DEVELOPMENT OF PRINCE-40 SOLAR CONCENTRATOR AS DO IT YOURSELF (DIY) KIT

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Abstract

Climate change issues and depletion of fossil fuels have forced civilized world to look for clean and green energy alternatives. Cooking is one of the most basic application area which consume large amount of fuels. Asian and African countries are blessed with ample Sun and Switching over to 'Solar Cooking', can help to resolve the issues to some extent. In India community cooking is practiced on large scale at mid- day- meal schemes in schools, Aanganwadis (Pregnant women, mothers and child care center), old age homes, temples, aashrams and charitable organizations. It is possible to shift many such institutions on community solar cooking and save lot of fossil fuels and firewood. In recent years development of community dish cookers like SK-23 and PRINCE-40 have shown great potential in energy saving and mass deployment of technology. Adoption of 360 nos. of SK-23 solar community dish cookers for residential tribal schools by tribal ministry in Maharashtra, 42 PRINCE-40 community dish cookers by 'Catholic Relief Society' in Madhyapradesh and Chattisgarh and 25 systems by WOTR (Watershed Organisation TRust) in Maharashtra for mid-day-meal scheme at schools has shown viability and acceptance by rural and tribal communities. These projects show huge potentia for large scale deployment in Asian and African continent. PRINCE-40 concentrator in fabricated version is upgradation from SK-23, on account of transportability and performence. In recent months PRINCE-40 design has been further improvised from fabricated dish to segmented dish, constructed in FRP. Applications of PRINCE-40 concentrators are now extended to autoclaving and microenterprise, apart from community cooking. These PRINCE-40 concentrators of 4 m^2 aperture area fill the gap between domestic cookers of 1.5 m^2 and Scheffler dishes of 16 m^2.

Keywords: solar concentrator, community cooker, SK-23, PRINCE-40, square dish, DIY kit

Nomenclature

A_a Aperture area m^2	C_{pal} Specific heat of aluminum kJ/kg-K
C_{pw} Specific heat of water	I_b Solar beam radiation, watts/sqm
M_{pal} Mass of aluminum pot	M_w Mass of water
ηb Efficiency with beam radiation %	ζ Time sec.
Ta Ambient temperature °C	T_{w1} Start temperature of water °C
T_{w2} End temperature of water °C	

1. Introduction

With all the talk around the globe on emission reduction, solar cooking is still on lower priority with many governments. Solar cooking technology do have limitations of climate dependency and also limitations on cooking operations like frying, still the technology has the potential for large scale adoption in Asia and Africa. Individual or family sized cookers have limited use, but the community cooking does have huge market potential, especially in country like India. Temples, old age homes, residential schools, hostels, hotels, public health centers, Aanganwadis (pregnant mother and child care centers), mid-day-meal schemes in schools are the primary areas where community cooking is practiced on very large scale and many million meals are prepared on daily basis. More than 50% of these meals can be switched over to solar cooking, saving fossil fuels & firewood and which lead to substantial emission reduction and saving forests.

2. Review of Community Cooking Options

There are few installations demonstrating the feasibility of community cooking primarily at temples in India. Most of these community cooking systems use 'Scheffler Concentrators', in direct cooking mode or in steam cooking mode (Gadhia 2009). Scheffler technologies, even though successfully adopted, have few limitations as described below.

- High capital investment: Scheffler concentrators typically cost ₹ 180000 i.e. US $ 4000, for a concentrator of 16 m^2, which is not affordable by many prospective users.
- Scheffler concentrators demand typical orientation of kitchen with east-west wall and shadow free south side. Most of the time, existing kitchens are not suitable and new kitchens need to be constructed.
- Designing, manufacturing and installation is complex and there are very few competent manufacturers in the market. It is not possible to design concentrators in DIY kit form. For this reason large scale adoption in short time is impossible.
- System has permanent installation and needs shadow free area throughout the year.
- Seasonal adjustment of the concentrator and tracking mechanism needs skilled operator.

