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Development of a solar thermal storage cum cooking device using salt hydrate

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ABSTRACT

In family size solar cookers commercially available in India, cooking has to be done outdoors during sunshine hours. Some solar cookers for community cooking provide thermal storage facility as steam, while the small scale cookers do not provide thermal storage. A concentrating type solar cooker using magnesium chloride hexahydrate (m.p. = 118 °C) as the thermal storage material was designed for boiling type of cooking. The developed device was able to store a charge of heat in about 50 min and cook about 140 gm of rice in 30 min from the stored heat.

1. Introduction

Fossil fuel-based energy resources dominate our society with the highest share of global energy consumption. However, renewable energy utilisation is becoming more crucial due to the growing environmental issues and limited reserves of fossil fuels. Solar energy is one of the most promising renewable energy sources since it is free, available at all locations, and non-polluting. In India, energy need for cooking is mostly met by non-commercial fuels such as firewood, agricultural waste and cow dung in rural areas, and kerosene, liquified petroleum gas and piped natural gas in urban areas. Pohekar et al. (2005) report that 90% of rural households in India are still dependent on biomass fuels, while the World Health Organization (WHO) states that 4.3 million people a year die prematurely from illness attributable to household air pollution caused by the inefficient use of solid fuels for cooking (WHO website). Utilization of solar cookers provides advantages like no recurring costs, high nutritional value of food, potential to reduce drudgery, high durability (Cuce and Cuce, 2013), absence of pollution, reduced deforestation and global warming.

The three common types of solar cookers in use are box type cookers, Scheffler type and parabolic dish type cookers. Additionally, large-scale solar steam cooking systems mainly based on parabolic dishes have also been developed worldwide.

Box type cookers of various designs are commonly used in many countries for cooking of rice, vegetables and dal (a preparation made from pulses, a staple food in south Asian countries), which involve boiling of the food at 100 °C. They are simple, low cost and easy to operate. Scheffler dishes (Sukhatme and Nayak, 2008) focus the beam of the sun on the bottom of a cooking vessel or pan located in a separate kitchen, thus enabling community cooking to be done safely in the shade, and preparation of various dishes, including boiling, frying and roasting.

The dish cookers consist of a 3-D paraboloid reflecting surface with the cooking vessel placed at the focus of the parabola. The dish is tracked manually every 15–20 min so that the beam of the sun is perpendicular to its aperture. It concentrates the beam radiation onto a smaller area, normally a pressure cooker, with a concentration ratio of around 60–80. Higher temperatures from 100 °C upto 180 °C can be obtained, thus making cooking possible by boiling, frying and baking, as well as production of distilled water. Their cooking speed is faster than box type cookers, and they are suitable for domestic and community scale cooking and for use in remote areas and villages. Small scale cookers available commercially in India do not provide thermal storage, and cooking has to be carried out in the sun by the user.

Pohekar and Ramachandran (2006) carried out a study under which nine common cooking devices used in India were ranked for their utility. Energy technology, economics, environmental/social, behavioral and commercial aspects were issues considered for evaluation. The LPG stove was found to have the maximum utility with no. 1 ranking, with the parabolic dish solar cooker 5th, and the conventional chulha (Indian biomass cookstove) lowest at 9th. They concluded from the analysis that if the parabolic dish solar cookers have to become more widespread their utility has to be increased.

Research was initiated in the Renewable Energy Laboratory of our college in Mumbai, to improve the utility of parabolic dish solar cookers by considering: i. Improving ease of operation by introducing thermal

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Nomenclature

η	efficiency	T_m	melting point of PCM (°C)
m	mass (kg)	T_a	ambient temperature(°C)
Q_{us}	useful heat gained during storage (kJ)	Cp	specific heat (kJ/kg °C)
Q_{uc}	useful heat gained during cooking (kJ)	Cpl	specific heat of liquid (kJ/kg°C)
HTF	heat transfer fluid	Cps	specific heat of solid (kJ/kg.°C)
PCM	phase change material		
m.p.	melting Point (°C)	*Suffix*	
PSC	parabolic dish solar cooker	-*i*	initial
A_p	absorber plate area (m^2)	-*f*	final
A_a	aperture area (m^2)	*m*	melting point
H_L	latent heat of phase change of PCM (kJ/kg)	-*w*	water
H_{fgw}	latent heat of evaporation of water (kJ/kg)	-*pcm*	phase Change material
I_b, I_{bm}	beam radiation (W/m^2)	-*o, oil*	oil (HTF)
ΔT	temperature difference (°C)	*l*	liquid
T	temperature (°C or K)	*rice*	rice
		req	required

storage, and ii. Types of dishes cooked.

