Influence of Brining on the Drying Parameters of Tilapia *(Oreochromis Niloticus)* in a Glass-Covered Solar Tunnel Dryer

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ABSTRACT

The objective of this study was to determine the effect of brining on the drying rate of tilapia (Oreochromis niloticus) in a glass-covered solar tunnel dryer. Tilapia fish, eviscerated, and split into pieces of approximately 4cm by 3cm by 9mm was soaked in brine at varying concentrations of 0, 5, 10 and 15%. The samples were dried in a glass-covered solar tunnel dryer for 40 hours. The moisture content was evaluated by the oven dry method. The moisture content of fish was found to reduce linearly from 5.58 to 2.76 kg/kg (db) as brine concentration increased from 0 to 15%. The drying rate reduced with increase in brine concentration. The effective diffusion coefficient decreased from 8.56 - 5.72x10^{-11} m^2/s, and the drying rate constant from 0.1217-0.0813 h^{-1}, as the brine concentration increased from 0-15%. These results provide useful information in the modelling and design of solar drying systems for tilapia fish drying

Keywords: Solar, tunnel dryer, brining, diffusivity, moisture content, drying rate constant

1. INTRODUCTION

The importance of fish in Kenya lies in its contribution to food and financial security. The annual production of fish in the country is over 350,000 metric tonnes, earning about US$105 million, and constituting about 5% of the national GDP. Currently about half a million people in Kenya depend on fish for proteins and employment. In addition, the annual fish harvest fluctuates seasonally, with periods of high and low supply. During the periods of high supply, a lot of fish is spoilt and wasted due to poor processing and preservation at artisanal fishermen level, while acute shortage and increased costs of fish are experienced in periods of low harvest. According to Orengoh and Kisumo (2007), 50% of total annual fish harvest goes to waste due to poor treatment, management and storage. In addition, the landing sites are usually far from markets and consumption points, which leads to large amounts of fish being spoilt and wasted**.** 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 as well as

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affordable processing and preservation techniques for fish especially in the artisanal fishermen's environment.

Dry salting, sun drying, deep frying and smoking constitute the most common methods of fish processing and preservation for rural fishermen in Kenya. The last two methods impact negatively on environmental degradation, since they use biomass, while smoking introducing cancer causing substances in fish flesh (Delgado *et al.,* 2005). Drying of fish by sun- or solar-dryers 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, 2006). About 50% of the fish consumed in Kenya is sun-dried (Abila, 2003). The disadvantages of 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 nutrients, intensive labour and a large area requirement, while drying in solar dryers shields fish from agents of contamination and destruction and accelerates rate of drying. Therefore, alternative affordable, safe, hygienic and environmentally friendly methods must be developed and adopted for fish drying.

Solar dryers have not been extensively used in Kenya, though a few designs such as the box dryer have been used especially in mango drying (Kerr, 2000). Other solar dryers found mainly in Asian countries include the cabinet dryers, the batch dryers and green house dryers (Whitfield, 2000). The disadvantages of these dryers include exposure of products to direct sun-light, resulting in destruction of light-sensitive nutrients, and lack of temperature regulatory mechanisms leading to high dryer chamber temperatures. The high dryer temperatures lead to over-drying and subsequently to poor quality of the dried fish, and therefore these dryers are unsuitable for the drying of fish. Thus there is a need to seek alternative techniques in solar drying of fish. An alternative that has been tried in drying of vegetables is a solar tunnel dryer, which has a dark drying chamber, therefore eliminating the destruction of light sensitive nutrients in the other solar dryers, and a temperature regulating fan.

Sodium chloride has traditionally been used in curing and preservation of meat and fish due to its capacity to improve the 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) and Graivier *et al*. (2006) 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 carrying out separate osmotic dehydration or solar drying. The objective of this study was therefore 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 glass- covered solar tunnel dryer.

