International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 9 Issue 4, Jul-Aug 2025 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Energy, Exergetic and Economic Evaluation of a Trapezoidal Mixed Tunnel Dryer

Mamadou Lamine Coly[1], Mamadou Seck Gueye[2],
Bou Counta Mbaye[3], Waly Faye[4], Omar Ngor Thiam[5]

[1,2]Semiconductor and Solar Energy Laboratory, Cheikh Anta Diop University, Dakar, Senegal
[3,4,5]Laboratory of Fluid Mechanics, Hydraulics and Transfer, Cheikh Anta Diop University, Dakar, Senegal

ABSTRACT
This article analyzes the energy, exergy, and economic performances of a mixed forced convection solar tunnel dryer designed for drying fishery products. This system integrates an air collector equipped with fans and a drying cabin. Tested by Coly et al. Under empty and loaded conditions under different climatic conditions (clear, cloudy, or rainy skies), the dryer has thermal efficiencies of 17% to 60% for the collector and 0% to 5.7% for the cabin, depending on the sunlight. This work performs an exergy analysis to identify energy losses and propose ways to optimize the overall efficiency of the system. Economically, the study highlights benefits in terms of hygiene, product quality and profitability, with an estimated payback period of 0.6 years for oily fish, 1.1 years for lean fish, 1.5 years for shrimp, and an average of 0.7 years for these three products, over an operating period of 150 days per year.

KEYWORDS: *solar dryer; exergy; collector; drying cabin, economy.*

How to cite this paper: Mamadou Lamine Coly | Mamadou Seck Gueye | Bou Counta Mbaye | Waly Faye | Omar Ngor Thiam "Energy, Exergetic and Economic Evaluation of a Trapezoidal Mixed Tunnel Dryer" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-9 | Issue-4, August 2025, pp.955-962, URL: www.ijtsrd.com/papers/ijtsrd97351.pdf

IJTSRD97351

Copyright © 2025 by author (s) and International Journal of Trend in Scientific Research and Development Journal. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0) (http://creativecommons.org/licenses/by/4.0)

International Journal of Trend in Scientific Research and Development ISSN: 2456-6470

I. INTRODUCTION

The processing of fishery products is a key issue in promoting local products. It is of paramount importance due to the quantity of products consumed, but also due to a diverse range of processed products. Its importance is reflected in a growing local and sub-regional market. But also by the sensitivity of this sector, occupied mainly by women. The product obtained during processing is often of undesirable quality due to open-air drying or the product is exposed to the sun, wind, and dust. The real problem with drying lies in the climatic conditions and the devices used to carry out the drying. The devices found in various sites across the country are racks in the form of handcrafted wooden tables, on which the fish are exposed to the open air for drying. The other device is a direct natural convection dryer, whose support is a cement construction. The use of these devices has not resolved the drying problem. Several solar conservation devices have been designed over the years, depending on their end uses, with the aim of solving this problem. These devices different² according to the drying method carried out, namely direct dryers[1], and indirect dryers[2]. The shape and type of collector used, such as flat collectors[3], cylindrical-parabolic collectors sand sensors with fins[4]. The type of storage used, storage tanks with heat pumps[5], and phase change materials[5]. In the field of drying fish products two types of dryer are used namely the direct dryer and the mixed dryer. The direct dryer is used by,(OI Alonge, 2018)[6] for drying catfish and tilapia. While for the tunnel dryer, some works are to be noted, among them:(Bala and Mondol, 2001a)[7] studied a 20 m² tunnel solar dryer for drying fish;(MS Saveda et al., 2004) [8] proposed the economic study of a 1.5 ton tunnel in the form of a dome. And finally(Basunia et al., 2011)[9] studied drying in a 50-100 kg tunnel solar dryer for sardinella. Although the scientific literature explores various types of dryers, the trapezoidal collector dryer model has, to our knowledge, not yet been studied.

