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Feasibility and Economic Analysis of Solar Thermal Cooking

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ABSTRACT: Solar Energy has been used for human applications from time immemorial. Some of its direct use in the current scenario can be found in solar photovoltaics, solar thermal power generation, heating and cooking. Although cooking is mainly dominated by the use of LPG in urban areas, people still use firewood for cooking in many rural areas. The burning of firewood causes many health problems, which can be mitigated by completely avoiding the usage of firewoods. But the cost of LPG resorts people to use firewood due to its ease of availability and its price. Cooking using solar energy can done using solar cookers or reflecting surfaces. In this paper, the feasibility and economic analysis of parabolic dish for cooking has been evaluated. Four parabolic dishes are used to focus the sunlight is used as the reflecting surfaces. The cooking has been done using different vessels. The cooked items show a better scope and feasibility for the usage of solar energy for cooking during the mid day.

KEYWORDS: LPG, solar energy, reflecting surfaces, feasibility, cooking.

I. INTRODUCTION

Biomass such as fuel wood, charcoal, agricultural waste and animal dung are used in rural areas of the developing countries for meeting their cooking energy needs. The shift to cleaner and more efficient use of energy for meeting the cooking demands has actually slowed in the recent years in the rural areas. There are many adverse effects on health, environment and economic development due to the combustion of biomass. The exposure to indoor air pollution from biomass causes nearly the death of nearly 1.3 million people, the majority of them being women and children. Not only the bad consequences, but also time is also being wasted in collecting fuel. The damages to the environment may in the form of land degradation and air pollution. This problem can be tackled by promoting energy efficient biomass based technologies and by using modern cooking fuels and technologies. The selection of an alternative depends on many factors such as per-capita incomes and the availability of resources. 110 g of CO_2 equivalent per mega joule of useful energy is the total GHG from the wood fired stoves. This can be compared with 42, 5, 2, 350, 166 and 196 g CO_{2-e}/MJ_{useful} in case of improved wood, biogas, producer gas, kerosene, natural gas and LPG fired stoves, respectively [2]. Combustion of fuel wood, roots, agricultural residues and animal dung all produce high emissions of unwanted matter in the atmosphere. Burning of dung for fuel gives the highest hydrocarbon emission and the burning of agricultural wastes produces the highest particulate emissions. There is some localized deforestation due to the use of firewood, but depletion of forest cover on a large scale has not been found to be attributable to demand for fuel wood. Two thirds of fuel wood for cooking worldwide comes from agricultural land and roadsides.

Solar based lighting, stand alone small scale wind energy conversion system, biogas plant and solar cookers are the few renewable based systems that can be used in rural areas. Many villages are located in remote and inaccessible areas that have no access to electricity grids. There has been a significant improvement in the children's education and in the standard of living after the installation of solar based lighting systems in this areas [3].

The policy formulation for cooking energy substitution by renewables is addressed by many authors. Nine cooking energy alternatives were evaluated on 30 different criteria comprising of technical, economic, environmental/social, behavioral and commercial issues. Based on Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE),it was found that liquefied petroleum gas (LPG) stove is the most preferred device, followed by kerosene stove, solar box cooker and parabolic solar cooker (PSC) in that order [9]. Solar parabolic dish collector cooker constructed and evaluated under African climatic conditions gave an optical efficiency of 17.86% and cooking power of 96.53 W. The parabolic solar dish collector cooker can be used by families for cooking in rural areas to minimize the purchase of other cooking fuels for at least cooking the afternoon meals [1]. The dimensions of the ribs and rings supporting the reflecting surface can be optimized to minimize the entire weight of the dish. It is recommended to use landscape orientation for the reflective facets and increase the ribs angle and the distance between the connecting rings [4]. The dish mirror can be formed from a finite number of optimal-shaped thin flat metal petals with highly reflective surfaces. The concept permits flat mirror elements to be easily fabricated and assembled into the parabolic dish concentrators [6]. A parabolic dish solar thermal cooker having aperture diameter 1.8 m, depth 29.0 cm and focal length 69.8 cm was designed and constructed to cook food equivalent of 12 kg of dry rice per day. The cooker was capable of cooking 3.0 kg of rice within 90 – 100 minutes [7]. Institutional level cooking can be done using Parabolic dish, Scheffler dish and ARUN dish [5]. Large scale utilization of solar energy for cooking can be made efficiently using thermal energy storage. This option can be used whenever occurs a mismatch between the supply and the use of energy [8]. The solar energy can be used to maintain a stovetop surface at temperatures around 300 °C using a fresnel lens[10].

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II. MATERIAL SELECTION

For the cooking system to be feasible, the components have to be selected that must be locally available. 5mm and 6mm mirrors are available generally. Taken into account the fragility of the glass, the 6 mm glass is used as the reflection surface in the present work. They are produced only on specially manufactured high clarity premium base low iron glass. The 6mm mirror is used for laying on the surface of the dish. The dish used for trapping television signal is used as the concentrating surface. The thickness of the dish is 3mm. A prototype model for the concentration of sun light with the help of reflecting mirrors is designed with the help of Pro-Engineer Wildfire 4.0 software.

III. METHODOLOGY

Initially the point where the reflected radiation from the 4 dishes is falling is found using physical observation by placing a paper near the focal point. At a particular point the temperature rise will be high. This point is noted and the cooking vessel is placed in this point.

