International Journal of Engineering Applied Sciences and Technology, 2022
Vol. 7, Issue 7, ISSN No. 2455-2143, Pages 207-213
Published Online November 2022 in IJEAST (http://www.ijeast.com)

MODELING AND SIMULATION OFCHARCOAL FIRED FISH SMOKING PROCESS USING MATLAB SOFTWARE

Ibrahim Shuaibu, Ibrahim Saidu Sintali, Adekunle Moshood Abioye, Sunusi Jamil Alaramma
Department of Mechanical/Production Engineering,
Abubakar Tafawa Balewa University, Bauchi, Nigeria.

Abstract–**This paper presents the theoretical approach for the heat and mass transfer phenomenon at the fish layer during smoking using energy balance equations. Charcoal fired fish smoking kiln is the best preservation technique for faster smoking with efficient utilization of time and energy. The aim of this work is to establish a mathematical model describing the heat and mass transfer phenomena at the fish layer and in the air during smoking and to investigate the effects of two aero thermal factors by simulating the smoking process. Mathematical model was developed using energy balance equation on a various component of the kiln. The smoking process is simulated under real operating conditions based on a thin layer model and experimental drying kinetics. The results revealed that the rate of smoking increased with increase in drying air temperature and velocity respectively.**

Keyword–**Heat and mass transfer, Kiln, Modeling, Simulation**

I. INTRODUCTION

Post-harvest loss still remain one of major factor affecting the fishing communities due to poor processing technique and inadequate preservation practices which leads to damage of the end product[1]. Spoilage is a metabolic process that causes food to be undesirable or unacceptable for human consumption due to changes in sensory and nutritional characteristics [2]. If fish is not sold fresh, preservation methods should be applied to extend the shelf-life, these include freezing, smoking and drying. Report revealed that local farmers in different part of the world account for about 50 to 70 percent of the national catch in most countries, out of which 30 to 40 percent are usually lost due to poor handling and inadequate processing [3]. Efficient preparation of fish is important when top quality, maximum yield and highest possible profits are to be achieved. Smoking of fish still remain predominant in most communities where fish processing is carried out in Nigeria [3][4].Fish smoking is a process of treating fish by exposing it to smoke from smoldering wood or plant materials [5]. This process is heat and mass transfer phenomenon which occur due to application of heat energy, moisture move from the inner part of the fish to the outer surface from where it migrate to the surrounding by diffusion [6]. The aim of fish smoking is the removal of water to a certain level that can prevent the growth of mould and fungi and thus minimize microbial degradation [7]. There are various types of smoking techniques that can be applied to reduce the water and hence attains the purpose of fish preservation. The most commonly used are cold smoking and hot smoking, the temperature used for hot smoking can vary from 338.15K to temperatures as high as 393.15K [8]. The fish are partially or wholly cooked within a short time (2-4 hours) while Fish which are to be cold smoked are hung after preparation at a set distance from the smoke source. They are maintained at a temperature below 302.15K which may be raised to 305.15K for half hour of smoking. Conventionally, fish smoking is burning wood or charcoal in an uncontrolled environment which have complex effect on the fish, this include exposing the fish to germs and contamination and very low drying rate due to energy waste to the surrounding hence increase the cost of smoking the fish. For optimum smoking process, it is important to developed a model equation and simulate the smoking process so as to improve the existing technique using charcoal.

II. MATERIAL AND METHOD

A. Description of fish smoking kiln–

The charcoal fired fish smoking kiln is a rectangular in shape with inner lining made of Aluminum sheet. Sawdust was used as insulating material which conserves the heat energy from being loss and also to keep the working environment conducive for the user. It made of three compartments fish tray, charcoal pot and ash collector as shown in figure 1. The blower was attached to the smaller shaft of the pulley and the rotating spindle to the bigger pulley. The power was transmitted from the driver to driven pulley through belt drive.

International Journal of Engineering Applied Sciences and Technology, 2022
Vol. 7, Issue 7, ISSN No. 2455-2143, Pages 207-213
Published Online November 2022 in IJEAST (http://www.ijeast.com)

Fig. 1. Charcoal fired fish smoking kiln

The mathematical model was developed based on the following assumptions:

- Air density is constant.
- Air velocity distribution in the kiln is uniform.
- Air and water vapour are considered as perfect gases.
- The shrinkage of the product during the drying is neglected.
- The phenomenon of water condensation on the inner metal walls of the kiln chamber is neglected.
- The exchange surfaces air-product remain constant during smoking.
- All the products are considered a homogeneous, which are characterized by its superficial temperature.

