but always as an integrated part of a holistic community development project, producing synergetic benefits.

The Jumla design SMS has always been installing as one part of an integrated Holistic Community Development (HCD) project, first through UMN in Jumla, and then through KU RDC and now through RIDS-Nepal, in Humla.

Our secondary combustion stove is still in the design, research and testing phases. But it has been shown that through the KU-2 prototype already increased energy for cooking and heating can be made available with the same fire wood energy input. That shows that even though its combustion systems are not yet stable, a better combustion has been achieved, even sporadic secondary combustion has taken place. Better energy transfer for do the required cooking and heating tasks has been achieved with overall higher burning and heating efficiency.

This indicates the potential of such a new generation of smokeless metal stoves for high altitude areas, and research and development must continue to build on our understanding of the processes involved.

9. Acknowledgement

The authors acknowledge with gratitude the ongoing assistance, encouragements and advice provided by Professor John Cannell in helping to obtain the right instrumentation and equipment for the laboratory, in testing the various stoves and in the interpretation and presenting of the test results. Also thanks to the Humla RIDS–Nepal staff, who are the main project implementing partners among the local communities. Both, the local communities' and the RIDS-Nepal staff ongoing critical and constructive feedback on the long-tern performance of the installed "Jumla Design" SMS is invaluable for our ongoing strive for the development of the next SMS generation.

References and Footnotes:

[1] UNICEF report, Household energy, indoor air pollution and health impacts, March 2004, Winrock

[2] Biomass energy uses: an experience and application of alternative energy technologies in Nepal, Bishwa S. Koirala Environment Advisor, Rural Energy Development Program, UNDP, Nepal, http://bioproducts-bioenergy.gov/pdfs/bcota/abstracts/30/z324.pdf

[3] Zahnd Alex, "Firewood consumption survey on 16 villages in Jumla district", Unpublished report 1999.

[4] Household energy,indoor air pollution and health impacts, page 17,March 2004, Winrock
[5] Final Report on High Altitude Smokeless Metal Stove, Unpublished report 2005
[6] Renewable Energy in South Asia, *Country Reports Nepal*, chapter 2, http://www.worldenergy.org/wec-eis/publications/reports/renewable/country_reports/chap_2_5.asp
[7] IEA, 2002; Haddix McKay and Zahnd, 2005
[8] Household energy,indoor air pollution and health impacts, page 17,March 2004, Winrock
[9] Household energy,indoor air pollution and health impacts, page 17,March 2004, Winrock
[10] Smoke - the killer in the kitchen, Hugh warwick et al, ITDG Publishing 2004.
[11] Household energy,indoor air pollution and health impacts, page 17,March 2004, Winrock UNFPA at http://www.unfpa.org/swp/2003/presskit/pdf/indicators_eng.pdf
[12] Working for 5 years with the United Mission to Nepal (UMN) as the Jumla Rural Development Project Director