2. MATERIALS AND METHODS

2.1 Description of the Solar Tunnel Dryer System

The solar tunnel dryer system used in this study (Figure 1) consisted of two chambers: the tunnel and the chimney sections. The tunnel section is used for heating the drying air before it enters the chimney. Both chambers are completely sealed from light to preserve light sensitive nutrients in fish. The tunnel section of the dryer measures 2.24m long, 1.2m wide and 0.54m high, and has a 19mm thick rectangular galvanised iron (GI) collector plate, which is painted black for enhanced absorption and emission of solar energy, and a glass cover-plate. The drying air is heated as it passes through the tunnel chamber, below the collector plate. The hot collector plate transmits heat to the drying air, which heats up before entering into the chimney chamber where drying takes place. Air temperatures in the solar energy harnessing section are measured between points A and B, respectively, using thermocouples, which log the temperatures to an automatic electronic data logger (Thermodac Eto Denki E, Shimadzu, Japan).

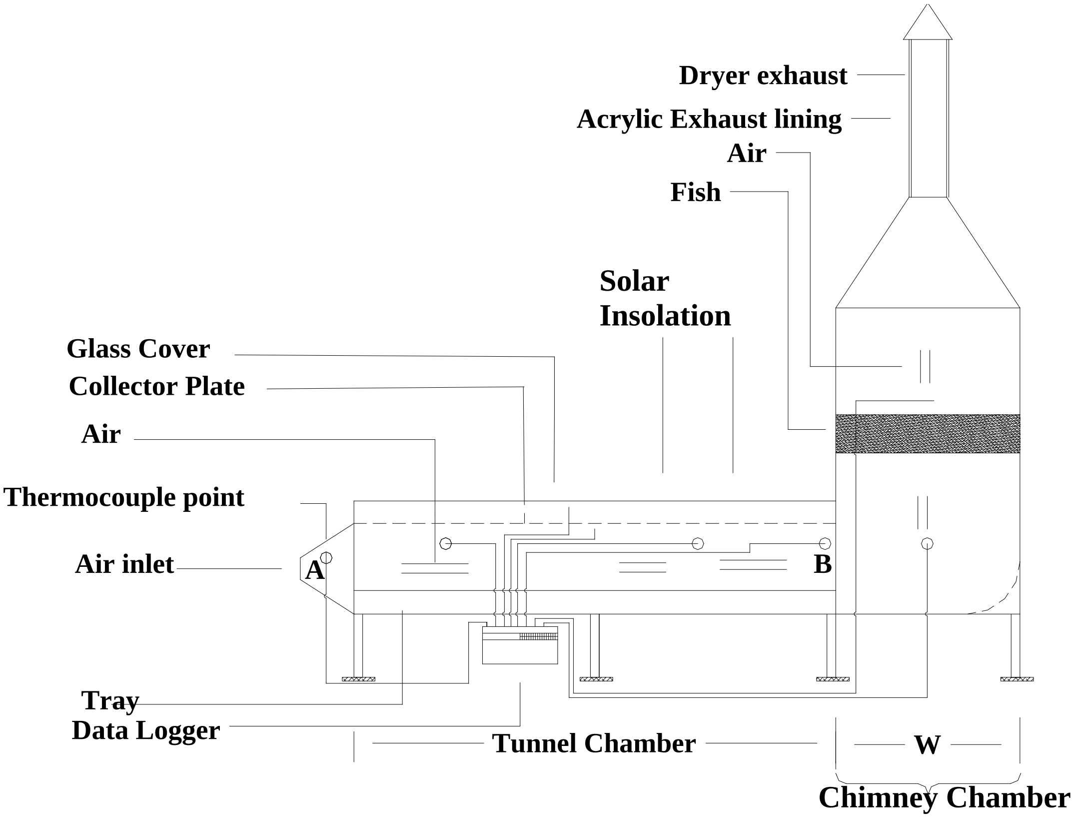

Figure 1. A schematic of a tunnel-cum-chimney solar dryer.

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 temperature sensing thermocouples were inserted into the chamber. 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 chamber measured 1.2 m by 0.9 m by 0.7 m for the rectangular cross-section, and 1.2 x 0.7 m at the bottom, and 0.2 m 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 trap solar energy for heating the exhaust air, in order to enhance natural convection. At the base of the exhaust pipe was a solar-driven suction fan which could induce forced convection in the dryer whenever necessary.

