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Development of Solar Community cooking systems in India

Sandeep S. Joshi [1] Prashant P. Jagtap [2]

1. Shri Ramdeobaba College of Engineering and Management, Nagpur

2. Robert Bosch GmbH, Bexbacher Str. 72, 66424 Homburg, Germany

Abstract

Cooking is a prime requirement of human civilization. In the developing country like India, the conventional fuels such as LPG, crude oil, coal and biomass are extensively used for cooking. The use of solar energy for cooking application is documented first time in 1767 by Horace de Saussure, a Swiss naturalist. A lot of development in the solar cooking technology has been reported in the literature. The current article highlights a present status of solar community cooking systems in India. Also, the ongoing research activities in the solar community cooking systems have been discussed.

Keywords: Solar Cooking, Community kitchens, CSP

1. Introduction

The urbanization is rapidly increasing in all corners of the world. As a result, the demand for energy is increasing with alarming rate. The conventional energy sources are depleting and are not sufficient to meet the increasing energy demand. Also, the fossil fuels are the most significant sources of global warming and greenhouse gases. Global warming and depletion of conventional energy sources is the biggest challenge of mankind in this century. Thus, it is indeed essential to switch to renewable energy sources. According to International Renewable Energy Agency (IRENA) [1] more than 170 countries have established renewable energy targets and nearly 150 have erected policies to catalyze investment in renewable energy technologies. The popular renewable energy sources are solar energy, wind energy, ocean energy, tidal energy, geothermal energy and energy from biomass. Most of the renewable energy comes either directly or indirectly from the sun. Thus, solar energy is the most important source of renewable energy. The solar energy is very large and inexhaustible source of energy.

The power from the sun intercepted by the earth is approximately 1.8 x 10^{11} MW, which is many thousand times larger than the world energy consumption today [2]. The solar energy is sufficient to meet the energy demand of entire present and future civilization. The solar energy is gaining ground in all the developed and developing countries in the world. Fig.1.1 shows the Indian solar resource map for an annual average of direct normal irradiance (DNI) based on hourly estimation of radiations over 10 years (2000-2014). Most of the part in India, receives average irradiance of 4-5 kWh/m^2/day. The solar energy is being used for electricity production and for various thermal applications. The solar based electricity production includes solar photovoltaics (PV) and concentrated solar thermal power (CSP). The solar thermal applications mostly include solar water heating, space heating, industrial process heat, cooking and allied applications. Though the solar energy utilization is rapidly growing, inefficient conversion processes, costly equipments and expensive storage are few hurdles in its widespread commercialization.

In solar thermal systems, the solar energy is absorbed by the absorber surface and the heat is utilized for thermal applications. To collect more heat, concentrating type systems are evolved. These systems concentrate the solar radiations at the absorber surface, thereby improving their thermal performance.

2. Classifications of Solar cooking systems

Cooking is a prime requirement of human civilization. In the developing country like India, the conventional fuels such as LPG, crude oil, coal and biomass are extensively used for cooking. The use of solar energy for cooking application is documented first time in 1767 by Horace de Saussure, a Swiss naturalist [4]. A lot of development in the solar cooking technology has been reported in the literature. The conventional solar cooking technology is the 'Box Type solar cookers'. In the last century and especially in the last three decades several solar cooking technologies have been invented and implemented successfully. The major challenges in solar cooking technology are collection of distributed solar energy for cooking application, utilization and storage of collected thermal energy effectively. In the conventional systems, the cooking vessels are attached to the solar collectors and thus the cooking systems are outdoor systems. In the today's era of globalization, the indoor solar cooking systems are most popular.

To utilize the maximum amount of solar energy reaching the earth's surface different solar concentrator are developed. Solar concentrators are the devices which collect solar radiations. The solar collectors are broadly classified as non-tracking and tracking type collectors. The non-tracking collectors are kept at rest and also known as fixed or stationary collectors, whereas tracking collectors are designed to track the movement of the sun so that the incoming solar radiations always fall perpendicular to them. The tracking solar collectors are further classified as one axis tracking and two axes tracking collectors. Non-tracking collectors are categorized as flat plate, evacuated tube and compound parabolic collectors. Parabolic trough collector, cylindrical trough collector, and linear Fresnel reflector fall under the category of single axis tracking systems, whereas central tower receiver, parabolic dish reflector, and circular Fresnel lens belong to dual axes tracking systems. Table 1 shows the various types of solar collectors along with their applications.

