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Experimental Evaluation of Drying Characteristics of Animal's Hide and Skin with Different Drying Media

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Authors' contributions

This work was carried out in collaboration between all authors. Author JNO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors CEO and JAU managed the analyses of the study. Authors CEO and JNO managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The design and development of low-cost drying technologies suitable for animal hides and skins in rural areas require a clear knowledge of its characteristics. Therefore, the aim of this study is to carry out the experimental evaluation of drying characteristics of animal's hide and skin with different drying media.
Study Design: Experimental Study Design was used in the study.
Place and Duration of Study: The study was conducted in the Faculty of Engineering workshop, Nnamdi Azikiwe University, Awka, Nigeria from June 2016 and July 2017.
Methodology: Samples of cattle hides, donkey hides and sheepskins were used. The hides and skins were thoroughly washed to ward off blood and dirt. Different drying techniques employed include solar drying, oven drying, open sun drying and hot air conventional drying. The effect of drying air speed and temperature on the drying of cattle hides, sheepskin and donkey hide was also investigated under varying conditions. Classical equations were utilized in calculating Water Activity, Mold-Freed Shelf Life (MFSL), Effective Moisture Diffusivity D_{eff}, Shrinkage Ratio (S_R) and Moisture Ratio (MR).

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Results: Computation of mold-free shelf life (MFSL) showed 1790 days for the dried products. The result revealed that the effective moisture diffusivity of Donkey hide is generally greater than that of Sheepskin and Cattle hide. The moisture diffusion constant ranged from 1.1213 x 10^{-8} m^2/s to 2.2797 x 10^{-8} m^2/s, 1.0128 x 10^{-8} m^2/s to 1.5046 x 10^{-8} m^2/s and 1.34815 x 10^{-8} m^2/s to 1.7326 x 10^{-8} m^2/s for Solar Dried Donkey Hide (SDDH), Solar Dried Sheep Skin (SDSS) and Solar Dried Cattle Hide (SDCH) respectively as the air speed increased from 2.0 to 4.0 m^2/s.

Conclusion: The drying of Cattle hide, Sheepskin and Donkey hide occur mainly in the falling rate period. The drying time decreased with air-speed and temperature. The water activity-dependent of the moisture content and its value affects the estimated mold-free shelf life. The effective moisture diffusivity increased with the air speed and temperature.

Keywords: Solar drying; oven drying; open sun drying; hot air conventional drying; water activity; Mold Free Shelf Life and shrinkage ratio.

ABBREVIATIONS

UDCH= Undried Cattle Hide
UDSS= Undried Sheep Skin
UDDH= Undried Donkey Hide
CDCH= Conventional Dried Cattle Hide,
CDSS= Conventional Dried Sheep Skin
CDDH= Conventional Dried Donkey Hide
SDCH= Solar Dried Cattle Hide,
SDSS= Solar Dried Sheep Skin,
SDDH= Solar Dried Donkey Hide
ODCH= Oven Dried Cattle Hide
ODSS= Oven Dried Sheep Skin
ODDH= Oven Dried Donkey Hide
*S*DCH= Sun Dried Cattle Hide*
*S*DSS= Sun Dried Sheep Skin*
*S*DDH= Sun Dried Donkey Hide*

1. INTRODUCTION

Hides and skins are one of the most valuable exports for many developing countries and play an integral role in the livelihoods of communities as a source of income and employment. However, decaying of this bye product of animal husbandry is caused mainly by the activities of the micro-organisms and enzymes on the product. Raw hides and skins are 60-70% water and 25-30% protein [1]; therefore preservation of animal hides and skin is to limit the activities and growth of micro-organisms on it.

Raw material quality is a primary concern of tanners the world over. The tanning industry and its downstream industries entirely depend on supplies of cattle hides and sheepskins, plus a small number of goat and other skins like donkey. The factors that affect the growth of the micro-organisms are intrinsic and extrinsic factors [2]. The intrinsic factors involve pH, moisture content, water activity, oxidation-reduction potentials, the physical structure of the produce, available nutrients, presence of anti-microbial agents etc., while the extrinsic factors involve temperature, relative humidity, carbon IV oxide or oxygen, types and numbers of micro-organisms in the produce. The water activity and moisture content are considered the major factors among these factors because water is one of the most critical factors for life. Without water, agricultural items become inhospitable for the growth and activities of enzymes and micro-organisms.

