Nigerian Journal of Technology (NIJOTECH)
Vol. 40, No. 6 November, 2021, pp1104 –1109
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
http://dx.doi.org/10.4314/njt.v40i6.13

Performance Evaluation of Mixed Mode Passive Solar Stock Fish Dryer

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Abstract
The performance evaluation of Mixed-Mode Passive Solar Dryer for drying codfish (Gadusmorhua) was conducted. The dryer is comprised of among other things, materials for sensible heat storage to discharge heat during the off-sunshine period. The drying chamber is integrated with a suction device to aid the convective airflow to avoid reversible reaction during the discharge of accumulated moisture. The solar dryer was evaluated with fresh codfish samples at the initial moisture content of 79% (wet basis). The samples were divided into sets. A set was treated with Moringa Oleifera and the second set with salt solution. The results showed that, for Moringa and salt treatments, the moisture content of the codfish was reduced to 16.03% and 13.33% (wet basis) respectively using the solar dryer while 19.55% and 13.46% respectively under ambient condition in six days. Laboratory tests showed that bacteria and fungi count for Moringa and salt treated codfish under solar dryer were below consumable limits.

Keywords: Solar, Dryer, Fish, Passive

1.0 INTRODUCTION

Among the various factors affecting food production, efficient food preservation has been identified as the major obstacle which if not well done leads to the growth of microbial actions that finally destroy the fresh food stuff like fish. Fish which provides a number of important vitamins and minerals to the diet is an extremely perishable food that becomes inedible within twelve hours at tropical environment [1]. These nutrients include vitamin D, B_{12}, Iron, Potassium and calcium, high in lean protein and low in fats and calories, cod oil high concentration of omega 3-fatty acid. Transporting live fish in tanks on wagons from ponds and lakes to delivery centers requires extra husbandry to keep them alive until ready to be consumed [1]. The cost of husbandry influences the rising cost of fish. Dry salting, open-air sun drying, deep frying and smoking constitute the most common methods of fish processing and preservation for rural fishermen. The last two methods contribute to environmental degradation, since they use biomass, while smoking introduces cancer causing substances in fish flesh [2]. With epileptic and exhaustibility of convectional power supply in addition to abundant solar radiation in the tropics, solar drying is the last resort for fish preservation [3,4].

Several works have been reported on the use of solar dryers to mitigate the limitations of open-air sun drying [5-10]. However, the use of solar drying systems by farmers is still unpopular in Nigeria. The present study is an ongoing work to improve on the efficiency of the passive solar fish drying with the introduction of passive suction fan.

2.0 DESCRIPTION OF THE SOLAR STOCK FISH DRYER

The dryer consists of two compartments: the solar collector/heater and the drying chamber (Figs. 1 and 2). The solar collector is made up of glass cover, absorber plate and heat storage unit with air inlet and outlet at each end while the drying chamber is made up of hot air inlet, fish drying trays and a suction fan at the outlet to aid moisture evacuation. The design considerations for the system are outlined in [11] a technical report submitted to the department of Agricultural and Bioresources Engineering, University of Nigeria, Nsukka.

The flow diagram (Fig. 3) shows the drying process of the solar dryer. Solar radiation strikes the glazing covering the absorber plate and the Perspex (acrylic plastic material) covering the drying chamber. As

