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Institutional cooking with solar energy: A review

Sunil Indora*, Tara C. Kandpal

Centre for Energy Studies, Indian Institute of Technology Delhi, Hauz Khas, New Delhi 110016, India

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ABSTRACT

A review on various aspects of institutional solar cooking is presented. Starting with an overview of energy requirement for cooking, the review includes cooking technologies developed for institutional solar cooking, polices and programs for their promotion and case studies reported in the literature on field level application. State of the art concentrating solar technologies suitable for institutional level cooking includes Parabolic dish, Scheffler dish and ARUN® dish. Design, construction and operational details of both direct and indirect types of concentrating solar cookers have been discussed. The case studies, mainly from India, included provide useful feedback on the experiences of using large scale institutional solar cooking systems. A Few installations of each type of solar cooker have been reviewed and major findings and observations on various aspects of the same are reported.

1. Introduction

Food is essential for mankind to survive and fulfil their daily energy and nutrition requirements [1]. Raw food is cooked to enhance its taste, texture, digestibility and shelf life as well as to reduce food borne diseases [2]. Cooking is a heat treatment process of raw food and depending on the temperature requirement, method of application of heat and duration, cooking may be categorized as baking, roasting, broiling, boiling, frying, stewing etc [1]. Besides, at household level, cooking is also performed in institutional/community/commercial sectors such as hostels, hotels, canteens, refugee camps, jails, religious centres, orphanages, etc. [3–5]. In institutional cooking a group of persons takes their meals from a common kitchen. Depending on the number of people, the institution might be referred as small (up to 50 persons), medium (50–100 persons) and large institution (above 100 persons). The number of meals in case of institutional cooking could vary from as low as 20–25 meals to a few thousands of meals at a time. This gives opportunities for economics of scale that might result in solar cooking being both environmentally and economically beneficial. One of the favourable characteristic of institutional cooking is that a large share of a cooked meal essentially involves boiling of the ingredients of food in the water (such as rice, pulses, potato etc.). In boiling type of cooking using water, a major fraction of energy is required during sensible heating of the food and water from initial temperature to the boiling temperature of water [6].

The daily useful energy requirement for cooking reportedly varies in the range of 1.7–2.7 MJ/person/day [7]. Therefore, a significant amount of fuel(s) is required on daily basis for cooking of foods both at household as well as institutional level [8–13]. In developing countries (such as India), the cooking sector accounts for nearly 40% of the total energy consumption [14]. A variety of choices among commercial and non-commercial cooking fuel such as LPG (liquefied petroleum gas), PNG (pressurized petroleum gas), kerosene, diesel, biomass, electricity etc. are available with households/institutions [9,15–17]. However, the selection of cooking fuel(s) by household/institutions depends on various factors that include cost and availability of fuel and/or cook stove, ease of operation, cooking rate, social-economic paradigm etc. [9,11,12,14,16]. While, approximately 52% of the world population relies on biomass to meet the energy requirement for cooking [8], the institutional kitchens mostly utilize commercially available fuels such as LPG, PNG and diesel [18–20] due to ease of operation, availability and faster cooking rate. Use of renewable energy sources such as solar energy for cooking may significantly reduce the dependence on conventional fuels along with reduction in human drudgery and also in environmental degradation and in global warming [4,21–24]. Besides being a renewable resource, most of the developing countries (such as India) have adequate solar radiation availability to consider use of solar energy for cooking so as to substitute conventional fuels [25–27]. For example, in India the daily average value of global horizontal irradiance varies between 4 and 7 kWh/m^2 depending on the location [28–30].

Despite, many benefits offered by solar cookers as well as significant efforts made by different organizations and national governments to promote their use, their actual potential remains underutilized

* Corresponding author.
E-mail address: esz128092@ces.iitd.ac.in (S. Indora).