2.2. The Brining Process of Fish

Tilapia fish was procured from the fish landing sites along Tana River at Sagana, Kenya, then eviscerated, de-scaled and thoroughly washed, its heads removed, split open longitudinally and cut into a minimum of 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, divided into four sets of samples, each containing 40 pieces were soaked in brine with concentrations between 0 and 15%, in steps of 5% for 12 hours. After brining, three pieces of fish from each treatment were used to determine the moisture content before solar drying.

To determine the moisture content, a fish sample was weighed in a moisture dish of known weight using an electronic balance (Shimadzu, Japan) and its wet weight recorded, and then placed in a constant-temperature oven set at a temperature of 105°C for 12 hours. The sample was removed from the oven, and cooled in a desicator, after which its dry weight recorded. The dry basis moisture content was determined using equation 1, Where M is moisture content (kg/kg, db), W_t is the weight of wet sample and W_d is the weight of dry sample (Bala, 1997):

$$M = \frac{W_t - W_d}{W_d} \qquad (1)$$

2.3. The Fish Drying Process

After brining and initial fish moisture content determination, the remaining samples were placed in the solar tunnel dryer to dry. All the samples were placed on the same tray in the chimney section with clear separation, based on brine concentration. A plate of the tunnel dryer is presented in Figure 2, while the fish in the drying tray are presented in Figure 3. The dryer was 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 the electronic balance, at 30 minutes intervals for 40 hours. The 40 hours drying time was selected based on earlier studies Kituu *et al*. (2008) in which fish drying took 37 hours for moisture content to reduce to 15%.

Figure 2. The solar tunnel dryer.

Figure 3. Fish samples in dryer.

The data collected was used to plot graphs of moisture content and moisture ratio against drying time. Based on the Newton model of thin layer drying and observations by (Kingsly *et al.* 2007) and Uluko *et al.* (2006) for material drying under varying relative humidity as in solar drying, the moisture ratio equation can be expressed as equation 2, where MR is the moisture ratio (dimensionless), Mo is the initial moisture content (kg/kg, d.b), k is the drying rate constant (per sec) and t is the drying time (sec).:

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

The effective diffusivity was evaluated based on planar geometry for drying trays in which effective diffusivity is given by equation 3, where D is the effective diffusivity (m^2/s), L is half thickness of the drying fish (m) (Hassini, 2006):

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

3. RESULTS AND DISCUSSIONS

The relationship between the moisture content of tilapia fish and brine concentration after 12 hours of osmotic dehydration is presented in Figure 4. The figure shows that as the brine concentration increased the moisture content decrease linearly. The decrease in moisture content is consistent with the observations by Sereno *et al*. (2006), Kituu *et al*. (2007), and Mujaffar and Sankat (2006). This can be explained by the fact that since salt is hygroscopic, increase in its concentration increases the amount of salt particles for absorbing water molecules from the fish samples (Graivier *et al.*, 2006). In addition, more salt particles will be available to enter any voids in the fish samples for the aforementioned purpose. The best line of fit relating the moisture content of the fish samples and the brine concentration was drawn, and an equation corresponding to the line of fit established. The equation and the coefficient of determination are shown in Figure 4. Since the coefficient of determination (R^2) is high (0.9755), there is a strong correlation between moisture content and brine concentration.