One of the important ways of preserving animal produce is through drying. Drying is one of the major engineering unit operations. It does not involve chemical reactions but the physical process of removing moisture through mass transfer. Food drying reduces the water activity of the foodstuffs in order to extend the shelf life thereby preventing its decay [3], It is defined as a process of moisture removal due to simultaneous heat and mass transfer [4-6].

However, materials derived from wild animals (generally referred to as game skins) may also be significant, particularly in Africa where the ranching and farming of species of antelope, crocodile, ostrich and even some fish, is increasingly important. Hides are 1.5-4.5 square meter in size and weigh about 15-30 kilograms (kg) and similarly, skins are 0.4-0.5 square meter in size and around 20 kg in weight [7]. Behailu [8] reported that hides and skins have been used since antiquity as clothes, vessels, bedding, and possibly structurally in ancient dwelling places.

Hides and skins, raw materials for the tanning industry, are renewable and easily perishable [9].

Development of low-cost drying technologies suitable for animal hides and skins in rural areas requires a clear knowledge of its characteristics. Behailu [8] examined major factors affecting the production and quality of hide and skin. Mohamed, VanKlink & ElHassan [10] established dimensions of damages caused by spoilage bacteria to the structure of cattle hides and sheepskins. Different strategies for hides and skins preservation is well documented in the literature, Sivabalan & Jayanthi [11] carried out a study to reduce salt usage in preservation of skins and considered an alternate use of plant extract. Kudit, Nour, Gasmelseed & Musa [1] evaluated the effect of re-used salt and biocide preservation method on various characteristics of sheep leather and concluded that each time salt is re-used for 'stack' salting, the number of bacteria and other contaminants increases.

Obviously, poorly preserved hides and skins are of very little economic and commercial value [12], hence the objective of drying should be to dry the hides and skins whilst optimizing the quality and area yield. Ertekin & Yaldiz [4] considered thin layer drying model for egg plant, Waewsak, Chindaruksa, & Punlek [5] conducted mathematical modelling study of hot air drying for some agricultural products. Afolabi & Agarry [6] carried out mathematical modelling and simulation of the mass and heat transfer of batch convective air drying of tropical fruits, Alam [3] modelled thin layer drying kinetics of grape juice concentrate of grape leather.

The physical quality of the hide or skin is to a large extent related to the amount of damage to the outside surface [8], hence the major problem affecting the tanning industry is similar to poor processing and handling of hides and skins. There is need to minimize or avoid damages to animal's hides and skins altogether by better management of the hide and skin through structure drying procedure. The aim of this study, therefore, is to analyze the drying characteristics of animal's hide and skin in different drying media.

2. MATERIALS AND METHODS

Cattle hides and Sheepskins were obtained from Gariki Amansea cattle market, Awka, Anambra State, Nigeria whereas Donkey hides were obtained from Nkwo market 135 Ezzamgbo in Ohaukwu L. G. A Ebonyi State, Nigeria. The samples measuring 730 sq cm with an average thickness of 0.45 cm each were stored in a refrigerator that was maintained at 4℃ and 60% relative humidity for tissue stabilization. Samples of cattle hides, donkey hides and sheepskins were used. The hides and skins were thoroughly washed to ward off blood and dirt. Readings of temperature were taken using LCD Multi-Thermometer (Mextech) with the mean deviation of $\pm$ 1℃, + 2℉. All the mass measurements were obtained using Lab Tech BL7501 Electronic Compact Scale with the mean deviation of ± 0.1 g and a stopwatch. Measurements involving length were carried out using Raider Digital Caliper with mean deviation + 0.1 mm. relative humidity reading was taken using Hygrometer and Humidity calculator of capacity -10℃ to 120℃, considering dry and wet bulb temperatures.