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Nomenclature

Symbols

A_c	aperture area of solar cooker (m^2)
$B_{a,m}$	annual monetary benefits (INR/year)
C	geometrical concentration ratio (A_c/A_t)
CV	calorific value (kJ/kg)
$F'U_L$	heat loss factor
h_g	enthalpy of steam (kJ/kg)
M	mass (kg)
P_s	standardized cooking power (Watt)
Q	useful energy delivered (kJ)
T	temperature (°C)
U_L	overall heat loss coefficient (W/m^2-°C)

Greek symbols

τ	time interval (s)
τ_o	time constant (s)
τ_{boil}	time required for boiling of water (s)
η	thermal efficiency
η_o	optical efficiency
θ	inclination angle (°)

Subscripts

a	ambient
f	final
i	initial
m	mean
r	receiver
s	steam
w	water
fu	fuel
sc	solar cooker
A_t	surface area of cooking pot (m^2)
C_o	capital cost
C_p	specific heat (kJ/kg-°C)
$F'\eta_o$	optical efficiency fact
h_{fg}	latent heat of evaporation (kJ/kg)
I_b	intensity of direct solar irradiance on the aperture (W/m^2)
P_a	cooking power (Watt)
P_{fu}	unit price of fuel (INR/kg)
S_h	annual number of sunshine hours
S_{sc}	salvage value (INR)
V	wind velocity (m/s)

Acronyms

DNI	direct normal irradiance
INR	Indian national rupee
IBR	Indian boiler regulations
LPG	liquefied Petroleum Gas
NPV	net present value
PDSC	parabolic dish solar cooker
PNG	pressurized Petroleum Gas
RPM	revolutions per minute
SBC	simple box cooker
SSC	solar steam cooking

[22,29,31–35]. Quadir et al. have discussed various barriers that have led to poor dissemination of solar cookers in the context of India [36]. Authors stated that indigenous development of renewable energy technologies and realistic assessment of resource potential should be prioritized in policy making. Macclancy has examined different socio-economic dimensions that contribute to poor dissemination of solar cookers [37]. A list of relevant variables and their interactions that could influence the adoption of solar cookers have been discussed by Otte [38]. Vanschoenwinkel et al. identified solar cooker specific factors that influence the adoption of solar cooking in Senegalese villages [39]. Besides, fulfilment of end users needs and requirements authors reported that program factors such as availability of after-sales network, communications and creation of customers awareness are also necessary for successful implementation of solar cooking. Some major drawbacks of solar energy application to cooking include variability in availability of solar radiation, inability to cook during off-sunshine hours (unless a provision for storage is made), slower cooking rate compared to conventional cooking etc. [29,35,40–47]. However, the reasons cited in literature for low acceptance of solar cookers for domestic cooking are less applicable for institutional cooking since infrastructure, operational, functional and alternative cooking facilities are already available with such large kitchens [48]. Therefore, better opportunities and potential for adoption of solar cooking in institutional kitchens exists and the same can be promoted in the initial phase. A review of recent installations of solar cooking systems also validates that the interest in institutional solar cooking is growing in India [18]. Various researchers have reviewed the available solar cooking technologies considering different aspects of solar cooking [49–53]. A comprehensive review on various aspects of solar cookers is presented by Cuce and Cuce [49]. Saxena et al. [54] and Lahkar et al. [55] have presented reviews on thermodynamic aspects of solar cookers. To enable solar cooking during cloudy and off sun-shine hours in late evening, arrangement for heat storage either in sensible or latent form using phase change materials (PCM) is required [56–61]. Investigations on solar cooker designs with heat storage have also been made by the researchers [40,41,43,62–64]. A review on solar cooking using latent heat storage is presented by Gore and Tandale [65]. However, these studies are more focused on solar cooking of food at household level.

To facilitate decision making and also to enhance motivation for the adoption of solar cooking in institutional kitchens, a review of institutional/community solar cooking systems is needed. Also, techno-economic review of the few existing institutional solar cooking system would provide relevant details to the potential users of such systems. In this review paper, an attempt to review and consolidate different solar cooking technologies that may be considered for institutional/community scale cooking is made. Various aspects of institutional/community solar cooking technologies including their design features, performance characteristics, economics etc. have been reviewed in this study. A brief review of some functional institutional/community solar cooking systems in India is also presented as case studies.

The structure of the paper is as follows: Section 2 presents the characteristics and scope of institutional solar cooking particularly in India. In Section 3, an overview of different types of solar cooking technologies applicable for institutional solar cooking is presented, followed by a detailed review and some case studies of each of the concentrating solar cooking technologies; namely parabolic solar cooker (Section 4), Scheffler dish systems (Section 5), and Fresnel (ARUN) based systems (Section 6) respectively. Financial feasibility of institutional solar cooking is discussed in Section 7. Section 8 summarizes the programs and policies for promoting solar cooking by different governmental and non-governmental organizations. Conclusions and discussion are presented finally in Section 9.