Therefore, Coly et al [10]. designed and evaluated this dryer for drying fishery products, in order to determine its thermal performance and efficiency. The results reveal a strong dependence on sunlight, highlighting the need to optimize thermal insulation and heat recovery. This work thus aims to analyze the energy, exergy and economic performances of this dryer, with the aim of improving its efficiency and viability for agri-food applications.

II. EXERGY AND ENERGY ANALYSIS

1. EXPERIMENTAL DEVICE

We designed and tested a mixed forced convection solar tunnel dryer, consisting of a photovoltaic module, a solar collector, and a drying cabinet. The tests were carried out under two weather conditions: clear sky and cloudy sky. During the tests, temperature probes (thermochrons) were placed on the various walls of the dryer, at the inlet and outlet of the drying cabinet, as well as on the dried product. Thermocouples were placed inside and outside the dryer to monitor variations in ambient temperature and that of the heat transfer fluid.

Measurements were taken at 30-minute intervals, from 9 a.m. to 5 p.m., covering the morning and evening periods.

Figure 1: Mixed tunnel solar dryer

2. THEORETICAL STUDY

Thermal exergy represents the usable portion of energy in a thermal system, while anergy is the unusable portion [11]. Exergy measures the quality of energy, corresponding to the maximum work extractable when a system reaches equilibrium with its reference environment [12]. Exergy analysis, based on the second law of thermodynamics, is a key tool for evaluating and optimizing the thermal performance of systems [13]. It identifies the locations, types, and magnitudes of energy losses, enabling more efficient use of resources at the system and component levels.

➤ **Input exergy**

$$Ex_{in} = \dot{m}c\left[(T_{in} - T_a) - T_a \ln\frac{T_{in}}{T_a}\right] \quad (1)$$

➤ **Output exergy**

$$Ex_{ou} = \dot{m}c\left[(T_{ou} - T_a) - T_a \ln\frac{T_{ou}}{T_a}\right] \quad (2)$$

➤ **Exergy losses**

$$Ex_p = Ex_{in} - Ex_{ou} \quad (3)$$

➤ **Exergy efficiency**

$$\eta_{Ex} = \frac{E_{in}}{E_{ou}} \quad (4)$$

➤ **Energy calculation**

Thermal energy is calculated from the product of the thermal power supplied by the dryer and the drying time, according to the following equation:

E= P*t (5)

P = thermal power
T = drying time

3. Results and discussion

A. Clear-sky exergy

The input, output and lost exergy during periods of strong sunshine are shown in Figure 2.

According to this figure, the variation of exergy evolves according to the climatic conditions due to the sinusoidal shape of the curves. The exergy entering and leaving the dryer follow the same

evolution, they increase until reaching maximum values around noon when the solar radiation is at its maximum, before decreasing in the afternoon. Exergy losses in the dryer are greater during the first hours of drying and at the end of the day. These losses are significant at the beginning of drying, then they become non-existent during periods of strong sunshine, before reappearing in the afternoon.

This is explained by the fact that at the beginning of drying, the significant losses are due to the low power of the radiation in the morning. Because if the energy is low, the output exergy is very low or even non-existent. Around 12 o'clock the trend reverses and the outgoing flow is greater due to the contribution of the solar radiation incident on the window of the drying cabin. At the end of the day, the same phenomenon resumes with the drop in solar radiation.