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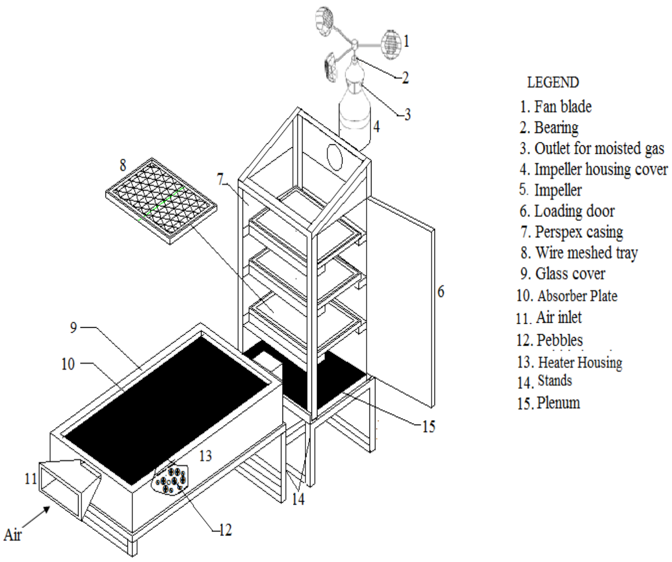

Figure 1: Skeletal Drawing of Mixed Mode Passive Dryer

Figure 2: Fabricated Diagram of Mixed Mode Passive Solar Stock Fish Dryer

the sunlight passes through the glazing and then strikes the absorber plate, which heats up converting solar energy into heat energy. The absorber, the dark surface covering the storage elements (stones) then soaks the thermal mass (heated air stream). The heat is conducted and transferred to storage materials as sensible heat. At the same time the incoming air stream picks up part of the transmitted solar radiation from the transparent glazing material by convection current; the heat laden air passes through the outlet of the heat storage unit into the drying chamber. Also, during the night, when there is no sunshine the inflow air stream by convection current picks the dissipated heat conducted by the absorber plate from the heat storage materials and then transfers it into the plenum to the drying chamber. As the heat laden air passes into the chamber and in contact with the wet solid it picks the vaporized moisture expelled from the fish materials and is evacuated with the aid of suction fan though the outlet. Within the drying chamber, drying undergoes constant drying rate periods and followed by falling rate periods. Constant drying rate propels the moisture generated upwards through the fish material resulting to evaporation at the surface of the upper chamber. This period is followed by the falling rate period which corresponds to the drying cycle where the surface of the fish is no longer wet and the drying front moves inside the fish leading to decreased drying rate. This is because more time and energy will be needed to draw moisture from the internal cells of the fish. The effectiveness of flow of air though the system is enhanced by the outlet duct with fan to improve its energy efficiency. The dryer is a passive type. Although it has fan, but the fan is driven by natural convention instead of external power input.

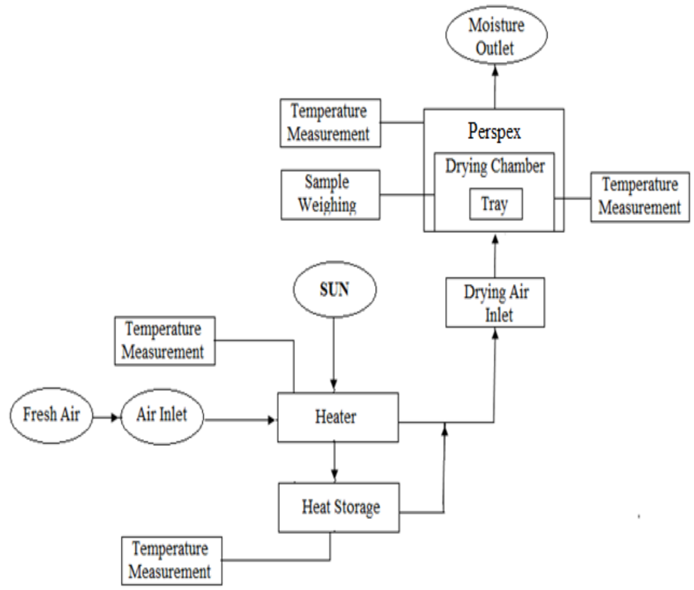

Figure 3: Flow diagram of the drying process

3.0 MATERIALS AND METHODS

Temperatures were recorded with MTM-380SD thermometer monitor made in Taiwan using k type thermocouples wires fixed respectively on the glazing, absorber plate, storage pebbles and drying chamber. The moisture content was determined in the laboratory using oven method before and after drying. The fresh cod fish was procured from Enugu, eviscerated, thoroughly washed, its heads removed, split open longitudinally, either treated with *Moringa Oleifera* or salted and weighed using digital balance. Each set was again divided into two for the solar dryer and open sun drying (Figs. 4 and 5), the weight loss which was assumed to be only moisture loss was monitored periodically by weighing the samples until the weight was constant. After drying, the total bacterial count (TBC) and total fungal count (TFC) of the samples were determined using spread plate technique.