B. Mathematical Model–

The model was developed base on energy balance equation on a various components of the fish smoking kiln.

Energy released by the charcoal

The amount of energy released by the charcoal during smoking was modeled as the energy released by the charcoal =conductive heat transfer to the charcoal pot +convective heat transfer from charcoal to the kiln air + radiative heat transfer from the charcoal to the fish + radiative heat transfer from the charcoal to the inner wall of the kiln + the heat generated by charcoal.

$$M_{Ch} Cp_{ch} \frac{dT_{ch}}{dt} = U_1 A_{cp}\left(T_p - T_{ch}\right) + h_a A_{ch}(T_a - T_{ch}) + A_{ch} F_1 \sigma(T_w^4 - T_{ch}^4) + A_{ch} F_2 \sigma((T_f^4 - T_{ch}^4) + Q_{ch} \quad (1)$$

$$h_a = Nu \frac{k_a}{L} \quad (2)$$

Nu is the Nusselt number established on the basis of Reynolds number (Re), which gives an idea about the flow regime

The Reynolds number is expressed as

$$Re = \frac{v_a L}{\upsilon} \quad (3)$$

υ, is the Kinematic viscosity of air $(m^2 s^{-1})$

The airflow will certainly be turbulent in the smoking kiln; to calculate the number of Nusselt number the following correlation were used [9]

$$Nu = 0.036. Re^{4/5}. Pr^{1/3} \quad (4)$$

Pr = 0.7073 (Air Prandtl number).

$$U = \frac{k}{b} \quad (5)$$

k is the thermal conductivity of the material

d is the thickness of the material

Energy gain by the charcoal pot

The heat gained by the charcoal pot was modeled as change in internal energy of the charcoal pot = conductive heat transfer from the charcoal to the pot – convective heat transfer from the pot to the kiln air – conductive heat transfer from the pot to the inner wall of the kiln.

$$M_{cp} Cp_{ms} \frac{dT_{cp}}{dt} = U_1 A_{cp}\left(T_{ch} - T_p\right) - h_a A_{cp}\left(T_{cp} - T_a\right) - U_2 A_{fl}(T_{cp} - T_w) \quad (6)$$

U_2, Conduction heat transfer coefficient between charcoal pot and the inner wall (WK^{-1})

Energy Gained by the Kiln Air

The thermal energy gained by drying air were model as change in internal energy of drying air = difference between enthalpy of air flow into the kiln and the enthalpy of air flow out of the kiln + enthalpy of water evaporated from the fish − the heat exchange by convection between the drying air and the fish tray − the heat exchange by convection between the drying air and the fish −convective heat transfer between the drying air and inner wall of the kiln − convective heat transfer between the drying air and ash collector

$$M_a Cp_a \frac{dT_a}{dt} = \dot{M}_{a(i)} Cp_a T_{a(i)} - \dot{M}_{a(o)} Cp_a T_{a(o)} + \dot{M}_v Cp_v T_a - h_a A_f(T_a - T_f) - h_a A_w(T_a - T_w) - h_a A_{ft}(T_a - T_{ft}) - h_a A_{ac}(T_a - T_{ac}) \quad (7)$$

$$Nu = 0.036. Re^{4/3}. Pr^{1/3} \quad (8)$$

Energy gained by the Fish Tray

The amount of energy received by the fish tray was modeled as change in amount of energy of the tray = convective heat transfer to the tray – conductive heat transfer from the tray to the fish.

$$M_{ft} Cp_{ms} \frac{dT_{ft}}{dt} = h_a A_{ft}(T_a - T_{ft}) - U_3 A_{ft}(T_{ft} - T_f) \quad (9)$$

ρ_{ms} , is the density of mild steel (kg/m^3)

Energy absorbed by the fish

Convection and radiation are the major heat transfer modes while balancing energy within the fish. The change in internal energy of the fish = convective heat transfer between the fish and the drying air + conductive heat transfer from the fish tray to the fish + radiative heat transfer from the charcoal to the fish −the energy of evaporation of water from the product.

$$M_f Cp_f \frac{dT_f}{dt} = A_f h_a(T_a - T_f) + U_3 A_{ft}(T_{ft} - T_f) - \dot{M}_v L_v + A_f F_2 \sigma(T_{ch}^4 - T_f^4) \quad (10)$$