The Oven drying experiment was carried out using Lab-Tech Oven 14 by 14 with Serial Number 03108 and rating 500 Watts. The Natural convection solar cabinet dryer was used which has solar collector plate, glass cover, air blower of maximum speed 6 m/s, etc whereas the laboratory hot air conventional dryer with a temperature controller of maximum temperature reading of 0℃ to 500℃ and drying speed between 1.5 m/s to 4.5 m/s. The direct sun drying had the hide or skin hung on a crossbar with metallic peg and the drying took place under the climatic weather condition. Each sample was dried until there was no more change in mass for about 3 hours. Reading of time and mass were properly taken and error due to parallax avoided. Water in hides and skins which is not bound to the molecules of the hides and skins can support the growth of bacteria, yeasts and molds (fungi). Therefore, the term water activity (a_w) refers to this unbound water. The term water activity is widely used in the leather industry as an indicator of water available in a product. Water activity can be defined as

$$a_w = \Phi = \frac{P_w}{P_{ws}} \tag{1}$$

Where Φ = relative humidity, P_w = partial pressure of water vapour at any particular conditions; P_{ws} = partial pressure of water vapour at saturation and the temperature specified.

Thus, water activity is the Equilibrium Relative Humidity (ERH) decimal form for a product at any given temperature and moisture content. Olaoye et al., [13] developed and alternative model in equation 2 for calculating water activity a_w

$$a_w = 1 - \exp[-\exp(0.914 + 0.5539 \ln M)] \quad (2)$$

Where

$$M = \frac{M_f}{100 - M_f} \quad (3)$$

M_f = Moisture content and then

$$ERH = 100a_w \quad (4)$$

Mold-Freed Shelf Life (MFSL) is the estimated period of time that a dried hide/skin sample can stay before it can be attacked by molds and bacteria. It is influenced by the water activity of the sample. It is expressed by the formula given by Man and Jones [14] as:

$$MFSL = 10^{7.91 - 8.1a_w} \quad (5)$$

The moisture transfer during drying process is checked by internal diffusion [15] and the internal diffusion occurring during the falling rate period for most materials is defined by Fick's second law ofdiffusion [16] of equation 6 with the assumptions of moisture transfer by diffusion, negligible shrinkage, and constant diffusion coefficients and temperature.

