Project Report 8/10

August 24, 2010

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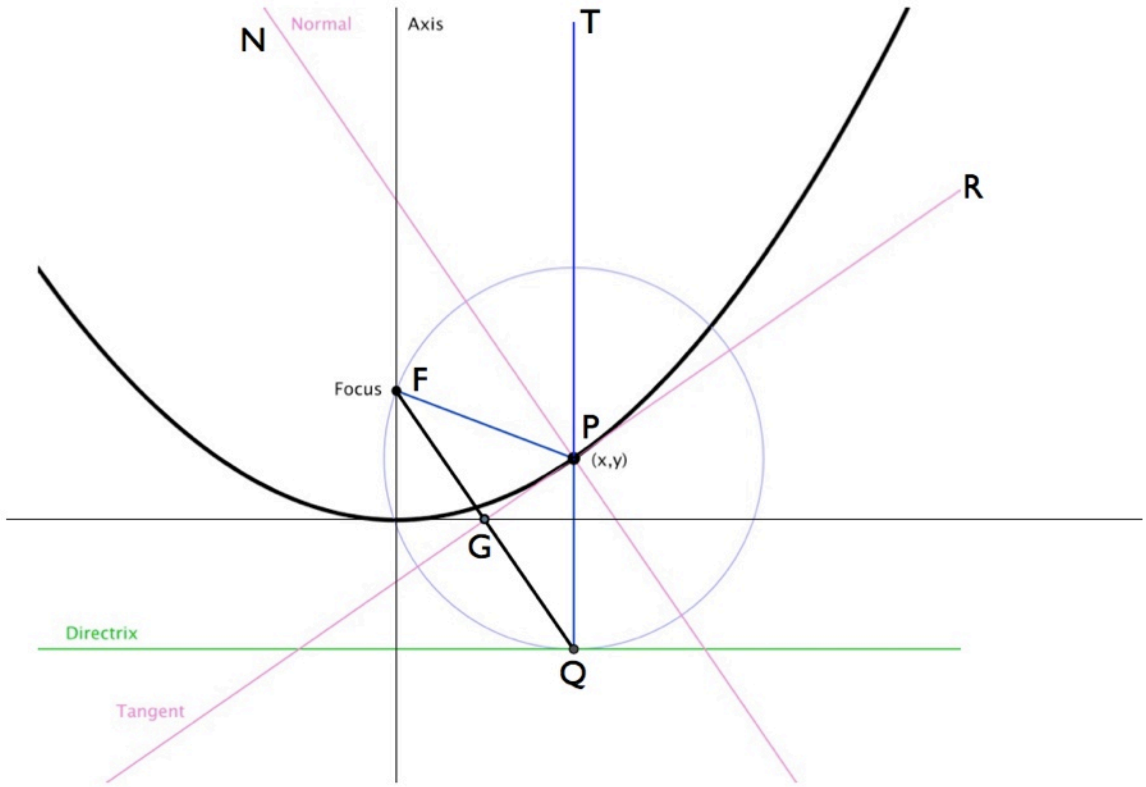
Background

Nearly two years ago, as the Lighting Project, and with the help of the Foundation for Ecological Security (FES), our NGO partner in India, we distributed two solar lights to each of the 391 households in the villages of Karech, Rajasthan and Hadagori, Orissa. The lights were distributed free of charge and the villagers signed an agreement to take good care of the lights and return them when we distributed solar cook stoves to them later on.

This solar light project has been an unqualified success. The lights have helped the villagers expand their day time and improve their productivity. They are able to work at night indoors and their children are able to study at night with the help of the lights. In addition, the solar lights have helped the women in the villages avoid snake bites during their early morning forays into the forest. This deliverance from snake bites has been an amazing, unexpected outcome of the solar light project. Best of all, using the solar lights did not require any change in the daily routines of the villagers as they charge the lights on their rooftops or porches unattended during the day, and use the lights at night once they return from their field work. The solar lights have also served to enhance their community experience as they are used during festivals and weddings to light up the night for dancing in the village commons.