$\dot{M}_v$ is the mass flow of vapor (kg/s)

L_v Latent heat of vaporization (J/kg)

$$L_v = L_{v0} + (Cp_v - Cp_l)T_f \quad (11)$$

Energy gained by the ash collector

The heat transfer by convection to the ash collector was modeled as change in the amount of energy of ash collector = convective heat transfer to the ash collector

$$M_{ac} Cp_{ms} \frac{dT_{ac}}{dt} = h_a A_{ac}(T_a - T_{ac}) \quad (12)$$

Heat transfer to the inner wall

The energy balance equation of the inner wall of the smoking kiln was modeled as change in internal energy of the inner wall of the kiln is equal to some of convective heat flow between the air and inner wall, conduction heat transfer from the charcoal pot, conductive heat flow between the inner wall and kiln frame and the conductive heat flow to the insulator

$$M_w Cp_{alu} \frac{dT_w}{dt} = U_3 A_{fl}(T_p - T_w) + A_{ch} F_1 \sigma(T_{ch}^4 - T_w^4) + h_a A_w(T_a - T_w) - U_4 A_w(T_w - T_{in}) \quad (13)$$

Heat loss to the insulator

The heat transfer by conduction to the insulating material was modeled as change in internal energy of the insulating material = conductive heat flow between the inner wall and the insulator − conductive heat flow between the insulator and the outer wall.

$$M_{in} Cp_{sd} \frac{dT_{in}}{dt} = U_4 A_{in}(T_w - T_{in}) - U_5 A_{ow}(T_{in} - T_{ow}) \quad (14)$$

Heat loss to the outer wall

The energy change of the outer wall of the kiln was modeled as change in internal energy of the outer wall of the kiln = conduction heat transfer between the insulator and the outer wall of the kiln – convection heat transfer between the wall and the surrounding air.

$$\rho_{ms} V_{ow} Cp_{ms} \frac{dT_{ow}}{dt} = U_5 A_{ow}(T_{in} - T_{ow}) - h_a A_{ow}(T_{ow} - Tam \quad (15)$$

Mass balance of the fish

The mass conservation of water in the fish can be written as Change in the amount of water in the product = − Water evaporated from the fish

$$M_f \frac{dX}{dt} = -\dot{M}_v \quad \text{Or} \quad (16)$$

$$\dot{M}_v = h_m A_f(P_{vs} - P_v^i) \quad (17)$$

h_m is the mass transfer coefficient (ms^{-1}) determined by Colburn–Chilton analogy [10]

$$h_m = \frac{h_a}{\rho_a Cp_a}(Le)^{-2/3} \quad (18)$$

P_{vs} is the saturated water vapor pressure (Pa) at the surface of the fish and is given by the Bertrand relation:

$$\log_{10}(P_{vs}) = 17.443 - \frac{2795}{T_f} - 3.868 \log_{10} T_f \quad (19)$$

P_v^i is the partial vapor pressure (Pa) of the moist air in the smoking chamber, it's often given by this relation below

$$P_v^i = P_{vs}(T_a) - \gamma(T_{ai} - T_a) \quad (20)$$

Where γ is the psychometric constant

Moisture in the air

The balance of water masses in the air exchanged during the smoking was modeled as;

Change in the amount of water in the air = water outside air entering + water evaporated from the fish − water of the exhaust air

$$M_a \frac{dY}{dt} = \dot{M}_{ai} Y_{in} + \dot{M}_v - \dot{M}_{ao} Y \quad (21)$$

$\dot{M}_{ao}$ is the exiting air mass flow and is given by [11]

$$\dot{M}_{ao} = C_d \frac{\rho_a A_o}{\sqrt{1 + A_o/A_i}} \sqrt{\frac{2gL(T_a - T_{am})}{T_{am}}} \quad (22)$$

A_i and A_o are inlet and outlet area of the chimney openings

C_d is the coefficient of discharge of air channel.