Figure 4: Vertical Loading of the Solar Drying

Figure 5: Sun Drying of Stock fish by Hanging

The overall thermal efficiency, η of the dryer was computed using the following expression [12]:

$$\eta = \frac{\lambda \sum_{t=1}^{24} M_{ev}(t)}{3600 \sum_{t=1}^{24} I\,(t)} \quad (1)$$

where

M_{ev}, λ *and* I *are* the hourly rate of moisture evaporated from fish, the latent heat of vaporisation per unit mass, and solar irradiance on an inclined plane

4.0 RESULTS AND DISCUSSION

Table 1 shows the mean temperature profile of the dryer. The ambient temperatures were lowest at all times during the study. The drying chamber temperature being higher even at nights is a clear indication of the positive effect of thermal storage unit of the dryer on the drying operation. Hence, drying continues even after sunset.

Table 1: Day and Night Time Average Temperatures of the Stock fish Solar Dryer

	Daytime Temps	Night time Temp
Ambient temp	30°C	26°C
Glazing temp	57°C	25°C
Absorber plate temp	72°C	28°C
Heat Storage temp	48°C	29°C
Drying Chamber	68°C	28°C

4.1 Moisture Content of Fresh Cod

The initial moisture content of the fish from oven method analysis was 76.6%. In treating the cod with *Moringa Oleifera* and drying under the two conditions – solar and the open sun drying, it was observed that there was significant difference between the dryer and the open sun drying with moisture drop from 79.67% to 16.03% and 19.55% respectively (Fig. 6). These results were gotten after six days of drying when the moisture content reached its equilibrium level. This further showed that drying with the solar dryer gave better result with about 3.52% difference to open sun drying.

The results showed that the sun drying was initially faster and later overtaken by the solar dryer. This is due to the fact that the evaluation was done during harmattan period of late December. This resulted in high wind pressure which aided the open sun drying system. That was possible because it is of note heat and wind pressure are responsible for drying. This led to the open sun drying attaining early equilibrium moisture content due to lower air temperature and higher wind speed. However, the solar dryer with higher air temperatures continued drying beyond the equilibrium moisture content of open sun system leading to a better dried stock fish.

The moisture content of salt treated cod fish under the two conditions – solar and the open sun drying were 13.33% and 13.46% respectively. These values showed that treating the cod fish with salt resulted in better drying than with *Moringa Oleifera*. That was because salt been hygroscopic in nature acted like drying enhancer. The chemistry was that there was salt deposit which created osmotic effect that enabled it to absorb the moisture out of