Table 1

A range of values for operating temperature and efficiency of the collector

Motion	**Type of collector**	**Indicative temperature range (^{0}C)**	**Efficiency (%)**	**Applications**
Stationary	Flat plate collector (FPC)	30-80	20-	Solar Water heating, Indirect water heating systems, Space heating & cooling, Adsorption cooling, Industrial air and water systems.
	Evacuated tube collector (ETC)	50-200	30-	
	Compound parabolic collector (CPC)	60-300	30-	
	Linear Fresnel reflector (LFR)	60-250	20-	

Single axis tracking	Cylindrical trough collector (CTC)	60-300	40-	Industrial process heat, Solar refrigeration, Solar desalination, Solar stills
	Parabolic trough collector (PTC)	60-400	30-	
Two-axis tracking	Parabolic dish reflector (PDR)	100-1500	40- 70	Solar cooker, Water heating system, Solar furnaces, Steam generation systems
	Heliostat field collector (HFC)	150-2000	60-	Solar thermal power plant

3. Layout of solar steam cooking systems

The main system components in concentrated solar steam based cooking systems are the collector-receiver system, and cooking vessels. Fig. 1. shows the layout of the solar steam cooking system with direct steam generation. Whereas, another option is to use the thermic fluids (such as therminol, heat transfer oils etc.) as a primary working medium. The steam loop would be secondary as shown in fig.1.4.