A Scheffler concentrator of 16 m^2 area can cook meals for around 125 people while the domestic parabolic cooker available in the market like SK-14, which can cook for 8 people. Seifert et al (2006), inventor of the domestic cooker SK-14, also worked on possibility of using SK-14 and other clean cooking technologies for gaining carbon credits. However there is limited success in promoting domestic cookers on large scale. A need was also felt to design and develop a midsized solar cooking system that can cater to 50-60 people and will overcome the limitations of the Scheffler concentrator. A series of dish cooker of 4 m^2 aperture area were developed by the authors. Circular dish cookers of 2.3 m diameter called SK-23 was the first design, then square paraboloidal dish called PRINCE-40 as DIY kit in fabricated version and recently PRINCE-40 dish is modified as segmented dish in sheet metal or fiber reinforced plastic as base material.

3. Experiences with SK-23 Community Dish Cookers

Author[1] developoed a simple dish cooker of 2.30 m diameter with 4 m^2 aperture area, referred as SK-23, which costs 20% of the cost of 16 m^2 Scheffler and delivers up to 50% performance. This community dish cooker has disadvantage that the cook need to visit the solar cooker in the Sun for loading, unloading and occasional tracking. However because of immense cost advantage and ease of operation, SK-14 was reasonably well received by the society as well as state government.

Fig. 1 Installation at Hotel Emrald Park Nasik and at a tribal school in Nandurbar district

These community cookers were tested by regional test center of government of India at Pune University and cooking tests show that the cookers are capable of cooking mid day meal for 50 students in just one hour (RTC Pune 2007). More than 500 community dish cookers were installed for private users as well as government organisations through manufactures, trained by authors. These installations included world's largest installation with community dish cookers, with 360 dish cookers having total aperture area of 1440 m^2 installed at 160 tribal residential schools in Maharashtra. (Chandak et al 2009). These systems are cooking meals for more than 25000 students, saving 54 tons of LPG equivalent i.e. around 150 tons of carbon emission reduction per year. Fig. 1 shows two installations one on a rooftop of a commercial hotel in a city and other in remote tribal school in hilly terrain. Even though SK-23 community dish cookers were reasonably successful, large scale dissemination of the technology was difficult, as the dish of 2.3 m diameter was fabricated in single piece, and was very difficult to transport. Transportation cost was also substantially high and for this reason the promotion of the systems could not go beyond state of Maharashtra.

4. Development of PRINCE-40 Concentrator

Realising limitations of SK-23 concentrator dish, author[1] developed new compact design named as PRINCE-40. This innovation (Chandak 2008) utilizes a special geometry where all construction members of the dish are of same geometry and hence it is possible to design the dish as knock down assembly, which can be assembled at site. This is a square paraboloidal dish. The design was acknowledged as best innovation in renewable energy at a national event Innovation 2009 (Innovation 2009). As it is possible for novice people to assemble and use PRINCE-40 concentrator as per the instructions in the manual, the units are distributed as DIY (Do It Yourself) kit. This concentrator was tested at regional test center of Govt. of India at Pune University (RTC Pune 2010). Field tests were also conducted on the concentrator for cooking test against time as well as controlled cooking tests for LPG saving potential. Simultaneous tests were also carried out on both the concentrators SK-23 and PRINCE-40, to have record comparative performance.

4.1 Test Procedure: Cooking power and efficiency were calculated as per test procedures proposed by Mullick et al (1991), Paul A. Funk (2000) and draft test procedure of MoNES (2006). SK-23 and PRINCE-40 concentrators were simultaneously tested. 12 kg of water is used per pot and water is allowed to reach to a temperatue of 85°C. Corresponding time is recorded. Reflector is defocused at this point. Average heat duty and efficiency are calculated over this period. Aluminum pressure cookers of same size and weight were used as pots for holding water. These pots were blackened on bottom and lower half from outside. Weight of each of aluminum cooker was 7.75 kgs

4.2 Observations: Measurements were recorded using Sunpro data logger for ambient temperature, solar beam radiations and water temperatures. Weights of the pots and water were measured with weighing machines. For heat duty measurement, temperature of water was kept below 90^0C to avoid error that can creep in because of evaporation of water. Pressure cookers were used as a pot and during the test lid was kept closed so that any steam formed does not leave the pot. Table 1, shows sample set of observations.

