THERMODYNAMIC EVALUATION OF A LOW-PRESSURE FISH DRYER

[1*]Ola I. A., Agu C. I., [1]Olayanju T. M. A., [1]Tomori O. T., [1]Adenipekun T. S., [2]Afolabi O. and [1]Ajisegiri E. S. A.

[1]*Department of Agriculture and Bio-Resources Engineering, College of Engineering. Federal University of Agriculture, Abeokuta, Nigeria.*
[2]*Department of Physics Obafemi Awolowo University Ile-Ife, Osun, Nigeria.*
* *olaia@funaab.edu.ng (corresponding author).*

ABSTRACT

Fish products are major sources protein supplements for human nourishment composing of low - fat diet cherished by consumers for health wise consequence. Quite substantial amount of this products during harvest cum handling are lost to spoilage due to lack of short time drying technology systems and untimely removal of moisture content amidst activities of bacteria. The inappropriate and inadequate processing methods must be eliminated by providing advance short time drying outfits to assist the local processors to stall the activities of bacteria orchestrating fish spoilage. To meet this short time drying needs and increase fish storability and shelf life for overall good productivity, an indigenous affordable vacuum dryer was conceived and developed locally. The unit was fabricated using locally sourced materials and was tested on water cans and cat fish samples. A constant vacuum head of 3.6 KPa was attained at pumping rate of 320 l/hr, at observed temperature range of 38 and 42°C, energy and power level of 498.6 KJ and 13.6W with an effective moisture diffusivity $8.41\times10^{-7}m^2/s$ and $2.05\times10^{-7}m^2/s$ were recorded for the fish samples; gutted and un-gutted respectively dried within 10 hours. Total moisture content removal efficiency of 85% was attained This method of drying was very effective in drying the fish samples but still requires further optimization studies to scale up the unit for commercial purpose.

Keywords: *Vacuum, Low-Pressure, Fish, Dryer, Diffusivity*

INTRODUCTION

The dynamics of fish drying using ample technologies readily available in the industry at the cottage level would be an added advantage to the timely processing of fish products to a stable storable form. This would enhance the marketability of fish products as well as improve the quality of products and overall reduction of losses experienced at post harvesting stage of fish production. Fish consumption provides the highest source of protein, vitamins and minerals with the lowest fat content food item for over 250 million people around the world. Health wise (HW) fish consumption is advantageous to consumers as reiterated in (FAO (2010).

Yearly losses of fish product were estimated to be 10 to 12 million tons (FAO (2010). This creates high demand of fish products which in turn affects the cost and makes it unreachable to peasant consumers and children all over the world. Due to its extremely perishable nature (Clucas,1975), drying it requires instant processing within twelve hours else spoilage set in. Drying fish is essential to prevent bacteria growth. Fish are known to consist 80% moisture content and a reduction to around 25%, would prevent bacteria growth while a further drying to 15% or less would disallow mold formation (Clucas,1982). Among the various methods preservation such as; salting, drying or tray batch smoke screens which may entail; application of hot air, indirect or contact drying, dielectric drying, freeze drying (Fernanda de *et al* 2021, Viji *et al* 2019, Mehmet *et al* 2015 and Jianzhen *et al* 2019), supercritical drying other than natural air drying, the low-pressure drying was investigated here using a readily available vacuum drier sought locally. The feasibility of this locally made indigenous drier was investigated for possible means of adoption by stakeholders over all other methods of fish preservation in the region.

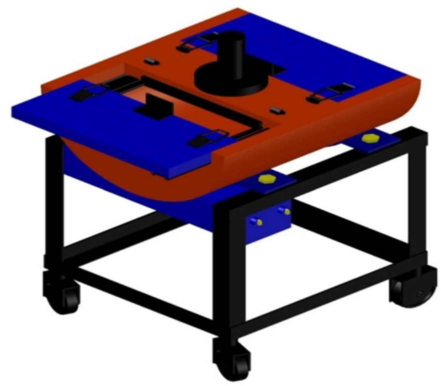
Additionally, the use of improper methods of drying might increase the risk of fish infestation and food poisoning hence the need to explore a new frontier of technology in fish drying and preservation.

