DESIGN AND MODELING OF A PARABOLIC SOLAR CONCENTRATOR WITH A SPIRAL RECEIVER

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Annotatsiya: Spiral issiqlik yutuvchi bilan jihozlangan parabolik idish quyosh kollektori ishlab chiqilgan, modellashtirilgan va eksperimental tasdiqlangan. Tizim ham issiq suv, ham issiq havo ishlab chiqarish uchun ishlaydi. Eksperimental sinovlar Buxoro iqlim sharoitida o'tkazildi. Matematik model optik, issiqlik va eksergetik tahlillarni o'z ichiga olgan. Maksimal issiqlik samaradorligi kirish harorati 16,2 ° C va chiqish harorati 52,85 ° C bo'lgan 780 Vt / m² quyosh nurlanishi ostida 66,4% da hisoblangan. Eksergetika samaradorligi ish sharoitlariga qarab 5,2% dan 14,8% gacha bo'lgan.

Kalit so'zlar: parabolik idish, quyosh kollektori, spiral lasan absorber, issiqlik samaradorligi, eksergiya tahlili, eksperimental tekshirish.

Аннотация. Солнечный коллектор параболической тарелки, оснащенный спиральным поглотителем тепла, был спроектирован, смоделирован и экспериментально проверен. Система работает как для производства горячей воды, так и для производства горячего воздуха. Экспериментальные испытания проводились в климатических условиях Бухары. Математическая модель включала оптический, тепловой и эксергетический анализы. Максимальная тепловая эффективность была рассчитана на уровне 66,4% при солнечном облучении 780 Вт/м² с температурой на входе 16,2°C и температурой на выходе 52,85°C. Эксергетическая эффективность варьировалась от 5,2% до 14,8% в зависимости от условий эксплуатации.

Ключевые слова: параболическая тарелка, солнечный коллектор, спиральный змеевик-поглотитель, тепловая эффективность, эксергетический анализ, экспериментальная проверка.

Annotation. A parabolic dish solar collector equipped with a spiral coil heat absorber was designed, modeled, and experimentally validated. The system operates for both hot water and hot air production. Experimental tests were conducted under Bukhara climatic conditions. The mathematical model incorporated optical, thermal, and exergetic analyses. The maximum thermal efficiency was calculated at 66.4% under 780 W/m² solar irradiation with an inlet temperature of 16.2°C and outlet temperature of 52.85°C. The exergy efficiency ranged between 5.2% and 14.8% depending on the operating conditions.

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Keywords: Parabolic dish, solar collector, spiral coil absorber, thermal efficiency, exergy analysis, experimental validation.

Introduction

Global concerns about climate change, depletion of fossil fuels, and increasing energy demand have fueled the pursuit of clean and renewable energy solutions[1]. Solar energy, being environmentally friendly and versatile, is set to become an important component of the future global energy mix[2].

Among various solar thermal technologies, parabolic trough solar concentrators offer unique advantages due to their high optical concentration ratio, compact design, and ability to produce high temperatures suitable for low- to medium-temperature thermal applications[3], [4]. These systems use a parabolic reflector to concentrate solar radiation onto a receiver located at a central point, where the heat is absorbed and transferred to the working medium.

Several studies have investigated different absorber designs, such as cavity receivers, spiral coils, and bulk absorbers, to optimize heat transfer and minimize thermal losses[5], [6]. In particular, spiral coil receivers have attracted attention due to their high heat transfer area, compact geometry, and favorable fluid dynamics[7].

Despite extensive research efforts, there is a gap in the experimental verification and practical application of such systems under real-world climatic conditions, particularly in arid regions such as Central Asia. This work aims to fill this gap by designing, modeling, and validating a parabolic trough solar collector concentrator with a spiral receiver for hot water and air production in Bukhara, Uzbekistan, where solar radiation is high and heat demand is high.

Materials and Methods

Table 1.