The Prototype (Namaste) Solar Cook Stove

Right from the outset, it was apparent that the Lighting Project would be merely a charity venture that cannot be supported using carbon credits, since the primary usage of carbon-based energy in the remote villages of India was for cooking: 1 liter of Kerosene for lighting vs. 400-600kgs of firewood per household per month for cooking. Therefore, Climate Healers was born. For our initial prototype solar cook stove, we partnered with the Innovative Design Engineering Animation (IDEA) of Ahmedabad, India,



to produce a solar cook stove that rivals a traditional chula in terms of performance and can cook bhajra rotis, vegetables, dhal and rice, which formed the staple diet of the two village communities. The basis of this cook stove was the parabolic solar collector which rests on the property of the curve $y=x^2$ that any ray, TP, parallel to the y axis has a reflection, PF, that passes through a focal point F at (0, 1/4). Recall that a parabola is defined as the locus of a point (x,y) that is equidistant from a fixed point called the Focus, F, and a straight line, called the directrix. Without loss of generality, if F is at (0,f) and the directrix is the line, x = -f, then by definition, $x^2+(y-f)^2 = (y+f)^2$ or $x^2 = 4fy$. A reflecting surface can be created by rotating this parabola about its axis to form a 3-D surface that reflects all of the solar energy to the focal point when the surface is oriented to be perpendicular to the sun. The Namaste cook stove, designed at IDEA, uses two segments of such a paraboloid that can be folded to form a relatively, compact, closed structure that can then be wheeled for storage. It also has a heat trap at the focal point so that the heat energy is not dissipated through convection air currents. The orientation of the reflector can be changed with a turning screw in order to ensure that the axis of the paraboloid is always directly pointing at the sun. The area of the reflector surface was chosen to be 2.1 m^2 to ensure that there is at least 1KW at the focal point between 10am and 4pm on a sunny day at any time of the year and at any latitude within India. This is the minimum power necessary to adequately cook Bhajra rotis.

Feedback from the Namaste Cook Stove Deployment

Six units of the Namaste Cook Stove were deployed in and around the villages of Karech and Hadagori during January of 2010 and feedback was collected from the villagers about their experience with the stoves. Unlike the solar lights for which the feedback was overwhelmingly positive, the feedback in the case of the Namaste solar cook stoves has been overwhelmingly negative. Here is a compilation of the villagers' reactions to the stoves, gathered through personal visits and FES:

1. The solar cook stove is difficult to use in hilly terrain without leveling the ground.

2. It is uncomfortable to stand facing the sun to cook without an umbrella shade.

3. The cook stove is too tall for the women who actually prefer to sit and cook.

4. The solar cook stove requires constant adjusting which makes it inconvenient to use.

5. It is difficult to use the solar cook stove within the normal routine of the village women, since they are rarely in or around the house during the day. (This was pointed out to be so unlike their experience with the solar lights.)

6. It takes more time to cook Bhajra rotis on the solar cook stove than on the chula. (This was due to the bubbles that developed on the reflector surfaces because of a process defect during the manufacturing. This defect has since been corrected.)

7. The solar cook stove is difficult to use with a child in arm or a youngster in tow as it requires the user to stand and stretch to reach the cooking surface.

8. The solar cook stove is unstable and topples over in windy conditions, spilling the food.

9. The solar cook stove can only be used outdoors and during day time when the woman has various unending chores to tend that center around her children and animals.

10. Since the solar cook stove was only given to a few families in the villages, the recipients feel left out of the social activity of gathering firewood in the forest in the company of their friends.

Though most of the negative feedback above is applicable to any parabolic solar stove design, the net result is that over time, the Namaste solar cook stoves have been moth-balled in the villages. This experience has been so unlike that with the solar lights which continue to be treated as the prized possession of each household. In that context, the villagers' feedback has been truly humbling. In the prototype deployment, we did not install meters to measure the stove usage and provide incentives for the users, but it is unlikely that payments on the order of 4c per hour of usage would have improved the feedback substantially. This is especially because the Indian Government has instituted the National Rural Employment Guarantee in these villages and as a result, households are earning an additional $2 per day which dwarfs our proposed incentive rates.

To better respond to the feedback, we asked Rupam from FES Udaipur and Swapna from FES Angul to describe the typical daily routine of the village women in Karech and Hadagori, and what their ideal solar cook stove solution would be. Their inputs are given below.

Typical Daily Routine of the Women of Karech (source: Rupam, FES)

1. Wake up at 5 or 5:30am in the morning.
2. Go to the forest to take care of ablutions, collect firewood.
3. Take care of cattle.
4. Reheat left over food, make tea, around 7 or 7:30am.
5. Go out to the field or to the forest to work - where they work depends on the season.
6. Return home in the evening around 5 or 5:30pm.
7. Cook rotis and dinner, the main meal of the family.