4.3 Calculations and Results: Heat gain by pot and heat gain by water is taken as useful heat gain while from the beam radiation and aperture area of the solar dish heat input is calculated. Following formulaes are used for calculations of heat dury and efficiency.

$$HeatDuty = (Mp \times C_{pal} + Mw \times C_{pw}) \times \frac{Tw_2 - Tw_1}{\zeta} \qquad \text{(eq. 1)}$$

$$\eta \mathrm{b} = \frac{\text{Heat duty}}{\frac{Ib \times Ap}{1000}} \qquad \text{(eq. 2)}$$

Results of average heat duty and efficiency are shown in last two columns of the table 1.

Table 1 Sample observation and results of comparative study of SK-23 and PRINCE-40 concentrators

Parameter	SK-23	PRINCE-40
Mass of the pot in Kgs Mp	7.75	7.75
Mass of water in kgs Mw	12	12
Avg. Beam radiation Ib	775	775
Ambient temperature Ta	32	32
Start temp. of water Tw_1	30	30
End temp. of water T_{W2}	85	85
Time Interval ζ *in seconds*	1835	1610
Results		
Avg. Heat duty in W thermal	**1618**	**1814**
System efficiency ηb in %	**52.19**	**58.51**

Results show around 13% improvement in performance of PRINCE-40 concentrators over SK-23. PRINCE-40 concentrators were accepted and approved as community solar cooker by Ministry of New & Renewable Energy, Govt. of India (MNRE 2010), and at present are entitled for subsidy of ₹8400 per system.

5. Adoption of PRINCE-40 Concentrators for Community Cooking

With successful laboratory and field tests, technology was disseminated to few prospective entrepreneurs. Initial installations were made in the state of Maharashtra itself and few field problems were rectified in design changes. First sizable project came up from CRS (Catholic Relief Services) through their organisation MPSSS (Madhya Pradesh Samaj Seva Samiti). This organisation works in central India, in the states of Madhya Pradesh and Chattisgarh. The organisation runs residential facility for tribal students at more than 200 locations. Initially two installations were made and reviewed by cooks from different schools. On recommendations of the cooks total forty two PRINCE-40 community cookers were installed to serve more than 2500 children. Feedbacks from the end users are quoted herewith show high level of satisfaction. These feedbacks also highlighted other positive side effects like protecting cooks from the smoke and additional time they have for other works. Improved taste was other motivation for the users.

"Feedback 1 from Fr. Joseph Porimattam, Director Samaritans addressed to Fr. Mathew of MPSSS": Dear Father, Greetings from Samaritans! This to inform you that we have already installed PRINCE-40 solar cookers in four places viz. Asha Bhavan, Panna, St. Joseph Balabhavan, Panna, Samaritan Hospital , Satna, & Uday Balabhavan, Karimatti. As the result, everywhere it is functioning very well and it is used to cook Chaval and Dhal, which reduces the use of Gas and really they benefit out of it. Taste of food is great.

"Feedback 2 from Fr. Sebi Thottankara, to Fr. Mathew of MPSSS": 16 nos. PRINCE-40 solar cookers are installed at different schools. Rice, pourage, Dall, vegetables and boiling eggs are cooked within 50 to 65 minutes at present. The hostel management and cooks are happy because it not only saves time and money but also protect eyes from smoke and fire to persons who are in the kitchen. Along with the cooking in the solar cooker, cooks are able do other kitchen work. Once again we are grateful to CRS and MPSSS for your kind support.