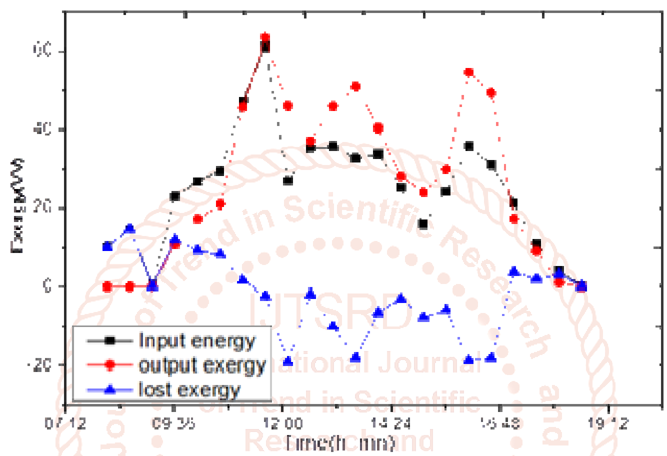


Figure 2: Variation of exergy as a function of weather in clear skies

B. Exergy in cloudy skies

The exergy variation of the dryer under cloudy skies is shown in Figure 3. It shows the evolution over time of the input, output and lost exergy. We note that the exergy loss evolves during drying, with the fluctuation of solar radiation. These losses have considerably decreased due to the small difference between the input and output exergy. The maximum input exergy coincides with the peak sunshine hours.

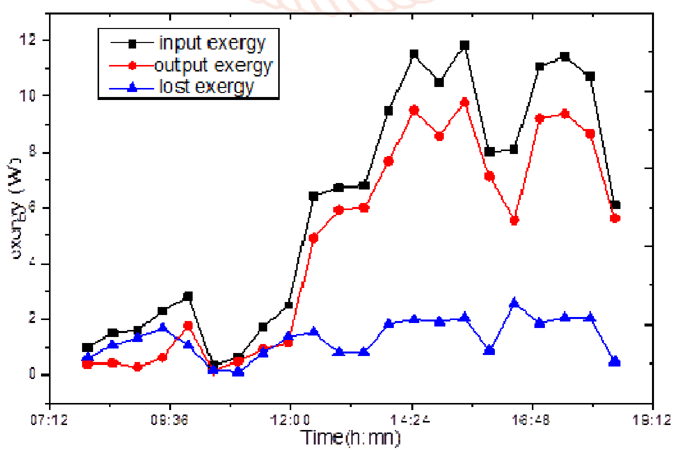


Figure 3: Variation of exergy in cloudy skies as a function of time

C. Exergy efficiency

Exergy efficiency is used to determine the sources of inefficiency in the dryer. Figure 4 shows the variation in efficiency during sunny and cloudy periods. This efficiency also depends on climatic conditions; it increases with increasing solar radiation. During cloudy periods, it varies between 20% and 80%, while in clear skies, it is above 100% at times where the sunshine is strong.

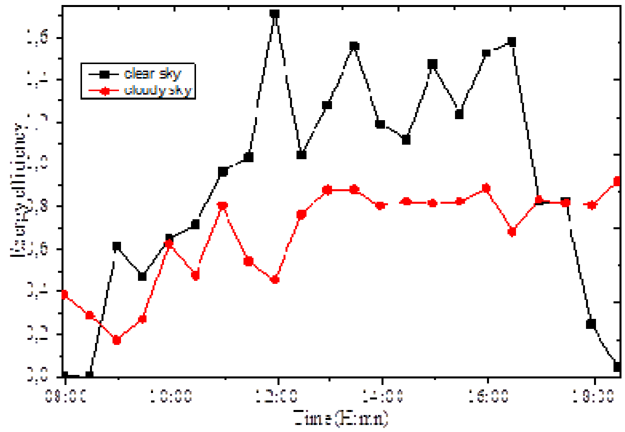


Figure 4:Variation of exergy efficiency as a function of time

D. Energy analysis

The figure 5 illustrates the energy consumption of a mixed tunnel solar dryer over two days of operation. The solar energy input covers the dryer's needs between 12 p.m. and 4 p.m., even generating excess energy that is lost. However, this input is insufficient in the morning and at night. An analysis of energy requirements reveals deficits during these periods of low sunlight. By integrating phase change materials (PCMs) into the dryer, it is possible to store excess energy, thus improving overall energy efficiency.

