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

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Abstract

Meat preservation is a major challenge in Sahelian regions due to high ambient temperatures and the lack of refrigeration infrastructure. In Abéché, Chad, tradi-tional open-air drying exposes meat to contamination and results in uneven dry-ing. This study aimed to design, construct, and evaluate the performance of an in-direct 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 temper-ature 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%, en-suring 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.

Introduction:-

Meat preservation remains a critical issue in Sahelian regions where high tempera-tures, 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 there-fore 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 qual-ity and inconsistent drying. Indirect solar dryers provide a safer alternative by sepa-rating 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 natu-ral-convection solar dryer adapted to the local climate, evaluate its thermal perfor-mance, 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 tem-perature differences, eliminating the need for electrical fans. This makes such sys-tems 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 fo-cused 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].

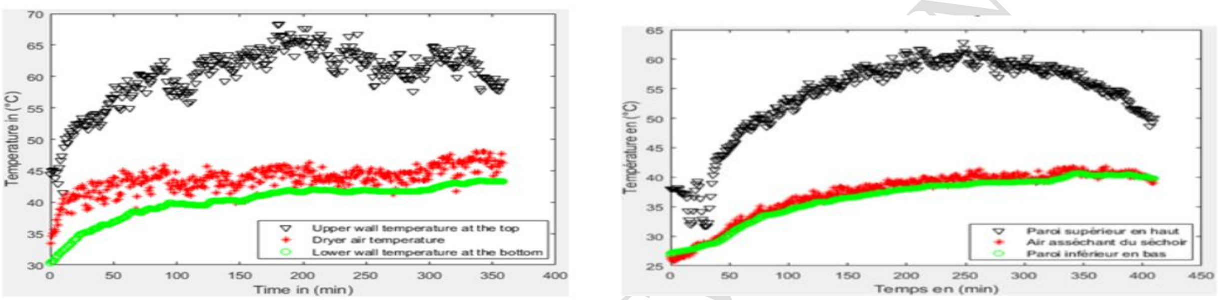

***Figure 1**.The figures show respectively the evolution of the temperatures obtained experimentally during the drying tests in vacuum [11].*

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, mak-ing 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 in-clined 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 re-duce heat losses. Its internal dimensions are 1.2 m (height) × 1.0 m (width) × 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 continu-ous 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 col-lector 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.

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

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

$m_{initial}$: Meat Mass before Drying

m_{dry} : Meat Mass after Complete Drying

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

Moisture Content of 68%

Beef contains 68% water

- **Drying Kinetics**

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

Table 1. Experimental Data for Beef Drying

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

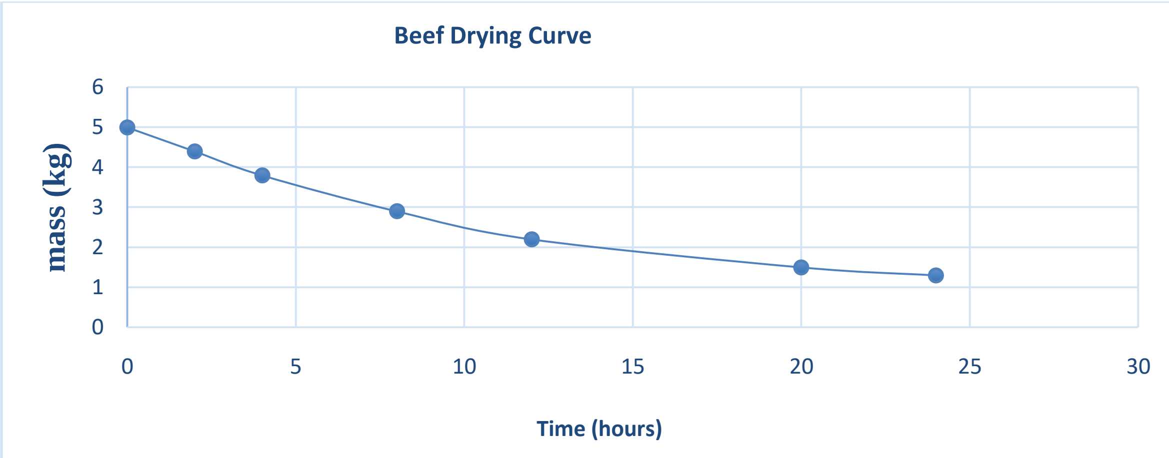

Figure 4. Beef Drying Curve Showing the Decrease in Meat Mass over Drying Time

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, corre-sponding 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 natu-ral-convection solar dryer adapted to the Sahelian climate of Abéché. The system significantlyreduced 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 insula-tion, and extending the application of the dryer to other agricultural products such as onions, tomatoes, and mangoes.