Rate of drying

The theory of drying will be describe by Lewis theory [12] base on analogous of newton law of cooling in heat transfer and is often use to mass transfer in thin layer drying and is given as follow;

$\left(\frac{dX}{dt}\right)$ Is of the most important parameters use in process drying

The following drying rate equation was obtained by Lopez et al [13]

$$\left(\frac{dX}{dt}\right) = -k(X - X_e) \quad (23)$$

k is the drying constant and it is related to the temperature of the moist air in the kiln by

$$k = 0.00719 \exp\left(-\frac{130.64}{T_a}\right) \quad (24)$$

X is the instantaneous moisture content and X_e is the equilibrium moisture content of a fish

$$X_e = \frac{W_m C k a_w}{(1 - k a_w)[1 + (C - 1) k a_w]} \quad (25)$$

W_m , Cand kare parameters related with air temperature by the following expression

$$W_m = 0.00142354 \exp\left(\frac{1072.5}{T_k}\right) \quad (26)$$

$$C = 0.5923841 \exp\left(\frac{1072.5}{T_k}\right) \quad (27)$$

$$K = 1.00779919 \exp\left(-\frac{43.146}{T_k}\right) \quad (28)$$

T_k is the air absolute temperature (0K) [14].

III. RESULTS AND DISCUSSION

The model equation have been developed for the simulation of the fish smoking process using charcoal fired fish smoking kiln and the calculations have been made by using the system parameters (Table 1). The MATLAB software was used for the simulation of the model developed.

International Journal of Engineering Applied Sciences and Technology, 2022
Vol. 7, Issue 7, ISSN No. 2455-2143, Pages 207-213
Published Online November 2022 in IJEAST (http://www.ijeast.com)

Table-1 Values of parameters used in simulation

Parameters	Values
M_{ch}	1kg
M_{cp}	5.02kg
M_f	7.2 kg
M_{in}	11.79kg
M_{ft}	3.43kg
M_{ow}	18.76kg
M_w	6.453kg
M_{ac}	2.37kg
M_a	0.2268kg
T_{am}	307.65K
A_{ch}	$0.0625m^2$
A_{cp}	$0.1828m^2$
A_{ac}	$0.21m^2$
A_{ft}	$0.293m^2$
A_f	$0.3304m^2$
A_w	$2.39\ m^2$
A_{ow}	$2.5869\ m^2$
A_i and A_o	$0.01m^2$
d_{in}	0.0254 m
d_{ow}	0.00127m
d_w	0.001m
d_{cp}	0.003m
V_{ow}	$5.11 \times 10^{-3} m^3$
V_{ft}	$4.3746 \times 10^{-4} m^3$
V_w	$2.39 \times 10^{-3} m^3$
V_{in}	$0.05989m^3$
V_a	$0.252\ m^3$
Q_{ch}	30000KJ
Cp_{ch}	1004.16 J/kgK
Cp_v	1900J/kgK
Cp_a	1006 J/kgK
Cp_f	3650J/kg K
Cp_v	1900J/kgK
Cp_l	4200J/kgK
Cp_{sd}	900J/kgK
Cp_{ms}	510.7896 J/kgK
Cp_{alu}	896 J/kgK
ρ_{ms}	$7850\ kg/m^3$
ρ_{alu}	$2700kg/m^3$
ρ_{sd}	$210\ kg/m^3$
ρ_a	$0.9\ kg/m^3$
k_a	0.026W/mK
k_{ms}	$54\ Wm^2K^{-1}$
k_{sd}	$0.08\ W/m^2K$
k_{alu}	240 W/mK
F_1	0.705
F_2	0.506
σ	$5.67 \times 10^{-8} W/m^2K^4$
L	0.6m
v_a	$1.608 \times 10^{-5} m^2 s^{-1}$
U_1	18000W/K
U_2	18000W/K
U_3	11.49W/K
U_4	3.1496W/K
U_5	45000W/K
r	0.025.4m
L_{v0}	2500.9kJ/kg
a_w	0.9 to 1
g	$9.8\ ms^{-2}$
l	0.2 m
γ	$66\ PaK^{-1}$