OPERATION OF THE LOW-PRESSURE DRYER

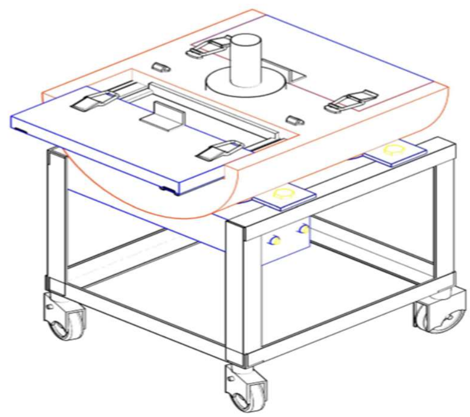
A low scale fish dryer shown in Figure 1 whose working principle is based on creation of low vacuum head initiated by high suction head of a wet vacuum motor was developed Ola et al 2019. The suction motor creates a vacuum head as it operates at a very high average speed of 24,000 rpm. This creates the suction of air molecules in the cabinet containing the fish being dried. The suction of air molecules in the cabinet by vacuum, initiates the outward movement of water molecules within the cells of the fish samples and boiling it up at room temperature. To control the temperature and maintain a steady state of the vacuuming for uniformity of drying, a thermocouple pre-set to a temperature of 42^{o}C was connected as temperature sensor and regulator. An electric heater of 350 Watt was also included to fast track the drying time.

Theoretical background

The equations given in **Table 1** were equations used in design of the drier. It expresses the important parameters of evaluation in the study of the performance of the low-pressure drier;



(a)



(b)

Figure 1: Low-pressure fish dryer (a) rendered View (b) Isometric view Adapted from Ola *et al.,* 2019.

MATERIALS AND METHODS

The low vacuum dryer shown in Figure 2.was evaluated to determine the drying efficiency as well as modeling the drying time cum moisture content removal curve of two different scenarios. The first test of the unit was done using water cans of known weight and the unit was used to obtain data for the curve. The second test was the real time test using catfish samples to obtain the second data for the plot. The instrument used to monitor and regulate the cabinet temperature was a thermocouple set to control a 200-watt heating element and a vacuum pump of1100watts with a suction head of 350l/hr.

TABLE 1 DESIGN EQUTIONS FOR MACHINE PARTS SPECIFICATION

S/N	PHENOMINA	MODEL	RELATED MACHINE PARTS	SOURCE
1	Water removal	$M_w = \frac{hA(T_a - T_w)t}{h_{fg}}$	Drying Cabinet	Holman 1997
2.	Energy heat transfer	Q=MC $\Delta\theta$	Heater	Stainless, Outer Casing Made Of Mild Steel
3	**Moisture diffusivity**	$\left(\frac{\Pi^2 D_{eff}}{4L^2}\right)$ $\ln(MR) = \ln\left(\frac{8}{\Pi^2}\right) - \left(\frac{\Pi^2 D_{eff}}{4L^2}\right.$	Drying Chamber	Sarimeseli,2011 & Al-Harahsheh *et al.*, 2009
4	Energy required to de-gas the chamber	$E = P_O V \left[1 - e^{\frac{-st}{v}}\right]$	Drying Chamber	
5	Thickness of drying chamber	$\boldsymbol{\sigma_t} = \frac{\boldsymbol{PD}}{\boldsymbol{2t}}$	Drying Chamber	Khurmi et al 2005 -

A sensitive weighing balance was used to monitor the weight difference of the dried fish samples intermittently as the drying time proceeds. Samples of cat fish used in the evaluation of the drier were obtained in Osiele Market, Abeokuta environ Nigeria. The samples were prepared with the gut removed. The physical properties; fish weight and size of the samples were determined before and after drying. These dimensional details of the fish samples measured were the height, length, width and weight. During the drying process a constant vacuum head of 3.6 KPa was maintained with the aid of thermocouple that controls vacuum pump and temperature. The drier was operated in this manner for 10 hours when there was no change in weights of fish samples being dried. The difference in weight was observed every thirty minutes interval throughout the 10 hours of drying with temperature varying from 38 to 43^o C.