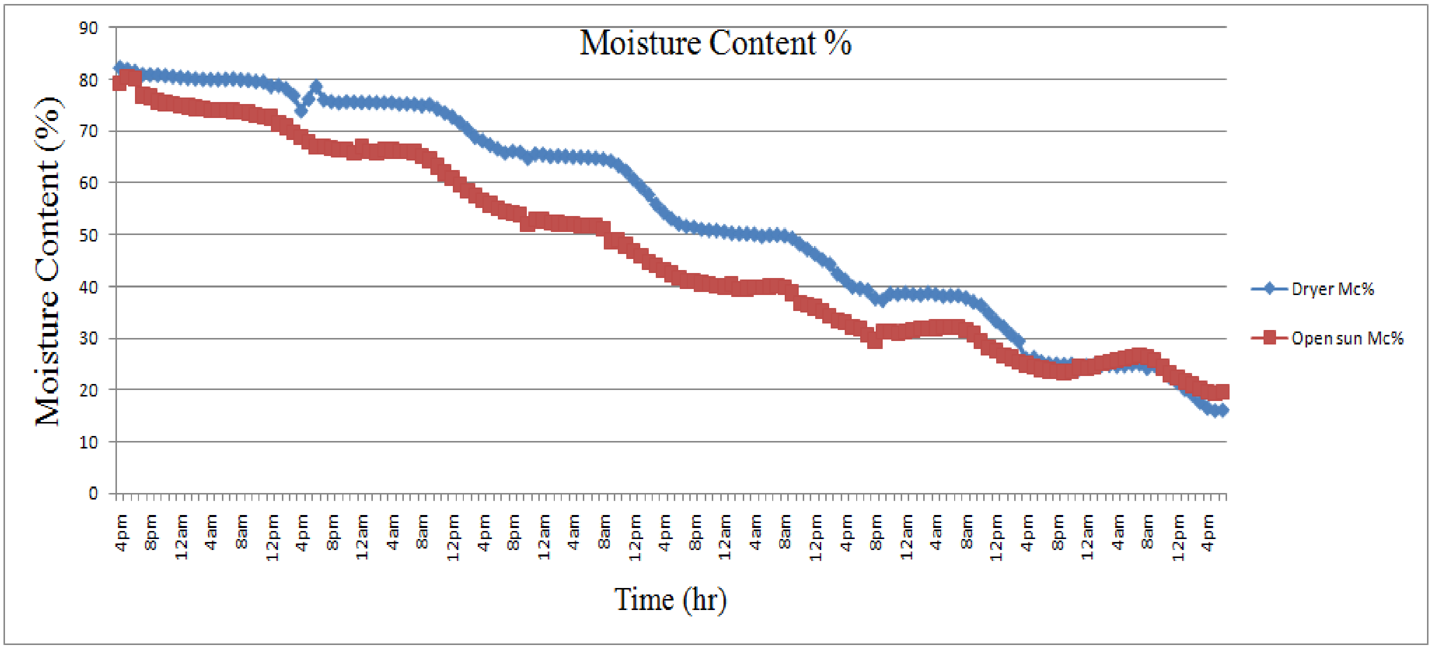

Figure 6: Moisture Drop *MoringaOleifera* Treated Cod between the Open Sun Drying and Dryer

the fish. This result is in agreement with literature as observed by [1], who compared drying rates of brined (that is, salted) and spiced *Clariasgariepinus* (Catfish) using solar dryer. The result revealed that catfish dried using brine solution only is the best since its drying rate constant has the highest value of 0.375 units per day followed by ginger (0.273 units per day) and then garlic (0.254 units per day) is the least. The results also show that spicing with ginger and garlic reduced the drying rate of catfish when dried in a passive solar dryer. Again, comparing the salted fish under the solar dryer and open sun drying, there was noticeable slight difference of 0.13% which was insignificant.

The overall efficiency of the dryer was calculated using equation 1 to be 29.22%. The efficiency of a solar dryer is dependent upon the air flow rate, the radiation generated, the period of drying and the loading nature of the system [13]. No doubt, 29.22% was quite low because the experiment was carried out in April, exactly when the rainy season had started in earnest at Nsukka. The atmosphere was expected to be saturated which made the relative humidity to be equally high. The above-mentioned efficiency was bound to increase or decrease due to the unsteady changes of the climatic factors like the wind speed, solar radiation, ambient temperature and relative humidity.

However, these peak efficiencies are welcomed development when compared to a peak efficiency of 17 – 22% for single cover systems as obtained in the literature [14,15].

