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NOTE: IVAN YAHOLNITSKY IS AN ASSOCIATE OF THE BRACE RESEARCH INSTITUTE. HE HAS MAINTAINED AN ACTIVE,ONGOING COLLABORATION WITH TOM LAWAND OVER THE PAST DECADE. HE HAS VISITED THE INSTITUTE AND TOM LAWAND ON MANY OCCASIONS. HIS WORK IN THE APPLICATION OF RENEWABLE AND APPROPRIATE TECHNOLOGIES TO THE REAL NEEDS OF PEOPLE ESPECIALLY IN RURAL AREAS ARE EXEMPLARY .

A Parabolic Trough Baking Device Developed in Lesotho

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1. Introduction.

This paper describes technical parameters and experience of a parabolic trough bread baking device developed in Lesotho. From the author's experience, precise blueprints for replicating the apparatus are not warranted, because often developers in remote or poor areas may not have access to precisely the same materials used in this device. What will be provided in this report are the dimensions and factors that do matter, while leaving other details to local adaptation and improvisation. The design of a few important aspects will be described carefully, as will operational experience. It seems more important, to me, to create a community of exploration and common problem solving, rather than inflexible assertion about this or that particular detail. While this researcher used square tubing for the structural elements, it could probably be built out of flat bar, wood, pipe or plastic sections, depending on regional resources, local ingenuity and shop equipment available.

The device illustrated in Fig. 1 has operated continuously since June 2005. It is located in the author's front garden, and is about 10 paces from the kitchen door. The receiver tube is exactly 200mm in diameter, and holds 3 large bread pans, or 4 smaller ones, or any combination of pans not longer

than 1200mm all together. Under clear sunshine the device performs very well, and reaches good baking temperatures (over 200°C) for up to 7 hours per day (9:00-16:00), and can be used even later in summer. It has a concentration ratio of approximately 10:1. Cool windy weather hampers operation of the device significantly, as advective cooling reaches a point where internal temperature in the baking tube drops below tolerable limits. In Lesotho, however, these instances are infrequent. Possible solutions for dealing with advective cooling will be mentioned in the conclusion.

Fig. 1: Front view of concentrator type baking device. Author's daughter Thung-Thung in foreground. Absorber tube is loaded/unloaded by removing plywood plug on end.

Advantages of the device are low cost, simplicity of fabrication, and ease of operation. Drawbacks are that some of the materials may be difficult to source. Nevertheless, Bethel is remote and not well served by transportation or communications facilities. We were able to track down the special inputs required and obtain them for a reasonable price.

Presently this device is being used by the author's wife to operate a bread baking cottage enterprise. There are only 3 pivot points, as illustrated in

Fig. 2. Neither of the pivot points requires precision engineering. The horizontal rotation "T" is a pipe in pipe swivel with a collar tack welded on, and the 2 vertical pivot points are just bolts with flat washers. While the oven must be manually actuated and adjusted (every 15 minutes), no mechanical or power driven devices are installed, which lowers the development costs and reduces maintenance problems. A small circular section of metal is allowed to protrude on one side of the trough. Aiming of the device is by means of checking on the shadow cast from the focus point on the ground (through the circular metal section) or on the circular metal section itself. Once the operator is accustomed to the fact that the shadow moves down in the morning and up in the afternoon (after the apparent altitude of the sun), it is relatively easy to keep the device focused and slightly ahead of the sun's position.

Fig. 2: View of device from rear, and illustrating dual axis tracking and adjustment.

2. Technical Specifications.

The dimensions of the parabola in <u>mm</u> are given by the formula:

$$y=x^2/1500$$

This gives a center of focus at 375mm from the central axis. This solution was arrived at by comparing potential solar capture with different parabolic geometries. It was chosen because it combined sufficient solar capture with a focal position near enough to the trough to minimize optic distortion and advective losses. The absorber is quite large, which means that some distortion in the reflecting surface can be tolerated without too much loss of reflective radiation. I met Michel Grupp at the world conference on solar cooking in Kimberley, RSA in 2001 and explained to him what I wanted to do. He suggested that the focus be kept near to the central axis, while ensuring that the mouth of the trough was wide enough to obtain enough energy. Following a few sketches and number plots on graph paper with different parabolic functions, $y=x^2/1500$ (in mm) was settled on because it provided a 10:1 concentration ratio, and a 200mm diameter baking tube which is the necessary dimension for standard full size loaves of bread. A survey of the literature suggested that a 10:1 concentration ratio would provide the desired temperature range (Whillier, 1958).

