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Research Article

Suppression of the Horizontal Temperature Gradient on the Drying Tray in an Artisanal Firewood Dryer

Tsegaing Tchatchueng Fabrice[1*], Kamta Martin[2], Ahmed Ali[3], Tchatchueng Jean Bosco[4], Voncila Ion[5]

[1]Department of Process Engineering, ENSAI, PO Box 455 Ngaoundere, Cameroon
[2]Department of Energetic, Electrical and Automatic Engineering, ENSAI, PO Box 455 Ngaoundere, Cameroon
[3]Department of Chemical Engineering, IUT of Ngaoundere, PO Box 454 Ngaoundere, Cameroon
[4]Department of Applied Chemistry, ENSAI, PO Box 455 Ngaoundere, Cameroon
[5]Department of Automation Electrical Engineering, University "Dunarea de Jos", PO Box 800008 Galati, Romania

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Abstract

Analyses on many artisanal firewood fish dryers have permitted to say that the operators have good experience-based processing skills, but loss due to some fish calcination during the process, or other poorly dried, has always been a deep concern amongst the producers. This has been investigated throughout literatures too where few works have been done to acquire an isotherm on the drying surface. By upgrading a selected dryer with an intermediate layer of iron sheet between fire and fish, plus an opening on the back wall of the burning chamber, we successfully achieved an isothermal drying surface which is one prerequisite for standardization of the overall drying process.

Keywords: *Firewood fish dryer, Temperature control, Heat distribution, Isothermal surface, standardization*

1. Introduction

Food preservation is a major concern in developing country such as in Africa, particularly in Cameroon where the 2008 food starvation crises led to massive strikes. Fish, as an important and good source of protein (Seki et Bonzon,1993; Jonathan Kuje Yohanna *et al*. 2011, Hassan E. M. Farag *et al*., 2011), is mainly caught in rural areas in Cameroon. For their availability in urban markets, they should be preserved to avoid loss (Kapseu, 2000). In those decentralized zones, electricity is seen as expensive to used congelation. The most practiced method of fish preservation is firewood drying (Mujumdar, 2000, Ali Ahmed *et al*. 2011).

Previous studies have shown that traditional dryers, as seen in Cameroon, are source of a number of complaints from the operators point of view (Tsegaing, 2009), which can be grouped as two. Firstly, on human health: eyes irritation, headache, cough due to smoke, skin burns, tiredness, etc. Then, on the process: lot of firewood, heat loss, calcination, etc. It was reported to us that "the fire you see is not a very good indicator of the process temperature, one must keep his eyes on the drying fish every time or one might end up with charcoal". We clearly see the need of heat control in artisanal dryers, and this has made the reason of this paper.

Curious about the different types of dryer constructions (Chorkor and Altona promoted by PNUD 2006, Aby cited by Bleu Goueu 2006, FTT-Thyaroye of Ndiaye and al. 2014) we started asking ourselves if there were a scientific reason to have either one or two combustion spots inside artisanal firewood fish dryers. Apart from the evidence of adding other burning points with the growing length of the tray, we have seen no demonstrations of why and how to positioned them. We had to analyse the heat distribution behaviour in a firewood artisanal dryer.

Authors working on dryers have produced number of papers on interlaying different materials between the product and the heat source (Jaishree and al. (2006), Madhlopa and Ngwalo (2007)), mostly in solar dryers coupled to biomass heater, but this has not been done to our knowledge, on traditional firewood types of dryers. The case of the FTT-Thyaroye, a recently designed dryer is of some interest. They put an intermediate iron tray with big covered holes between the fire and the rack for the purpose of grease collection during heat treatment (Ndiaye and al. 2014). In our case, a layer of iron sheet is placed between fire and the fish to dry.

2. Experimental equipment and operating principles

2.1. Experimental equipment

To collect our data, we have used a laptop from Toshiba (Core i7 at 2GHz, RAM 6GB), USB temperature

*Corresponding author's ORCID ID: 0000-0001-9170-8693
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sensors type K and TRH Central Omega software, type K sensors and a Mastech multimeter turn on function thermometer and its data logging software MAS view, an infrared camera Model C6 from FLIR.