"Feedback 3 from Fr. Praful Kujur to Fr. Mathew of MPSSS": PRINCE-40 solar cookers are installed at 16 different schools catering to 907 students. Mr. Oscar Xalxo GVK the administrator visited most of the centers and took feedback about its functioning.All the Solar Cookers are functioning well and the center in-charges are happy to have this set. In the beginning they had little problem only because they were not setting according to the sun ray. Now they are happy to receive it and saving lots of fire wood, also the extra expenditure has been reduced.

Fig. 2 Tribal workers installing PRINCE-40 concentrators and Cooking in action.

All 42 installations were carried out by the local people as per instruction manual, which confirmed the utility of the product as DIY (Do It Yourself) kit. Photographs in Fig. 2 show the cooker during assembly and in use. It is encouraging to see that even tribal women were involved during assembling of the community cookers.

WOTR (Watershed Organisation TRust) which expanded its scope of work beyond watershed development to rural energy needs and approached PRINCE group for the appropriate technology options. Encouraged with the experience of MPSSS, WOTR initially placed order for four systems, with one system at a time and meticulously exposed their prospective users to these systems. Few suggestions were also made for minor modifications, which were duly adopted. With positive responses from the user community WOTR also installed total 25 systems catering to more than 1500 children in Sangamner tahsil of Maharashtra. Project was funded by GTZ of Germany. Projects by MPSSS and WOTR have shown possibility of adoption of the technology on large scale for community cooking applications.

6. Experimenting with PRINCE-40 Concentrators Beyond Cooking

To popularise new solar concentrator PRINCE-40, efforts were made by the authors to develop new applications. For developing autoclaving applications a collaborative project was carried out with a team of doctors from Government Medical College Dhule.

Fig. 3 Dr. Mrudula Dravid with author[1] during autoclaving trials.

All clinical autoclaving tests were carried out by the doctors, for one month, for sterlisation of surgical tools and accessories. Separate tests were also conducted to neutralize biomedical waste. All the tests showed 100% acceptance and complete sterlisation. Fig. 3 shows a photograph of PRINCE-40 concentrator during testing for autoclaving application. Team of doctors, headed by Dr. Mrudula Dravid, head of pathology department at government medical college Dhule, won first award at a state level medical conference for this research work.

Use of solar concentrator for sterlisation can prove to be very useful, especially in rural public health centers, where availability of the power is very uncertain. It is possible to sterilize the autoclave with contents, when sun is available, and store the ready autoclave for 2-3 days. Such successful tests have opened doors for deployment of solar concentrators in medical applications.

Further trials were carried out for developing accessories for establishment of applications like solar two stage distillation and solar bakery with reasonable success.

7. Financial Analysis

Apart from the technical tests as above, controlled performance tests were carried out to find out cooking capacity as well as fuel saving potential. For calculating fuel saving potential weight of the LPG cylinder before and after test was measured. Sample observations are shown in Table 2. Same concentrator has alos been proposed for autoclaving application and electricity and fuel saving potential for autoclaving was also recorded. Annual saving and payback periods are calculated to establish financial viability of the system. Cost of the system is taken at ₹35000 i.e. US $ 775.

Daily 4 hours of use is envisaged in community cooking applications while daily 6 hrs of use is envisaged in autoclaving application. 250 days per year operation is considered for calculations of savings and paybacks. Cost of LPG is taken at ₹ 55 per kg while cost of electricity is taken at ₹ 7 per kWh. Cost saving was also calculated in comparison with electrical autoclaves.

Table 2 Controlled performance tests for fuel saving for PRINCE-40 concentrators

Activity	Time in minutes	Fuel (LPG) Saved in kgs	Fuel saving per year in kgs	Cost of fuel saved per year in ₹	Payback period in years
Boiling 5 kg of rice	55	0.65	709	39000	0.90
Boiling of 5 kg of potatoes	65	0.74	683	37569	0.93
Boiling of 5 kg Khichadi	60	0.71	710	39050	0.90
Autoclaving one batch full load with 40 liter capacity	48	0.58	725	39875	0.88
Autoclaving one batch full load with 40 liter capacity (compared for electricity)*	50	2.7*	4725*	33075	1.1
	* Autoclaving done on electrical heaters and saving recorded in kWh				

All calculations show that payback period for PRINCE-40 will be in the range of 1 years which is very attractive investment by any means. As per the JNNSM (2010) if subsidy of ₹8400 is permissible by Government of India, in that case payback period will come down to 8 months.

