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Performance evaluation of solar Fresnel lens cooker

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Abstract
The Solar Fresnel lens system was designed and developed at Department of Unconventional Energy Sources & Electrical Engineering, Dr. PDKV, Akola. The dual axis Fresnel lens solar concentrator (FLSC) system was integrated with dual axis control panel system, lens, heat exchanger, cooking pot with fluid pipe network and insulation. The study on dual axis solar Fresnel lens system was conducted for cooking application. The effect of parameter viz., flow rate, focal length and oil type was studied for water temperature in cooking pot. Selected oil flow rate range were 0.5, 1 and 1.5 lpm, Focal length of the lens were 1450, 1650 and 1850 mm and oil type were 66, 68 and 15W40, respectively. The food material like tea, rice, eggs, mung dal, tur dal and chicken were cooked in the system took 20, 25, 30, 45, 60 and 75 min, respectively for complete cooking. Based on optimized parameter maximum cooking pot efficiency, temperature of oil and temperature of water in cooking pot were found to be 25.50 per cent, 108.60 ^{0} C and 102.261 ^{0} C, respectively.

Keywords: Fresnel lens, solar cooking, solar cooker and indirect cooking

Introduction
The continuous increase in the level of green house gas emissions and the increase in fuel prices are the main driving forces behind efforts to more effectively utilize various sources of renewable energy. In many parts of the world, direct solar radiation is considered to be one of the most prospective sources of energy. Among the different energy end uses, energy for cooking is one of the basic and dominant end uses in developing countries. Solar energy, which is an abundant, clean and safe source of energy, is an attractive to substitute for the conventional fossil fuels. To gain worldwide scale acceptance, solar cookers must meet certain social conditions besides cost and performance requirements. Clearly, no cook prefers to do his cooking while standing outdoors in the hot sun. So, the energy from the sun needs to be transmitted to the kitchen for indoor cooking. Indirect solar cookers (i.e. flat-plate collector solar cookers and evacuated tube collector cookers) are more expensive than direct solar cookers, but they have several advantages. They provide high thermal power and temperatures with automatic dual axis tracking, and at the same time, cooking can take place in the shadow or in conventional kitchens inside buildings, hence this study has most importance in research point of view. Indirect type of cooking can be possible by using the Fresnel lens. The Fresnel lens can collect the solar radiation falling on it and concentrate it on a single focal point. This is the new approach of solar cooking with economically viable.

Material and methods
The steps in the process of manufacturing and assembling are outlined as follows:
1. FLSC system was fabricated using mild steel sheet, rods aluminium rods, glass, press brake machine and welding machine.
2. Heat exchanger was made up of stainless steel and 32 copper tubes were used to heat transfer and it was coated with black paint to absorb maximum solar radiation.
3. The size of cooking pots is 2 lit and it was made up of aluminum. it was insulated by polyurethane foam cover with glass insulation.
4. The stand were fabricated with mild steel angle of 35 × 35 × 5 mm to rest the Fresnel lens dual axis tracking system with connecting rods and heat exchanger was kept vertical to the ground surface.
5. Glass required was cut and placed on the support and by using silica gel was fixed on heat exchanger. rubber sealant was provided to hold toughened glass in contact with heat exchanger surfaces
6. The capacity of the hot oil flow meter was 1 liter per minute and required capacity of motor to circulate the oil was 90 watt.

7. Two numbers of motors with 15-watt capacity were used to rotate in east to west (zenithal) and north to south (azimuthally) direction in tracking system.
8. SPV panel were used to supply power to the temperature sensors and motor in tracking mechanism of the solar Fresnel lens system

Plate 1: Experimental set-up dual axis FLSC system

System description of dual axis FLSC system

In dual axis solar Fresnel lens system lens was fixed on heat exchanger with the help of aluminum shaft and fluid pipe network connected to cooking pot and fuel tank. It was again connected to heat exchanger which was blackened at its inside surface with a selective coating to absorb maximum concentrate solar radiation. The cooking pot and fluid pipe network was coated with glass wool insulation. The circulation of oil in different component was possible with the help of hot oil circulation pump. Fresnel lens tracks the sun with the help of solar tracker. Temperature sensors were provided to measure temperature inside the cooker and inlet, outlet of heat exchanger. Solar tracking system was powered with the help of solar photovoltaic panels. The system was fixed on stand and provided with castor wheel for its movement from one place to another place. The hot oil circulate through the cooker jacket where the cooker gets heated and the food inside the cooker was cooked by taking its time.

