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Effect of brining on the drying rate of tilapia *(Oreochromis niloticus)* in a solar tunnel dryer

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Abstract

This study determined effect of on the drying rate of tilapia in a solar tunnel dryer. Tilapia fish was split into pieces of 4cm by 3cm by 9mm and soaked into four brine concentrations varying between 0-15%. Moisture content was evaluated by oven drying method, while air temperatures were with an automated data logger. The moisture content of fish reduced as brine concentration increased. The effective diffusion coefficient varied between 5.061 $*10^{-11}$ and 3.323$*10^{-11}$ m^2/s as brine concentration increased, and it decreased with increase in brine concentration.

Key Words: Solar, tunnel dryer, brining, diffusivity, moisture content.

Introduction

In Kenya, fish is an important source of local and foreign currency earnings, in addition to being a source of proteins. Over 350,000 metric tonnes of fish produced annually earn the country about US$ 105 million, and contributes about 5% of the country's GDP (Abila, 2003). Out of the total production, 30% is exported mainly to the European Union (EU), the United States (US) and the Middle East countries, and earning Kenya US$58 million (Gitonga et al., 2003). Of the total annual fish harvest in Kenya, 50% is wasted due to poor processing and preservation (Orengoh and Kisumo, 2007).

The amount of fish harvested in Kenya fluctuates seasonally, with periods of high supply and low supply. During the periods of high supply a lot of fish is spoilt and wasted due to the poor preservation methods at artisanal fishermen level, while acute shortage and increased costs of fish are experienced in periods of low harvest. In addition the landing sites are usually located far from the main markets and consumption points and this leads to large amounts of fish being spoilt and wasted. Similarly, the livelihood of about half a million people in Kenya depends on fish as a source of proteins and for employment, hence measures must be taken to ensure the fish industry is protected and wastage minimised (MOLF, 2006). In order to reduce the wastage and spoilage of fish during periods of oversupply, and to enhance long storage, it is necessary to adopt appropriate and affordable processing and preservation techniques for fish at the artisanal landing sites.

The most common methods of fish processing and preservation at the village or artisanal level in Kenya are dry salting, deep frying, sun drying and smoking. Frying and smoking require high quantities of cooking oil, charcoal and wood, which result in the reduction of organic ground cover. Although smoking imparts desirable colour and taste attributes, it introduces cancer causing carcinogenic substances in fish (Delgado *et al.*, 2006). Therefore, alternative affordable, hygienic and environmentally friendly methods should be developed and adopted for drying of fish.

Drying of fish by open sun-drying or by solar would offer alternative methods to smoking and deep frying dryers. Drying reduces or completely eliminates physiological, microbial and enzymatic degradation of biological materials such as fish (Shitanda and Wanjala, 2003). About 50% of the fish consumed in Kenya is dried by open sun-drying (Abila, 2003). The disadvantages of open sun-drying of fish include destruction by birds, animals and man, contamination by excreta from birds and animals, soiling, fungal growth and mycotoxins, loss of both nutrients and quality, intensive labour and a large area is required. On the other hand, drying in solar dryers offers advantages such as shielding of fish from agents of the contamination and destruction stated above, accelerated rate of drying due to concentration of heat in the drying chamber, and conservation of light-sensitive fish nutrients by indirect solar drying.

Common solar dryers existing in Kenya are the black-box solar and tent dryers. Other solar dryers found mainly in Asian countries include the cabinet dryers, the batch dryers, and green house dryers. Although these dryers have been successfully utilised in the drying of fruits and vegetables their disadvantages in fish, fruits and vegetables processing, include exposure of products to direct sun-light which results in the destruction of light-sensitive nutrients, and the lack of temperature regulation mechanisms, leading to high drying chamber temperatures. With unregulated temperature, over-drying is possible, leading to poor quality of dry fish. Thus the dryers are unsuitable for the drying of fish, and there is need to try the tunnel dryer as an alternative to the existing dryers. However, none of the above dryers including the tunnel solar dryer has been tested in the drying of tilapia fish.

Sodium chloride has traditionally been used in curing and preservation of meat and fish due to its capacity to preserve and modify water holding capacity of proteins. While Kiaye, (2004) stated that brining reduces the micro-organisms count on dry fish, studies by (Oliviera *et al.*, 2006, Graivier *et al.*, 2006, FSA, 2007) indicated that concentrations of salt used in osmotic dehydration in excess of 5% are beyond the permissible levels for human consumption. Therefore, limiting the amount of salt used in brining, and subsequently dehydrating fish with a solar tunnel dryer would probably achieve a more stable and suitable dried fish product than osmotic dehydration or solar drying process separately. The objective of this study is to determine the influence of brining on the drying rate constant, and the effective diffusion coefficient for Tilapia fish (*Oreochromis niloticus*) when dried in a solar tunnel dryer.

