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Performance Evaluation of an Indirect Natural-Convection Solar Dryer for Beef Drying in Abéché, Chad

Manuscript Info

Manuscript History

Received: xxxxxxxxxxxxxxxxx

Final Accepted: xxxxxxxxxxxxxxxxx

Published: xxxxxxxxxxxxxxxxx

Key words:-

Solar drying, indirect solar dryer, natural convection, beef, Abéché.

Meat preservation is a major challenge in Sahelian regions due to high ambient temperatures and the lack of refrigeration infrastructure. In Abéché, Chad, traditional open-air drying exposes meat to

Abstract

contamination and results in uneven drying. This study aimed to design, construct, and evaluate the performance of an indirect natural-convection solar dryer adapted to local climatic conditions. The dryer was built using locally available materials and tested with beef slices of 35 mm thickness. Thermal parameters (temperature and relative humidity) and drying kinetics were monitored during the experiments. The results showed that the dryer achieved internal air temperatures up to 58 °C, with an average temperature increase of about 17 °C compared to ambient conditions (37–43 °C). This allowed a significant reduction in drying time from 2–3 days in open-air drying to approximately 15–20 hours in the solar dryer. The final moisture content of the dried beef reached approximately 18–26%, ensuring improved preservation and hygienic quality. The results demonstrate that the indirect natural-convection solar dryer is an efficient, low-cost, and suitable technology for beef drying under the climatic conditions of Abéché, Chad.

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Introduction:-

Meat preservation remains a critical issue in Sahelian regions where high temperatures, low relative humidity, and the absence of cold-chain infrastructure accelerate meat spoilage. In Abéché, eastern Chad, post-slaughter losses are significant due to rapid microbial growth and unfavorable environmental conditions. Drying is therefore a traditional and effective method for extending meat shelf life. However, conventional open-air drying exposes meat to dust, insects, and animals and offers no control over temperature or humidity, resulting in poor hygienic quality and inconsistent drying. Indirect solar dryers provide a safer alternative by separating the solar heating process from the drying chamber, thus protecting products from direct radiation and external contamination. Although many studies have reported the effectiveness of solar drying technologies in Sahelian countries, limited research has focused on Chad, particularly in Abéché, where climatic conditions and the availability of local materials strongly influence dryer performance. The objective of this study is to design an indirect natural-convection solar dryer adapted to the local climate, evaluate its thermal performance, and analyze the drying kinetics of beef compared with traditional open-air drying.

1. Literature Review

1.1 Principle of Solar Drying

Drying is a preservation technique based on reducing the moisture content of food to inhibit microbial growth. Solar energy, abundant in Sahelian regions, is a renewable and cost-free resource commonly used for drying agricultural and animal products.

1.2 Types of Solar Dryers

Solar dryers are generally classified into direct, indirect, mixed, and hybrid systems. Indirect solar dryers are particularly suitable for food products as they offer better control of drying conditions and preserve color, texture, and nutritional quality.

1.3 Natural Convection

In natural-convection dryers, airflow is driven by buoyancy forces caused by temperature differences, eliminating the need for electrical fans. This makes such systems especially appropriate for rural areas without reliable electricity access.

1.4 Previous Studies

Several studies conducted in Niger, Mali, and Burkina Faso show that indirect solar dryers increase the internal temperature by 10 to 30°C compared to the outside temperature and significantly reduce drying time. However, few studies have focused on meat in the Chadian context. The study examined vacuum dryers using natural and forced convection drying modes. Two tests were carried out during the day between 9 a.m. and 4 p.m. We observed a difference in temperature between different areas of the dryer during these tests. We also noticed that temperatures in natural convection mode were higher than those in forced convection mode. In forced convection, the air does not have time to reach the temperature, which shows the influence of the drying air speed on the different temperatures in the dryer. The two figures are the results of previous work [11].