The ideal solar cook stove should store energy during the day without intervention, just like the solar lights, and should enable the user to cook the main meal at night and reheat the food and make tea during the next morning.

Typical Daily Routine of the Women of Hadagori (source: Swapna, FES)

1. Wake up at 5am in the morning.
2. Go to the forest to do ablutions, work in the field
3. Come back home by 10am.
4. Cook some vegetables and eat with left over rice.
5. Go out to the field or to the forest to work and gather firewood.
6. Return home in the evening around 4pm.

7. Cook double boiled rice and dhal, the main meal of the family.
8. Use the solar lights to stitch leaves together in the night. This has become a new social activity.

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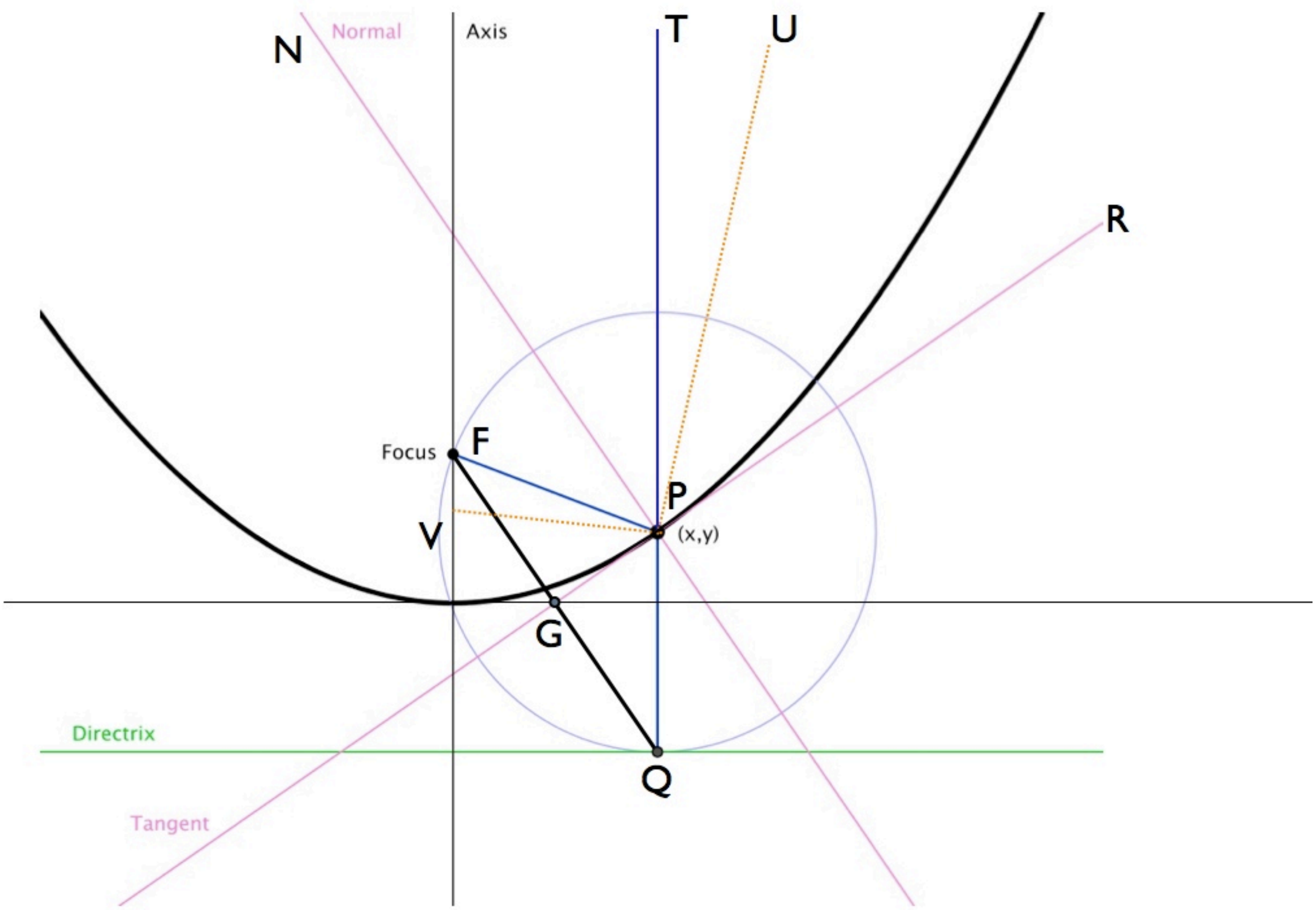
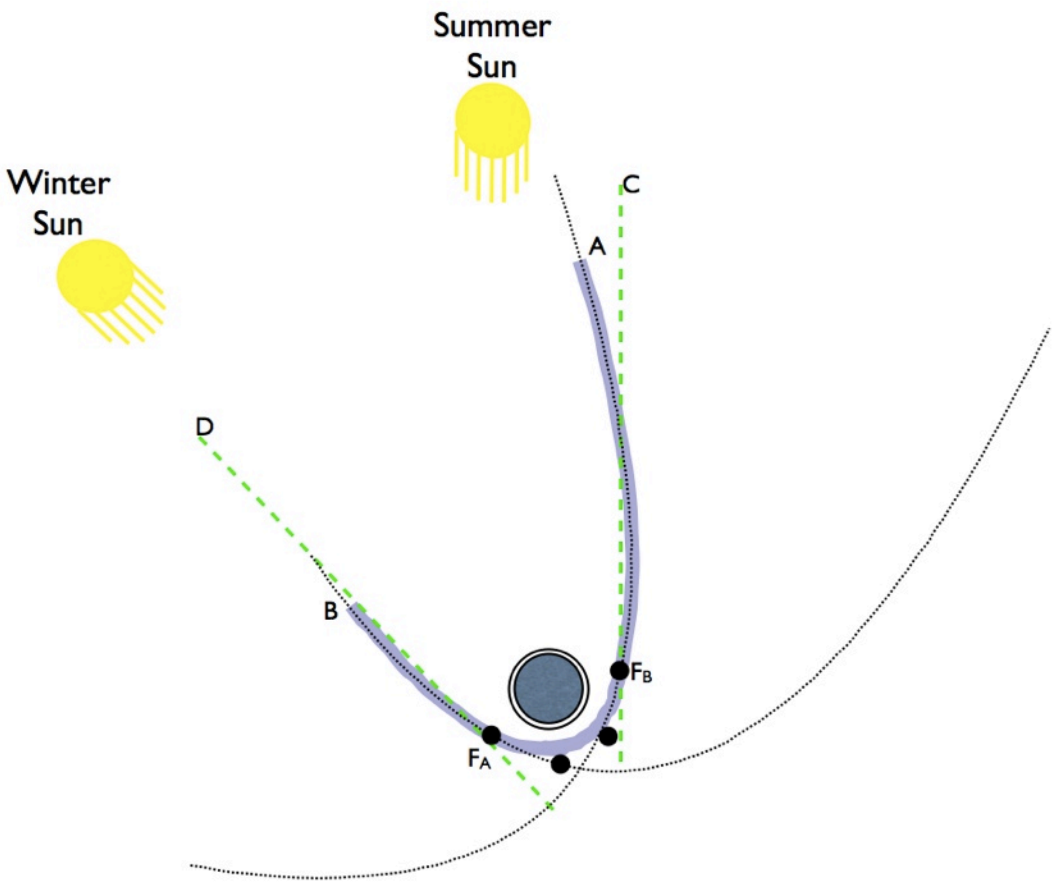
Solar Energy Collection without User Intervention