Figure 2 show the influence of drying temperature with variation of air temperature during drying. It was observed that the temperature of the drying air reaches the smoking temperature ($343.15K$, $363.15K$ and$383.15K$) very quick from where it then maintained a constant temperature throughout smoking process. Figure 3 show the influence of drying air velocity with variation of air temperature during smoking. It was observed that as the drying velocity increases the drying air temperature also increases. The velocity of air at $0.6m/s$ takes more time before it reaches the drying time temperature as compare to the others temperature. This is obvious due to the fact that at a higher velocity of the air, the radiative and convective heat transfer will increase thus higher temperature of the air. Figure 4 provided the influence of drying air temperature with variation of fish temperature during smoking. The fish temperature continues to rise until it reaches a smoking temperature. From where it maintained a constant temperature throughout the smoking process. Figure 5 depicted the influence of drying air velocity with variation of fish temperature smoking. Figure 6 show the influence of drying air temperature with variation of fish moisture content during smoking. It is cleared that the air temperature is an influential parameter in the variation of the moisture content, because increasing the air temperature gives the air more evaporative power which is reflected in the drying time by making it shorter. Thus, the evaporation front moves faster and consequently the necessary time for smoking decreases. Figure 7 show the influence of drying air velocity with variation of fish moisture content during smoking. It was observed that when the air velocity increases the rate of moisture removal increases but not as that of temperature increases, this indicated that the effect of drying air temperature during smoking is more pronounce compared with that of drying air velocity. Figure 8 shows the evolution of air, inner wall and fish temperature inside the kiln for $0.8m/s$air velocity and $363.15K$ air temperature. It takes more time for the fish to reaches the smoking temperature when compared with that of inner wall and the drying air. This slow change in the temperature of the fish in the drying process characterizes the difference in thermal conductivity of the material and thermal properties of the drying air.

International Journal of Engineering Applied Sciences and Technology, 2022
Vol. 7, Issue 7, ISSN No. 2455-2143, Pages 207-213
Published Online November 2022 in IJEAST (http://www.ijeast.com)

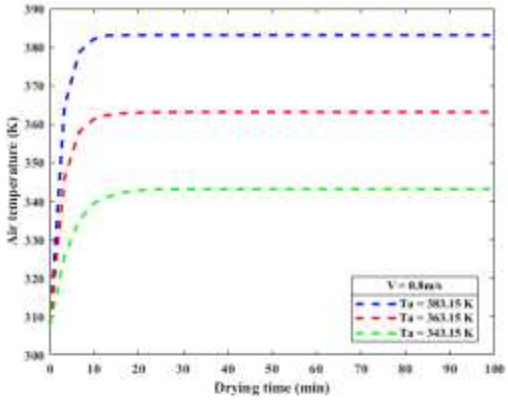

Fig 2: Influence of drying temperature with variation of air temperature during drying.

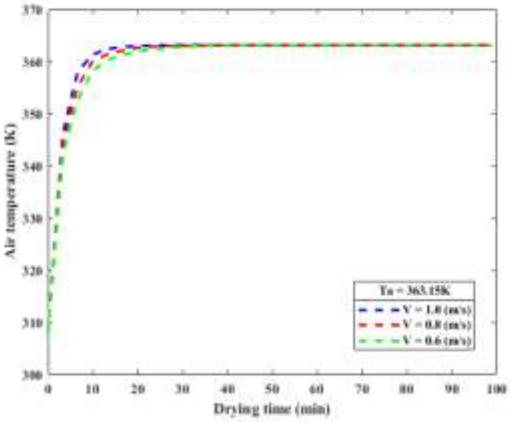

Fig 3: Influence of drying air velocity with variation of air temperature during drying.

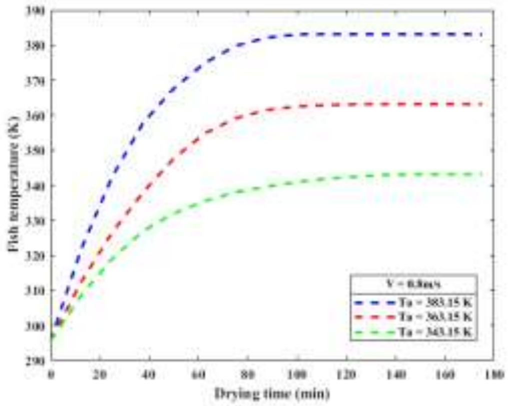

Fig 4: Influence of drying air temperature with variation of fish temperature during drying.

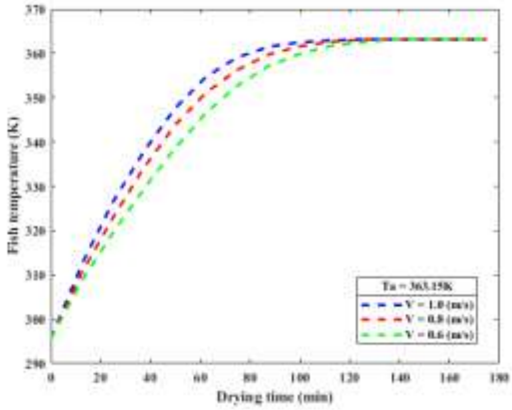

Fig 5: Influence of drying air velocity with variation of fish temperature during drying.