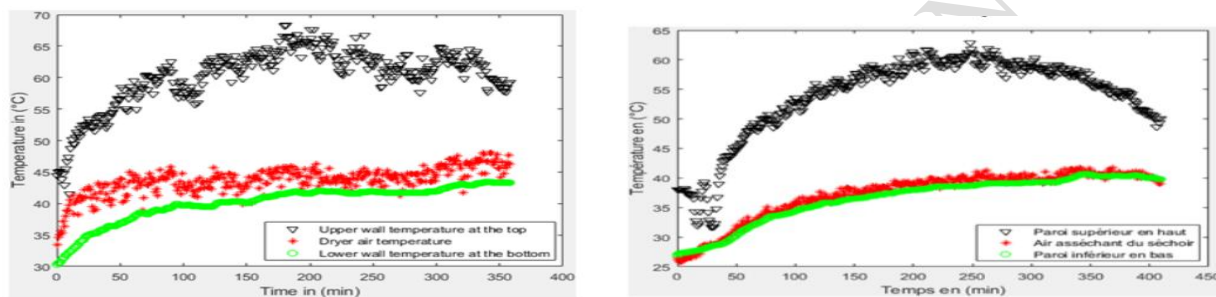


Figure 1. The figures show respectively the evolution of the temperatures obtained experimentally during the drying tests in vacuum [11].

2. Materials and Methods

2.1 Study Area

The study was conducted in Abéché, located in the Ouaddaï region of eastern Chad (altitude ≈ 545 m). The climate is Sahelian, characterized by high temperatures, low relative humidity, and strong solar radiation averaging 5–7 kWh/m²/day, making the region well suited for solar drying applications.

2.2 Description of the Solar Dryer

The experimental device is an indirect natural-convection solar dryer consisting of a flat-plate solar air collector and a separate drying chamber. The solar collector is inclined at 23° and covered with transparent glass. A black-painted absorber plate heats the air, which then flows naturally into the drying chamber due to buoyancy effects. The drying chamber is constructed from locally available wood and insulated to reduce heat losses. Its internal dimensions are 1.2 m (height) \times 1.0 m (width) \times 1.5 m (depth). Stainless steel mesh trays are arranged inside the chamber to allow uniform air circulation around the meat slices. Air inlet and outlet openings ensure continuous natural airflow.



Figure 2. Indirect Natural Convection Solar Dryer

2.3 Raw Material Preparation

Fresh beef obtained from thigh muscles was cut into slices of 35 mm thickness. The initial total mass of the samples was approximately 5 kg.



Figure 3. Beef after drying in the solar dryer

2.4 Experimental Procedure

Drying experiments were carried out between 8:00 a.m. and 4:00 p.m. Measurements were recorded every 30–60 minutes and included ambient temperature, solar collector temperature, drying chamber temperature, relative humidity, and meat mass.

2.5 Data Analysis

Moisture content and drying kinetics were determined from mass loss measurements over time to evaluate dryer performance.

20

66 The initial and final moisture content was calculated using the following formula:

$$\text{Moisture content (\%)} = \frac{m_{\text{initial}} - m_{\text{dry}}}{m_{\text{initial}}} * 100$$

67 m_{initial} : Meat Mass before Drying

68 m_{dry} : Meat Mass after Complete Drying

$$\text{Moisture content (\%)} = \frac{5000 - 1560}{5000} * 100$$

69 Moisture Content of 68%

70 Beef contains 68% water

71 • **Drying Kinetics**

72 Drying kinetics describe how the moisture content of the meat decreases over time in the dryer. It is a key tool for
73 predicting drying time, optimizing temperature, and understanding the different phases of the drying process. The
74 average ambient air temperature during the experiment was 52 °C.

75 **Table 1.** Experimental Data for Beef Drying

76

Time (hours)	Mass (kg)	Moisture Content (%)
0	5	100
2	4.4	88
4	3.8	75
8	2.9	55
12	2.2	40
20	1.5	25
24	1.3	20

