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Experimental Evaluation of an Indoor Solar Cooking System Entailing Evacuated Tube Collector and A Pump

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Ranjan Chaudhary
Mechanical Engineering Department
Panipat Institute of Engineering and Technology
Samalkha, India.
rnjn.chaudhary@gmail.com

Vishal Dabra
Mechanical Engineering Department
Panipat Institute of Engineering and Technology
Samalkha, India.

Rajinder Kumar
Mechanical Engineering Department
Panipat Institute of Engineering and Technology
Samalkha, India.

***Abstract*—It is a well-known fact that an exigent number of people globally still rely on the fuels which emits hazardous fumes. The way out for such predicament needs to be found out and one of the pragmatic approaches is the harnessing of solar energy. Hence, presented manuscript entails the experimental study of a solar energy based indoor cooking system with evacuated tube as heat collector. A heat transfer fluid circulating pump is employed to carry heat from the solar collector to the cooking cabinet. The system shows the possibility of parallel cooking in two differently closed cooking pots. Cooking experiments are performed on the presented cooking system to check the feasibility of the system to cater the lunch and dinner cooking needs of a small family. Cooking time for the before noon and after noon cooking is observed as 180 minutes approximately. Power supplied to the cooking cabinet lies in the range of 121 Watts to 1119 Watts.**

Keywords—Indoor Solar cooking, Evacuated tube, Thermal Fluid.

I. INTRODUCTION

Although cooking is the most basic need of human being, but still 2.3 billion of global population relies on the fuel other than clean fuel [5] This leads to the premature deaths of women and children largely in Asian and African subcontinent. Also, unavailability of clean fuel hampers the economic aspect of the poor family whose members invests their wage time in collecting woods for cooking. Hence, there is an enormous need to develop a sustainable cooking system for such people. Solar energy based cookers proved a pragmatic solution for this issue. Many researchers developed numerous designs of solar cooking since a century. Cuce and Cuce (2013) evaluated numerous designs of cookers based on solar power and manifested that solar cookers have the capability to counter the problem of cooking with conventional fuels like wood, cow dung [5]. Mohod et al. (2010) presented a concentrating dish based solar cooker which was capable to cook rice, fish, pulses and fish [8]. Lokeswaran & Eswaramoorthy (2012) experimentally investigated solar cooking using dish collector for cooking purposes [6]. They incorporated a porous receiver with cooking vessel and observed that there had been a rise of 8˚C rise in the stagnation temperature. Mahaveret al.(2012) compared the performance of two types of solar box type cookers and concluded that both cookers were capable to cook food for 2 persons in a day[7]. Shukla and Khandpal (2016) compared the various performance parameters of concentrating dish based cooker and thermal storage based box type cooker. Their study inferred that thermal storage based box type cooker showed better results with reference to thermal efficiency than other designs. Singh etal.2014 evaluated the performance of solar cooking system with the incorporation of PCM, ETC and Thermal oil [10]. They inferred that the use of thermal fluid as HTF had increased the energy stored in PCM significantly as compared to water. Panchal & Sadasivuni (2018) studied a solar cooking device with Scheffler reflector as heat collector and PCM [9]. They concluded that sand and acetamide combination of sensible heat storage reflected the best results than other sensible materials used. Wang et al. (2019) presented a Fresnel lens and thermal fluid based indoor solar cooker and concluded that conical receiver showed the best results for optical efficiency. Chaudhary & Yadav (2020) showed the capability of ETC based cooking system to prepare jaggery[3]. Chaudhary & Yadav (2020) investigated a ETC based solar cooking system for the pressurized cooking of various cooking articles[1]. They demonstrated that the family could cook their meals three times a day. Chaudhary & Yadav (2020) experimentally investigated the solar cooker for the concurrent cooking by two unlike methods and inferred that the cooker had the capability to cook the two different food stuffs in parallel for a small family[2].

As proved, that solar energy for cooking is a practical approach to resolve the issue of cooking without clean cooking fuel. Maximum studies focused on outdoor solar cooking systems, but a few studies came up with an indoor solar cooker. Hence, it is the need of the hour to develop a feasible indoor solar cooking system which enables the cooking in the conducive environment. The manuscript demonstrates a solar radiation based system for the indoor cooking using thermal fluid, ETC and a pump.