2.2. Operating principles

We have registered the temperature during drying with a simple recommendation to follow, taken from the literature, "stay between 100°C and 140°C" (FAO, 2005). The dryer inner dimensions are 140 x 90 x 125 cm3, made of soil bricks (adobe) of 30 x 15 x 15 cm3. An iron sheet covers the top side after fish is disposed on the rack. At the bottom of the front wall an opening of 50 x 40 cm2 is done for firewood feeding and air entrance is regulated by covering it partially. A pack of ten kilograms of yellow wood is placed is the burning chamber and 33cc of kerosene is poor upon. When fire is ignited, data acquisition starts. To make sure combustion will follow without any further help, we let it burn 5 to 10min before regulating it's intensity. After that, if fire is considered as too much, some water is thrown on it. On the contrary, when fire is considered not enough, the sticks are rearranged or some lugs of wood are added.

At first, two temperature sensors are positioned. One is in the middle and the other on the lateral edge of the drying surface (fig 1) at 20 cm from the front side to fit our sensor length. Temperatures are registered and compared. Then, a layer of iron sheet (135 x 85, 0.6mm thick) is placed between fire and fishes to dry at different distance from the drying rack: 40cm, then 30, 20 and 10 cm and the temperature of the process is monitored. We have 2.5cm of space left all around between the iron sheet and the walls to give smoke access to the drying flour. Finally, based on graphic responses and statistical analyses, the best position is chosen.

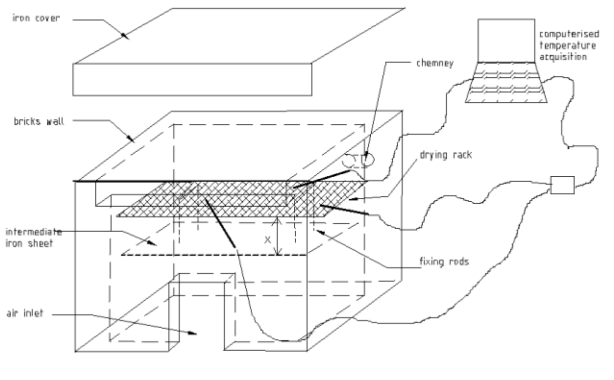


Fig. 1 Temperatures data acquisition in the new designed dryer

3. Mathematical considerations

The heat power or heat flow is fundamentally written as :

$$\Phi = K.S.\Delta T \tag{1}$$

where

K is the global heat transfer coefficient
S the surface of heat exchange
ΔT the difference of temperature between the milieus separated by S

For conduction in homogenous milieu we can write

$$\Phi = \frac{\lambda.S}{e}.\Delta T \tag{2}$$

For convection

$$\Phi = h.S.(T_f - T_p) \tag{3}$$

And radiation in all direction by one body is:

$$\Phi = \sigma.\varepsilon.S.T^4 \tag{4}$$

And when exchange between two bodies we have:

$$\Phi = \alpha_1.\alpha_2.F_{1\rightarrow 2}.S.\sigma.(T_1^4 - T_2^4) \tag{5}$$

But it is always possible to present is as

$$\Phi = h_r.S.\Delta T \tag{6}$$

Since the ambiance is an outdoor dryer, wind convective coefficient is generally estimated using the McAdams correlation:

$$h_{wind} = 5,7 + 3,8V_{wind} \tag{7}$$

The electric model of heat flow keeping all the heat transfer into account could be represented as follow:

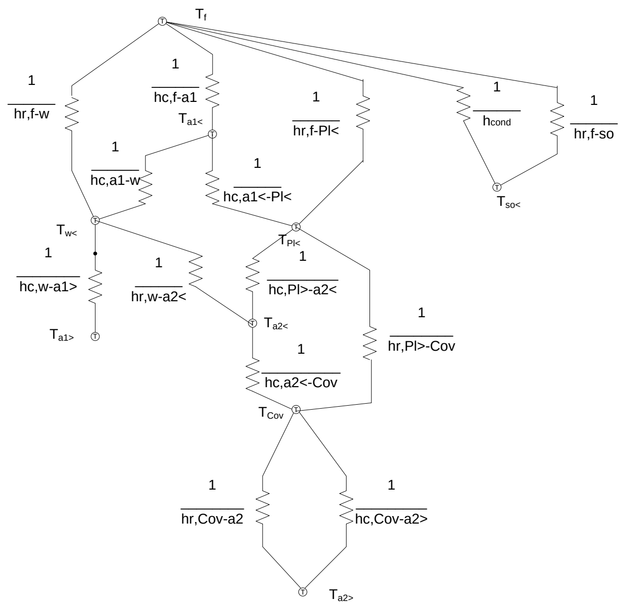


Fig. 2 Electrical model representing the heat exchanges in the case of our dryer

hr: equivalent radiative coefficient

hc: convective heat exchange coefficient
hcond: equivalent conduction coefficient
Associated indexes represent:
f : fire
so: soil or ground
w<: interior wall
w>: exterior wall
Pl<: downside face of the intermediate iron plate
Pl>: upside face of the intermediate iron plate
a1<: internal air under the iron plate
a1>: external air on the brick wall
a2<: internal air above the iron plate
a2>: external air above the iron lid of the dryer
Cov: iron cover of the dryer
f-w: fire-wall
f-a: fire-air
f-so: fire-soil
a-w: air and wall
a-Pl: air and plate

By using the first principle of thermodynamics we can write the balance as follow for the intermediate iron plate:

$$h_{r,f-Pl}(T_{Pl}-T_f)+h_{c,a1-Pl}(T_{Pl}-T_{a1}) = h_{c,Pl-a2}(T_{a2}-T_{Pl}) + h_{r,Pl-Cov}(T_{Cov}-T_{Pl}) - h_{r,w-a2}(T_{a2} - T_w)$$

Being a thin plate (e<< L, e<< l), the conduction inside the iron can be neglected since quick and the two sides (up and down) of the plate is supposed to be at the same temperature.

4. Results and discussions

4.1. Measurements on a typical dryer

We decided to take the geometry of a typical artisanal oven and built it up (Tsegaing, 2012). During drying, we measured the central and the edge temperature. This was made to see if any difference in temperature is noticeable. Fig 1 shows how this was done.

The results obtained on Fig 3 clearly speak of themselves. The two temperatures are different. But contrary to common sense, here, it is not the central temperature that is the highest, but that of the edge. Rivier and al. (2010) have studied the temperature profile in a Chorkor dryer and they obtained the same behaviour between the central sensor registering the "striking" temperature and the internal edge of the dryer. This gradient could be explained, in our case, by the air circulation which is driving heat out by the sides where we have lateral hole used as chimney and that is not placed at the centre as in most dryers. This is a factor of modification and non-standardization of the final product as pointed by N. Achir and *al.*(2010).

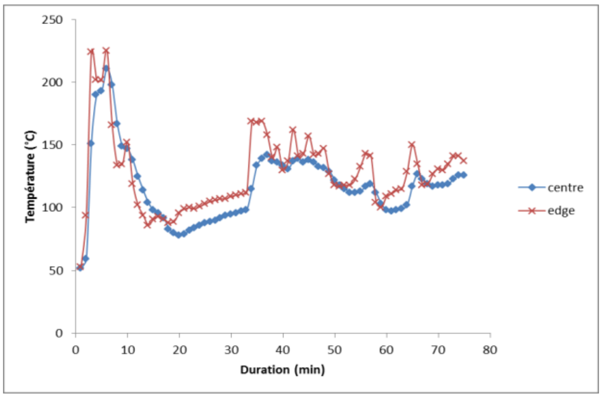
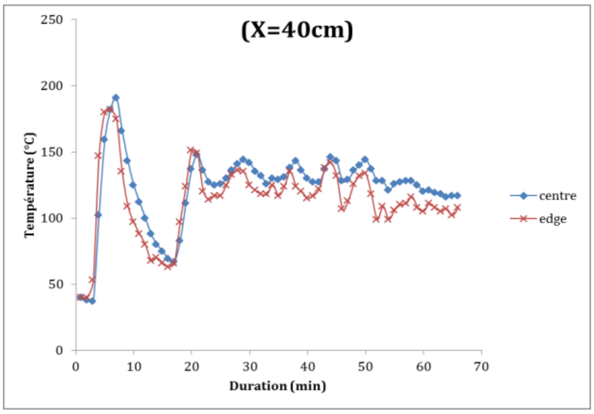
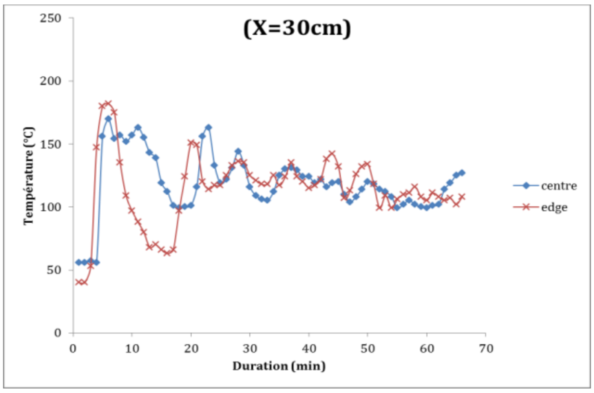