Result & Discussion

Performance of the system depends on the available solar radiation, ambient temperature, wind velocity and operational parameter. The Fresnel lens concentrator is the main parameter which directly effect on the heat exchanger performance during the water boiling test. A water boiling test for 2 liter capacity carried out in winter and summer season. The main parameter that effect the Fresnel lens solar concentrator on heat exchanger hence the performance of the system was evaluated at 2 litter of water boiling test in winter and summer season. Water boiling test was carried out at different dependant & independent parameter to evaluate the performance of the system. Temperature of the heat exchanger surface, heat exchanger inlet and outlet, temperature of cooking inlet and outlet, temperature of water in cooking pot were recorded with the help of calibrated thermocouple in combination with digital temperature indicator. The performance in term of energy and exergy efficiency is calculated.

Test-1. Winter season test in year 2017-18.

Effect of oil type and focal length of the lens on cooking pot temperature (°C)

Table 1 represents the effect of oil type and focal length of the lens on cooking pot temperature in winter season march to February 2017-18. From table 5.2 it was observed that as the focal length of the lens increased from 1450 to 1850 mm, at that time the cooking pot temperature was found to be increased from 98.34 to 101.27, 95.77 to 100.58 and 93.11 to 99.95 °C by using the oil type 66 (O1), 68 (O2) and 15W40 (O3), respectively. Also, it was observed that by using the oil type 66, the maximum cooking pot temperature was obtained as 101.27 °C at the focal length of the lens 1850 mm than that of oil type 68 and oil type 15W40.

Table 1: Effect of oil type and focal length of the lens on cooking pot temperature

S. No.	Oil Type	Focal length of the lens (mm)		
		L_1=1450	L_2=1650	L_3=1850
1	O_1=66	98.34	100.79	101.27
2	O_2=68	95.77	98.96	100.58
3	O_3=15W40	93.11	97.09	99.95
	F test	Sig.		
	SE(m)±	0.34		
	CD at 5 %	0.98		

The minimum cooking pot temperature was obtained as 93.11°C by using the oil type 15W40. The earlier study by Kapurkar and Kurchania (2013) performed on distillation by Fresnel lens, the maximum temperature of hot water outlet was found to be 71.42℃.

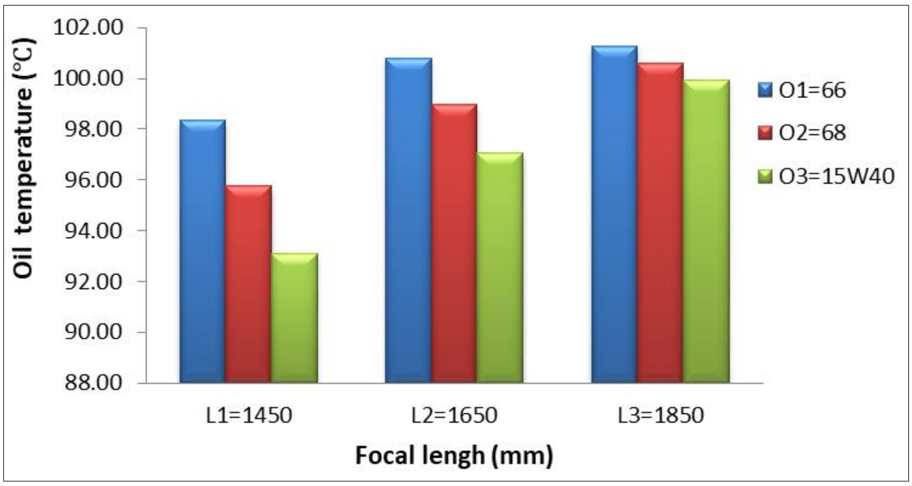

Fig 1: Effect of oil type and focal length of the lens on temperature of cooking pot (°C)

Fig 1 shows that the per cent increase in the cooking pot temperature (°C) was found to be 2.98, 5.02 and 7.35 from focal length of the lens 1450 to 1850 mm by using the oil type 66, 68 and 15W40, respectively. The combine effect of oil type and focal length of the lens was found to be significant.