Materials and methods

Description of the solar tunnel dryer system

The solar tunnel dryer system used in this study (Figure 1) consisted of two main components: the tunnel and the chimney chambers. The tunnel is used for heating the drying air before it enters the chimney. Both the tunnel and chimney drying chambers are completely sealed from light in order to preserve light sensitive nutrients in drying material. Drying can take place in either chamber. Since the tunnel section is a solar energy collector, drying in this section would not take full advantage of the energy collection process. In addition, the drying of fish in the tunnel section contributes moisture to the fish undergoing drying in the chimney section when both sections are used. In this study, the drying was carried out in the chimney section of the dryer. The study was conducted at the Biomechanical and Environmental Engineering Department, Jomo Kenyatta University of Agriculture and Technology, in Kenya.

The tunnel section measured 2.24m long, 1.2m wide and 0.54m high. The section had a rectangular galvanised iron (GI) collector plate painted black for enhanced absorption and emission of solar energy, and an acrylic cover located above the collector plate. The acrylic cover acted as a green house to absorbed energy which resulted in increased energy concentration in the chamber. Plate 1 shows a plate for the developed tunnel solar drier.

The bottom plate of the tunnel section was made of aluminium painted GI sheet to reflect energy incident on the surface. The rear side wall of the tunnel chamber was made of aluminium coated GI sheet. The front wall of the tunnel chamber had two sets of overlapping doors through which fish was placed in the chamber, and through which thermocouples from various data logger channels were inserted. The inner walls of the doors were made of aluminium coated GI sheets. The bottom and the side walls of the sheets were insulated with fibre glass which was sandwiched between the inner and outer GI sheets to minimise energy losses.

The chimney drying chamber measured 1.2m by 0.9m by 0.7m for the rectangular cross-section, and 1.2m x 0.7m at the bottom and 0.2m by 0.2m at the narrow end. It was made of GI sheets, with the inner walls coated with aluminium while the outer walls were painted black. An exhaust system secured above the chimney drying chamber was lined with acrylic glass to enable solar heating of the exhaust air, for increased natural convection. At the base of the exhaust pipe was a solar-driven suction fan that induced forced convection in the dryer.

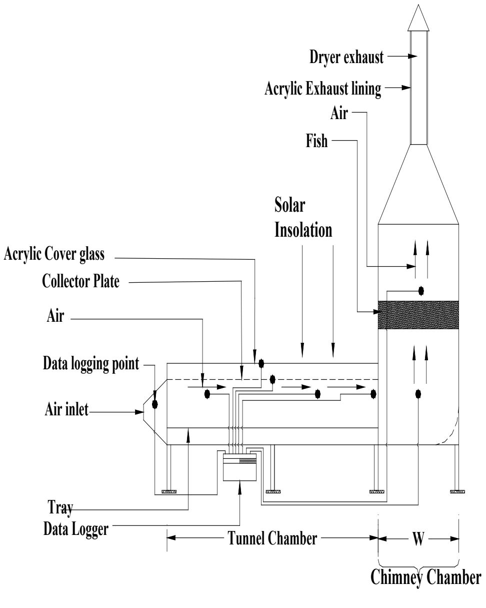

Figure 1a: A schematic of a tunnel-cum-chimney solar dryer.

Plate 1: Developed tunnel solar drier

The brining process of fish

Tilapia fish was procured from the fish landing sites along Tana River at Sagana, Kenya. It was eviscerated, de-scaled and thoroughly washed, after which the heads were removed. It was then split open longitudinally and cut into about 163 small pieces of approximately 4cm by 3cm by 1cm. Three pieces of fish were used to evaluate the initial moisture content of the fish by the oven dry method. The remaining pieces were divided into four sets of samples, each containing 40 pieces. The fish samples were soaked in brine with concentrations between 0 and 15%, in steps of 5%. For each treatment, the fish samples were soaked for in brine 12 hours and kept in a cooler at a temperature between 9 and 11°C. Single pieces of brined fish from each treatment were used to determine the moisture content of the fish before solar drying, using the oven dry method.