Fig. 3 Temperature profile without the intermediate iron sheet layer

4.2. Suppression of the longitudinal gradient of temperature



a



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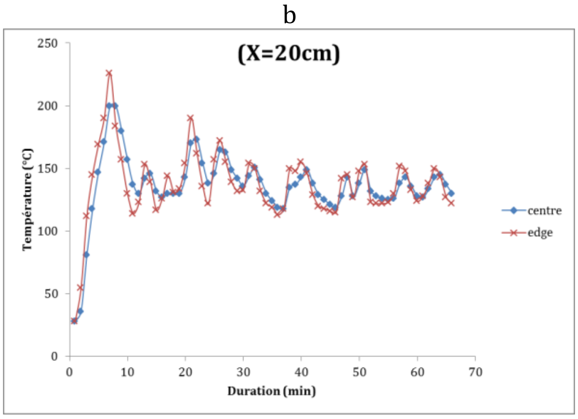

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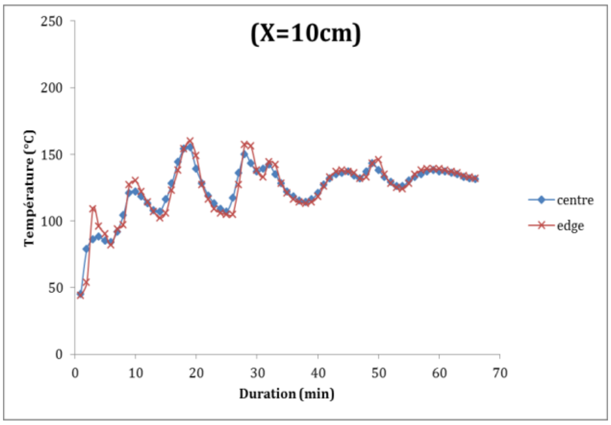


d

Fig. 4 Temperature profiles with the iron sheet at X=40cm, 30cm, 20cm and 10cm under the drying rack

Now a layer of iron sheet is placed, between fire and fishes to dry, at different distance (X) from the drying level. At X=40cm, then 30, 20 and 10 cm, the temperature of the process is monitored. The sheet is 135 X88 cm2 which is a bit smaller than the internal dimensions of the dryer. This allows the smoke produced to reach the fish.(Fig. 1)

It appears clearly on Fig. 4 that the closer we come to the drying rack, the better the two curves are fitted. In the position at 10cm under the rack, the behaviour during the first ten minutes is different, there is not this high increase of temperature before a fall and regulation. The only reason from our understanding is a slower combustion ignition compared to the other cases.