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II. EXPERIMENTAL SET-UP

The system includes ETC based solar collector, Cooking cabinet, HTF transfer pipes, HTF circulation pump. Fig.1 and Fig.2 shows the pictorial and schematic diagram of proposed solar cooking system for indoor cooking.

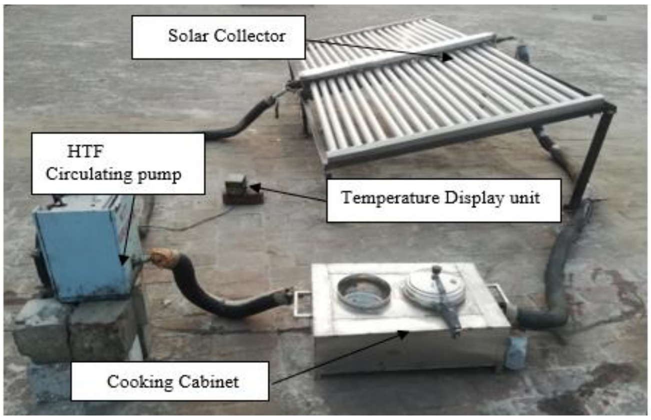

Fig.1. A picture of indoor solar cooking system

1	Header
2	Evacuated tubes
3	Collector outlet
4	Cooking Cabinet
5	HTF Circulating Pump
6	Collector inlet
7	Stainless steel pipes

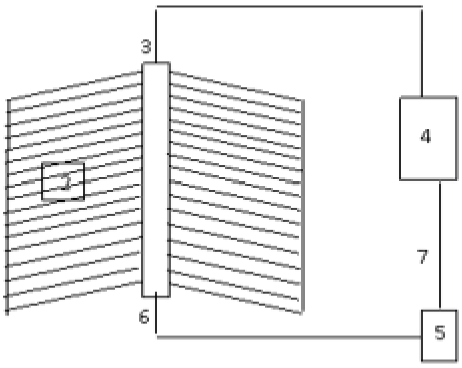

Fig.2. Line diagram of indoor solar cooking system

A. *Solar collector*

It inhibits 40 evacuated tubes and one header. Evacuated tubes are inserted with the help of silicon seals on opposite faces of cuboidal header made up of stainless steel. The header is positioned on an iron stand at 15° to the horizontal. Two openings are provided at the two faces of the header (face at the lower part and face at the higher part).Opening at the higher part acts as the HTF outlet to the collector and opening at lower side acts as the inlet to collector.

B. *Cooking cabinet*

It consists of two pots, one with tightly closed lid and valve (Ptcl) and other with loosely closed lid (Plcl).These two pots are welded in a cuboidal shaped stainless steel container in a partially inserting manner as shown in the Fig.3. The stainless steel container is further jacketed by outer stainless steel container excluding the upper face of prior container. The gap of these two containers is filled with glass wool to contain the heat loss.

C. *HTF transfer pipes*

Three insulated pipes, one having the length of 3048 mm is used to connect solar collector and cooking cabinet, other having the length of 3657 mm is used to connect pump and the collector and third one having the length of 914 mm is used to connect cooking cabinet and solar collector.

D. *HTF circulation pump*

This entity of the system is used to circulate the HTF between cooking cabinet and the solar collector. It incorporates a gear pump and an AC motor which runs on 60 W Power.

III. SYSTEM OPERATION

Initially the whole system accompanying the solar collector and cooking cabinet is filled with HTF. Collector receives the insolation and it transfers the energy to the fluid inside it. Subsequently the HTF inside the evacuated tubes raise its thermal energy and hence temperature. The HTF circulating pump enables the transferral of thermal energy of HTF from the collector to the Cooking cabinet. The energy is conveyed from the collector and provided to the cooking cabinet continuously. With the passage of time HTF becomes heated to an appreciable temperature at which the cooking inside the pots of cabinet can be performed. The HTF passes through the stainless container and transfers its heat to the Ptcl & Plcl.. These pots are immersed in the HTF partially in the stainless steel container. Ptcl & Plcl are charged with water for two times, so as to check the feasibility of cooking twice a day.The system includes ETC based solar collector, Cooking cabinet, HTF transfer pipes, HTF circulation pump. Fig.1 and Fig.2 shows the pictorial and schematic diagram of proposed solar cooking system for indoor cooking.