The coordinates of the location is 11.2681° N and 77.5906° E. According to this coordinates, the dish has to be positioned to achieve maximum concentration. Water, wax and oil are used as the heat gain medium inside a vessel. Stainless steel, Aluminium and mud pot vessels are taken for the experiment. The temperature readings were taken from 2.30 pm to 3.30 pm. Water is placed in a stainless steel vessel with a black paint coated on it and in an Aluminium vessel separately. 3 litres of water is initially taken in the vessel. Similarly water temperature rise is also measured using a mud pot. Wax in a stainless steel vessel and oil in an Aluminium vessel were tested. The initial quantity of crystal paraffin wax taken was 1 kg and the quantity of oil taken was 1 litre.

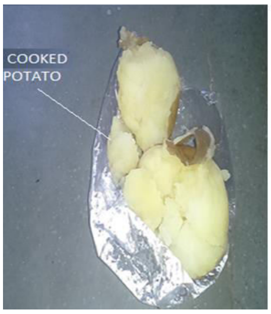

Fig.1: Potato and rice cooked using dish

Fig.2: Potato and rice cooked using dish

Temperatures of 82°C and 102°C were obtained in an hour by using stainless steel and Aluminium vessel respectively. The temperature attained by the water, wax and oil in the different vessels is shown in the figure 3. Due to the satisfactory rise in temperature within a short span of time, it was decided to cook rice and boil potato. Rice was cooked using a black coated pressure cooker. Initial temperature of water was 30 ºC. Starting time for the cooking process was 2:00 PM. 250 gm. of rice was taken and it took about 30 minutes to cook the rice using the arrangement. Similarly the potato was completely cooked within 20 minutes.

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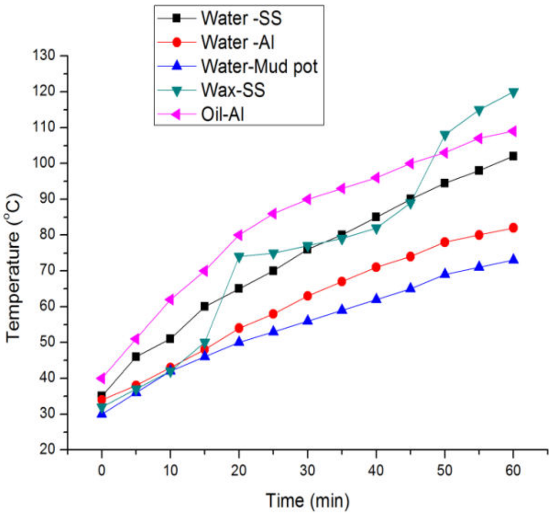


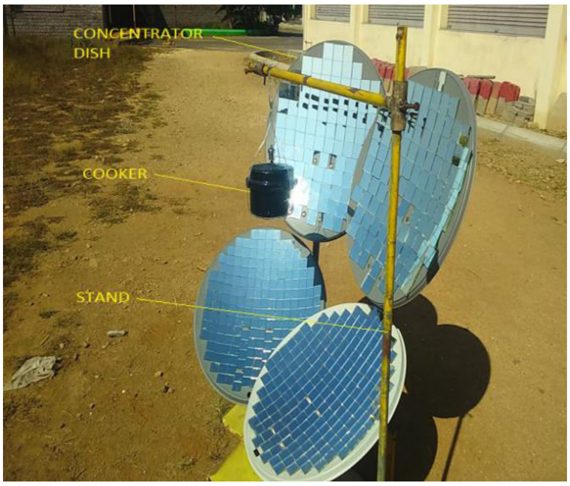
Fig.3:Temperature variation in the Stainless steel, Aluminium vessel and mud pot

IV. ECONOMIC ANALYSIS

In this section, the cost savings due to the usage of solar dish for cooking instead of LPG cylinder is discussed. The cost of making the present cooking system comes around Rs 3600.

The energy content in 1 kg of LPG is approximately 45 MJ. So the total energy in a commercially available 14.2 kg LPG cylinder will be around 639 MJ. The fuel consumption for cooking 1 kg of food varies from 7 MJ (minimum) to 22 MJ (maximum). So on average, for cooking 1 kg of food the fuel requirement can be taken as 15 MJ.
For a family consisting four members, the number of days a single cylinder can last is approximately (~639/15) 42 days. Solar energy can be available for almost two thirds of a year. It can be said that 6 cylinders will be consumed in that two thirds of a year.

Cost of a subsidized cylinder = Rs 700
Cost of 6 subsidized cylinders = 4,200/-
For 5 years, a family's spending for subsidized LPG gas alone = Rs 21,000/-
Difference in fuel cost between solar cooking and LPG cooking for 5 years = Rs. 17,400/-



V. CONCLUSION

Many progresses has been made in the field of solar energy applications for cooking. But more research and development has to be done to make it cost-competitive with fossil fuels. Costs can be reduced by increasing demand for this technology worldwide as well as through improved component design and advanced systems. Concentrating solar power technologies currently offer the lowest-cost solar electricity for large-scale power generation. Advancements in the technology and the use of low-cost thermal storage will allow future concentrating solar power plants to operate for more hours during the day and shift solar power generation to evening hours.

In this work, the size of the dish adopted was about 15.5×16 inches. For this size the maximum temperature attained was about $120^{o}C$. If the size of the dish is increased higher temperatures can be obtained. Rather than using a single large dish collector, multiple smaller dishes can be used to obtain the same cooking power with minimum space requirement. Also the smaller dishes can be easily handled compared to the larger ones.

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