In order to determine the moisture content, a fish sample was weighed in a drying dish of known weight using the Shimadzu electronic balance, and its wet weight recorded as W_t. The sample was placed in a constant-temperature oven set at a temperature of 105°C for 12 hours. The dry fish was removed from the oven and its dry weight, W_d, recorded. The percent dry basis moisture content M_{db} was evaluated from the expression (Bala, 1997):

$$M_{db} = \frac{W_t - W_d}{W_d} * 100 \qquad (1)$$

The Fish Drying Process

After brining and initial fish moisture content determination, the remaining samples were place in the solar tunnel dryer to dry. All the samples were placed on the same tray in the chimney section of the tunnel dryer, in order to maintain the same drying conditions, with clear separation for samples under different brine concentrations. The dryer was in an open space exposed to the sun and the prevailing atmospheric conditions. The quantity of water removed during drying was determined by periodic weighing of the samples using an electronic balance. The data acquired included the initial moisture content, which was taken from weights taken before the samples were brined, post-brining initial moisture content taken after brining, just before the drying and drying period moisture content. The drying process took 40 hours.

Drying temperatures were taken using thermocouples which relayed data to an ETO Denki E Thermodac electronic data logger. In addition, the relative humidity was recorded using a digital thermo-hygro humidity sensor, while air flow was measured using a 21X8B EMPEX air flow meter.

Data analysis

The moisture data collected was used to plot graphs of moisture content against drying time, and to evaluate equation 2, which is based on the theory of thin layer drying (Kingsly *et al.*, 2007, Uluko *et al.*, 2006):

$$MR = \frac{M}{M_o} = e^{-kt} \tag{2}$$

Where;

MR = Moisture ratio (dimensionless),
M = Moisture content at time t hours, (% dry basis)
M_o = Initial moisture content (% dry basis)
A = Constant (dimensionless)
k = Drying rate constant (per hour)

The effective diffusivity was evaluated based on the fact that the fish drying took place in trays, which in diffusion analysis are considered slabs as opposed to cylindrical and spherical geometry. For fish drying in slabs, the relationship between the moisture ratio and effective diffusivity is given as (Hassini, 2006):

$$MR = \frac{M}{M_o} = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 Dt}{L^2} \right) \tag{3}$$

Where;

L = Half of the thickness of the drying sample (m),
D = Effective diffusivity (m^2/s).

Results and discussions

The moisture content for the fish samples after the brining treatments for 12 hours are presented in Figure 2, which shows a decrease in osmotic dehydration as brine concentration increased. This is consistent with the observations by (Sereno *et al.*, 2001, Mujaffar and Sankat, 2006). By brining, fish proteins are denatured, the water holding capacity of fish improved, and the rate of fish drying reduced. In osmotic dehydration, the salt enters the fish voids and displaces some of the water in the voids, while making proteins to coagulate and tissue cells to shrink due to loss of large proportion of cell moisture (Graivier *et al.*, 2006). However, brining processes provide dried products that are too salty and unacceptable to most consumers (Jittinandana *et al.*, 2002), and would require desalination. Desalination involves rehydration process which results in further leaching of nutrients from the fish. To avoid the effects of over-salting fish, it is necessary to combine brining and air drying to reduce moisture content to safe storage moisture content.

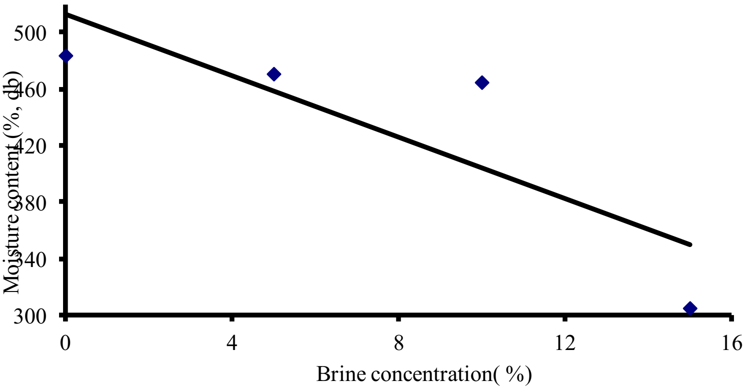

Figure 2: Variation in moisture content as brine concentration increased under osmotic dehydration.

Figure 3 presents the best curves of fit for the drying process of fish at different brine treatments. The figure shows that the moisture content for the four levels of treatment reduced steadily to equilibrium moisture content in about 40 hours for the un-brined sample and 35 hours for the brined samples.