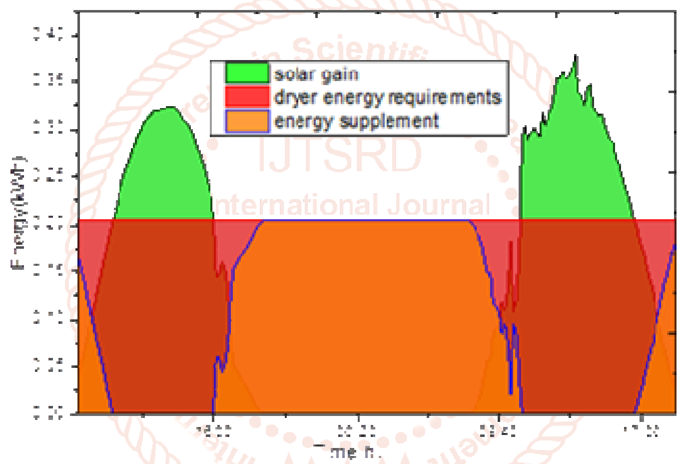
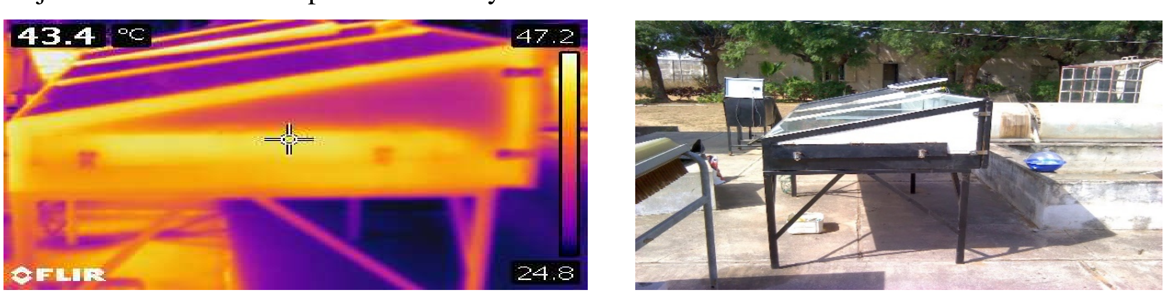


Figure 5: Energy consumption of the dryer

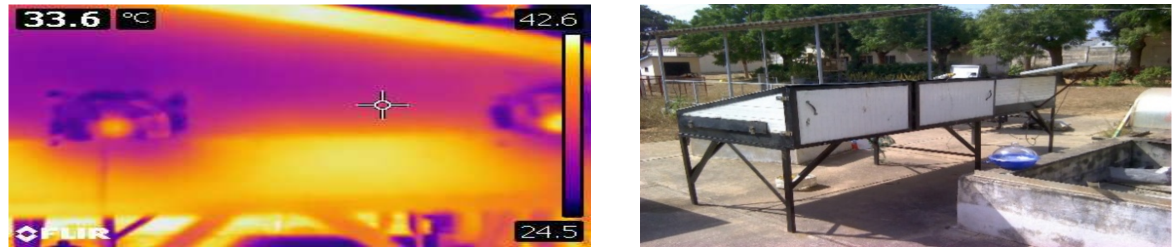
E. Thermogram of the dryer

Thermographic analysis has been used by some authors to observe the greenhouse effect occurring inside a dryer [15] or to confirm theoretical results on the temperature distribution in a dryer [16]. Thermographic images of the dryer were taken using a FLIR thermal camera. We observed the thermal behavior of the dryer, on the four sides and on the bottom, as shown in the Figure 6.