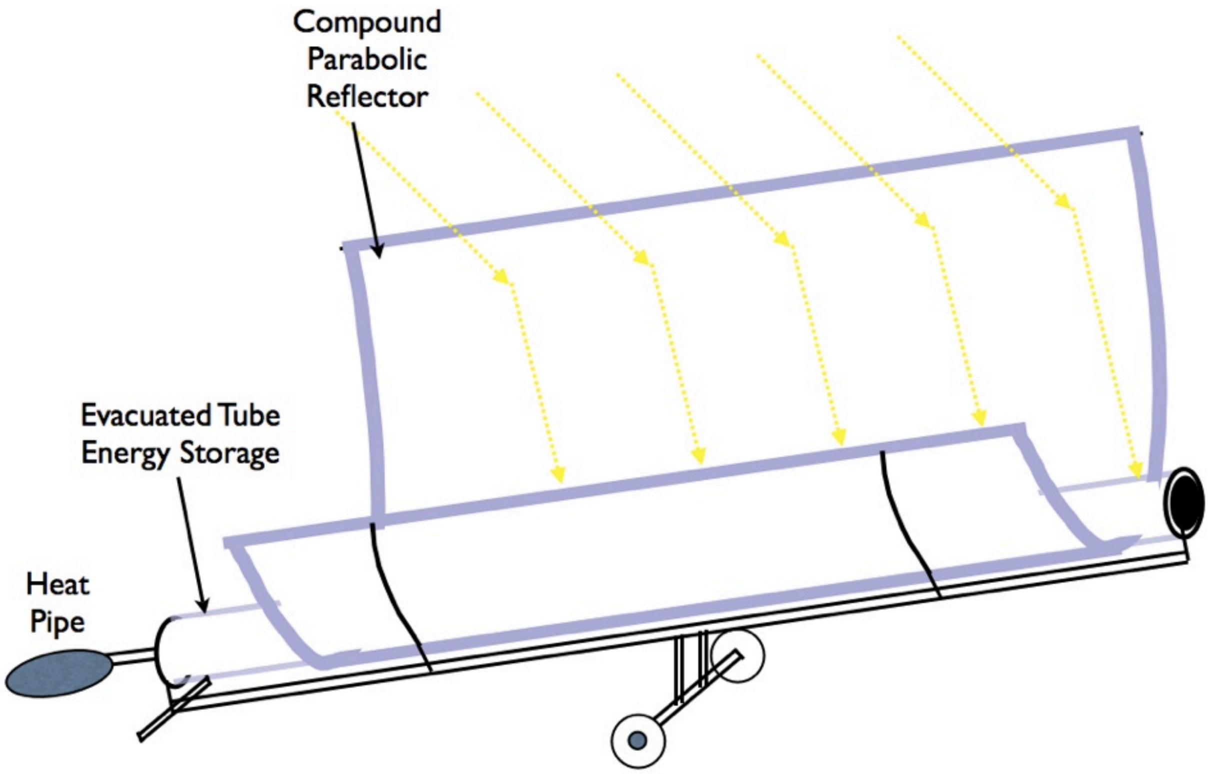
It was clear from the feedback that the pressing requirement of the users is for collecting solar energy without intervention during the day and storing it for use at night. This is difficult to achieve with a parabolic collector design without using motors or other mechanisms for automatically tracking the sun. On the other hand, Winston's compound parabola can be readily adapted for this purpose.



Winston's compound parabola rests on the property of the simple parabola that any ray UP, that has a larger angle of incidence with respect to the normal than the axis-parallel ray, TP, will reflect to a point V on the axis that is below the focal point, F. Therefore, a compound parabola can be constructed by using two simple parabolas as follows. Let B-F_A be the segment of a parabola with focal point F_B and let A-F_B be the segment of another parabola with focal point F_A, but that is rotated with respect to the first parabola by 47 degrees. Please note that the focal point of one parabola rests on the other and vice-versa. The two focal points, F_A and F_B can then be connected together with a circular arc segment and the energy collector placed in an evacuated tube between F_A and F_B. The compound parabola is constructed as A-F_B-F_A-B which ensures that any ray that falls on either parabolic segment at any angle