$$\frac{\partial M}{\partial t} = D\nabla^2 M \quad (6)$$

Where D = diffusivity, M = mass, t = time

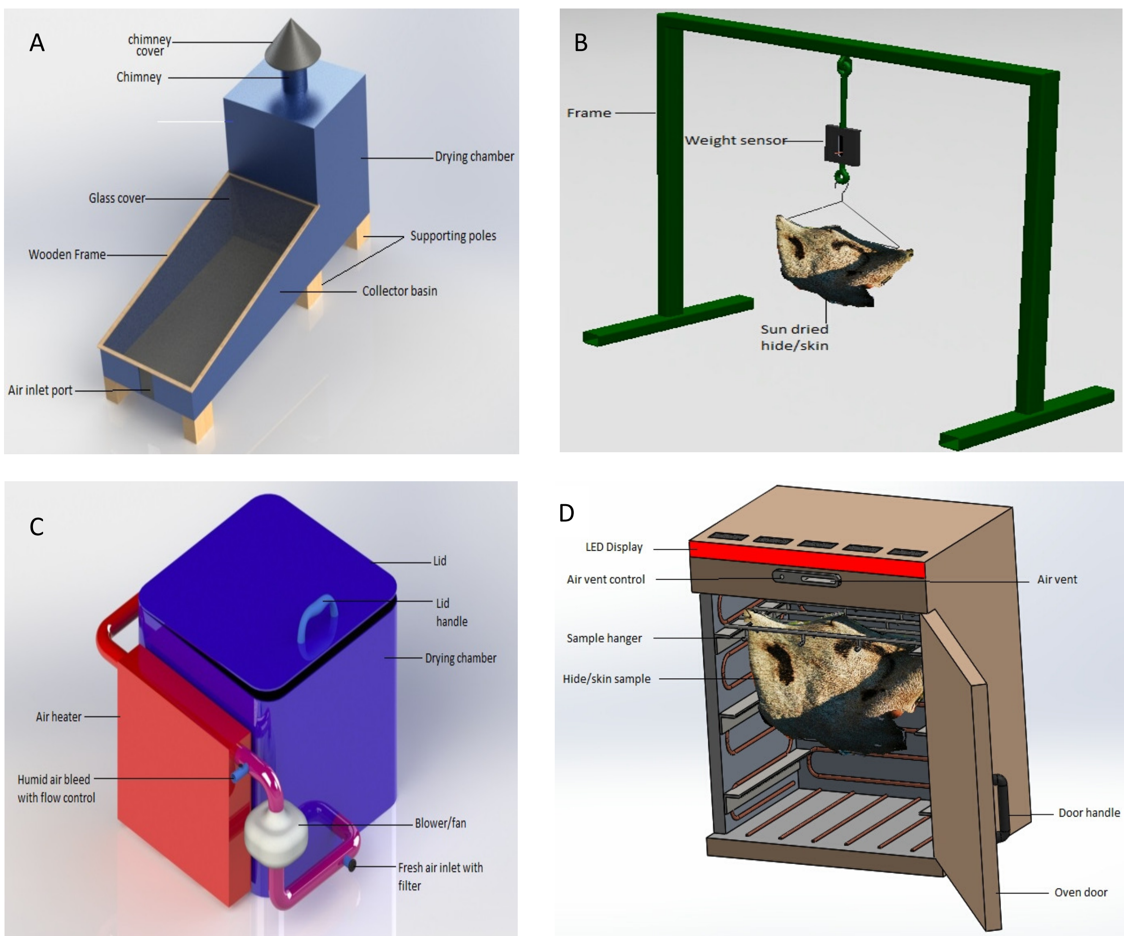

Fig. 1. Schematics of experimental setup for (A) Solar dryer, (B) Sun drying, (C) Hot Air Conventional dryer and (D) Oven dryer

The effective moisture diffusivity D_{eff} was determined by plotting the experimental data in terms of an(MR) against drying time (t) and then using the slope in equation 7. Also, the Moisture Content (MC) was determined from equation 8.

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$$D_{eff} = \frac{-\text{slope}}{\left[\frac{2.4674}{H^2}\right]} \quad (7)$$

$$MC(\%) = \frac{M_i - M_d}{M_i} \times 100 \quad (8)$$

Where H = half thickness of sample; M_i = mass of sample before drying and M_d = mass of sample after drying.

To describe the shrinkage of the hides/skins, Volume Ratio (V_R) and Apparent Density (g_t) were given by

$$V_R = \frac{V_t}{V_o} \quad (9)$$

$$g_t = \frac{W_t}{V_t} \quad (10)$$

However, Volume Ratio (V_R) can be described by the linear empirical model of equation 11.

$$V_R = aM_t + b \quad (11)$$

Where *a* and *b* are the coefficient and the constant of the model, respectively. V_o = initial volume, V_t = volume of the material at a given time t and W_t the weight of the material at a given time t.

The mass Shrinkage Ratio (S_R) is one of the most important structural variations appearing on hides/skins due to weight loss and it is given by [17].

$$S_R = \frac{W_t}{W_o} \quad (12)$$

Where W_o = weight at initial time

Experimentally, moisture ratio can be determined assuming that the material layer is thin enough or the air velocity is high so that the conditions of the drying air (relative humidity and temperature) are kept constant throughout the material. Moisture ratio values can be calculated for the drying using the moisture contents at the initial time, equilibrium time and at that particular time:

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad (13)$$

Where MR = the moisture ratio (no unit), M_t = the moisture content at any given time (kg water/ kg solids), M_e = equilibrium moisture content (kg water/kg solids) and M_o = the initial moisture content.

The value of M_e is relatively small compared with M_t and M_0 especially for hide/skin materials [18,19,20]. Therefore, M_e can be assumed zero, hence the MR can be simplified further as

$$MR = \frac{M_t}{M_o} \quad (14)$$

Akpinar et al [21] reported that the rate of drying agricultural products can be expressed using the following equation.

$$D_r = \frac{M_{t+dt} - M_t}{dt} \quad (15)$$

Where D_r = the drying rate (g/mins), dt = the time interval

The drying rate was obtained by evaluating the time to remove a given quantity of moisture from the agricultural products. The drying rate normally decreases as air velocity and temperature increase during drying.

3. RESULTS AND DISCUSSION

3.1 Water Activity (a_w) and Estimated Mold-Free Shelf Life (MFSL)

In Fig. 2, the samples which were not dried have water activity of more than 0.9 which enhances the growth of most microorganisms. It is seen that the water activity decreased significantly after drying to less than 0.5 which do not trigger most microorganisms. The least water activity was observed in the oven dried products.