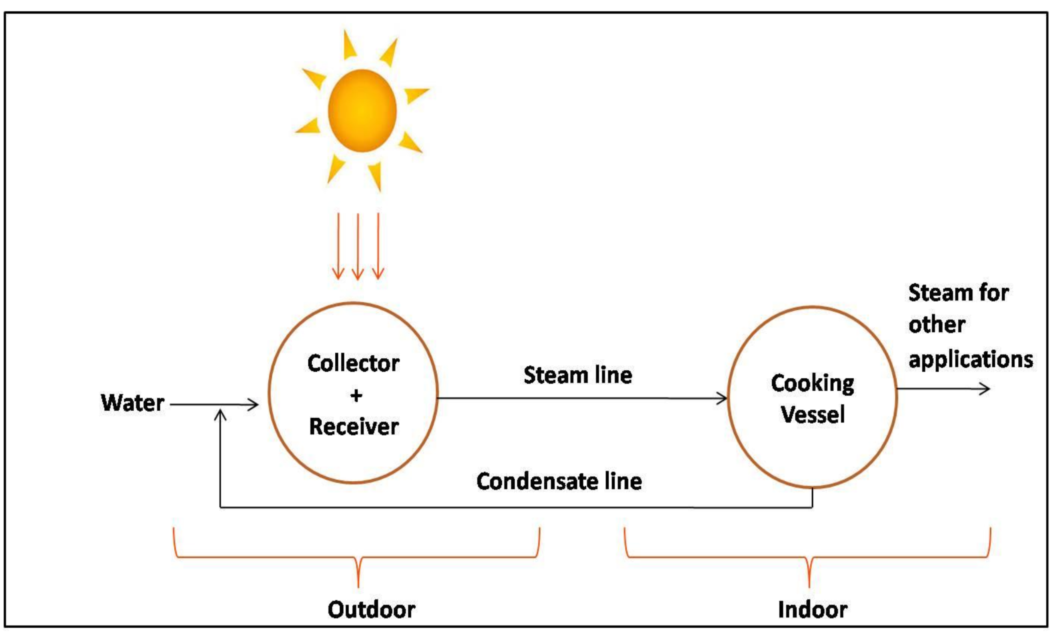


Fig. 1 : Layout of solar direct steam cooking system

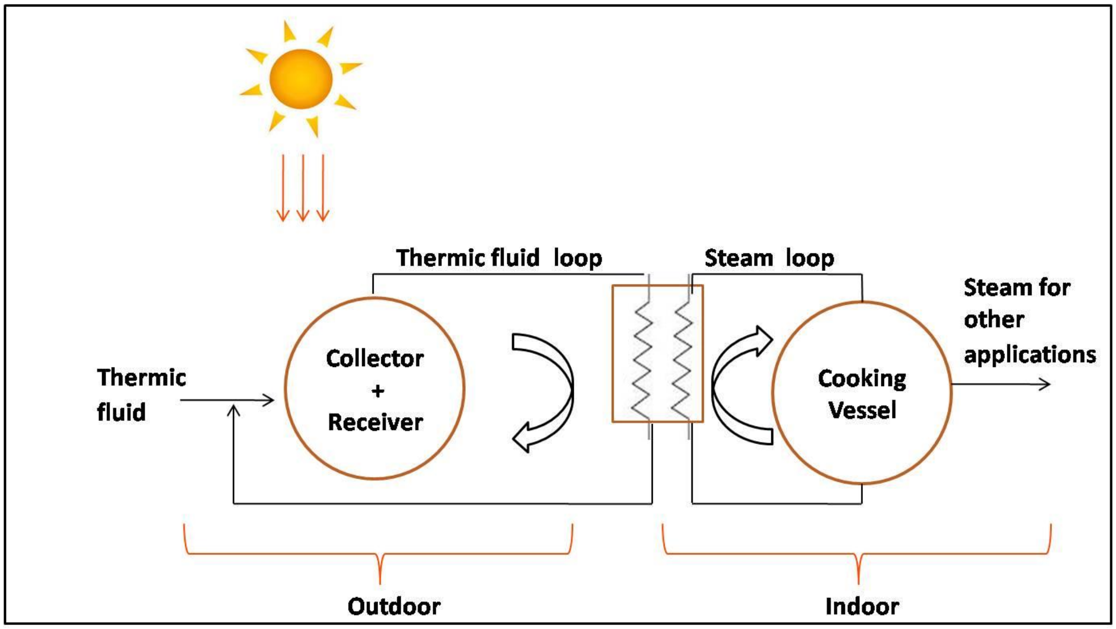


Fig.2 : Layout of solar steam cooking system using thermic fluid

4. Installed solar steam cooking system in various academic campuses in India

Solar water heating has been already an established technology and is in promotion at large scale for providing hot water for various applications. This technology is, however, limited to temperatures below 90C. Concentrating solar technologies (CSTs) are now emerging fast in the country which can provide high temperatures in the range of 100 to 450 C or more even. These technologies basically focus the sunlight at receiver to achieve higher temperatures for various applications. Since these technologies can focus the direct radiation coming from the Sun, they need to be tracked along with the Sun. The technologies can be based on single axis (E-W) tracking as well as dual axis (E-W & N-S) tracking. Depending on their tracking arrangement, they can be put in the category of medium or high temperature applications.

The solar steam cooking systems are the most popular indoor steam cooking systems. Almost all the courtiers in the world are installing these systems. The major installations include the community kitchens of hotels, restaurants, hostel mess, hospitals and kitchens of devotional places. In India, Ministry of New and Renewable Energy (MNRE-GOI) has taken initiative to develop the community kitchens at several places. Table-2 shows the installed solar community kitchens in India.