IV. DATA ANALYSIS

Power supplied to the cooking cabinet during cooking experiments is calculated as:

$$\mathrm{Power}_{\text{Cooking cabinet}} = \dot{m}_{\text{htf}}\left(T_{\text{cooking cabinet inlet}} - T_{\text{cooking cabinet outlet}}\right) \quad (1)$$

where $\dot{m}_{htf}$is the mass flow rate of the HTF and it is calculated as (volume flow rate * density of the HTF).

V. RESULTS AND DISCUSSION

The collector bring in to the solar radiation at 7:00 A.M. Upto 9:00 AM the HTF circulating pump is kept idle. The pump is started at 9:30 A.M which enables the HTF to start circulating between the collector and cooking cabinet. The circulating rate of HTF is 2 ltr/min. Temperatures at the sections like collector inlet, collector outlet, cooking cabinet inlet, cooking cabinet outlet, water temperature in tightly closed lid pot and water temperature in loosely closed lid are

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noted at the interval of 10 minutes. Thermocouples of PT-100 type and an exhibit unit are employed for the measurement of the temperatures at various sections. Cooking pots incorporated in the cooking cabinet are loaded with 1.5 litres of water in each at 10:00 A.M and 2:00 PM. Afterwards observations of temperature are done.

A. Cooking from 10:00 A.M onwards

1.5 litres of water is loaded in Ptcl & Plcl each at 10:00 AM till 1:30 PM. As depicted from the Fig.4 the HTF temperature atthe collector outlet and cooking cabinet inlet rises from 99.1°C to 153.8°C and 85.3°C to 136°C respectively. The HTF temperature at the cooking cabinet outlet and collector inlet varies from 70.7°C to 134.2°C and 53.7°C to 117.5°C respectively.The water temperature inside Ptcl&Plcl changes from 39.4°C to 91.1°C and 34.5°C to 86.8°C respectively.. It is inferred from the Fig. that the water temperature inside Ptclsustained the temperature of 60-90°C extent for more than 160 minutes and water temperature inside Plcl sustained the temperature in the range of 60-80 °C 130 minutes.Such time and temperature range is sufficient for the cooking of articles like rice, pulses as reported by Singh et al. (2014), Chaudhary & Yadav (2021). Moreover, power delivered to the cooking cabinet is shown in the Fig. The value of power is observed higher at the starting 60 minutes of the experiment and the value descending afterwards. Highest value of power delivered is notes as 1089 Watts and lowest power is noted as 121 watts.

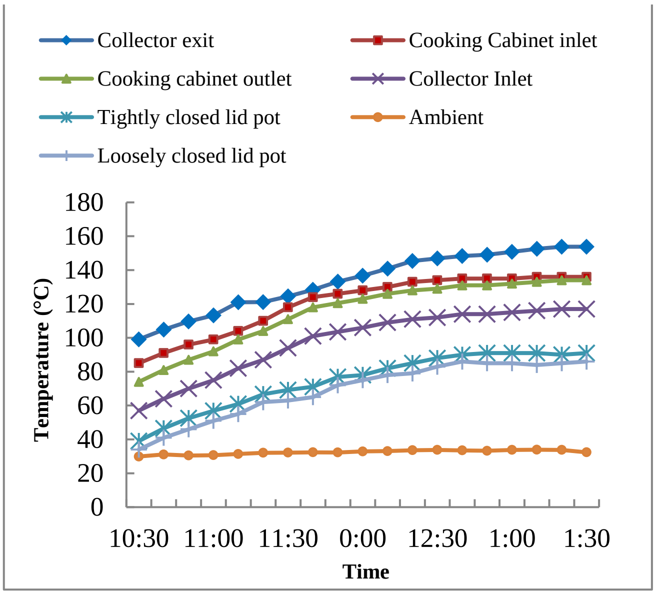

Fig.4. Shows the change in temperature values of HTF at various section of indoor solar cooking system for the cooking experiment between 10:00 AM and 1:30 PM

B. Cooking from 1:00 P.M onwards

1.5 litres of water is loaded in Ptcl & Plcl each at 1:30 PM to 5:30 PM. As shown in the Fig.5 the HTF temperature at the collector outlet and cooking cabinet inlet decreases from

152.5°C to 123.3°C and 137.3°C and 109.1°C .The HTF temperature at the cooking cabinet outlet and collector inlet varies from 120.8°C to 103.5°C and 103.2°C to 49.6°C and respectively.