Effect of oil type and oil flow rate on cooking pot temperature

Table 2 represents the combine effect of oil type and oil flow rate on cooking pot temperature in winter season of year 2017-18. From table 2 it has been observed that as the flow rate of the oil increased from 0.5 to 1.5 LPM, the cooking pot temperature was found to be increased from 99.393 to 101.197, 97.71to 99.33 and 94.74 to 98.04 °C by using oil type 66, 68 and 15W40, respectively.

Table 2: Effect of oil type and oil flow rate on cooking pot temperature (°C)

S. No.	Oil type	Focal length of the lens (mm)		
		F_1=0.5	F_2=1	F_3=1.5
1	O_1=66	99.393	99.816	101.197
2	O_2=68	97.718	98.258	99.333
3	O_3=15W40	94.74	97.359	98.044
	F test	Sig.		
	SE(m)±	0.34		
	CD at 5 %	0.98		

Also it was observed that by using oil type 66 maximum temperatures of cooking pot was attend to be 101.197 °C at flow rate 1.5 LPM than that of the oil type 68 and 15W40. The minimum cooking pot temperature was obtained as 94.74 °C by using the oil type 15W40 at flow rate 0.5 LPM.

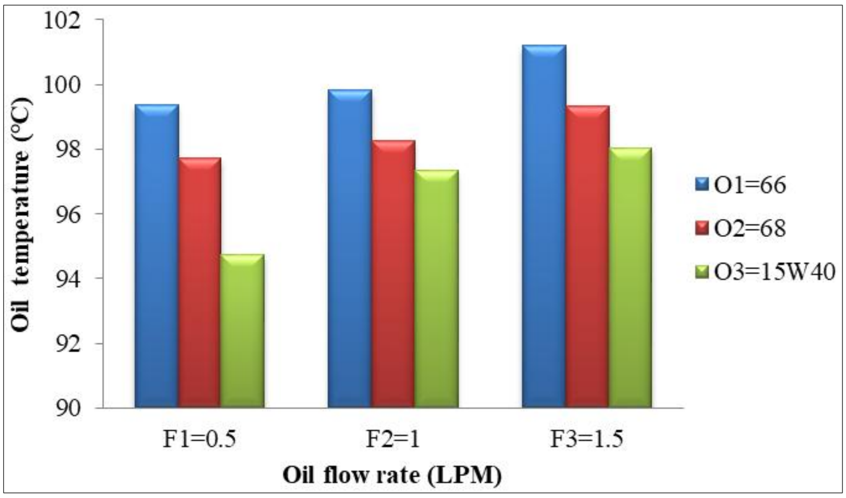

Fig. 2: Effect of oil type and oil flow rate on cooking pot temperature (°C)

Fig. 2 shows that the per cent increase in the cooking pot temperature (°C) was found to be 1.81, 1.65 and 3.48 from flow rate 0.5 to 1.5 LPM by using oil type 66, 68 and 15W40, respectively. The combine effect of oil type and flow rate was found to be significant.

5.3.3 Effect of focal length of the lens and oil flow rate on the cooking pot temperature

Table 3 revealed the effect of focal length of the lens and flow rate of the oil on the cooking pot temperature in winter season December-February (2017-18). It was observed that as the flow rate of the oil increased from 0.5 to 1.5 LPM, the cooking pot temperature was found to be increased from 94.1 to 97.08, 96.78 to 100.02 and 100.96 to 101.54 °C by using the focal length of the lens 1450, 1650 and 1850mm respectively.