Table –2 : Installed solar community kitchens in India

S.N.	Location	CSP Technology	Utility	Reference
1	SRM University Chennai	Scheffler dishes (37 Nos. 16 m^2 each)	Hostel mess Meal for 5000 students	UNDP-GEF-MNRE [5]
2	Brahma Kumaris World Spiritual University in Mt Abu, Rajasthan	Scheffler dishes (84 Nos.	38,000 meals per day	MNRE case studies [6]
3	IIMB Bangalore Karnataka	Scheffler dishes (16 m^2 X 6 Nos)	Hostel mess Meals for 1200 students	Case study CSH India [7]
4	NIT Hamirpur Himachal Pradesh	Scheffler dishes (16 m^2 X 6 Nos)	Hostel mess Meals for 500students	Case study CSH India [8]
5	JSSM Girls Hostel, Mysore, Karnataka	Scheffler dishes (16 m^2 X 18 Nos)	Hostel mess Meals for 2000 students	Case study CSH India [9]
6	Adharsh Nivasi Shala, Ukai, Songadh, Gujarat	Scheffler dishes (16 m^2 X 4 Nos)	Meals for 100 students	Case study CSH India [10]
7	Gurudwara Sri Hargobind Sidhwakalan, Punjab	Scheffler dishes (16 m^2 X 4 Nos)	150 meals	Case study CSH India [11]
8	Dayalbagh Junior Boys Hostel, Agra	Scheffler dishes (16 m^2 X 5 Nos)	Hostel mess 200 meals	Case study CSH India [12]
9	Shantikunj, Haridwar, Uttarakhand	Scheffler dishes (16 m^2 X 10 Nos)	1000 meals	Case study CSH India [13]
10	New Sai Prasadyala, Shirdi, Maharashtra	Scheffler dishes (16 m^2 X 40 Nos)	10000 meals	Case study CSH India [14]
11	National Engineering College, Tamil Nandu	Scheffler dishes (16 m^2 X 18 Nos)	Hostel mess 800 meals	Case study CSH India [15]

12	Girivanvasi Educational trust Maharashtra	Paraboloid Dish ($25\ m^2$)	1200 meals per day	MNRE case studies [16]

5. Current research in solar steam cooking systems

As mentioned, though, the solar steam cooking systems are being installed widespread, there are several techno-commercial challenges associated with these systems. To study the current ongoing research in the field of solar steam cooking, a comprehensive literature study has been carried out. The significant literature study is discussed.

Receiver is one of the most important components in the concentrated solar thermal applications. The receiver performs the two functions viz; collection of concentrated solar radiations and absorption of the collected energy. The absorption function is taken care by the selective coating discussed in the later part.

For better collection of the solar energy, all the concentrated radiations should get collected by the receiver. The collection of solar energy by the receiver is entirely dependent on the geometry of the receiver suitable for the collector and tracking arrangement. The receiver geometry decides the 'Concentration Ratio (CR)'; which in turn decides the power collected at the receiver. There are several receivers reported in the literature so far. Some of the significant studies are discussed.

K.S. Reddy et al [17] carried out numerical study of combined laminar natural convection and surface radiation heat transfer in a modified cavity receiver shown in fig 3. The convective heat loss from the modified receiver is significantly influenced by the inclination of the receiver where as the radiation heat loss is considerably affected by the surface properties of the receiver.

Two separate Nusselt numbers were proposed for both natural convection and surface radiation. A two-dimensional simulation model for combined natural convection and surface radiation is developed. The influence of operating temperature, emissivity of the surface, orientation and the geometry on the total heat loss from the receiver are investigated.