4.3. Numerical simulation

Considering the above results, we can say that with the chamber being divided in two parts by the intermediate iron sheet, We have the behaviour of heat in a confined chamber. With the fire in its centre, heat is more intense in the middle and smoke produce tends to distributes heat horizontally under the ceiling (intermediate iron sheet) in a second time. So just above the iron plate we have relatively uniform values of temperature as seen on numerical simulation. We fall in the case of convection in horizontal plate heated from below. That is why the nearer we are to the plate, the better the heat is distributed and temperatures are equals on the edge and at the centre. Rayleigh number is used to calculate Nusselt and convective heat exchange coefficient (Jacques Huetz and Jean-Pierre Petit, 2002, Yves Jannot, 2012).

$$Ra_L = \frac{g\beta\Delta T L^3}{a\nu} = \frac{\rho^2 Cp\beta g\Delta T L^3}{\lambda\mu} \qquad (9)$$

$$Nu_L = 0.27 Ra_L^{1/4} \qquad (10)$$

$$Nu_L = \frac{hL}{\lambda} \qquad (11)$$

Then on the edges, to add the contribution of the heat from the smoke to uniform the plate temperature through its transit up via the space between the wall and the plate, finite element calculation as proposed by Yves Jannot (2012) gives:

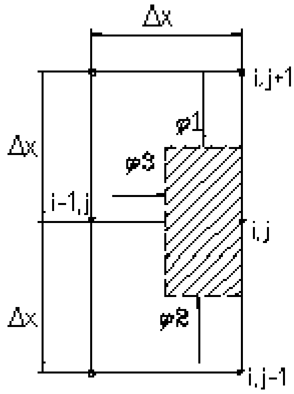


Fig. 5 Representation of elemental flow on a straight edge

Here :

$\varphi_1+\varphi_2+\varphi_3=h.l.\Delta x(T_p-T_\infty)$ (12)

or

$\varphi_1+\varphi_2+\varphi_3=\phi.l.\Delta x$ (13)

Thermal balance applied on the hatched part (rectangle with sides of Δx and Δx/2) gives for a determined ϕ:

$$T(i,j) = \frac{T(i-1,j)}{2} + \frac{T(i,j+1)+T(i,j-1)}{4} - \frac{\phi\Delta x}{2\lambda} \qquad (14)$$

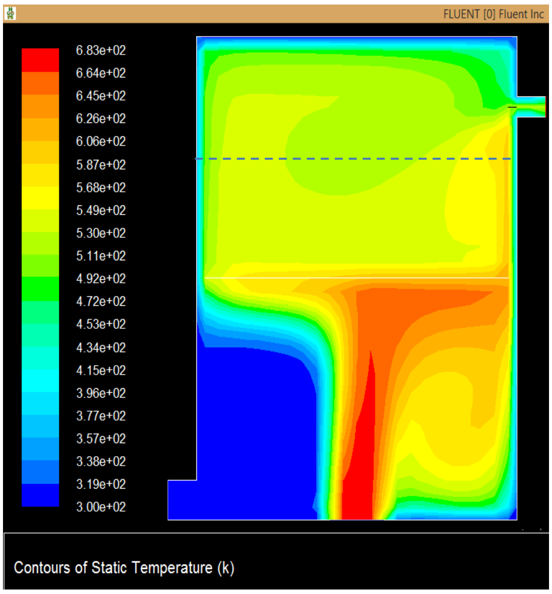
The above points are used by ANSYS/Fluent ®.

Material properties and some experimental values (especially to determine limit values) were then used in ANSYS/Fluent ® to verify graphically our results.
Experimentations during the previous experimental measurement gave this:

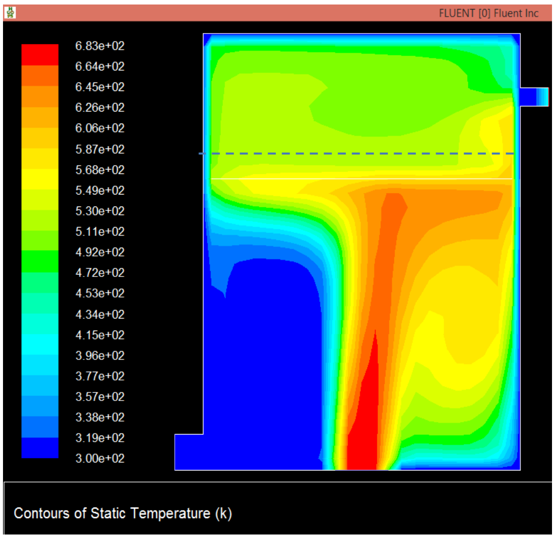
-Tf : fire 410°C on a surface of 40x40cm2 centred
-Tso : soil 23°C
-Tw< : interior wall 140°C
-Tm> : exterior wall 30°C
-Ta1< : internal air under the iron plate 140°C
-Ta1> : external air on the brick wall 25°C
-Ta2> : external air above the iron lid of the dryer 40°C
-Velocity of inlet air, from 0,015m/s to 1m/s
-Diameter of air inlet: 5x10 cm2
-Positions of the iron sheet under the drying rack: X à 40-30-20-10 cm
-Distance between the iron plate and the inner vertical walls: 2.5cm
-Diameter of smoke oulet (chimney): 5cm
-Dryer dimensions : 140x90x90cm3 internal and 170x120x90 cm3 external
- Brick :
•density ρ=1800kg/m^3, specific heat Cp= 900J/kg.°K,

•conductive coefficient λ= 0.75W/m/K ; thickness e = 15cm
- Iron plate :
•density ρ= 7870kg/m^3, specific heat: Cp= 452J/kg.°K,
•conductive coefficient λ= 73W/m/K ; thickness e = 2mm

The outcome was equally in agreement with our experiments (Fig 6)



a



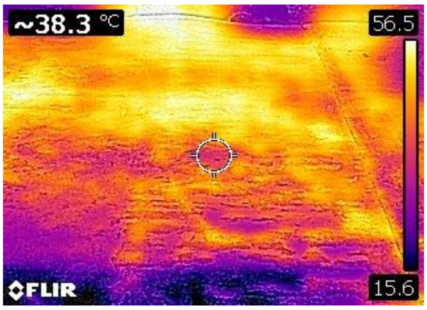
b

Fig. 6 Contours of static temperature for the intermediate iron sheet at 30cm (a) and at 10cm (b) of the drying rack with and inlet air velocity of 0.025m/s.

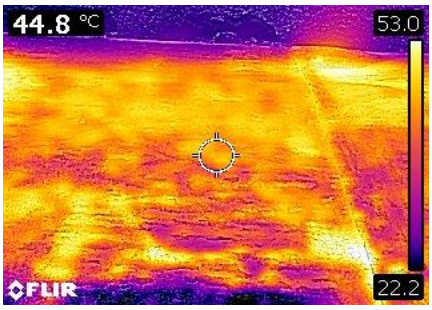
4.4. Isothermal drying surface

The previous results allowed us to inhibit a linear lateral gradient since the two sensors were on the same line and depth. To know if a depth temperature gradient exists too, we have used thermal photography. Fig 4a shows the picture obtained with FLIR C6 infrared camera on the top side of the dryer. This depth thermal gradient could be explained by the air inlet for combustion which pushes the hot air more at the back wall of the dryer. Rivier and al. (2010) have done numerical simulations that share this conclusion.

For a counter wind direction, a hole of 10 X 3 cm2, have been done on the back wall. This has improved the heat distribution by mixing the air and resulted in an isothermal drying plan as seen in fig 4b, the "after" picture of the same viewpoint. In the work done by Rivier and al. (2010), to have a uniform temperature, the size of the dryer has been reduced to less than a square meter which has been seen too scarcely in our countryside and it is not suitable for a context of semi industrial production.



a- with front air inlet arrière



b- Front and back air inlet

Fig. 7 Top cover infrared pictures of the dryer with and without a backside hole

Conclusions

From graphical and stats interpretations we can say that an intermediate iron sheet, between the fire and the fishes to dry, has permitted the annulation of the thermal gradient existing laterally during drying. A hole on the back wall of the furnace allowed a counter air inlet which contributed to obtain an isothermal drying surface in our dryer. Further studies are needed to see until what extent (dryer dimensions) this stays true, and when to add a second combustion spot and holes. As for now, most of our dried smoked fish producers could have all their fishes under the same conditions, which help the standardisation of their products. It is technologically easy to implement and will enhance dried-smoked fish quality.

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