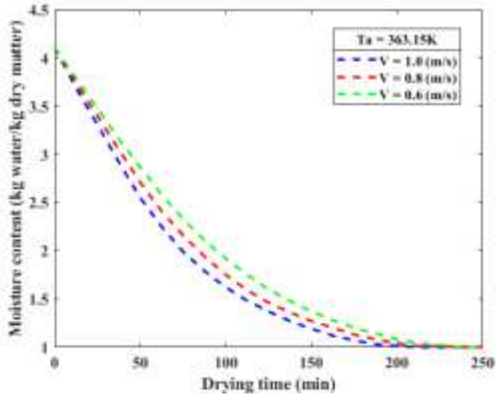

Fig 6: Influence of drying air velocity with variation of fish moisture content during drying.

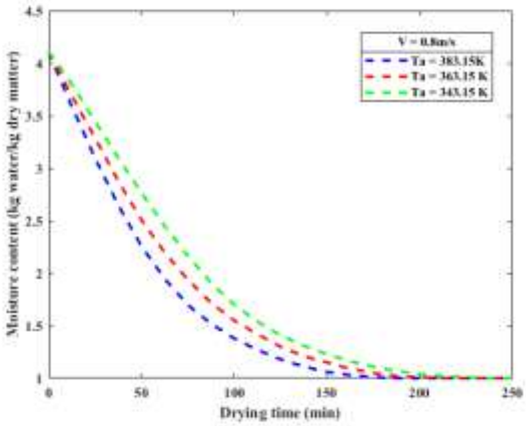

Fig 7: Influence of drying air temperature with variation of fish moisture content during drying.

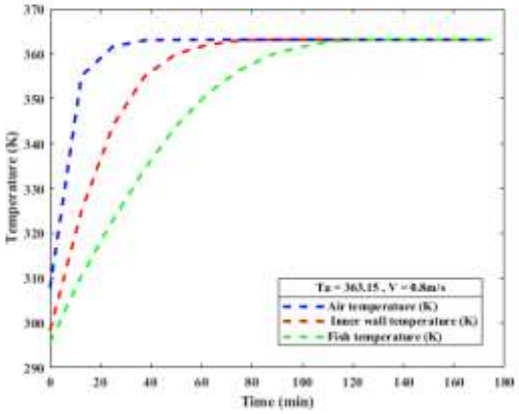

Fig 8: Variation of air temperature, fish temperature and inner wall temperature for $T_a = 363.15K$ and $V = 0.8m/s$.

IV. CONCLUSION

A model to predict the smoking process of the fish using charcoal fish smoking kiln was developed. The energy conservation principle was applied to the various component of the kiln. The model equations developed were implemented in a MATLAB environment in other to simulate the fish smoking process. Results shows that the moisture removal rate at the layer of the fish increases as the temperature and velocity of drying air increases. The fish temperature attained the drying temperatures for velocities 1m/s, 0.8m/s and 06.m/s at 100min, 110min and 120min respectively. Drying air temperature and velocity are the influential external parameters. This is notable for the evolution of the temperature profiles and moisture content.

A. Conflicts of Interest

The authors have declared that there is no conflict of interest regarding the publication of this paper.

B. Funding Statement

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

C. Acknowledgments

I thank Dr.Ibrahim Saidu Sintali and Dr.Adekunle Moshood Abioye for their expertise and assistance throughout all aspects of the study and for their help in writing the manuscript. Authors are thankful to Sunusi Jamil Alaramma who moderates this paper and in that line improved the manuscript significantly.