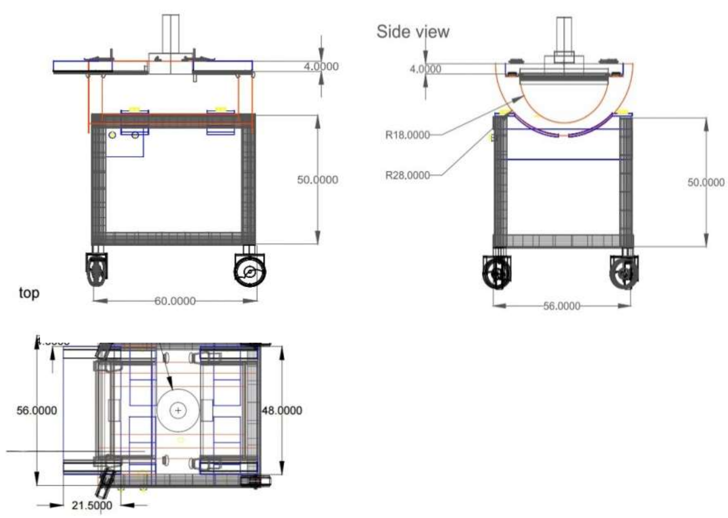


Figure 2 Orthographic Projection of the low-pressure drier Ola *et al.,* 2019.

RESULT AND DISCUSSION

The initial average weight, length, breath and width of fishes dried were observed to be 0.76g, 45.5, 6.5 and 4.3 cm respectively. The change in weight of both the water can and fish samples being dried at vacuum suction head of 350l/hr and temperature range of 38 to 42^{0}C is shown in Tables 2 and 3. Figures 3 and 4 also show the rate of weight reduction to the drying time.

Table 2 Change in weights of water can samples under 350l/hr vacuum suction head

TIME (mins)	SPICIMEN A	SPICIMEN B	SPICIMEN C
0	29.25	34.76	25.96
60	17.74	16.61	12.09
120	11.24	10.39	7.92
180	8.11	7.98	5.78

Table 3 Change in weights of dried fish samples under 350l/hr vacuum suction head

Time	**Temperature**	**weight of gutted(g)**	**weight of ungutted(g)**	**Drying rate of gutted(kg/min)X 10^{-3}**	**Drying rate of ungutted (kg/min)X 10^{-3}**
0	38	0.77	0.74	0	0
30	41	0.67	0.64	3	3.3
60	42	0.55	0.6	4	1.3
90	39	0.53	0.58	0.67	0.67
120	39	0.51	0.58	0.67	0
150	39	0.5	0.57	0.33	0.33
180	39	0.48	0.57	0.67	0
210	38	0.46	0.56	0.67	0.33
240	38	0.45	0.56	0.33	0
270	42	0.44	0.55	0.33	0.33
300	41	0.42	0.54	0.67	0.33
330	41	0.39	0.53	1	0.33
360	42	0.38	0.52	0.33	0.33
390	42	0.37	0.52	0.33	0
420	42	0.35	0.51	0.67	0.33
450	42	0.34	0.51	0.33	0
480	38	0.32	0.5	0.67	0.33
510	39	0.31	0.5	0.33	0.33
540	41	0.28	0.49	1	0.33
570	41	0.25	0.49	1	0.33
600	42	0.25	0.48	0	0

The reduction in weights of the water in the cans as the drying time commences showed a consistent water removal rate as given in the plots and model derived as shown in Figure 3. For all the samples subjected to vacuum drying,0.72 %, 0.77% and 0.78% reduction in weights over 3 hours of drying were obtained for specimens A,B and C respectively. These results showed a consistent favorable drying characteristic of the indigenously made vacuum dryer which was found feasible to dry fish samples. The reduction in weights of fish samples dried; gutted and un-gutted samples shown in Figure 4 gives a consistent drying trend obtainable using the same drier. For the fish samples dried, the longer time of 10 hours was observed to be the threshold value for obtaining perfect dried samples.