8. Development of Segmented Dish

Fabricated version of PRINCE-40 concentrator has 41 structural strip members which are bolted together to form structure of dish. Reflectors are tied on this dish structure. As the shape of each of these structural members is parabolic, skilled workers are required to bend the members in desired shape. Also bolting so many members is time taking. As reflectors are unsupported over span of

150 mm, thicker reflector sheets are required to have adequate strength. Author[3] came up with a geometry in which the dish can be assembled by joining symmetrical segments and each of these segments are manufactured either in sheet metal or in fiber reinforced plastic (Anurag et al 2011). First unit with new segmented dish design was manufactured in May 2011 in FRP. Initial trials show better results than fabricated version of PRINCE-40. It's very likely that after extensive trials on segmented dish, fabricated version of PRINCE-40 concentrator will be replaced with segmented version. Fig. 4 shows the model of the segmented dish in exploded view and complete concentrator assembly.

Fig. 4 Exploded view of model of segmented dish and assembly of concentrator.

Segmented dish has following advantages over fabricated version of dish.

a. Higher accuracy is possible because of standardization in tools and fixtures.

b. Mass production is possible.

c. Reflectors can be glued to the dish bowl instead of tying with wires.

d. As the strength of the dish comes from the segmented pieces, it permits use of thinner reflectors, saving on the cost of the reflectors, which are the costliest components.

e. Extremely easy to assemble. It is possible to send the reflectors factory fitted on each of the segment of the dish. With this new design, it takes less than an hour even for a novice person to assemble the complete concentrator.

9. Conclusions

Community solar cooker PRINCE-40 with 4 m^2 aperture area can cook comfortably for 50-70 people. This size fills in the gap between large sized Scheffler concentrators of 16 m^2 and domestic size of SK-14 at 1.5 m^2. This concentrator does have an advantage of transportability and ease of installation, and is truly a DIY (Do It Yourself) kit. Community cooking projects executed by organisations like MPSSS and WOTR by adopting PRINCE-40 concentrator show high degree of adoption by rural communities. In country like India where still 72% people live in rural areas, this technology has immense potential. Temples, old age homes, residential schools, hostels, hotels, public health centers, Aanganwadis (pregnant women, mother and child care centers), charitable organisations and mid-day-meal schemes in schools have huge potential for adoption of PRINCE-40 solar concentrator for community cooking. Adoption of community solar cookers will not only save precious petro fuels and firewood but also will reduce emission to large extent.

As many feedback reveals that adoption of solar community cookers has relieved cooks from smoky and unhealthy kitchens and they have more time for other activities.

Other trials show suitability of the technology for applications like autoclaving at rural public health centers. Applications like water distillation and bakery can be practiced as micro enterprise to generate revenue for rural folks and improve utilisation of the concentrator.

Recent development of change in the design with segmented dish has improved manufacturability and eased installation, making it truly a DIY kit.

One small version of the square dish is already available as PRINCE-15, as domestic dish cooker of 1.5 m^2. PRINCE-40 of 4 m^2 aperture area is good for cooking meals for 50-60 people. It will be worthwhile to explore possibility of developing bigger concentrating systems, something like PRINCE-60 and PRINCE-80 of 6 and 8 m^2, with new segmented design, which will be taken up in coming years. PRINCE-60 and PRINCE-80 systems are likely to cater meals for 80 and 125 people respectively.

Technology needs financial support from governments and by other means like carbon funding, to improve viability of the projects. Widespread demonstrations and pilot projects are also needed for the prospective users to get cooking experience. Entrepreneurs need to be developed to have wider network of manufacturers and dealers to improve availability of the new designs. Acceptance of technology by government of India and extending 30% subsidies to these systems is a first positive step in promotion of solar dish concentrators for cooking and other applications.

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