The designed parabolic solar concentrator has the following characteristics

Title	Parametr	Value
Dish diameter (D)		1.8 m
Focal length (f)		0.7 m
Tube diameter		8.6 mm (ID) / 9.3 mm (OD)
Reflectivity (ρ)		0.85
Absorber material	Blackened copper	
Reflector material	Glass mirror	

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Working fluid	Water	
Mass flow rate		0.03 kg/s
Rim angle		45.6°
Support structure	Metallic Base	
Spiral coil length (L)		6 m
Coil diameter		0.25 m
Number of turns		13

Thermal Efficiency

$$\eta_{th} = \frac{mc_p(T_{out}-T_{in})}{A_a G_b} \quad 2.2.1$$

where

$$A_a = \frac{\pi D^2}{4} \quad 2.2.2$$

is the aperture area.

Optical efficiency

$$\eta_{opt} = \gamma pa \quad 2.2.3$$

where γ is the intercept factor, and α is the absorptivity (assumed 0.95 for black-painted copper).

Exergetic Efficiency

Using Petela's model [9]

$$\eta_{ex} = \frac{mc_p(T_{out}-T_{in}-T_{am}ln\frac{T_{out}}{T_{in}})}{A_a G_b\left(1-\frac{4T_{am}}{3T_{sun}}+\frac{1}{3}\left(\frac{T_{am}}{T_{sun}}\right)^4\right)} \quad 2.2.4$$

where $T_{sun} = 4350K$.

RESULTS AND DISCUSSIONS

Experimental testing of a parabolic solar concentrator equipped with a spiral receiver was carried out in real environmental conditions typical of the city of Bukhara, Uzbekistan. This area is characterized by high levels of solar insolation, clear skies, and sunny days for most of the year.

The experiments were conducted in March 2025, under clear skies with minimal cloud cover to minimize fluctuations in solar radiation. The tests were conducted during peak solar hours (10:00-14:00 local time) to capture consistent solar energy. The parabolic solar concentrator system was manually adjusted at regular intervals throughout the experiment to ensure optimal solar tracking. The tracking ensured that the sun's rays remained normal to the reflector aperture for maximum optical capture.

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Measurement conditions: March 2025, Bukhara, 18°C ambient temperature, 780 W/m² solar irradiance[8], [9].

The optical performance of a parabolic trough solar concentrator plays a key role in determining the overall efficiency of the system, as it controls the amount of sunlight that is effectively delivered to the absorber surface[1]. High optical efficiency minimizes reflections and losses while maximizing the useful thermal input to the receiver. The designed system uses a parabolic dish with a 45.6° angle selected based on a trade-off between concentration ratio, design feasibility, and receiver location[2]. As noted by Bellos et al.[3], the rim angle has a significant effect on the concentration ratio and optical capture area. To ensure maximum energy capture, the absorber was positioned 0.65 m from the apex of the paraboloid - slightly adjusted from the theoretical center point to compensate for small surface inaccuracies and manufacturing tolerances, a practice that has been validated in previous optical alignment studies[4], [6].

The optical performance achieved in this work is consistent with previous experimental and numerical studies on parabolic dish collectors with spiral coil receivers[2], [4], [6]. The small improvement observed here is due to careful initial mirror calibration, consistent manual monitoring, and periodic mirror cleaning, which are highlighted as important maintenance procedures by Kalogirou [7] and Pavlovic et al. [3].

Exergetic efficiency.

The thermal and exergetic performance of a parabolic trough solar concentrator is strongly influenced by the interplay between solar radiation input, optical concentration, heat transfer characteristics within the spiral coil receiver, and heat losses to the environment. A proper assessment of thermal and exergetic efficiency provides a comprehensive understanding of the collector's energy conversion capabilities and irreversible losses[1]. The characteristics of the device thermal processes are presented in Table 2.

Table 2:

Characteristics of device thermal processes

Parameter	Value
Inlet temperature	16.2^0C
Outlet temperature	52.85^0C
Termal efficiency	66.4 %
Exrgetic efficiency	14.8 %
Pressure drop	0.03 bar

The heat flux per unit length of the spiral receiver of a parabolic solar concentrator is illustrated in Figure 1.