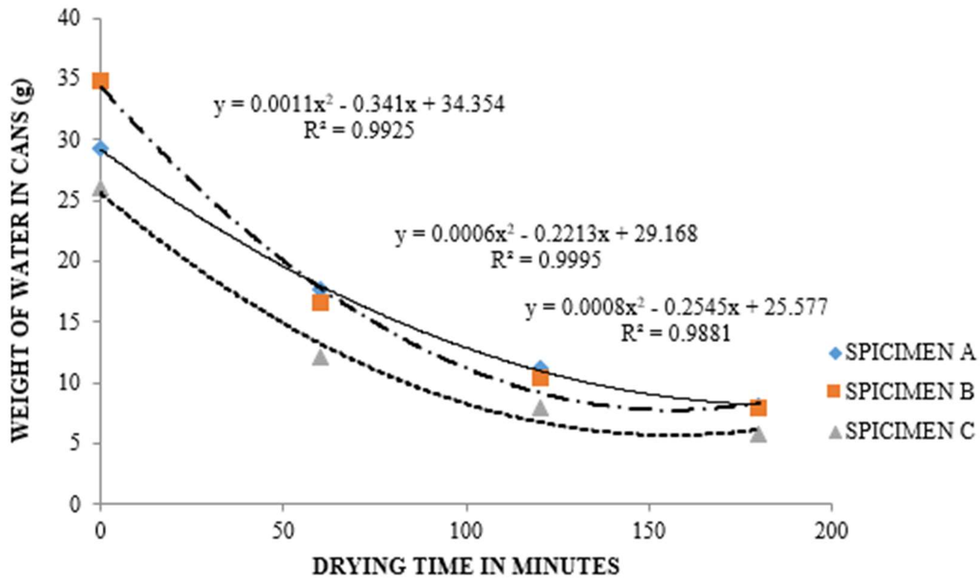


Figure 3: Reduction in weight of water in cans with respect to time under 3590l/hr vacuum suction head

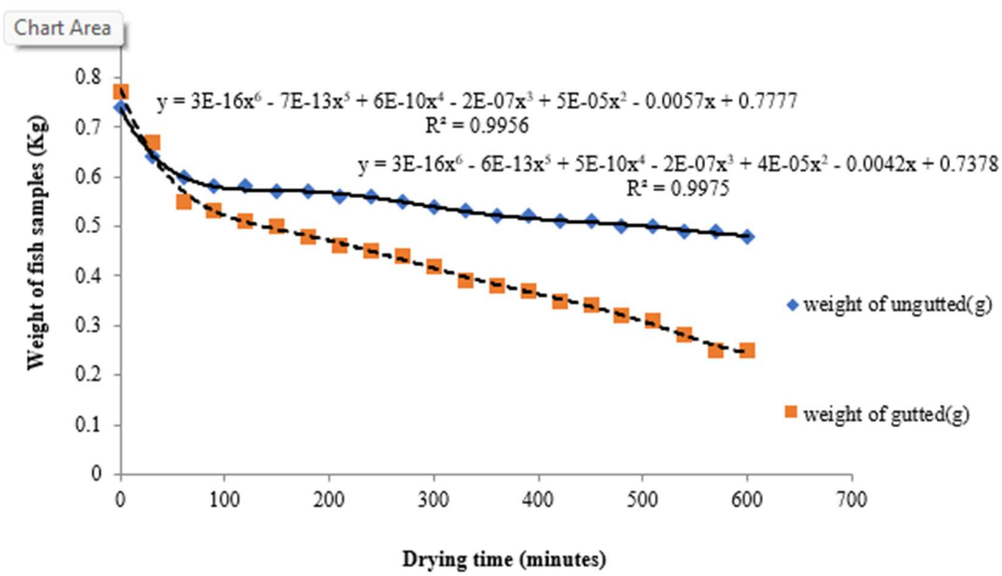


Figure 4: Weight reduction in response to drying time as driven by vacuum pump suction head of 350l/hr at average temperature of 40.3^{0}C.