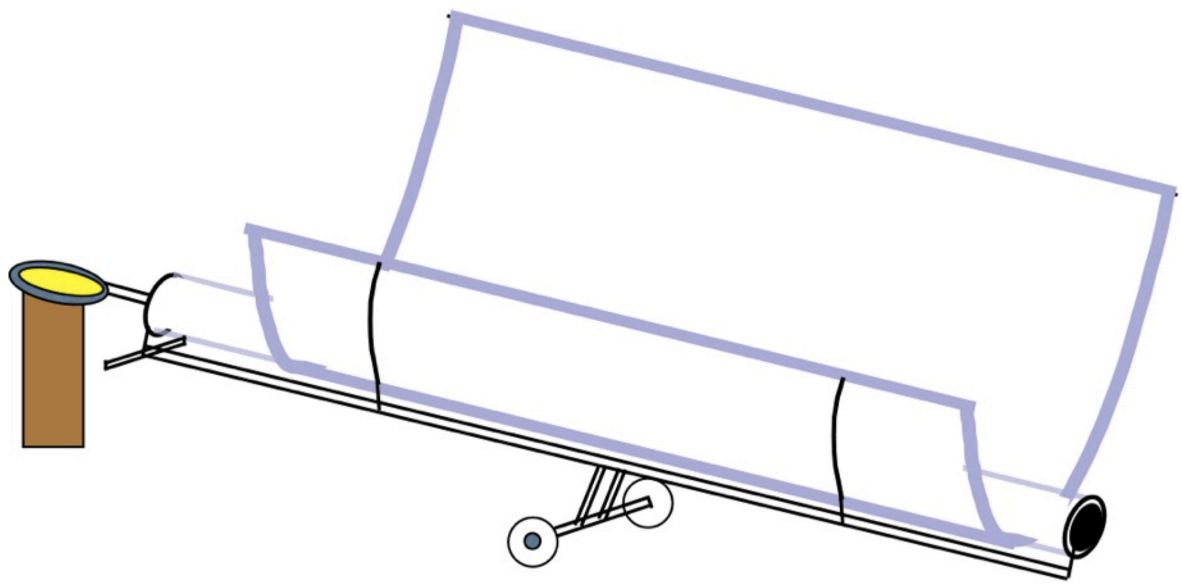
between the two axes will reflect to a point between F_A and F_B which necessarily would intersect the energy collector. Therefore, the compound parabola has a capture range of 47 degrees, which envelopes the total annual excursion of the sun between the Tropic of Cancer and the Tropic of Capricorn. Please note that the segments, B-F_A and A-F_B can be chosen to have different lengths which allows for an increased aperture of the compound parabola for the winter sun than for the summer sun. Depending on the latitude of the location, the compound parabola can also be rotated about the circular segment to envelope the total excursion of the sun at that location.



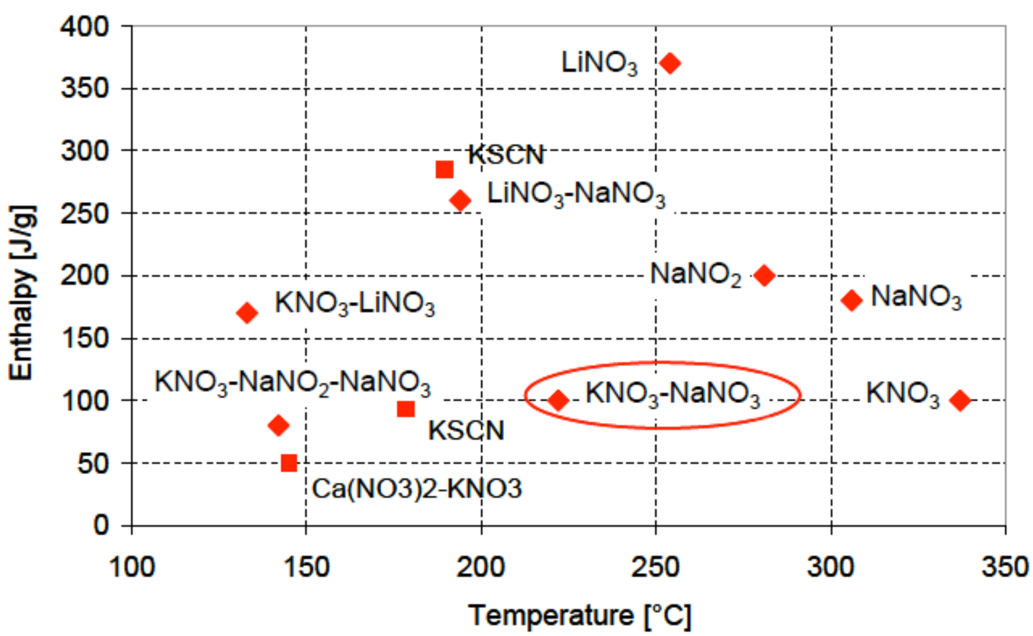
Unlike the parabolic cook stove design which used a simple parabola rotated about its axis to create a single focal point, the storage cook stove design uses a cylindrical 3-D extension of the compound parabola to direct the solar energy to a cylindrical evacuated tube energy collector as shown above. The stored energy in the evacuated tube is accessed through a sealed thermo-syphon or heat pipe which is filled with a fluid that converts to vapor at high temperatures within the tube and condenses on the cooking surface releasing the energy. During the storage phase, the heat pipe is oriented down by the user so that the fluid is outside the evacuated tube and does not participate in the heat transfer. The cook stove is positioned in an East-West orientation so that the solar energy is collected throughout the course of the day without any intervention from the user.