4.2 Microbial Analysis

Table 2 showed the result of the microbial analysis of the dried cod fish. While Table 3 showed the guidelines for interpretation of results of microbiological analysis of foods prepared for human consumption [16]

Table 2: Effects of *MoringaOleifera*and Salt Treatments on Stock fish

	*MoringaOleifera*Treatement Microbial Load (Counts)	Salt Treatment Microbial Load (Counts)	Non – Salted Microbial Load (Counts)
Solar Dryer	Bacillus - 1.09×10^5	Staphylococcus - 2.9×10^4 Mould - 1.0×10^3	Staphylococcus - 5.9×10^4 Mould - 1.0×10^3 Bacillus - 9.68×10^5 Coliform - 3.0×10^3
Open Sun Drying	Bacillus - 5.0×10^3 Coliform - 1.1×10^4	Staphylococcus - 1.48×10^4 Coliform - 1.2×10^3	Staphylococcus - 1.58×10^5 Bacillus - 2.35×10^5

Table 3: Guidelines for the Interpretation of Results of Microbiological Testing of Ready-to-Eat Foods Placed on the Market

Organism	Microbiological Quality Colony-forming unit (cfu/g) Satisfactory	Borderline	Unsatisfactory Potentially Hazardous
Standard Plate Count			
Level 1	$< 10^4$	$< 10^5$	$< 10^6$
Level 2	$< 10^6$	$< 10^7$	$< 10^7$
Level 3	N/A	N/A	N/A
Indicator			
*Enterobacteriaceae**	$<10^2$	10^2 - 10^4	$\geq 10^4$
Escherichia coli	<20	20 - <100	> 100
Pathogens			
Bacillus cereus and other pathogenic *Bacillus* spp.	$<10^3$	10^3- $\leq 10^5$	$>10^5$
Staphylococcus aureus	< 20	20 - $<10^4$	$>10^4$

Source [16]

It was observed that with solar dryer, there was no traces of *Staphylococcus*, mould, and coliform in stock fish treated with *Moringa Oleifera* solution but there was presence of *Bacillus* with higher bacteria load count of 1.09 x 10^5compared with open sun drying 5.0 x 10^3. With the same treatment, the open sun drying could not control coliform. This might be because the solar dryer produced more heat that prohibited the growth of coliform. This is in agreement with the the works of Eze et al who used solar still to reduce high total coliform count of 10 cfu/ml (of Lagos bar-beach water) which is far above acceptable maximum to zero coliform count.

Therefore *Moringa Oleifera* being an antioxidant could control staphylococcus effectively other than salt and non salt treatments.

Considering the bacteria load/counts on the table which were categorized as Satisfactory, Marginal and Unsatisfactory or potentially hazardous with exponentials: $<10^2$, 10^3- $\leq 10^5$ and $>10^5$ respectively indicated that the stock fish with bacteria count $<10^2$ would be satisfactory and consumable. The load with 10^3- $\leq 10^5$ was within the borderline or managerial and therefore could be consumed while the load with $>10^5$ would be unsatisfactory or hazardous and should not be consumed to avoid endangering the health. The tabled results showed that for health-wise the bacteria loads were within the marginal or consumable range of 10^3 – 10^5 (10^3 – $10^5 \leq 10^5$). To achieve the satisfactory level, stock fish handling controls and hygiene practices should be adequate.

5.0 CONCLUSION

The performance evaluation of the mixed mode passive solar stock fish dryer showed that the solar stock fish dryer performed better than open sun drying in-terms of drying rate and quality of the dried materials. Drying processes were continuous even during off-sunshine periods while open sun drying stopped drying operation immediately the sun sets. Treating fresh cod with *moringaoleifera* an antioxidant during drying was hygienic and was able to reduce many bacteria accounts to an acceptable level good for consumption of the fish and at the same time improve the nutritive and medicinal quality of the cod. Drying with solar dryer offers hygienic and protection against dust, rodents and flies' infestations, ravens and kites hovering all over drying samples while open sun drying was guarded against these deteriorating factors for successful drying operations. Utilization of solar drying system in stock fish drying could save a country like Nigeria huge sum of money. Presently, Nigeria imports stock fish from Norway at an estimated amount of 20 billion naira annually.