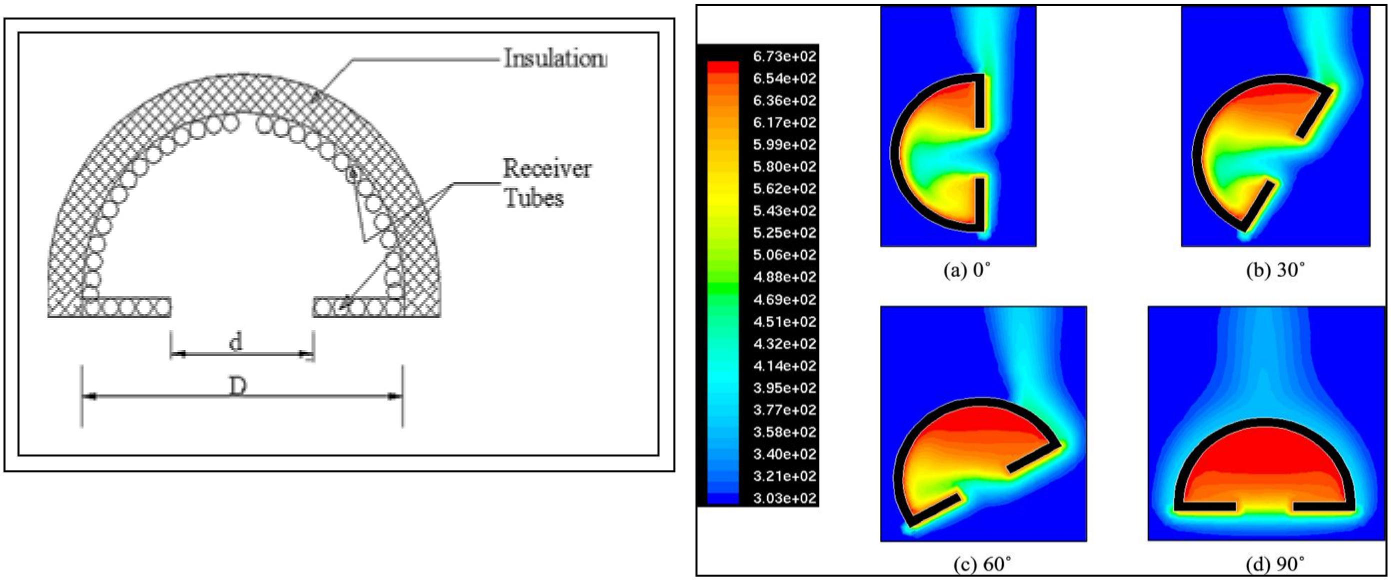
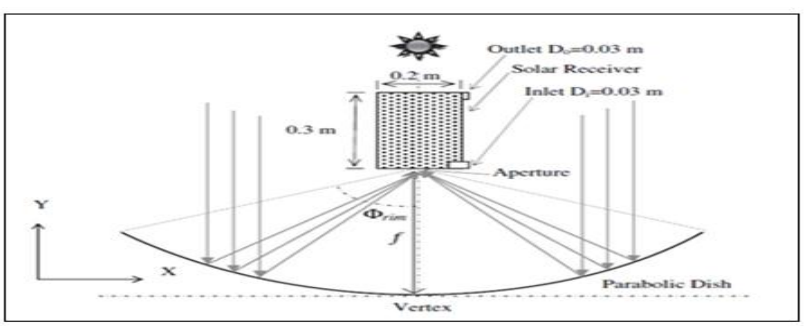


Fig 3: Cavity receivers used by ref. [17]

Mo. Wang et al [18] described a three-dimensional model of parabolic dish-receiver system with argon gas as the working fluid to simulate the thermal performance of a dish-type concentrated solar energy system as shown in fig. 4. The impact of the aperture size, inlet/outlet configuration of the solar receiver and the rim angle of the parabolic dish are Investigated. The results show that for the given operating conditions, as the aperture size reduces from 0.05 m to 0.025 m, the average wall temperature, and average argon temperature in the receiver increased by 7.5% and 9.2%, respectively. The rim angle of the parabolic dish has no impact on the Thermal behaviour of the receiver.



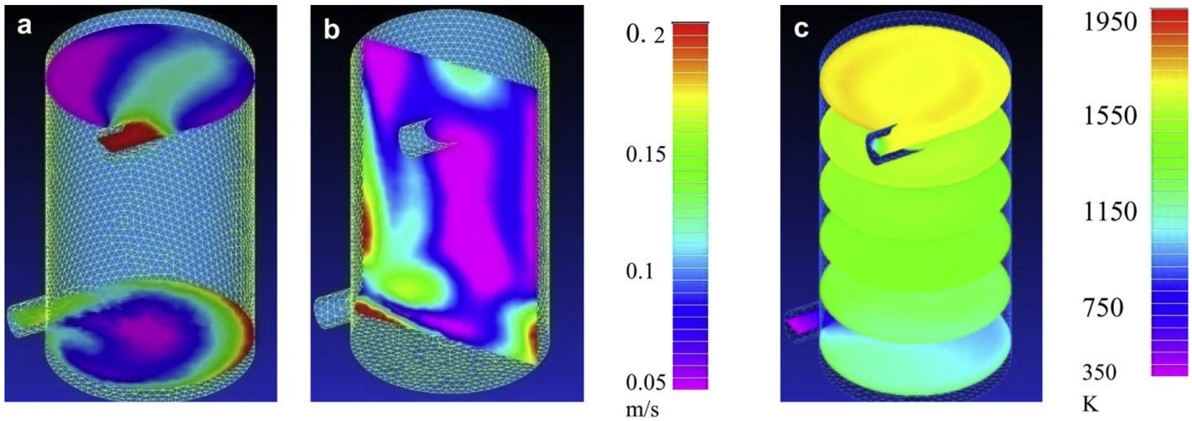


Fig.4: Receiver used by ref. [18]