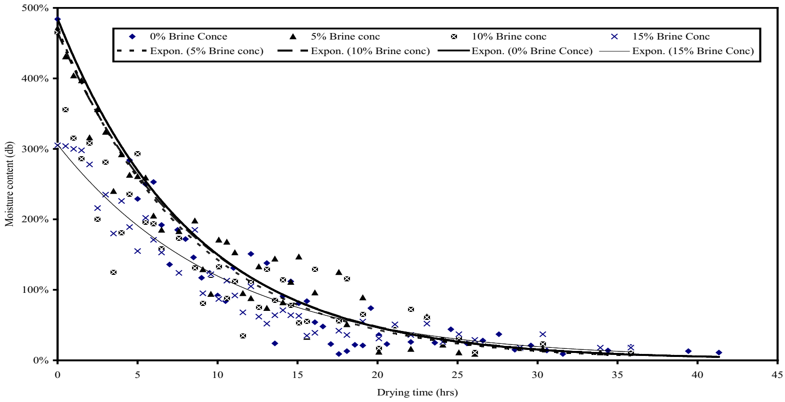

Figure 3: Drying curves for tilapia at different concentrations of brine.

The equilibrium moisture content obtained was 10% (db), which was much lower than the moisture content realised by (Bala and Mondol 2001) of 50.84% (db) over a longer drying period of 5 days (about 50 hours). According to (Braguy *et al.*, 2003) the safe storage moisture content for dried fish at 0 and 15% brine concentration was 15 and 35% (db), respectively. At the start of the drying process as observed from Figure 3, the un-brined sample had the highest moisture content values, which reduced as the brine content increased. As drying continued, this trend was reversed, with the un-brined sample loosing moisture rapidly while the sample with high brine concentration lost the least amount of moisture. This shows that the rate of drying reduced with increased brine concentration. The observation is partly explained by the hygroscopic nature of sodium chloride, which gives salted samples the ability to bind water molecules and reduce their availability for microbial activity (Graivier *et al.*, 2006), and partly by denaturing of proteins. One of the functions of salt concentration in meat is the extraction of myofibrillar proteins, which contributes to binding of meat molecules, fat emulsification and increased the water-holding capacity, resulting in improved quality and texture of fish (Graivier *et al.*, 2006). Due to the improved water holding capacity, the brined samples reached their equilibrium moisture content after about 35 hours, where as the un-brined samples continued losing moisture up to about 40 hours.

The best curves of fit for moisture ratio are presented in Figure 4, from which the drying equations similar to equation (2) were developed. The equations gave the values of the drying rate constant *k* and the corresponding coefficient of determination R^2 values for varying brine concentrations B_r as tabulated in Table 1.

The values of k in Table 1 decrease as the brine concentration increases. An increase in k implies a reduction in the moisture ratio and subsequently an increase in the drying rate. Therefore, the observed reduction in k with increasing brine concentration shows a reduction in drying rate as the brine concentration increased.

Table 1: Drying models for varying brine concentration.

B_r(%)	K(/hr)	R^2	$D*10^{-11}$
0	0.0888	0.7529	5.061
5	0.0724	0.8299	4.126
10	0.0701	0.8007	3.995
15	0.0583	0.9323	3.323

This agrees well with the earlier observation that drying rate decreased with increase in brine concentration.

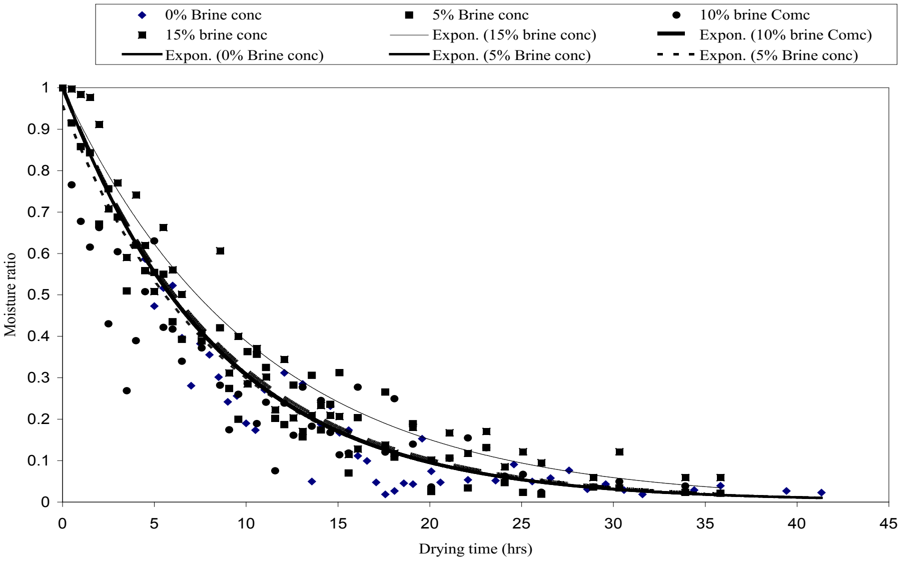

Figure 4: Moisture ratio curves for tilapia drying under different brine treatments