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Conflicts of Interest

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

References

[1] Afolabi, I. S. (2014). Moisture content, microbial load and sensory attributes of dried beef (“kilishi”) produced using three drying methods. International Journal of Food Science and Nutrition Engineering, 4(1), 1–6.

[2] Belessiotis, V., &Delyannis, E. (2011). Solar drying. Solar Energy, 85(8), 1665–1691. https://doi.org/10.1016/j.solener.2009.10.001

[3]Bennamoun, L. (2012). Reviewing the experience of solar drying in Algeria with presen-tation of the different designs, performance and applications. Renewable and Sustainable Energy Reviews, 16(5), 1381–1391.

[4] El-Sebaii, A. A., &Shalaby, S. M. (2012). Solar drying of agricultural products: A review. Renewable & Sustainable Energy Reviews, 16(1), 37–43.

[5] Esper, A., &Muhlbauer, W. (1998). Solar drying — an effective means of food preserva-tion. Renewable Energy, 15(1-4), 181–186.

[6] Ellows, P. J. (2009). Food Processing Technology: Principles and Practice (3rd Ed.). Woodhead Publishing.

[7] Hassan, M., & Shams El Deen, I. A. (2017). Design and performance evaluation of a solar dryer for drying meat. Journal of Food Processing & Technology, 8(4), 1–6.

[8] M. Daguenet, 'Solar Dryers: Theory and Practice', UNESCO, Paris, 1985.

[9] G. Nonhebel, 'Drying of Solids in the Chemical Industry', London: Butterworth & Co, Publishers Ltd, 1971.

[10] P. Dudez, 'Small-Scale Solar Drying of Fruit and Vegetables: Experiments andProcesses', Edition du Gret, France, 1999.

[11] Aboubacar CHAIBOU AOUTA et al,, Study of the Thermo-hydric Behavior of an Indirect Tunnel-type Forced Convection Dryer and the Drying of Meat Slices in the Form of Kilishi 2022 DOI:10.12691/ajfst-10-2-3

[12] Kra, K. A., Gbaha, P., Soro, Y., &Toure, S. (2011). Experimental study of the drying of beef in a solar dryer designed and constructed in Côte d'Ivoire. Food and Bioproducts Processing, 89(3), 215–221.

[13] Madhlopa, A., Ng'oma, H., &Kamadi, S. (2017). Solar dryers for agricultural products in Malawi. Renewable Energy, 113, 1114–1122.

[14] Mwithiga, G., &Olwal, J. O. (2005). The drying kinetics of kale (Brassica oleracea) in a convective hot air dryer. Journal of Food Engineering, 71(2), 307–313.

[15] Ndiaye, M. L., &Ndiaye, M. (2018). Solar drying in the Sahelian context: Performance of solar dryers for food preservation. Renewable Energy and Sustainable Development, 4(1), 85–94.

[16] Sena, E., &Toure, S. (1986). Traditional preservation of meat and fish in West Africa. FAO Animal Production and Health Paper, 29.

[17] Sharma, A., Chen, C. R., & Nguyen, V. L. (2009). Solar-energy drying systems: A review. Renewable and Sustainable Energy Reviews, 13(6-7), 1185–1210.

[18] Simate, I. N. (2003). Optimization of solar drying of fish fillets. Journal of Food Engi-neering, 58(2), 125–130.

[19] Aboubacar CHAIBOU AOUTA, Haoua AMADOU, Eloi Salmwendé TIENDREBEOGO, Modeling of Thin-layer Sun Drying of Slices of Meat in Kilishi Form, Science Journal of Energy Engineering 2020; 8(2): 25-32.

[20] G. Arditti, Technologie chimique industrielle, tome III", Edition Eyrolles, Paris, France, 1972.

[21] A. O. Dissa, E. S. Tiendrebeogo, S. Garba, J. Koulidiati, Modélisation et simulation du séchage solaire en couche mince de la Spiruline (Asthrospiraplatensis), Journal de la Société Ouest-Africaine de Chimie J. Soc. Ouest-Afr. Chim. (2016), 042: 1-7 21ème Année, Dé-cembre 2016.

[22] Tchatchoua, S., Tchinda, R., &Kenfack, J. (2016). Experimental and theoretical study of a mixed-mode solar dryer for drying beef. Renewable Energy, 97, 580–589.