Table 3: Effect of focal length of the lens and oil flow rate on the cooking pot temperature (°C)

S. No.	Focal length of the lens (mm)	Oil flow rate (LPM)		
		F_1=0.5	F_2=1	F_3=1.5
1	L_1=1450	94.1	96.11	97.008
2	L_2=1650	96.789	100.024	100.024
3	L_3=1850	100.962	99.298	101.542
	F test	Sig.		
	SE(m)±	0.34		
	CD at 5 %	0.98		

Also it was observed that by using focal length of the lens 1850mm. maximum cooking pot temperature obtained as 101.54 °C than that of the focal length of the lens1450 and 1650 mm. The minimum cooking pot temperature was obtained as 94.1 °C by using the focal length of the lens 1450 mm.

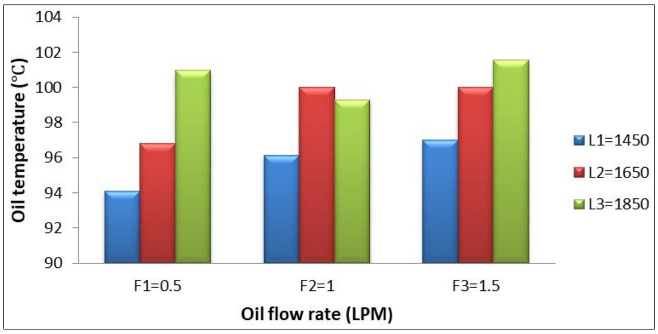

Fig 3: Effect of focal length of the lens and oil flow rate on the cooking pot temperature (°C)

Fig. 3 shows that the per cent increase in the cooking pot temperature (°C) was found to be 3.08, 3.33 and 0.55 from the flow rate 0.5 to 1.5 (LPM) respectively.

5.3.4 Effect of oil flow rate, focal length of the lens on cooking pot temperature (°C)

Table 4 shows that the cooking pot temperature was increased from 97.22 to 102, 95.11 to 101.48 and 89.963 to 99.407 °C at oil flow rate 0.5 LPM from the focal length 1450 to 1850 mm using oil type 66, 68 and 15W40 respectively. It was also observed that cooking pot temperature increased from 97.22

to 98.52, 98.96 to 102.257, 102 to 102.813, 95.117 to 96.78, 96.55 to 99.92, 101.48 to 101.293, 89.96 to 95.723, 94.85 to 97.89, and 99.407 to 100.52 °C as the oil flow rate increased from 0.5 to 1.5 LPM using of oil 66, 68 and 15W40 at focal length of the lens 1450, 1650 and 1850 mm, respectively. The trend of cooking pot temperature which was used for cooking purpose was found to be increased as the focal length of the lens & oil flow rate increased. The maximum and minimum cooking pot temperature found to be 102.813 & 89.963 °C at a focal length of the lens of 1850 mm with flow rate 1.5 LPM& oil type 66 and the focal length of the lens 1450 mm with flow rate 0.5 and oil type 15W40, respectively.

Table 4: Effect of oil flow rate, focal length of the lens on cooking pot temperature (°C)

Oil flow rate (LPM)	Cooking pot temperature (°C)								
	Oil type								
	O_1=66			O_2=68			O_3=15W40		
	L_1=1450	L_2=1650	L_3=1850	L_1=1450	L_2=1650	L_3=1850	L_1=1450	L_2=1650	L_3=1850
F1=0.5	97.22	98.96	102	95.117	96.557	101.48	89.963	94.85	99.407
F2=1	99.293	101.15	99.003	95.403	100.407	98.963	93.633	98.517	99.927
F3=1.5	98.52	102.257	102.813	96.78	99.927	101.293	95.723	97.89	100.52
F test	Sig.								
SE(m)±	0.604								
CD at 5 %	1.72								