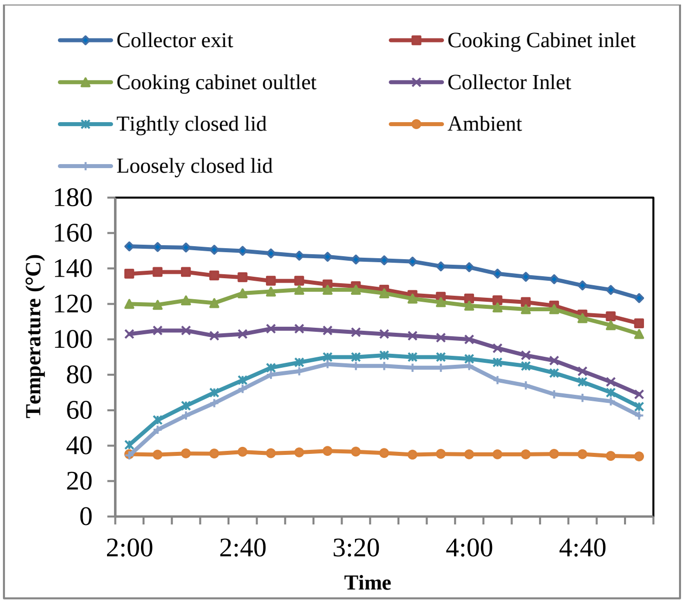

Fig.5. Shows the change in temperature values of HTF at various section of indoor solar cooking system for the cooking experiment between 2:00 PM and 5:00 PM

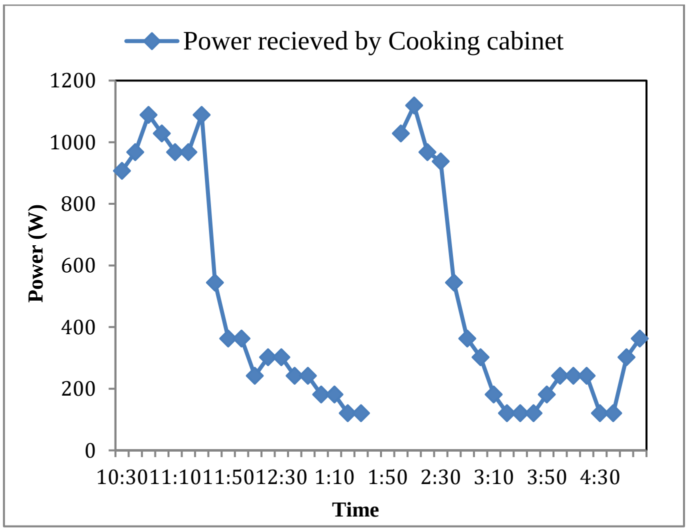

Fig.6. Represents the variation of power delivered to the cooking cabinet during cooking experiments

The water temperature inside Ptcl & Plcl changes from 120.6°C to 103.2°C and 34.5°C to 86.8°C respectively. It is inferred from the Fig. that the water temperature inside Ptcl sustained the temperature of 60-90°C extent for more than 160 minutes and water temperature inside Plcl sustained the temperature in the range of 60-80 °C 140 minutes. Such time and temperature range is sufficient for the cooking of articles like rice, pulses as reported by Singh etal.2015, Chaudhary & Yadav (2021). Moreover, power delivered to the cooking cabinet is shown in the Fig.6 The value of power is observed higher at the starting 30 minutes of the experiment and the value descending afterwards. Highest value of power delivered is notes as 1028 Watts and lowest power is noted as 121 watts.

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The value of power delivered to the cooking cabinet is observed higher in the initial stage after loading the cooking pots and starts diminishes after some time. This is due to the decrease in the rate of rise of water temperature and limit of water temperature to rise up to certain limit. The heat provided by the HTF inside the cooking cabinet has the limited capability to raise the temperature of water due to inappreciable temperature of HTF.

VI. CONCLUSIONS

Experimental results attained during the presented study concluded that the evacuated tube based indoor cooking system is competent to cook food twice a day for the family of 4 members. The maximum temperature for the water in Ptcl is observed as 91°C and 86°C for the water in Plcl. Mean power supplied to the cooking cabinet during experiment between 10:00 AM to 1:30 PM is accounted as 538.1 watts and Mean power supplied to the cooking cabinet during experiment between 10:00 AM to 1:30 PM is accounted as 401.4 Watts. Moreover, presented manuscript also enables the users to cook two different types of food in parallel.

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