Anodized aluminum sourced from Alanod in Germany was used for the reflector. The straight distance across the end of the trough is 2400mm and the distance along the curved edge is 3200mm from end to end. With a width of 1250mm this means that 4m^2 of the anodized aluminum is required. Its cost is R150.00/m^2. The effective solar aperture is 3m^2 or approximately 3000 watts under full sun. The absorber employs Mirotherm, (0.6mm in thickness) which is a spectrally selective material with excellent absorbent properties. The absorber tube is 200mm in diameter and 1200mm in length. Therefore the rolled surface of the Mirotherm is approximately .75m^2 at a cost of R300.00/m^2. The optical values of the Mirotherm as provided by the manufacturer are:

Solar sbsorption: $\alpha_{sol} = 0.94 \pm 0.02$

Thermal emission: $\varepsilon_{100^\circ C} = 0.05 \pm 0.02$

3. Operation, Experience and Performance.

Lesotho has good solar conditions. For example, the 7 day weather forecast for the period May 4-10, 2007 issued by the South African Weather service, predicted clear and cloudless skies, with light winds, and maximum temperatures of 27-28˚C over the period. Lesotho receives a lot of weather like this. The parabolic trough can bake bread in 40 – 60 minutes (1000g loaf), depending on conditions, and muffins, cookies and small buns in 20 minutes. Finding the right cooking utensils is as important as anything else. Fortunately we were able to find bread pans that measure 330mm x 130mm x 70mm and half doz. muffin pans (see Fig. 3) that fit perfectly in the tube and provide excellent heat transfer. I also

made a long pan especially for it out of copper sheet and with soldered corner joints (see Fig. 5).

Fig. 3: Cinnamon Buns baked in 20 minutes. Peace Corp Volunteer Timothy O'Connell and researcher's son John in background.

Fig. 4: Bread.

Fig. 5: Pizza.

Fig. 6: Turnovers.

Fig. 7: Tarts.

Fig. 8: Coffee/almond/coconut rolls.

Fig. 9: Herb rolls with sun dried tomato.

4. Fabrication.

A template was made for the fabrication of the parabolic sections from a piece of plywood. Points were plotted using a t-square, and then the shape carefully cut and sanded smooth. The parabolic end profile was shaped by making interval cuts with a hack saw ¾ way through 20mm x 20mm x 1.6mm square tubing. The current local price for this material is R11.00/m. The trough depicted in Fig. 2 used 24.0m of this material, for an approximate total cost of R264.00. These cuts were made symmetrically from the center so that the tube would easily bend to close the gap of the cut and wrap to the shape of the parabolic template cut from plywood. The plywood was clamped to a large steel welding table with a flat surface and true 90˚ corners. Straight sections of 20mm square tubing were then added behind the curved section and braced with small truss pieces. This is apparent from Fig. 10. Once the parabolic section was true and the truss sections securely clamped, these sections were welded using mild steel electrodes. The cuts made to achieve the curved shape were closed with rapid touch welds. Once the two end sections with a parabolic shape were completed, the device was set up and leveled carefully on a plane surface,

and the lateral sections across the mouth of the trough were welded in place. More lateral sections would reduce sag and distortion of the reflective material, but increase cost and weight of the device. As well, perfect optics may actually put more stress on the absorber than it can endure.

The anodized aluminum was pop-riveted to the square tubing using 4mm pop rivets, spaced 200mm on center.

The baking tube was made by rolling a sheet of Mirotherm, and pop-riveting it to a rectangular steel frame welded from 20mm x 20mm square tubing. Prior to installation of the Mirotherm sheet, the inside surface which "sees" the bread was painted with black high heat paint. This is important because the ε of shiny aluminum is extremely low, and undesirable. By painting the inside surface black, heat transfer by radiation is brought closer to its maximum potential. The loading end was kept unobstructed by rolling a 200mm steel ring out of 20mm x 5mm flat bar. Two pieces of 6mm round bar were tack welded to the outside of the steel ring on the loading end to form a groove. This enables the baking tube to rotate and level. A pipe rotates in a collar at the opposite end of the baking tube.

Fig. 10: Truss section used to maintain parabolic Profile. Note circular aiming device on far edge.

Fig. 11: Detail of altitude adjustment; note that radius arm is able to swivel on the vertical support. Device is locked in place with a pin.