Nomenclature

T Temperature (K)
Q_{ch} Heat generated by charcoal (KJ)
Cp Specific heat capacity(J/kgK)
A Surface area (m^2)
F_1 View factor between the charcoal and the inner wall
F_2 View factor between the charcoal and the fish
h_a Heat transfer coefficient of drying air (W/m^2°K)
Nu Nusselt number
k Thermal conductivity(W/mK)
L Characteristic length of the layer of the product (m)
U_1 Conduction heat transfer coefficient between charcoal and the pot (W/K)
U_2 Conduction heat transfer coefficient between charcoal pot and the inner wall (W/K)
U_3 Conduction heat transfer coefficient between fish tray and the fish (W/K)
U_4 Conduction heat transfer coefficient between the inner wall and insulator (W/K)
U_5 Conduction heat transfer coefficient between insulator and outer wall (W/K)
b Thickness (m)
A_{in} Is the inlet area of the blower duct
r Radius of the duct of a blower (m)
h_a Convective heat transfer coefficient of air
L_v Latent heat of vaporization (kJ/kg)
F_2, view factor between charcoal and the fish
h_a Convection heat-transfer coefficient (W/m2°C)
$\dot{M}$ Mass flow rate (kg/s)
M Mass (kg)
h_m Mass transfer coefficient (ms^{-1})
Le Lewis number
P_{vs} Saturated water vapor pressure (Pa)
P_v^i Partial vapor pressure (Pa)
C_d Coefficient of discharge of air channel
g Gravitational acceleration (9.8 ms^{-2})
l Height of chimney(m)
V Volume (m^3)
a_w Water activity

Greek letters

ρ Density (kg/m^3)
μ Kinematic viscosity of air (m^2/s)
γ Psychometric constant (66 PaK^{-1})

Subscripts

ch Charcoal
a Air inside the kiln
f Fish
p Charcoal pot
am Ambient temperature
w Inner wall
ow Outer wall
ac Ash collector
ft Fish tray
ms Mild steel
fl Flange
cp Charcoal pot
v Vapour
i Inlet

o Outlet
sd Sawdust
in Insulator

V. REFERENCE

[1] Issa, W. A., Fatile O. E., Abdulmumuni, B., Ologunye, O. B., Okpara, I. N. (2020). Design and fabrication of a charcoal fish smoking kiln.International Journal of Recent Technology and Engineering, pp.1487-1495.

[2] Doyle, E. M. (2007). Microbial Food spoilage-Losses and Control Strategies, Food Research Institute, University of Wisconsin – Madison, WI 53706.

[3] Ologunagba, F. O., Ale, M. O. & Imoukhuede, K. A. (2010). Development of a fish smoker a proceedings of the 10th international conference and 31st annual general meeting (Enugu, 2010). October 20th-23rd, 2010. Vol.31, pp.102-107

[4] Davies, R.M.& Davies, O.A. (2009). Traditional and improved fish processing technology in Bayelsa State, Nigeria. European Journal of Scientific Research vol. 26 No 4.

[5] Food and agricultural organization of the united nation (2007). An innovative way of fish drying and smoking, policy brief, no.1

[6] Eyo, A. A. (2001). Fish Processing Technology in the Tropics, University of Ilorin Press, pp 153-192

[7] Jangam, S.V., Law C. L. & Mujumdar A. S. (2011). Drying of Foods, Vegetables and Fruits, vol. 2 Singapore, 2011.

[8] Burt, J. R.(1988). Fish smoking and drying , Elsevier Applied Science, ISBN 9781851662470.

[9] Hatem, O., Mabrouk, S. B., Mami, A. (2012). System Design, Mathematical Modelling and Simulation of Process Drying in a Solar-Gas Convective Tunnel Dryer. International Journal of Scientific & Engineering Research,pp.1303-13I0

[10] Boukadida, N. &Nasrallah,S. B. (2001). Mass and heat transfer during water evaporation in laminar flow inside a rectangular channel validity of heat and mass transfer analogy. Int. J. Therm. Sci. 40: pp. 67–81

[11] Marti-Herrero, J. M. & Heras-Celemin, M. R. (2007). Dynamic physical model for a solar chimney.Solar Energy 81(5): pp. 614–622.

[12] Ertekin, C.&Firat,M. Z. (2017). A Comprehensive Review of Thin Layer Drying Models Used in Agricultural Products, Critical Reviews in Food Science and Nutrition.DOI: 10.1080/10408398.2014.910493

[13] Lopez, A., Iguaz, A. Esnoz, A. & Vırseda, P. (2000). Thin Layer Behaviour of Vegetable Wastes from Wholesale Market. Drying Technology, 18(4&5): pp. 985–994.

[14] Mabrouk, S. B. & Belghith, A. (2000). Development of the solar crop dryers in Tunisia. World Renewable Energy Congress VI, vol. 3, pp.2206 – 2212.