Using equation 3 and the k values in Table 1, the values of the effective diffusivity in Table 1 were evaluated. The values of effective diffusivity coefficients for the brine concentrations ranged between $3.323*10^{-11}$ and $5.061*10^{-11}$ m^2/s, and they reduced with increase in brine concentration. These values were slightly lower than the values obtained by (Park, 1998). The figures of diffusivity were consistent with diffusivity values obtained by (Graivier *et al.*, 2006, Josep, 2001). Thus although brining achieves osmotic dehydration, it reduces the rate of drying of tilapia. It can thus be concluded that brining achieves significant reduction in the moisture content of fish dried in a solar tunnel dryer. However, this study was not able to establish the optimum concentration at which fish should be brined to achieve stable moisture content with or without air drying.

While the changes in temperatures around the dryer are important, of necessity in drying is the drying air temperature, and subsequently the plenum chamber temperature which is the temperature of the air just before drying. The profile of the drying air temperature is presented in Figure 5. The profile was developed from data collected from air inlet, the centre of the tunnel chamber (TC), the tunnel exit (TE), the plenum chamber (PC) and above the drying tray (ADT).

The figure shows that the temperature of the drying air increased steadily from 37^0C at inlet to about 39.5^0C at the plenum chamber, and then reduced to about 38.5^oC as it entered the exhaust of the dryer. The gain in air temperature indicated gain in drying air energy in the tunnel chamber, while the reduction in air temperature showed the loss of latent heat in evaporating water from the fish.

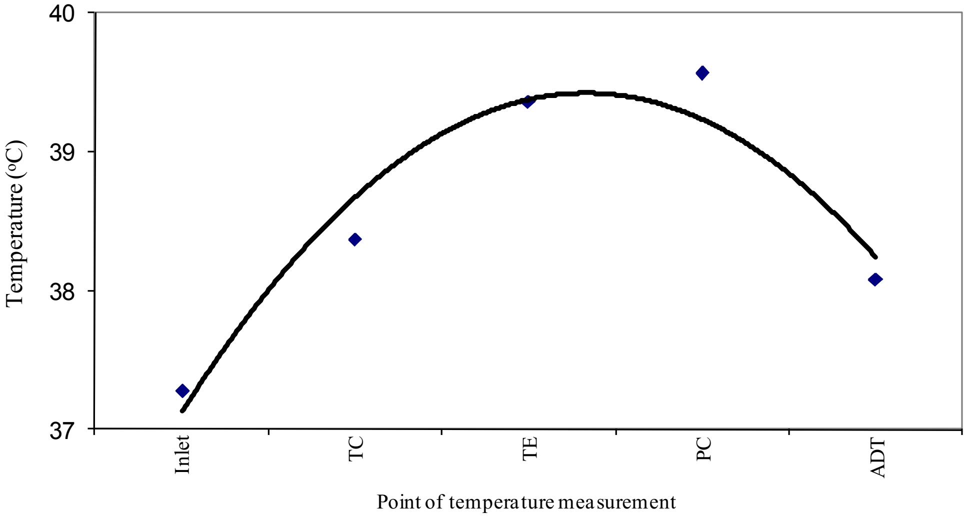

Figure 5: Variation of temperature across the dryer during drying.

Under the air temperatures of about 39^oC, the fish dried within 40 hours, and its moisture content was reduced from 484% (db) (moisture content before brining) to about 10% (db) for the plain dried samples and 15% dry basis for the brined salted samples. Subject to the analysis of the optimal drying rate based on the energy harnessing characteristics, and the quality characteristics of the dried fish, the solar tunnel dryer used in this study is a viable option to open sun drying of tilapia

Conclusions

Treating fish with brine achieves osmotic dehydration of up to 36% for a brine concentration range of 0-15%. Brining reduces the drying rate. Brined fish takes about 36 hours for the moisture content of brined fish to reduce from 484 to 15% (db) when the fish is dried in a solar tunnel dryer at mean inlet and plenum temperatures of 37 and 39°C, respectively. However, it takes about 40 hours for un-brined fish to dry to 10% moisture content, under the same drying conditions. The drying rate constant and the diffusivity values reduced with increase in brine concentration. The values of k varied between $5.83*10^{-2}$ and $8.88*10^{-2}$/hr, while the effective diffusion coefficient values varied between $3.323*10^{-11}$ and $5.061*10^{-11}$ m^2/s for brine concentrations ranging from 0-15%.

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