Cooking using the Stored Energy

At night or at any time when the user wishes to cook with the stored energy, the heat pipe is raised and placed on a fixed brick platform so that gravity forces the fluid in the pipe to descend into the evacuated tube. The fluid is converted to vapor within the tube and condenses at the cooking surface releasing the energy. The heat pipe should be designed to deliver at least 1KW at the cooking surface nominally so that Bhajra rotis can be cooked effectively. (Alternately, a valve can be used to control the heat pipe operation.)



The evacuated tube can be filled with a type of salt that melts at an appropriate temperature with high latent heat (enthalpy), thereby storing and delivering a lot of energy at that temperature. Of all the salt varieties studied by [Rainer Tamme](), $NaNO_3$, Sodium Nitrate, seems to be ideally suited for our application as it has a melting point of 310ºC or 590ºF which would limit the maximum temperature

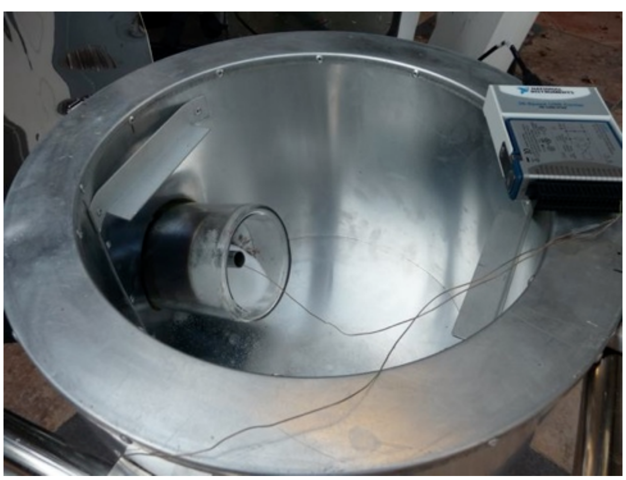


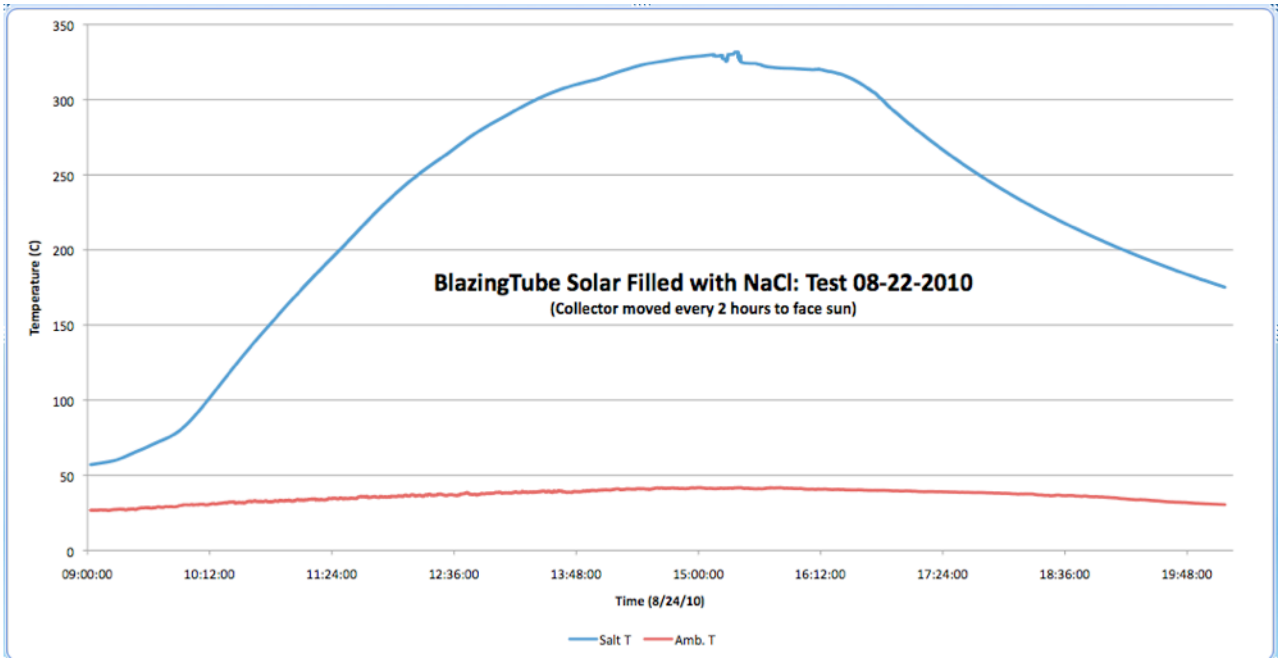
encountered in the evacuated tube. It is also the cheapest and most benign of all the salt combinations studied in their paper. Assuming an evacuated tube with a capacity of 3 gallons, the maximum amount of energy that can be stored in the solid-liquid phase change of Sodium Nitrate is roughly 1 KWhr, which is sufficient to allow the user to cook for an hour in a constant temperature setting using a 1KW heat pipe. In addition, there would also be more than 1 KWhr of sensible heat stored in the tube, which can be accessed at lower temperatures.