The time for obtaining the water reduction in the can was 3.3 hours. This lower duration of time observed here is allotted to the fact that, in the initial experiment, the water molecules in the cans water were not migrating by diffusion but by pure evaporation from water surface hence this reduces the time it takes for water molecules to be removed from the cans. For the fish samples, water molecules migrate by diffusion from the inner tissues of the fish to the outer cell surface before it is removed by evaporation hence the restrictions observed leading to the longer time of drying. This is also illustrated by the results of the two mode of fish samples being dried. The gutted fish samples showed more removal of water molecules over the un-gutted samples at the same drying conditions as shown in Figure 4. This is due to the fact that the gutted fish samples cells were broken and have more surface exposure for water molecules to easily migrate with less restrictions from inner cell to the surface, hence better dried samples were obtained. This indicates that the more exposed surface area of fish being dried the more faster water molecules are removed from the exposed surface and the lesser time it takes to dry the fish sample.

Further analysis of the moisture content removed from the water cans and fishes were obtained from Tables 2 and 3 were used to plot the moisture ratio of the drying time as given in Figures 5 and 6. Subsequent analysis of this data was made to obtain the values of the moisture diffusivity of the water cans and fishes dried, This was done to generate the values natural logarithm of the moisture ratio plotted against the drying time for the sets of data to obtain Figures 7 and 8.The slope of Figure 7 and 8 was obtained to calculate the value of effective moisture diffusivity using equation 3a in Table 1.

The drying rate of the gutted sample A was higher than that of the ungutted sample B. The energy and power required for this operation was approximately 579 kJ and 16 watt respectively. The average moisture content removed from the samples was 67.5% dry basis for the gutted fish. The total moisture content removed for the un-gutted fish was0.35%. This value of moisture removed un-gutted fish resulted in its spoilage over time. The drier was observed best suited for drying gutted fish at 10 hours of drying. To reach the same level of dryness as the gutted fish, more additional hours is required to dry the un-gutted fish.

The effective moisture diffusivity a value of $8.41 \times 10^{-7} m^2/s$ and $2.05 \times 10^{-7} m^2/s$ for gutted and un-gutted fish samples.

Determining the value of diffusivity for the water cans, which are purely inter-molecules cohesion restriction of water taken up by the drier a value of $3.71 \times 10^{-6} m^2/s$. comparing this value to that of gutted and un-gutted fish sampless it can be deduced the tissue cell restriction 77% and 94.% of water molecule flow and this even buttressed by the percentage time ratio of the drying time of the two experiment. The percentage flow water restriction in later showed that there is steep restriction of moisture from ungutted fish samples as also indicated in the plots Figure 4, 6 and 8. An overall drying efficiency of 85% was also obtained using this unit.

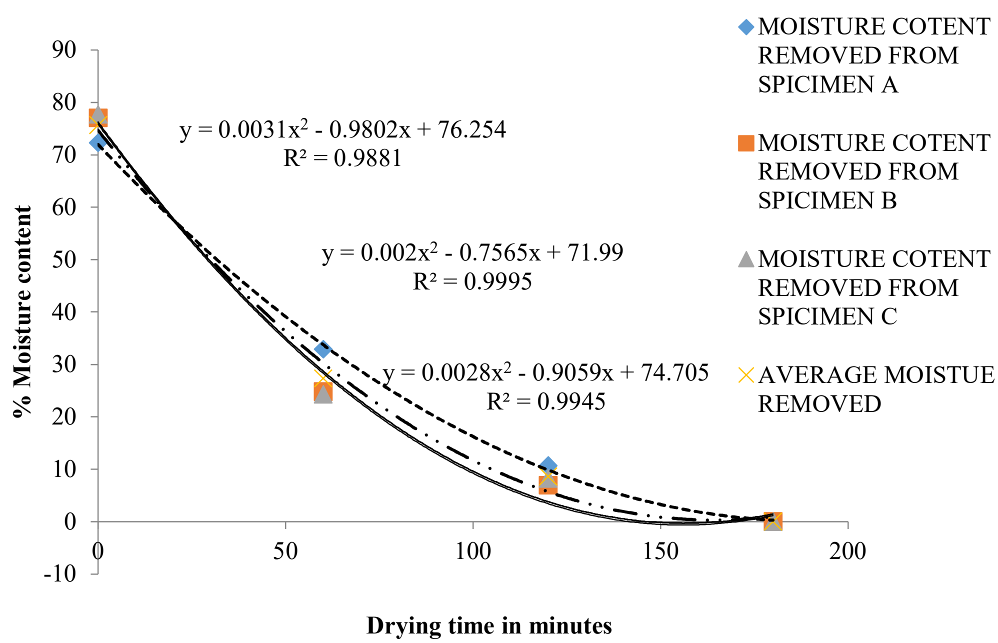


Figure 5: Moisture content curve in response to drying time as driven by vacuum pump suction head of 350l/hr at average temperature of 40.3^{0}C