REFERENCES

[1] Oparaku, N. and Ojike, O. "Studies on drying rates of brined and spiced *Clariasgariepinus* (Catfish)

using solar dryer", *International Journal of Physical Sciences*, 8(30), 2013, pp. 1551 – 1557.

[2] Delgado, J., Martinez, L. M., Sanchez, T. T., Ramirez, A., Iturria, C. and Gonzalez- Avila, G. "Lung Cancer Pathogenesis Associated with Wood Smoke Exposure*", Chest*, 128, 2005, pp 124-131.

[3] Uzodinma, E. O., Ojike, O., Etoamaihe, U. J. and Okonkwo, W.I. "Performance study of a solar poultry egg incubator with phase change heat storage subsystem", *Case Studies in Thermal Engineering*, 18, 2020, https://doi.org/10.1016/j.csite.2020.100593.

[4] Eze, J. I. and Ojike, O. "Studies on the effect of different solar dryers on the vitamin content of tomato (Solanum lycopersicon)*", Journal of Renewable and Sustainable Energy*. 4, 063102, 2012.

[5] Ojike, O. and Okonkwo, W. I. "Study of a passive solar air heater using palm oil and paraffin as storage media", *Case Studies in Thermal Engineering*, 14, 2019.

[6] Ugwu, S. N., Ojike, O., Okonkwo, W. I., Okafor, E., Ugwuishiwu, B. O. and Echiegu, E. A. "Evaluation studies of a mixed mode solar kiln with Phase change material and distributed-type solar kiln", *Case Studies in Thermal Engineering,* 22, 2020, 100748.

[7] Balasuadhakar, A. Fisseha, T., Atenafu, A. and Bino, B. "A Review on Passive Solar Dryers for Agricultural Products" *International Journal for Innovative Research in Science & Technology*, 3(1), 2016, pp 64- 70.

[8] Stephen, T. K. *Design and evaluation of solar maize grain dryer with a back-up heater*, A thesis submitted to Department of Environmental and Biosystems Engineering, University of Nairobi, 2016.

[9] Ojike, O., Nwoke, O.O. and Okonkwo, W. I. "The influence of different solar drying systems on the vitamin content of Pawpaw (*Carica papaya*)", *Australian J agricultural engineering*, 2(1), 2011, pp 8-11.

[10] Eze, J. I. and Ojike, O. "Analysis of thermal efficiency of a passive solar water heater", *International Journal of Physical Sciences*, 7(22), pp. 2891-2896.

[11] Udeinya, B. C. *Development and performance evaluation of mixed mode passive solar stock fish dryer,* M.Eng. project report, Dept. of Agric. and Bior. Eng'g, University of Nigeria, Nsukka, 2018.

[12] Pigott, G. M. and Singh, R. P. Fish Processing. Encyclopædia Britannica *Encyclopædia Britannica Ultimate Reference Suite*, 2015, Chicago.

[13] Ojike, O. "Characterization of a Flat Plate Double Glazed Solar Collector", *Continental J. Renewable Energy*, 2(2), 2011, pp 10 – 18.

[14] Enibe, S. O. "Performance of a natural circulation solar air heating system with phase change material energy storage", *Renewable Energy 27*, 2002, pp 69-86.

[15] Enibe, S. O. "Thermal analysis of a natural circulation solar air heater with phase change material energy storage", *Renewable Energy*, 28, 2003, pp 2269–2299.

[16] Health Protection Agency (HPA, 2016) Guidelines for Assessing the Microbiological Safety of Ready-to-Eat Foods Placed on the Market. Guidance Note 3: Food Safety Authority of Ireland. Accessed on Jan. 17th 2018.