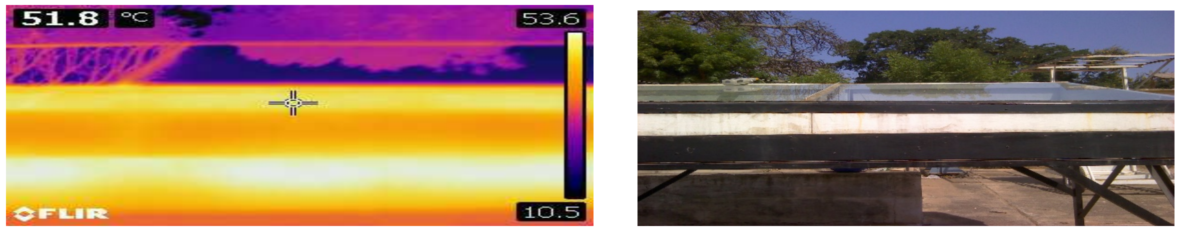
It allows to visualize the thermal insulation, the thermal bridges especially on the faces of the dryer. The observation made on the different walls (figure 6-b, 6-c, 6-d) shows a good insulation, which results in a low temperature of the external wall. Thermal bridges are recorded at the level of the doors (Figure 6-d) and on the different junctions between the plates of the dryer.



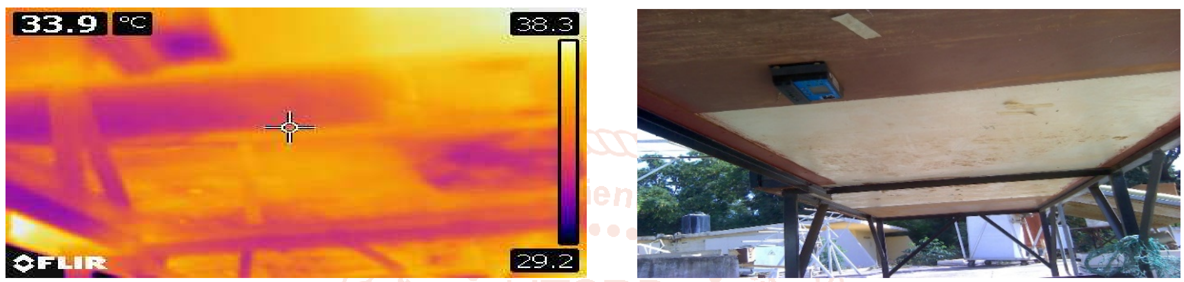
a)



b)



c)



d)

Figure 6 : Thermographic image of the dryer

III. Economic study of the dryer

1. Socio-economic analysis of the dryer

1.1. Market analysis

Solar drying of fish products is an activity practiced throughout the country. It is mostly dominated by women, who are often in communities whose know-how is passed down from generation to generation. Drying is done in a traditional way. Currently, several economic interest groups (EIG) have been established with the help of public authorities and non-governmental organization (NGO). Men are also involved in salting, displaying, and transporting fish for a daily fee. It is also worth noting the presence of independent entrepreneurs who are active in this sector, most of whom dry crustaceans and mollusks. They are also involved in

fishmeal processing. Most of these EIGs are reluctant to change their drying technology. This is because these systems require a high initial investment. Added to this is the fact that they use traditional drying methods such as floor drying and drying on racks, which are inexpensive. But this method of air drying has a negative impact on the health of consumers.

The popularization of this device can be done through several processes:

- HAS through sponsorship from the state, local authorities and NGOs: This involves getting the latter to finance the acquisition of solar equipment for the various economic interest groups.
- By targeting their various funding programs aimed at improving drying or women's conditions.
- By targeting development aid or environmental protection programs.

The other market share is found among entrepreneurs. These people are aware of the importance of these dryers, which makes them potential customers.

All these stakeholders are actors with whom awareness-raising and promotional activities must be conducted to promote the use of this solar dryer device.

1.2. Advantage of using a solar drying system

The advantages are multiple; nowadays, food hygiene regulations in developed countries are a hindrance to our processed fish products. Especially since most of the products processed in our various regions do not meet the most basic hygiene conditions. The use of solar dryers will allow the export of our products to these countries, thereby increasing their added value. Locally, we are witnessing a change in the mentality of a certain segment of the population concerned about the dangers associated with poor nutrition. This makes them a potential market for products dried with a solar dryer.

For users, this system is beneficial because it allows for faster drying, saving space, time, and money. The resulting drying product is more hygienic. This system should allow some people, especially in Casamance, to continue their activities, especially during rainy weather.