Rosnani Affandia et al [19] discussed a parabolic collector with cavity receiver to analyze the impact of the Direct Solar Irradiance (DNI), collector and receiver (fig.5). In this study, Matlab, Simulink was used as the simulation tool. From the simulation result, it can be concluded that, by minimizing the intercept factor, the fraction of solar power entering the receiver will be decreased. The losses of solar radiation that transferred from the concentrator to the receiver will increase.

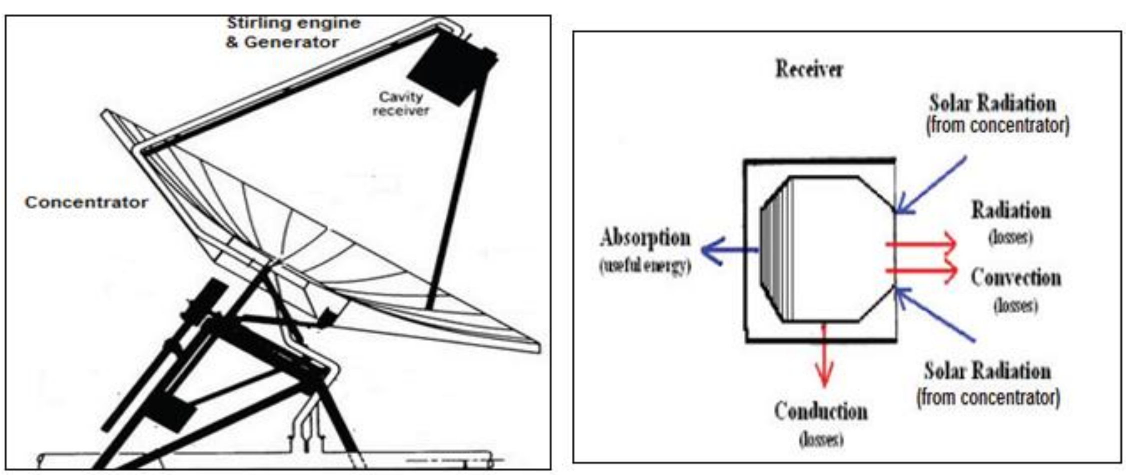


Fig 5 : Receiver used by ref. [19]

K.S. Reddy et al [20] described the effect of wind speed and direction on convective heat losses from solar parabolic dish modified cavity receiver shown in fig.6. The forced convection heat loss is found maximum at a receiver inclination of 60° for receiver opening ratio in the range of 0.8- 1.0. At higher wind speeds and all receiver inclinations, the variation in heat loss due to side-on wind is negligible. The heat loss from the receiver is higher for side-on wind when compared to head-on and back-on wind conditions. The natural convection heat loss decreases when the receiver inclination varies from 0 to 90. For side-on winds, at higher wind speeds above 5 m/s, irrespective of receiver inclination, the variation of forced convection heat loss is marginal (less than 5%). The maximum forced convection heat loss occurs for partly open receivers (receiver aperture diameter ratio, RAD = 0.4 and 0.6) at your = 0 (side-on wind) for all receiver inclinations and at u = 30^0 for RAD = 0.8 and 1. The receiver inclination has less effect on heat loss from the receiver for V > 2.5 m/s due to side-on wind. The highest convection heat loss occurs for fully open (RAD = 1) receiver as compared to partly open (RAD < 1) modified cavity receiver. Nusselt number correlation is proposed to calculate combined convection heat losses from the receiver as a function of receiver inclination, wind direction, wind velocity and aperture diameter ratio.