Fig. 3 showed that the dried products have an approximate MFSL of 1790 days. This implies that the products can be preserved after drying

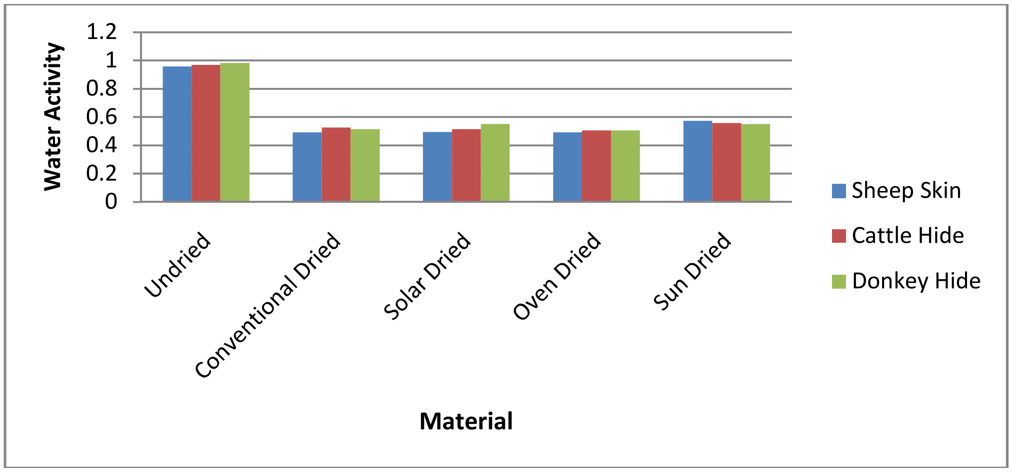

Fig. 2. Variation of water activity with different drying methods of cattle hide, sheep skin and donkey hide

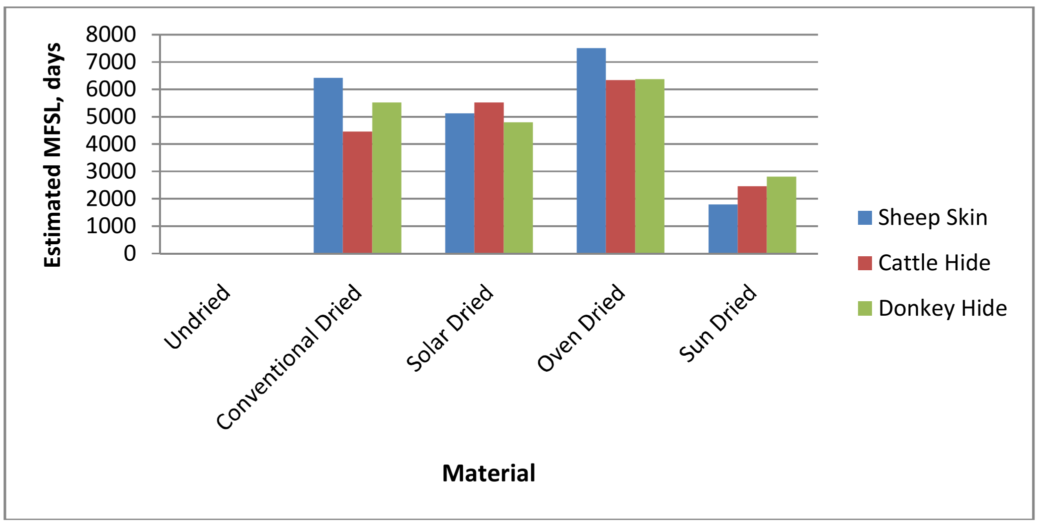

Fig. 3. Effects of the different drying methods on the estimated MFSL of cattle hide, sheep skin and donkey hide

for an estimated period of 5 years and above. The MFSL was found to be dependent on the water activity in such a way that the MFSL decreases with increase in water activity.