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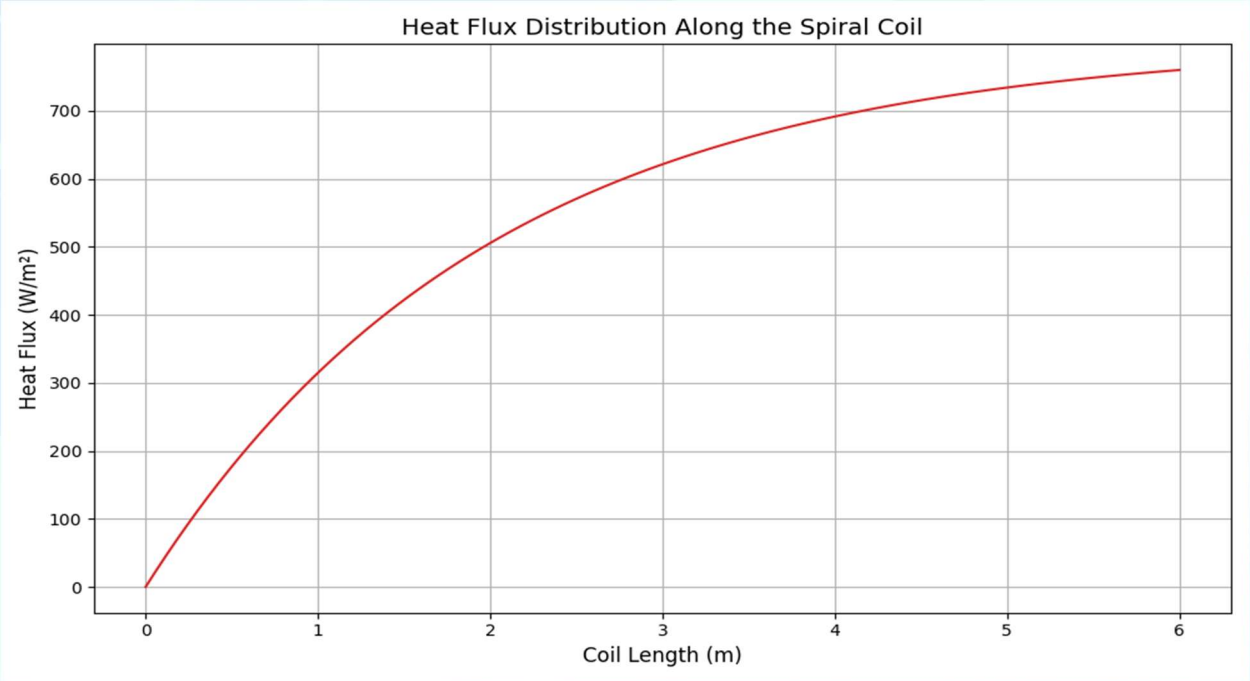


Fig. 1. Heat flux along the length of the spiral receiver

In a spiral receiver, the heat flow propagates along the direction of the incident solar radiation and the inlet and outlet temperatures(Fig.2).