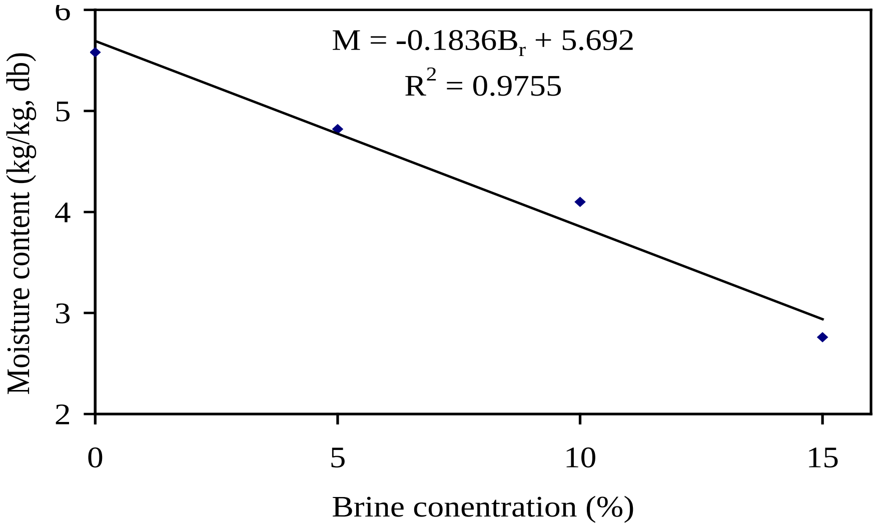

Figure 4. Relation between moisture content of tilapia fish and brine concentration during osmotic dehydration.

Figure 5 relates the moisture content of tilapia fish with drying time for different brine treatments (viz, 0, 5, 10 and 15%). The figure also presents the best curves of fit for the drying process for the various treatments. The figure shows that the drying process was faster for the first ten hours than in the later hours. In addition, it is seen from the figure that within the first twenty hours of drying the non-brined samples had the highest drying rate while the 15% brined samples had the least. Within this period the rate of drying of the fish decreased with increase in brine concentration. The bonding between the salt and water molecules seems to increase with increased brine concentration; hence, the reduced drying rate with increased brine concentration (Graivier *et al*., 2006, Jittinandana, 2002). The drying rate of the fish was not significantly different for the different treatments after 20 hours of drying. During this period, almost all the “free” water had diffused out of the fish samples, resulting in very low moisture being lost. The equilibrium moisture content values of 0.05, 0.09, 0.14 and 0.13 kg/kg (d.b) for brine concentrations of 0, 5, 10 and 15%, respectively, were obtained by extrapolating the curves in Figure 5. These values were attained after 40 hours of drying.

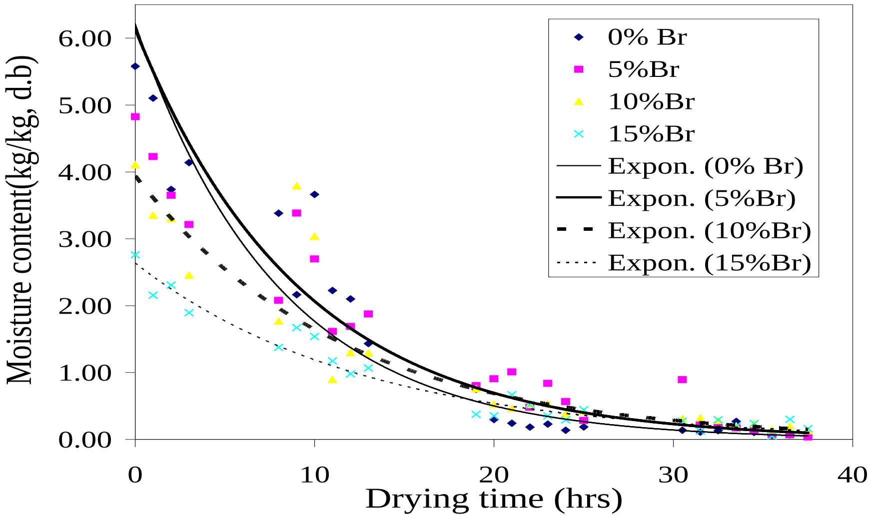

Figure 5. Characteristic drying curves for tilapia fish for different brine concentrations.

According to Brugay (2003) the safe storage moisture content values of fish at 0 and 15% brine concentrations are 0.15 and 0.35 kg/kg, d.b., respectively. From Figure 5 these values are attained after 30 and 27 hours of drying, respectively. Further drying of the fish samples beyond the established time limits may be unnecessary as extra time and energy will be expended at the expense of quality.