3.2 Effect of Water Content on Hides/Skins

The effect of water content of the hide/skin samples is given in Figs. 4 and 5 including Table 1 to 3. The moisture content was seen to decrease with time as expected because according to John et al. [22] drying removes the water molecules in agricultural materials. For the Sheepskin, S*DSS and SDSS attained equilibrium moisture content at 1860 minutes and 780 minutes respectively, Donkey hide required 2040 minutes and 960 minutes to achieve equilibrium moisture content for S*DDH and SDDH respectively while for the Cattle hide, a time of 1920 minutes and 840 minutes was needed to attain equilibrium moisture content for S*DCH and SDCH respectively. Donkey hide took a long time to attain equilibrium moisture content because of its larger thickness ratio at constant mass with other samples.

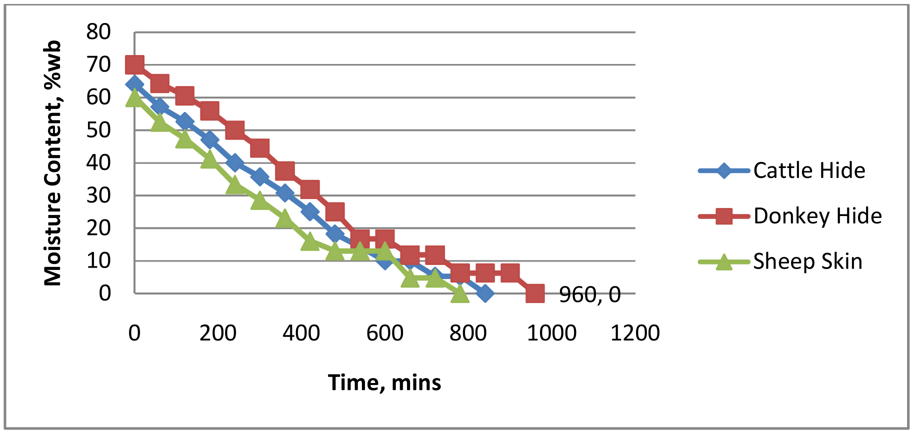

Fig. 4. Effect of moisture content against time for Solar dryer on hide/skin

These results showed that thicker product is slow in approaching equilibrium moisture content and with slower drying rate, this is in line with the reports of Etoamaihe and Ibeawuchi, [23] in the drying of cassava slices. Further considerations showed that the drying time increases as the product becomes thicker with lesser surface area at fixed temperature, this is similar to the results obtained by Aremu et al. [24] when investigating the effect of thickness on drying kinetics of mango.

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3.3 Effect of Temperature Variation on Drying Rate Using Oven Dryer

Figs. 6 to 8 showed the effect of temperature on the drying processes for oven dryer temperatures ranging from 40℃ and 70℃. This temperature was used because using a very high temperature may cause such item to be hardened on the surface [25]. The results explained that the drying time was reduced as the temperature increased. This is due to the fact that as the temperature increased, the average kinetic energy of the moisture increases making it easier for the moisture to diffuse out of the product samples.

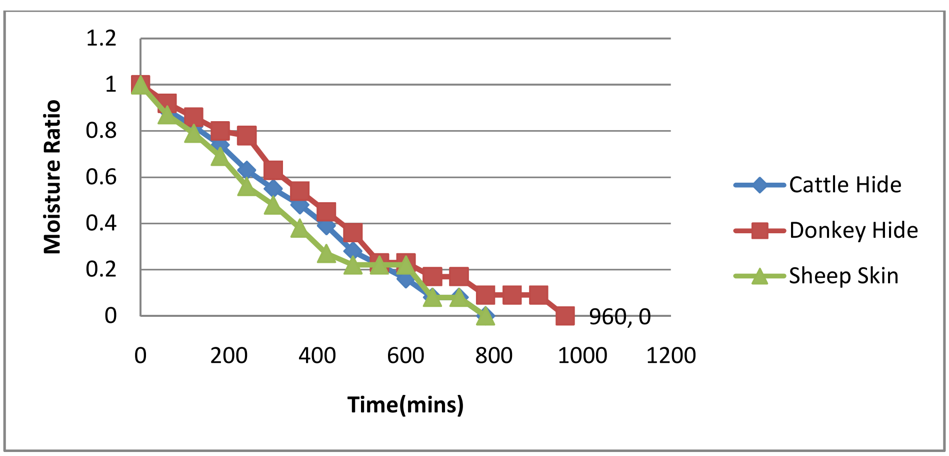

Fig. 5. Effect of moisture ratio against time for solar dryer on hide/skin

Table 1. Effect of moisture content and moisture ratio with time for conventional dryer on hide/skin