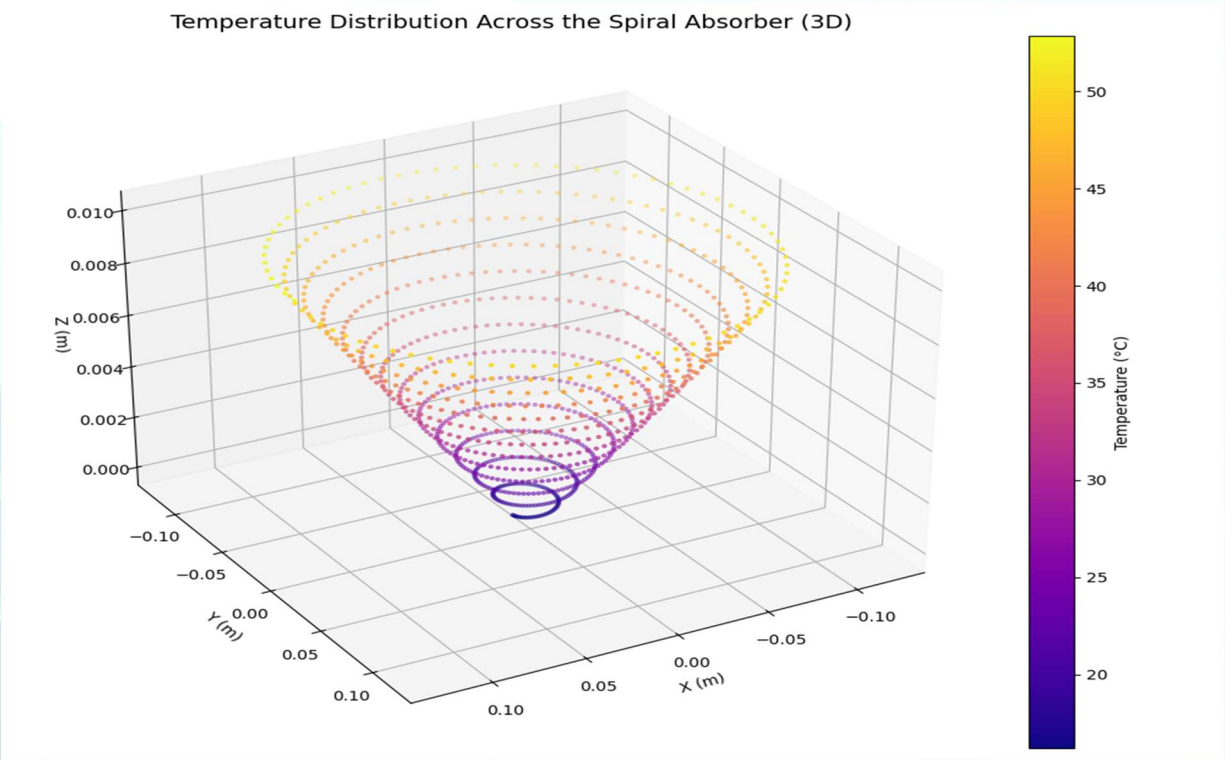


Fig.2. Temperature variation in the spiral receiver

Proper evaluation of exergetic efficiency allows for a complete understanding of the collector's energy conversion capacity and irreversible losses (Fig.3).

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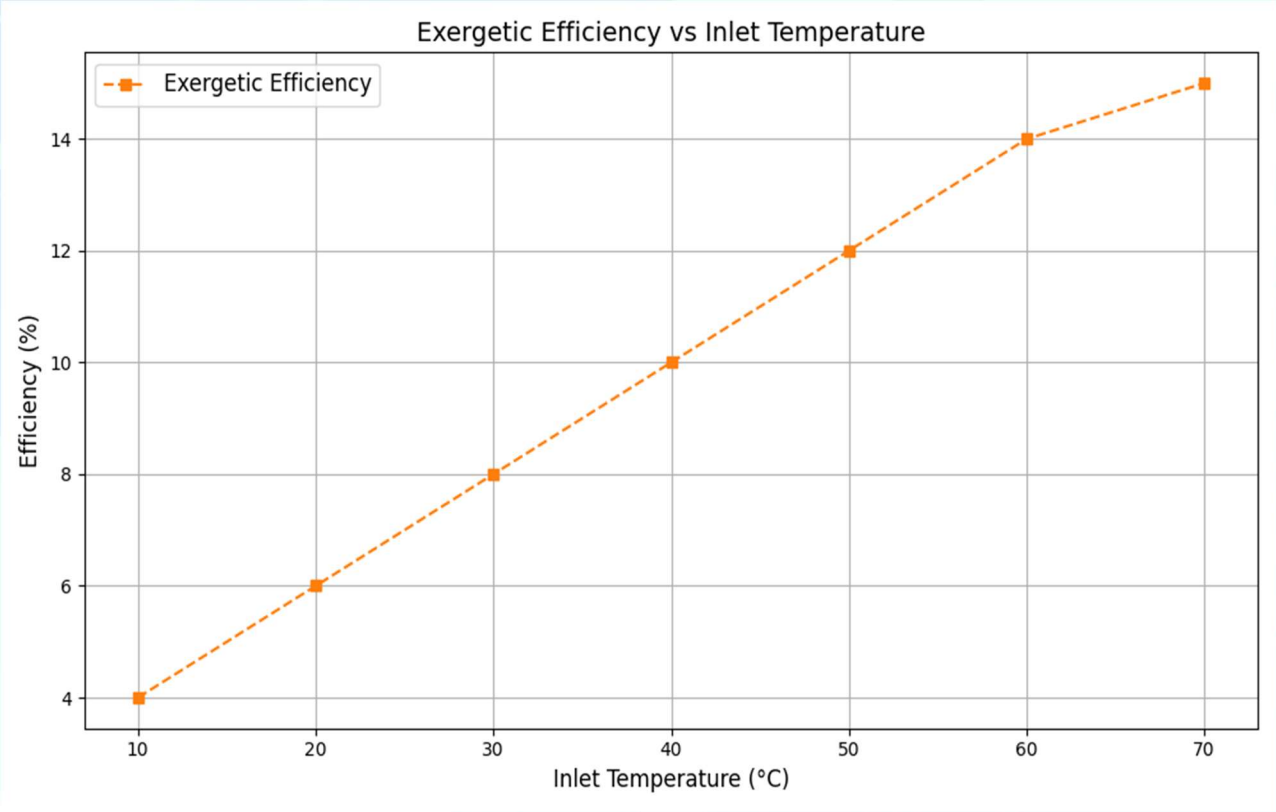