On the other hand, we also have companies that process crustaceans and molluscs, which are often intended for export. Offering them an efficient and more hygienic way would be more profitable.

1.3. Cost of drying

The cost of drying is often linked to the availability of the raw material, since it is less present at a certain time of the year. In the case of solar drying of fish products, the determination of the cost depends on several factors: the acquisition cost of the dryer, the maintenance cost, but also the operating cost. The latter refers to the labor related to the work of scaling, salting, displaying and transport. The analysis of the drying cost will be used through a technical-economic study, in order to allow to know the impact our system will have on fish processors. In this section, we will conduct a cost-based analysis to determine the payback time and savings achieved during drying in this solar dryer system.

2. The technical and economic study of the dryer

2.1. Determination of costs

2.1.1. Initial cost

Dryer costs are determined by taking into account manufacturing costs (purchase of materials, transportation) and labor.

It is defined at the level of equation (6).

$$C_{in} - C_{fa} + C_m \qquad (6)$$

C_{fa}: labor which is equal to 10% of the cost of materials

C_m: cost of materials

2.1.2. Annualized operating cost[17],[18].

This cost is defined as the sum of the total costs, maintenance and

Operation, it is given by the method of Audsley and Wheeler [19].

$$C_{annuel} = \left[C_{in} + \sum_{i=1}^{N}\left(C_{main,i} + C_{fonct,i}\right)w^{i}\right]\left[\frac{w-1}{w(w^{N}\ 1)}\right] \quad (7)$$

With $w - \frac{(100-i_d)}{(100-i_f)}$

id: interest rate if: inflation rate

$C_{main,i}$: maintenance cost for year i, it is equal to 2.5% of the total cost for each year of operation [20].

$C_{fonc,i}$: operating cost of the dryer

Cost of drying per unit of product dried in the dryer per year.

$$C_s = \frac{C_{annuel}}{M_s} \qquad (8)$$

2.2. Determination of the quantity of dry matter

$$M_s = \frac{M_d D}{D_b} \quad (9)$$

D: Number of days of use per year

D_d: Number of drying days per batch

2.3. Calculation drying savings[21].

Cost of fresh product per kilogram of dried product

$$C_{dp} = C_{fp}\frac{M_f}{M_d} \qquad (10)$$

C_{fp}: cost per kg of fresh product

Cost per 1 kg of dry product

$$C_{ds} - C_{dp} + C_s \qquad (11)$$

Savings for 1 kg of dry product

$$S_{kg} - C_b - C_{ds} \qquad (12)$$

Cb: Selling price of the dried product

Batch economy

$$S_b = S_{kg} * M_d \qquad (13)$$

Savings per day

$$S_d = \frac{S_b}{D_b} \quad (14)$$

Annual savings

$$S_J = S_d D(1+i)^{j-1} \qquad (15)$$

2.4. Recovery period

This is the time required for the profits made during drying to recover the cost of the initial investment. It depends on the initial cost of the dryer, the inflation rate (i), the interest rate (d), and the savings made during the first year of operation of the solar dryer (S).

It is defined by the relation (16)[22][23].

$$PR = \frac{ln\left(1-\frac{C_{in}}{S}(d-i)\right)}{ln\left(\frac{1+i}{1+d}\right)} \qquad (6)$$

2.5. Data input

1. Economic data

Quote for manufacturing the dryer

DESIGNATION	TOTAL PRICE ($ USD)
Component	562.09
Workforce	16.09
Transportation	16.09
	594.27

2. Operating costs

PaintingIV-2: Operating data

Description	
Cost of labor (1 person) (FCFA/day)	4.02
Number of drying cycles	100
Duration of a drying cycle (hours)	20
Number of days of operation on a Year (days)	300
Dryer Lifespan (Years)	15 years old
Maintenance fees (FCFA)	1% of the total cost for the first year
Interest rate (%)	6%
Inflation rate (%)	+1%