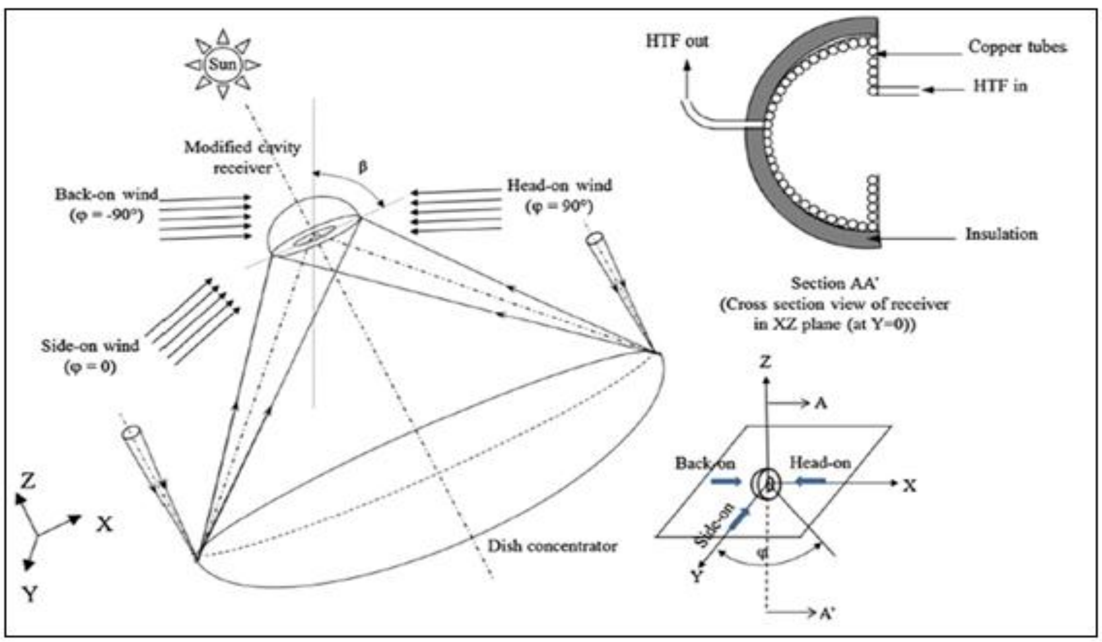
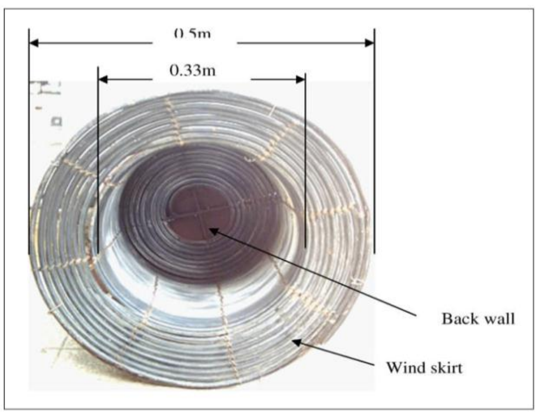


Fig. 6: Receiver used by ref. [20].

M. Prakash, S.B. Kedare, J.K. Nayak [21] carried out investigations on heat losses from a solar cavity receiver. Experimental and numerical study of the steady state convective losses occurring from a downward facing cylindrical cavity receiver of length 0.5 m, internal diameter of 0.3 m and a wind skirt diameter of 0.5 m is carried out. fig.7 . The experiments are conducted for fluid inlet temperatures between 50 ^{0}C and 75 ^{0}C and for receiver inclination angles of 0^0 (sideways facing cavity), 30^0, 45^0, 60^0 and 90^0(vertically downward facing receiver). The numerical study is performed for fluid inlet temperatures between 50 ^{0}C and 300^0 C and receiver inclinations of 0^0, 45^0 and 90^0 using the Fluent CFD software. The experimental and the numerical convective loss estimations agree reasonably well with a maximum deviation of about 14%. It is found that the convective loss increases with mean receiver temperature and decreases with an increase in receiver inclination. Nusselt number correlations are proposed for two receiver fluid inlet temperature ranges, 50–75 ^{0}C and 100–300 ^{0}C, based on the experimental and predicted data respectively.