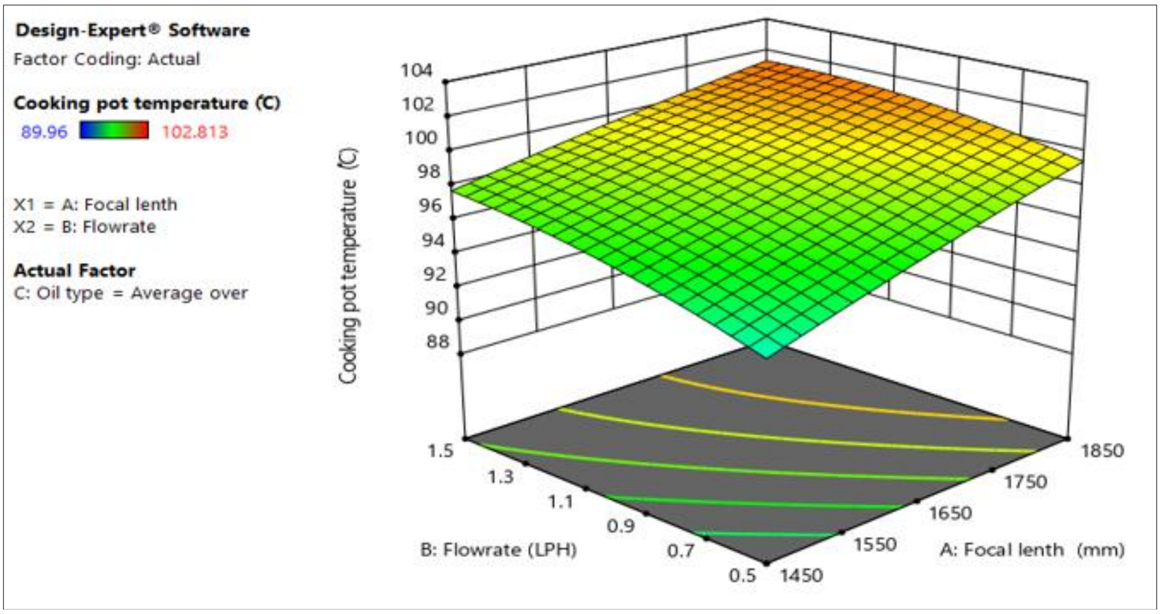

Fig 4: Effect of oil flow rate, focal length of the lens on cooking pot temperature (°C)

Fig. 4 shows that the per cent increase in the cooking pot temperature was found to be 2.813, 6.49 and 11.73 per cent at flow rate 0.5 to 1.5 LPM, focal length of the lens 1450 to 1850 mm and with oil type 66 to 15W40, respectively.

Table 5: Average exergy efficiency of cooking system in winter season

Time (h)	S. R.	Ambient temp. (℃)	Oil flow rate (m/s)	Cooker efficiency	Exergy Efficiency
11.00	426.35	30.16	1.11	32.15	23.98
12.00	600.31	32.62	0.20	21.98	20.52
13.00	631.26	32.40	0.14	17.52	20.64
14.00	566.88	32.60	0.30	17.46	24.18
15.00	420.76	31.78	0.30	20.45	32.14
16.00	322.14	31.21	1.37	22.52	36.79
17.00	193.90	29.50	0.20	29.78	61.55
18.00	89.42	28.71	0.30	48.73	48.22
Average	388.71	30.91	0.52	26.32	33.50

Conclusion

The heat energy supplied by the lens was sufficient to achieve the desired temperature for cooking application. The automatic dual axis sun tracking system was found to be feasible to track the solar radiation. The cooking test carried out which indicate that the size of lens (1 m^2) and other designed parameters are the least possible configuration required for 2 liters size of cooking pot. Three types of oil were used namely oil code 66, 68 and 15W40 for supply the heat to cooker and 66 type of oil was found to be best among the other by achieving the maximum temperature 135℃ in winter and 145℃ in summer season. The maximum and minimum efficiency of indirect solar cooker by Fresnel lens was found to be 27.62, 12.09 per cent respectively and can be further improved by using advance heat absorbing materials. The maximum and minimum steam temperature inside cooker was found to be 122 and 120℃ which was used to cook the any food material. The maximum average Exergy efficiency of indirect solar cooker was found to be 37 percent which showed that heat energy can be efficiently used. As the solar energy was used for the cooking purpose, it added the extra benefit to the free environment.

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