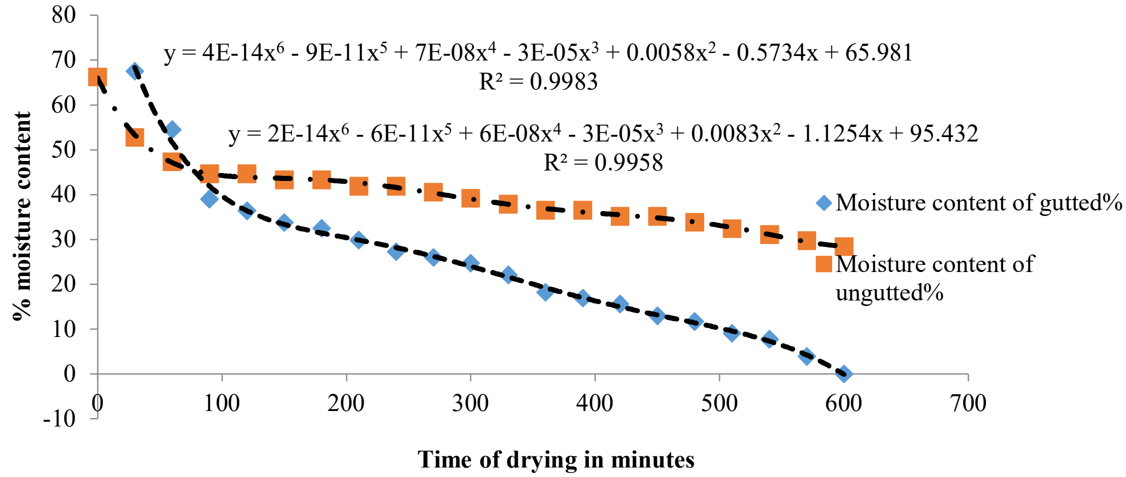


Figure 6: Moisture content reduction curve in response to drying time as driven by vacuum pump suction head of 350l/hr at average temperature of 40.3^0C.