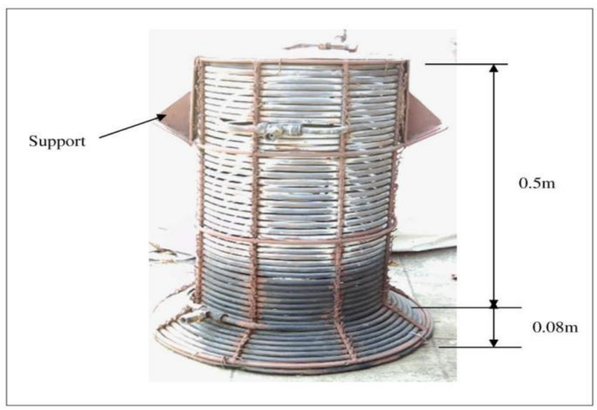


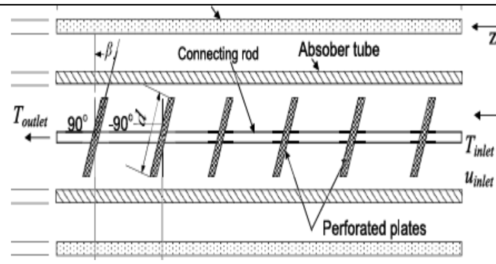
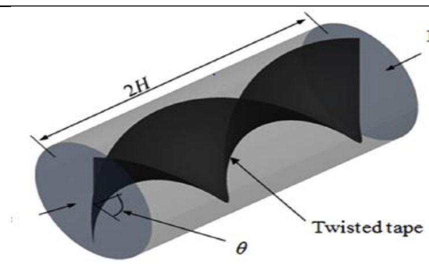
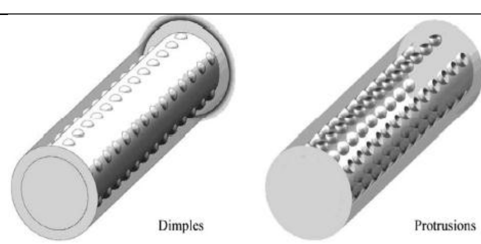
Fig. 7: Front and side view of the solar cavity receiver used by ref. [21].

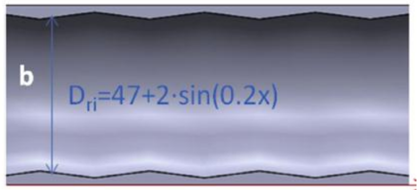
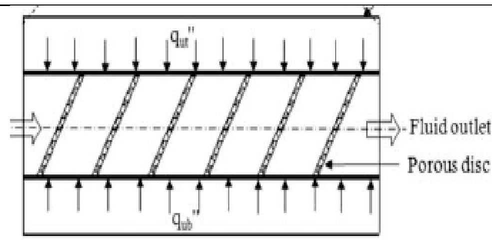
Table 3 shows the various receiver geometries reported in literature.

Table 3

Various Receiver Geometries reported in the recent literature

Sr.	Receiver	Image or Schematics	Findings	Ref.

No.	Geometry			No.
1	Receiver with perforated plate inserts		Heat transfer enhancement was found to be 192% to 211%. Below the optimal Reynolds number entropy generation rates are reduced by about 53%.	[22]
2	Cylindrical cavity receiver		The temperatures are higher near the back wall of the receiver. Radiation loss decreases since extended cylindrical aperture geometry.	[23]
3	Receiver with wall-detached twisted tape inserts		By numerical study and investigation, heat transfer enhancement was found to be 169%	[24]
4	Receiver with dimples and protrusions.		Heat transfer enhancement was found to be 123% to 137% by numerical study.	[25]

5	Receiver having Convergent divergent tube.		Heat transfer enhancement was found to be only 9% by numerical study and calculations.	[26]
6	Porous disc receiver		By experimental study and analysis, heat transfer enhancement was found to be 63.9% to 66.66%	[27]

Conclusions:

According to the literature study, following are the recent research areas in the field of Concentrated Solar Steam cooking systems.

- Designs of efficient receivers for Concentrated Solar Power (CSP)
- Designs of efficient collectors and efficient sun tracking systems for CSP
- Development of various selective coating material for CSP
- Use of various heat transfer augmentation techniques in CSP
- Thermal storage systems for CSP for off sunshine applications.
- Development of CSP for various thermal applications including space cooling

The solar community cooking systems are in developing stages. The focused research is required to bring the technology for its widespread use.

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