3. Products

PaintingIV-3: Price of fresh produce

Fresh Products per 1 (kg)	Unit price ($ USD/kg)
Lean fish (Banda)	0.97
Oily fish (Butter)	2.41
Crustaceans	4.02

PaintingIV-4: Price of dried products

Dried products per 1 kg	Price ($ USD)
Lean fish (Banda)	2.41
Oily fish (Butter)	5.63
Crustaceans (shrimp)	13.68

Variation of recovery period depending on the number of days of use

The importance of the utilization rate of the device is represented in figure7. We noticed that the increase in the number of days of use makes it possible to reduce the recovery period of the invested capital. Because, the income generated depends strongly on the quantity of processed products. The more the dryer works, the income willto increaseand will influence the capital recovery period. We also note that the recovery period depends on the different dried products, the drying yield and the added value. We note that oily fish, which has a drying yield of 30% and a high added value, has a short recovery period. This is followed by shrimp, characterized by a low yield (15%) and a high added value, and finally, lean fish with a drying yield of 25% and a low added value for a high recovery period.

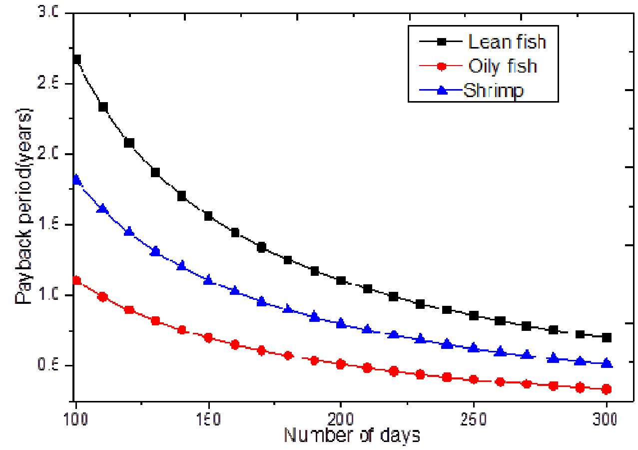


Figure7: Variation of the recovery period depending on the number of days of operation

References

[1] Djebli, A., Hanini, S., Badaoui, O., Haddad, B., Benhamou, A., 2020. Modeling and comparative analysis of solar drying behavior of potatoes". Renew Energy 145, 1494-1506, https://doi.org/10.1016/j.renene.2019.07.083.

[2] Arabhosseini, A., Samimi-Akhijahani, H., Motahayyer, M., 2019. Increasing the energy and exergy efficiencies of a collector using porous and recycling system. Renew. Energy 132, 308–325.

[3] Hegazy, AA, 2000. Comparative study of the performances of four photovoltaic/thermal solar air collectors. Energy Convers. Manag. 41, 861–881.

[4] Esen, H., 2008. Experimental energy and exergy analysis of a double-flow solar air heater having different obstacles on absorber plates. Build. Approximately. 43, 1046–1054.

[5] Daghigh, R., Ruslan, MH, Sulaiman, MY, Sopian, K., 2010. Review of solar assisted heat pump drying systems for agricultural and marine products. Renew. Sustain. Energy Rev. 14, 2564–2579.

[6] Alimohammadi, Z., Samimi Akhijahani, H., Salami, P., 2020. Thermal analysis of a solar dryer equipped with PTSC and PCM using experimental and numerical methods. Soil Energy 201, 157–177. https://doi.org/10.1016/j.solener.2020.02.079

[7] OI Alonge, SOO, 2018. Development and Quality Analysis of a Direct Solar Dryer for Fish.Food and Nutrition Sciences, 9,474-488 doi:10.4236/fns.2018.95037.

[8] Bala, BK, Mondol, MRA, 2001a. Experimental Investigation on Solar Drying of Fish Using Solar Tunnel Dryer. Dry. Technol. 19, 427–436. https://doi.org/10.1081/DRT-100102915

[9] Saveda, MS, Rathore, NS, Singh, P., 2004. Techno-economics of solar tunnel dryer-a case study. J Agric Eng 41, 13–17.