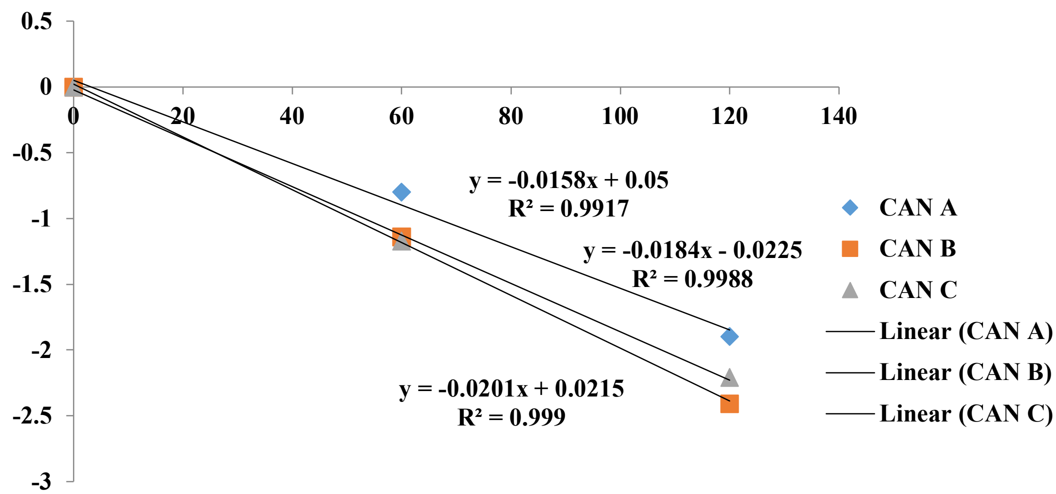


Figure 7: Plot of natural logarithm of moisture ratio against time of drying

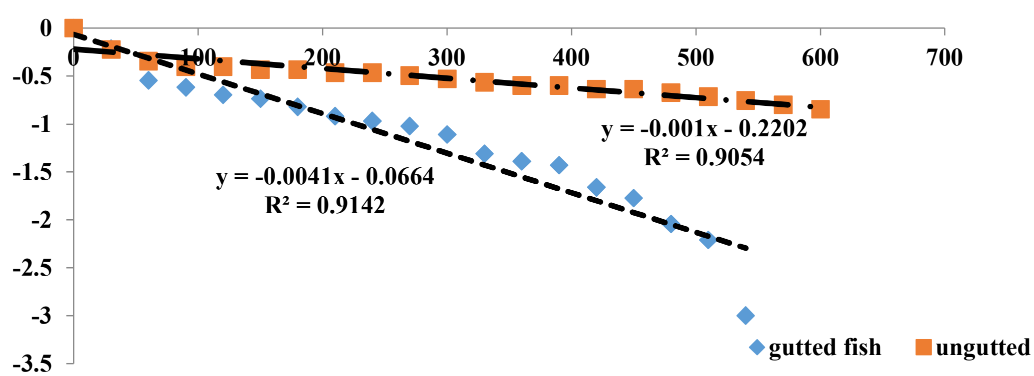


Figure 8 Plot of natural logarithm of moisture ratio against time of drying

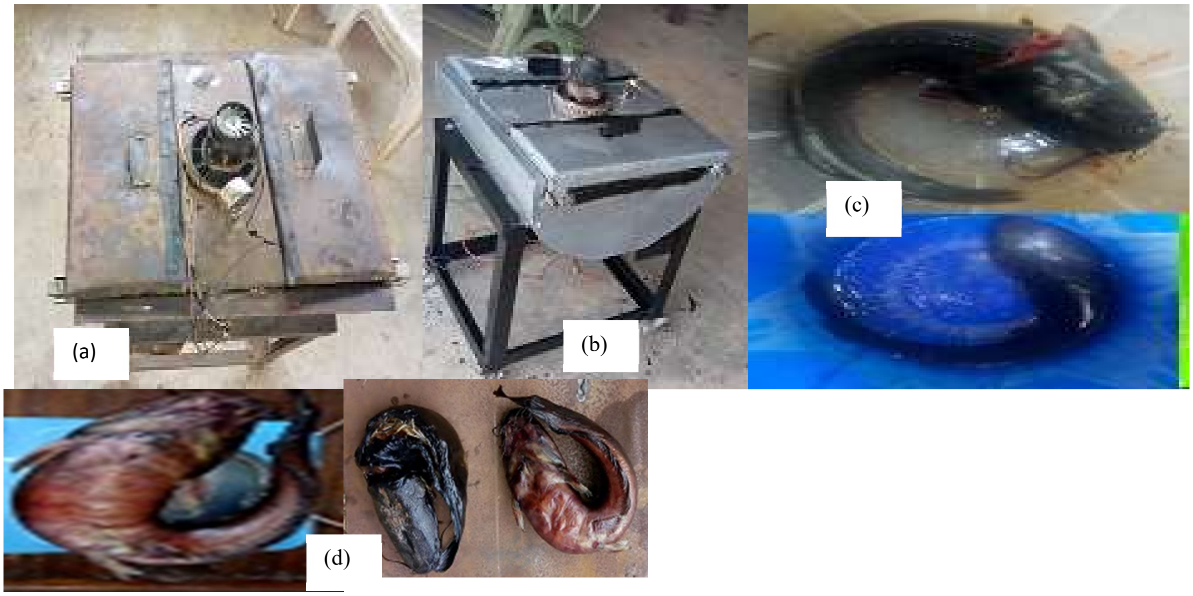


Plate 1: (a) Aerial view of the vacuum drier, (b) Isometric view of the drier, (c) fresh cat fish samples, (d) Dried cat fish samples Adapted from Ola *et al* 2019.