The first device to be developed would be one suited for cooking by boiling, which has been done and is described in this paper. It would enable the user to cook in a kitchen at the time desired. The second phase was to develop a device using a PCM with a higher melting point, making it suitable for cooking by frying, baking or operating a pressure cooker. This work is ongoing and not reported here.

Several researchers have reported studies on the use of phase change latent heat storage materials in solar cookers. Three of them are reported here briefly.

Sharma et al. (2009) have reported research work carried out by several investigators using PCM materials like magnesium nitrate hexahydrate, stearic acid, acetamide and acetanilide in box type solar cookers to extend the time when they can cook food.

Lecuona et al. (2013) of Spain filled the annular space between the main pressure cooker and an annular vessel enclosing it, and the space below it, with a PCM, viz. technical grade paraffin (m.p. = 100 °C), and erythritol (m.p. = 118 °C) in their studies. It was used in conjunction with a parabolic dish concentrator. Experiments and numerical studies were carried out with the heat being stored in the PCM simultaneously with cooking in the sun. The stored heat enabled them to cook the evening meal as well as breakfast. The vessel with PCM was kept in an enclosed insulated vessel overnight to prevent heat loss.

A system using evacuated tube solar collectors and a PCM heat storage unit with built in cooking vessel was reported by Sharma et al. (2005), developed in Japan (Fig. 1). Water is the HTF which transmits heat from the collectors to the PCM, where it is transferred into the PCM by a stainless steel tube heat exchanger immersed in the PCM and wrapped around the cooking vessel. The PCM is erythritol which melts at 118 °C. The cooking vessel is contained within the PCM container, surrounded from the sides and bottom by PCM. The system was successful in cooking noon and late evening meals from heat stored in the

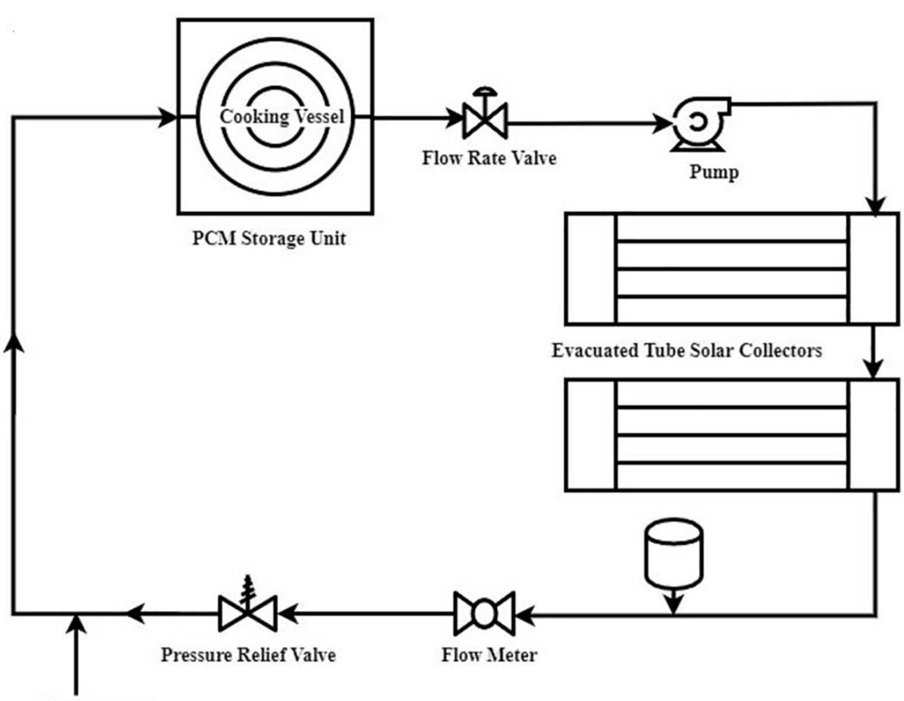

Fig. 1. Schematic of solar cooking system with evacuated tube collectors described by Sharma et al. (2005).