[10] Basunia, MA, Al-Handali, HH, Al-Balushi, MI, Rahman, MS, Mahgoub, O., 2011. Drying of fish sardines in Oman using solar tunnel dryers. J. Agric. Sci. Technol. B 1, 108–114.

[11] Mamadou Lamine Coly1, Bou Counta Mbaye2, Mamadou Seck Gueye1, Babacar Ndiaye3, Joseph Sarr1, A Tunnel mixed solar dryer for the drying of fishery products: design and experimentation, Journal of Scientific and Engineering Research, 2021, 8(2):87-101, ISSN: 2394-2630.

[12] Şevik, S., Aktaş, M., Dolgun, EC, Arslan, E., Tuncer, AD, 2019. Performance analysis of solar and solar-infrared dryer of mint and apple slices using energy-exergy methodology. Ground. Energy 180, 537–549.

[13] Chowdhury, MMI, Bala, BK, Haque, MA, 2011. Energy and exergy analysis of the solar drying of jackfruit leather. Biosystem. Eng. 110, 222–229. https://doi.org/10.1016/j.biosystemseng.2011.08.011

[14] Bennamoun, L., 2012. An Overview on Application of Exergy and Energy for Determination of Solar Drying Efficiency. Int. J. Energy Eng. 2, 184–194. https://doi.org/10.5923/j.ijee.20120205.01

[15] Tuncer, AD, Sözen, A., Khanlari, A., Amini, A., Şirin, C., 2020a. Thermal performance analysis of a quadruple-pass solar air collector assisted pilot-scale greenhouse dryer. Ground. Energy 203, 304–316. https://doi.org/10.1016/j.solener.2020.04.030

[16] Motahayyer, M., Arabhosseini, A., Samimi-Akhijahani, H., 2019. Numerical analysis of thermal performance of a solar dryer and validated with experimental and thermo-graphical data. Ground. Energy 193, 692–705.https://doi.org/10.1016/j.solener.2019.10.001

[17] Dejchanchaiwong, R., Kumar, A., Tekasakul, P., 2019. Performance and economic analysis of natural convection based rubber smoking room for rubber cooperatives in Thailand. Renewable Energy 132, 233–242. https://doi.org/10.1016/j.renene.2018.07.145

[18] Tiwari, AK, Somwanshi, A., 2018. Techno-economic analysis of mini solar distillation plants integrated with reservoir of garden fountain for hot and dry climate of Jodhpur (India). Solar Energy 160, 216–224.

[19] Hossain, MA, Woods, JL, Bala, BK, 2005. Optimization of solar tunnel drier for drying of chilli without color loss. Renewable Energy 30, 729–742. https://doi.org/10.1016/j.renene.2004.01.005

[20] Duffie, JA, Beckman, WA, 2013. Solar Engineering of Thermal Processes. John Wiley & Sons. ISBN 9781118671603 | DOI: 10.1002/9781118671603, Copyright © 2013 John Wiley & Sons, Inc.

[21] ELkhadraoui, A., Kooli, S., Farhat, A., nd Study on effectiveness of mixed mode solar greenhouse dryer for drying of red pepper. International Journal of Scientific Research 4.

[22] Banout, J., Ehl, P., Havlik, J., Lojka, B., Polesny, Z., Verner, V., 2011. Design and performance evaluation of a Double-pass solar drier for drying of red chilli (Capsicum annum L.). Solar Energy 85, 506–515. https://doi.org/10.1016/j.solener.2010.12.017

[23] Mr. Yahyaa,∗, Hendriwan Fahmia, Ahmad Fudholib,∗, Kamaruzzaman Sopian: Performance and economic analyzes on solar-assisted heat pump fluidized bed dryer integrated with furnace biomass for rice dryingSolar Energy 174 (2018) 1058–1067doi.org/10.1016/j.solener.2018.10.002