CONCLUSIONS

The vacuum drying unit was able to dry the fish gutted samples within 10 hours at a throughput drying of 84.4% moisture removal efficiency. For the un-gutted fish more hours of drying above 10 hours is required to prevent spoilage. The reduction in time of removal of water molecules in the water cans, less by 7 hours difference, illustrate the simple effect and advantage of increased surface area of sample exposure to drying. More also, 77% and 94 % effect of cell water flow restriction were observed for both gutted and ungutted fish samples as compared to the water cans which had no such cell restrictionsm is an indicator that surface exposure and cell characteristic of product being dried is an important factor affecting the drying time and energy required. There is need to optimize this method which would be of great value for fish farmers in preserving their fish harvest on time to have a good market value without the threat of spoilage of fish products. This drying method gives a better way which could be adopted if it is optimized in future research work in this area.

1. REFERENCES

Adebowale B.A., Dongo L.N., Jayeola C.O., Orisajo S.B. (2008) Comparative quality assessment of fish (Clarias gariepnius) smoked with cocoa pod husk and three other different smoking materials. Journal of Food Technology. 6: 5-8.

Baird-Parker T.C. (2000) The Production of Microbiologically Safe and Stable Foods. The Microbiological Safety and Quality of Food, Aspen Publishers. Gaithersburg. USA. pp: 3-18.

Cengel,Y.A, and Michael A. Boles 2006.Thermodynamics: An Engineering approach

Clucas I.J. 1975. Fish spoilage and general introduction to preservation. Food and agricultural organization of the united nations/Swedish international dev. Authority seminal on planning and implementation of utilization of programs in Africa.

Clucas.I.J. 1982.fish handling, preservation and processing in the tropics. part2 report of tropical institute.

David E. and Whitfield V. (2000), Solar Dryer Systems and the Internet: Important Resources to Improve Food Preparation, Retrieved February 27, 2011, from http://solarcooking.org/drying/Whitfield-drying1.html

Earle R.L. 1983 Unit operation in food processing

FAO (2010) Fisheries and aquaculture topics: Food security and fisheries. Topics Fact Sheets. Text by Peter Manning. Fisheries and Aquaculture Department, Rome.

Fernanda de M. R., Vivaldo S. J, and Ana S P. 2021 Impact of vacuum spray drying on encapsulation of fish oil: Oxidative stability and encapsulation efficiency. Food Research International, Volume 143, May 2021, https://doi.org/10.1016/j.foodres.2021.110283 Elsevier

Fraser O, Sumar S (1998) Compositional changes and spoilage in fish. Nutr. Food Sci. 5: 275-279.

Holman J.P. (1997), Heat Transfer 8th edition, p. 479, New York: McGraw-Hill, Inc

Jianzhen N., Binfan Z.,Xiujin G., and Tao Y. 2019 Effects of vacuum freeze-drying and vacuum spray-drying on biochemical properties and functionalities of myofibrillar proteins from silver carp Journal of Food Quality Volume 2019 | Article ID 9457835 | https://doi.org/10.1155/2019/9457835 HIndawi Pub.

Joseph H. Keenan, Frederick G. Keyes, Phillip G. Hill, & Joan G. Moore, (1992), steam tables: Thermodynamic Properties of Water Including Vapor, Liquid, and Solid Phases, Malabar Florida: Krieger Publishing Company

Khurmi R.S. and J.K.Gupta.2005. Machine Design.

Mehmet B., Mahmut K. and Barış Y. 2015 Dehydration kinetics of salmon and trout fillets using ultrasonic vacuum drying as a novel technique ***Ultrasonics Sonochemistry*** Volume 27, November 2015, Pages 495-502 https://doi.org/10.1016/j.ultsonch.2015.06.018

Ola I.A, Agu C.I. and Ajisegiri E.S.A 2019 Development of a low-pressure fish dryer *International Journal of Biological Research and Development* (IJBRD) ISSN (P): 2250-0022; ISSN (E): Applied Vol. 9, Issue 1, Jun 2019, 1-8 © TJPRC Pvt. Ltd.

Viji P., Sumanth Y. M., Jesmi D.. Madhusudana R. B 2019 Effects of microwave vacuum drying and conventional drying methods on the physicochemical and microstructural properties of squid shreds. Journal of the Science of Food and Agriculture First published: 04 June 2019 Volume 99, Issue 13 p. 5778-5783 https://doi.org/10.1002/jsfa.9846