Preliminary Tests using Common Salt

In order to assess the potential of this storage cook stove design, we acquired a [BlazingTube solar cooker](), thanks to the generosity of John Grandinetti, its designer. The [BlazingTube solar cooker]() uses a generic compound parabolic reflector (not of the kind described above) along with a 3 gallon evacuated tube to collect instantaneous solar energy and deliver it to the cooking surface. The 3 gallon tube is filled with a 2 gallon air bubble in the center and 1 gallon of cooking oil surrounding it. This arrangement increases the surface area of the cooking oil relative to its volume and all that surface area is exposed to solar energy through the outer glass tube. The cooking oil convects the instantaneous solar energy through gravity and delivers it at the vessel. While this is not precisely the design we had in mind, the BlazingTube solar cooker turned out to be an excellent vehicle for conducting our studies.

To conduct the experiment, we removed the inner "air bubble" tube in the BlazingTube cooker and filled the 3 gallon tube with finely granulated common salt, Sodium Chloride, instead of cooking oil. Common salt has a melting point of 810ºC or 1490ºF and it is extremely stable at temperatures of interest to us. A 2-foot metal pipe with a thermocouple attached at its end was inserted into the salt so that the temperature of the salt at the center of the tube can be measured as it gets heated up by the sun. The overall aperture area of the compound parabola in the BlazingTube cooker is less than 1m^2, but it is not designed to collect solar energy without user intervention as it has a symmetric profile and its acceptance angle is much less than 47 degrees. Therefore, we adjusted the position of the cooker every two hours in order to maximize the energy collection throughout the day. (Except between 3pm and 5:30pm, when the set up was left unattended.) The goal was to verify whether the salt at the center of the





evacuated tube can reach temperatures exceeding 590ºF despite radiation losses and other heat losses in the cooker set up.

The temperature of the salt reached as high as 330ºC or 626ºF at the center of the tube. Based on the thermal conductivity of granular salt, we estimate that the temperature at the wall of the inner tube reached around 700ºF which is the temperature at which the primary radiation heat losses occurred from the tube. If the tube had been filled with Sodium Nitrate, the temperature at the walls of the tube would have stayed at 590ºF while the salt melted, thereby reducing radiation heat losses as well. Therefore, it appears that the proposed approach for a storage solar cook stove for rural deployment is quite viable.

Acknowledgements

The Namaste solar cook stove design was based on numerous parabolic cooker designs, but primarily on the Butterfly design used in Tibet and Somalia. We acquired a large model of the Butterfly cooker from China, but found it very uncomfortable to cook rotis with because of the power leakage from the cooking area. Hence we embarked on a distinct design. We also gratefully acknowledge the pioneering work of Morrisson, Di and Mills of the University of New South Wales in Australia that described many of the principles utilized in the proposed storage solar cook stove design. Finally, we are thankful to K. Suresh of SuryaPrakash Energy Systems for conducting the common salt test using the BlazingTube Solar cooker and to K. Suresh and Dr. Gani Ganapathi of NASA Jet Propulsion Labs for many invaluable discussions on Thermal Energy Storage systems.