Figure 6 illustrates the relationship between moisture ratio and drying time for the four brine treatments. The best curves of fit for the four treatments are also presented the figure. The corresponding equations and their respective R^2 values are shown in equations 4-7. In these equations, $M_{0, 5, 10, 15}$ are the moisture content values at 0, 5, 10 and 15% brine concentration, respectively. The results show that moisture ratio decreased exponentially with drying time. They also show that there exists a strong correlation between moisture ratio and drying time as the values of R^2 are high (0.886-0.9393). The drying rate constant (k) values ranged from 0.0813-0.1217 per hour for 0-15% brine concentrations. However, the values decreased with increase in brine concentration.

$$MR_0 = \exp(-0.1217t),\ R^2 = 0.9228, \tag{4}$$

$$MR_5 = \exp(-0.0998t),\ R^2 = 0.886, \tag{5}$$

$$MR_{10} = \exp(-0.0889t),\ R^2 = 0.9393, \tag{6}$$

$$MR_{15} = \exp(-0.0813t),\ R^2 = 0.9228, \tag{7}$$

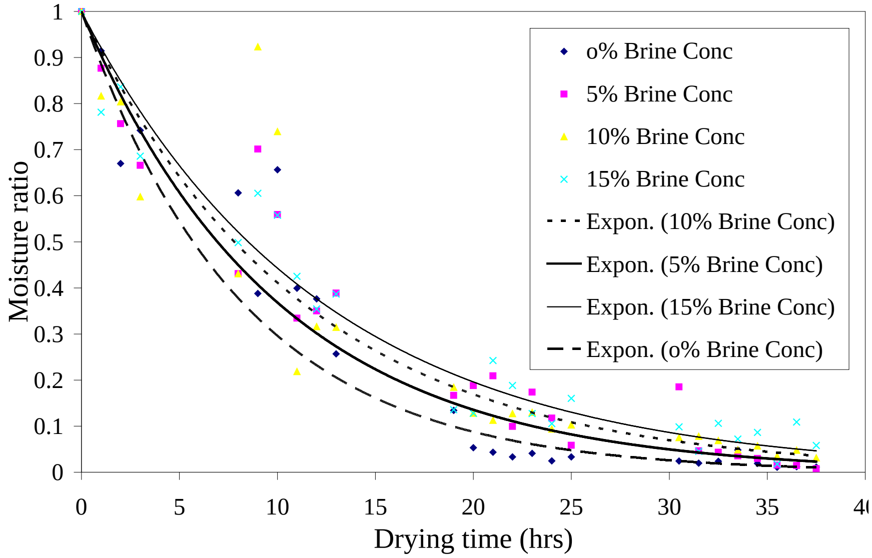

Figure 6. Moisture ratio curves for tilapia drying under different brine treatments.

Based on equation 3 and the k values in equations 4-7, values of the effective diffusivity (D) were found to range between 5.72x10^{-11} and 8.56x10^{-11} m^2/s for brine concentrations lying between 0 and 15% (Table 1). The values of D decreased as brine concentration increased. The values of D obtained in this study compare well with those established by Graivier *et al*. (2006) and Kituu *et al*. (2008). who carried similar work on pork meat. Thus, although brining achieves osmotic dehydration, it results in reduction in the rate of drying of tilapia in a solar tunnel dryer. It can thus be concluded that brining achieves significant reduction in the moisture content of fish when dried in a glass covered solar tunnel dryer and reduces the drying rate.

Table 1. Variation of drying rate constant (k) and effective diffusivity (D) with brine concentration

Brine concentration (%)	k (h^{-1})	Dx10^{-11} (m^2/s)
0	0.1217	8.56
5	0.0998	7.02
10	0.0889	6.26
15	0.0813	5.72

4. CONCLUSIONS

The results of this study show that when tilapia fish is brined, the moisture content reduces linearly with increased brine concentration, and that there exists a high correlation (R^2=0.9755). The results also show that brining reduced the drying rate of tilapia fish when dried in a glass-covered solar tunnel dryer. The drying rate constant and the effective diffusivity varied between 0.0813 and 0.1217 per hour, and between 5.72 and 8.56x10^{-11} m^2s^{-1}, respectively, for brine concentrations ranging between 0 and 15%, and that they also decreased with increased brine concentration. These results provide useful information that can be applied in the modelling and design of solar drying systems for tilapia fish.

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