5. Economics and Financial Analysis.

Summary of material costs for the device:

Material	Amount	Cost Per Unit	
20mm x 20mm x 1.6mm square tubing	24.0m	R11.00/m	264.00
Anodized Aluminum	$3.0m^2$	$R150.00/m^2$	450.00
Mirotherm	$0.75m^2$	$R300.00/m^2$	225.00
Pipe and other steel			150.00
Welding		(Estimate)	1000.00
Fastening			200.00
Concrete Footing			200.00
Paint/Finishing			50.00
Total:			R2539.00

$1.00 USD = R7.40 SA RAND (March 7, 2007)

Bread making is hard work. A present, the dough is being mixed by hand early in the morning. The quantity is sufficient for 12 x 1000g loaves. As well, a batch of 24 cinnamon buns is also typically prepared each day. The

bread is being sold for R5.00 per loaf and the cinnamon buns for R1.00 each, providing an average cash flow (12 x R5.00 + 24 x R1.00) of R84.00 per day. Thus far, there is no problem selling the output. The gross profit margin is about 60%, providing a return to labor of approximately R50.00/day (double the local statutory minimum wage). For Lesotho, this is certainly a worthwhile undertaking for the entrepreneur, not to mention a high quality product for the local community. Each loaf of unbaked dough is weighed on an electronic kitchen scale to ensure a consistent product.

The cost of the materials for the parabolic trough was approximately R1500.00. The researcher welded it together in spare time. Therefore a realistic price for the device is estimated to be R3000.00. It is interesting to note that a solar powered mini-grid provided all the power for welding and finishing. What counts ultimately, is the payback period and the amount of cycling and duty that the machine can sustain each day and for how long. Mechanization of the dough mixing would certainly enable more baking each day. Special orders for more bread are often received due to local functions, and there is also a steady demand for specialty items like pizza, muffins, cookies, biscuits and cakes, which command a higher margin. Readers can draw their own conclusions, but pay back is quite rapid. It should also be mentioned that Bethel is a small remote community. A device like this located near dense urban clusters or transportation hubs will find a ready and strong market for baked goods.

One advantage of a cottage enterprise is that on the chance that clouds suddenly appear and bread flops, it can still be consumed in the entrepreneur's own home. Occasional back up capacity is provided by conventional gas stoves. This minimizes waste. As well, the device is frequently used to prepare other items for the domestic menu. In summer, this keeps a lot of unwanted heat out of the kitchen. It also provides a recreational element and point of interest in the home (what can I do today…..).

There is no local competition. Bread is trucked in from Maseru, and sells locally for R4.70 for <600g loaf. It is not fresh. The SA price for bread is R3.80 for <700g loaf. Therefore the locally produced product at Bethel is fully competitive, at R5.00 for a 1000g loaf. The bread frequently sells as fast as it is pulled from the oven.


Fig. 12: Nthabiseng with baked bread from oven.

6. Problems Encountered and Discussion

Some heat stress occurred on the Mirotherm baking tube, causing short 15-20mm long tears in the material. The researcher plugged these with aluminum foil. It should be added that making the baking tube virtually air tight certainly raises its performance. As this was a prototype, the sealing of seams along the lateral edge and especially on the ends was not ideal. From my experience, efforts to seal up the baking tube as tight as possible will be rewarded with better performance. The use of heat resistant tapes and gasket type materials is warranted if they are available. Copper sheet with the seams brazed or soldered tight, and the surface coated with purpose designed black paint my also produce good results and needs to be tested. While the Mirotherm is certainly an exotic material and BBCDC was fortunate to be supplied with it as a research undertaking, equally good results may be obtained by using rolled copper sheet coated with heat resistant black paint specially formulated for solar absorption applications.

To reduce advective cooling, other developers and researchers may consider putting a clear polycarbonate sheet across the end of the trough, and closing the ends. This may provide more consistent temperatures, and

even allow for overall reduction of the size of the trough. If it was available, a clear polycarbonate cylinder designed for high temperatures, could be designed to fit over the absorber tube. This also would raise the thermal efficiency of the absorber and enable reduction of the size of the parabolic trough. Optimization along these lines requires further research.

In closing, this is a promising device. Nevertheless, the thermal technology is only one piece of the puzzle. If you do not know how to cook, a solar oven will not help you. If you have nothing to cook, it will not help you either. With this parabolic oven, there was a long learning period unrelated to the thermodynamics of baking operations. What also matters is good bread dough making procedures, time management, coordination of bulk shipping of flour, selection of complementary utensils, customer relations, market research, packaging, cost accounting and final retailing. To have dough ready to bake by 9:00 AM, you have to be a very early riser, as all bakers know.

With technology, the strangest things will happen and I end on a humorous note. In the resting position with the bottom lip down on the ground, the bread baking oven drew the ire of our free ranging muscovy ducks. Once the ducks saw their mirror image they would not leave these phantom intruders to their territory alone. The reflective surface was badly scratched along the lower surface by the ducks waging war on their own reflection. The ducks are now permanently penned up for this reason.