77

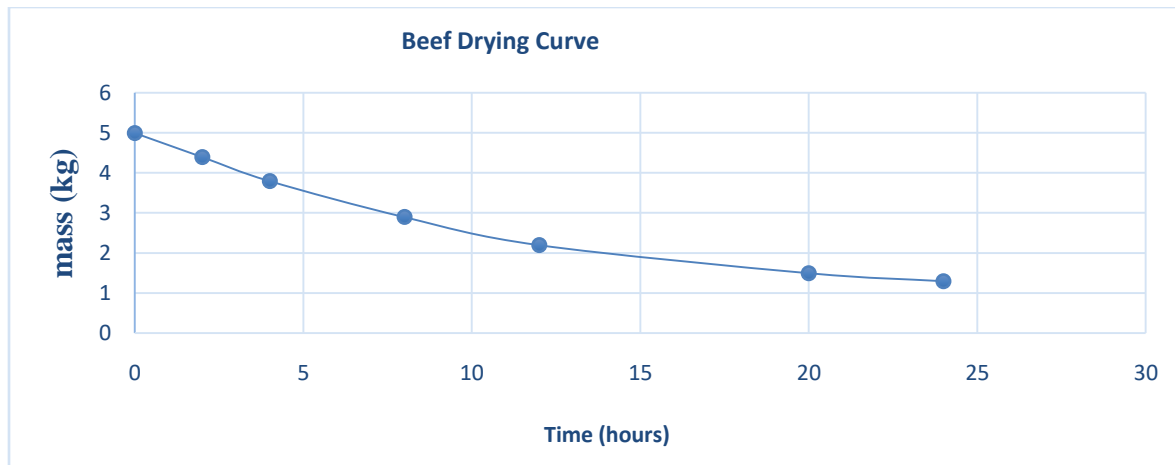


Figure 4. Beef Drying Curve Showing the Decrease in Meat Mass over Drying Time

The drying curve of the meat shows the drying of 5 kg of fresh beef in a solar dryer. It illustrates the decrease in mass as a function of drying time, directly representing the drying kinetics

• Comparison with Open-Air Drying

Table 2. Comparative Table of Solar Dryer and Open-Air Drying

Criterion	Solar Dryer	Open-Air Drying
Drying Time	15–30 h	2–3 days
Drying Temperature	45–60 °C (stable)	Variable: 30–40 °C
Ventilation	Controlled and continuous	Depends on wind
Air Humidity	Reduced due to heating	Fluctuating; higher risk
Mass Loss (from 5 kg)	1.4–1.6 kg (dry)	1.3–1.7 kg (more variable)
Risk of Insects / Dust	Very low	Very high
Hygiene	Excellent	Poor (flies, dust)

This drying experiment is evaluated during the dry season and rainy season in June 2025 and October 2025 in the province of Ouadaï, the department of Ouara, and the capital city of Abéché

- The solar dryer is faster, cleaner, and safer.
- Open-air drying is simpler but slower and less hygienic.
- For a product such as beef in Chad, the solar dryer offers significant advantages:
 - +50% in drying speed
 - +70% in hygiene
 - Superior quality

3. Results and Discussion

3.1 Climatic Conditions

During the experiments, ambient temperature ranged between 37 °C and 43 °C, with an average relative humidity of approximately 20%.

3.2 Thermal Performance

The solar dryer achieved a maximum internal temperature of about 58 °C, corresponding to an average temperature rise of 17 °C above ambient conditions. Internal relative humidity was reduced to approximately 40%, favoring effective moisture removal.

3.3 Drying Kinetics

The initial mass of 5 kg of fresh beef was reduced to approximately 1.3 kg after dry-ing. The total drying duration was 15–20 hours, representing a reduction of about 60% compared to open-air drying. Final moisture content ranged between 18% and 26%.

3.4 Comparison with Open-Air Drying

Compared to traditional open-air drying, the solar dryer provided faster and more uniform drying, better hygienic quality, and full protection against dust and insects.

4. Conclusion and Perspectives

This study demonstrated the successful design and evaluation of an indirect natural-convection solar dryer adapted to the Sahelian climate of Abéché. The system significantly reduced drying time and improved the hygienic quality of dried beef while relying on locally available materials and renewable energy.

The dryer represents a sustainable and cost-effective solution for reducing post-slaughter losses and improving food security in Chad. Future work will focus on integrating a solar-powered fan to enhance airflow, optimizing collector insulation, and extending the application of the dryer to other agricultural products such as onions, tomatoes, and mangoes.

Acknowledgements

The authors gratefully acknowledge the Islamic Development Bank, through the Ministry of Higher Education, Scientific Research, and Innovation of Chad, for financial support provided for this research

Conflicts of Interest

The authors declare no conflict of interest regarding the publication of this paper.

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