Fig. 3. Device exergetic efficiency and inlet temperature change dynamics.

Conclusions.

This study presents a comprehensive design, modeling, and experimental validation of a parabolic solar concentrator equipped with a spiral coil receiver for simultaneous hot water and air generation under real climate conditions.

A compact parabolic dish system with a diameter of 1.8 m, a focal length of 0.7 m, and a 13-turn spiral coil receiver has been successfully developed and tested in Bukhara, Uzbekistan. The system demonstrated excellent structural simplicity while maintaining high thermal performance.

The mathematical modeling framework included integrated optical, thermal, and exergy analyses based on the first and second laws of thermodynamics. Theoretical predictions were closely correlated with experimental measurements, confirming the robustness of the model.

Optical analysis showed a cross-section factor of 0.96 and an average optical efficiency of approximately 69% under daily operating conditions, highlighting the high focusing accuracy of the system despite its compact size.

The collector achieved a maximum thermal efficiency of 66.4% at a solar irradiance level of 780 W/m², which is consistent with previous literature for spiral coil receivers and demonstrates effective heat retention in an arid climate with clear skies.

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REFERENCES

1. “duffie 10.”
2. S. R. Pavlović, E. Bellos, V. P. Stefanović, C. Tzivanidis, and Z. M. Stamenković, “Design, simulation, and optimization of a solar dish collector with spiral-coil thermal absorber,” Therm. Sci., vol. 20, no. 4, pp. 1387–1397, 2016, doi: 10.2298/TSCI160213104P.
3. E. Bellos, C. Tzivanidis, K. A. Antonopoulos, and G. Gkinis, “Thermal enhancement of solar parabolic trough collectors by using nanofluids and converging-diverging absorber tube,” Renew. Energy, vol. 94, pp. 213–222, 2016, doi: 10.1016/j.renene.2016.03.062.
4. I. M. Saleh Ali, T. S. O’Donovan, K. S. Reddy, and T. K. Mallick, “An optical analysis of a static 3-D solar concentrator,” Sol. Energy, vol. 88, no. February, pp. 57–70, 2013, doi: 10.1016/j.solener.2012.11.004.
5. K. S. Reddy, T. S. Vikram, and G. Veershetty, “Combined heat loss analysis of solar parabolic dish - Modified cavity receiver for superheated steam generation,” Sol. Energy, vol. 121, pp. 78–93, 2015, doi: 10.1016/j.solener.2015.04.028.
6. S. Lokeswaran, T. K. Mallick, and K. S. Reddy, “Design and analysis of dense array CPV receiver for square parabolic dish system with CPC array as secondary concentrator,” Sol. Energy, vol. 199, no. January, pp. 782–795, 2020, doi: 10.1016/j.solener.2020.02.075.
7. S. A. Kalogirou, S. Karellas, V. Badescu, and K. Braimakis, “Exergy analysis on solar thermal systems: A better understanding of their sustainability,” Renew. Energy, vol. 85, pp. 1328–1333, 2016, doi: 10.1016/j.renene.2015.05.037.
8. N. N. Sadullayev, A. B. Safarov, S. N. Nematov, and R. A. O. Mamedov, “Research on facilities of power supply of small power capability consumers of bukhara region by using wind and solar energy,” Int. J. Innov. Technol. Explor. Eng., vol. 8, no. 9 Special Issue 2, pp. 229–236, 2019, doi: 10.35940/ijitee.I1047.0789S219.
9. Gogle Earth
10. https://earth.google.com/web/@39.76184365,64.42172368,223.0598182a,29608497798d,35y,359.99995618h,0t,0r/data=OgMKATA

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