Time (mins)	Moisture content			Moisture ratio		
	Cattle hide	Donkey hide	Sheep skin	Cattle hide	Donkey hide	Sheep skin
0	64.00	70.00	60.00	1.00	1.00	1.00
60	56.1	63.41	53.49	0.88	0.91	0.89
120	51.35	59.46	47.37	0.78	0.85	0.79
180	50.00	54.55	41.18	0.56	0.78	0.59
240	37.93	50.00	31.03	0.55	0.71	0.52
300	35.71	46.43	28.57	0.48	0.66	0.48
360	33.33	42.31	25.93	0.39	0.66	0.43
420	30.77	37.50	23.08	0.34	0.59	0.33
480	28.00	31.82	20.00	0.28	0.45	0.29
540	25.00	25.00	16.00	0.22	0.36	0.27
600	21.74	21.05	13.04	0.16	0.3	0.22
660	18.18	16.67	9.09	0.08	0.24	0.15
720	14.29	11.76	4.76	0.05	0.17	0.08
780	10.00	11.76	0.00	0.03	0.17	0.00
840	5.26	6.25	------	0.01	0.09	------
900	0.00	6.25	------	0.00	0.09	------
960	------	6.25	------	------	0.09	------
1020	------	0	------	------	0.00	------

Table 2. Effect of moisture content and moisture ratio with time for oven dryer on hide/skin

Time (mins)	Moisture content			Moisture ratio		
	Cattle hide	Donkey hide	Sheep skin	Cattle hide	Donkey hide	Sheep skin
0	64.00	70.00	60.00	1.00	1.00	1.00
60	57.14	64.29	52.38	0.89	0.92	0.87
120	52.63	60.53	47.37	0.82	0.86	0.79
180	47.06	55.88	41.18	0.74	0.80	0.69
240	40.00	50.00	33.33	0.63	0.71	0.56
300	35.71	44.44	28.57	0.56	0.63	0.48
360	30.77	37.5	23.08	0.48	0.54	0.38
420	25.00	31.82	16.00	0.39	0.45	0.27
480	18.18	25.00	13.04	0.28	0.36	0.22
540	14.29	16.67	4.76	0.22	0.24	0.08
600	10.00	11.76	0.00	0.16	0.17	0.00
660	5.26	6.25	------	0.08	0.09	------
720	0.00	6.25	------	0.00	0.09	------
780	------	0.00	------	------	0.00	------

It was seen that higher temperature drying did not affect the drying time so much as would have been expected. This is probably because the air circulation inside the Oven is insufficient. In the drying of ODCH, ODSS and ODDH, as the drying temperature reduces from 70℃ to 40℃, the time taken to reach the equilibrium moisture content in the product increased from 720, 600 and 780 minutes to 1500, 1380 and 1620 minutes for ODCH, ODSS and ODDH respectively.

3.4 Determination of Mass Shrinkage Ratio

The variation of the mass shrinkage ratio with time for the different drying methods is shown in Figs. 9 and 10 including Table 4. Shrinkage was observed to have occurred in the early stages of the drying and seen to be tending towards a constant value in the later stages. This is because, towards the end of the drying, the surface became drier than the centre making

Table 3. Effect on hide/skin of moisture content and moisture ratio with time as dried by Sun

Time (mins)	Moisture content			Moisture ratio		
	Cattle hide	Donkey hide	Sheep skin	Cattle hide	Donkey hide	Sheep skin
0	64.00	70.00	60.00	1.00	1.00	1.00
60	62.50	68.09	58.33	0.98	0.97	0.97
120	60.87	67.39	56.52	0.95	0.96	0.94
180	59.09	65.91	54.55	0.92	0.94	0.91
240	57.14	64.29	52.38	0.89	0.92	0.87
300	55.00	62.5	50.00	0.86	0.89	0.83
360	52.63	60.53	47.37	0.82	0.86	0.79
420	50.00	58.33	44.44	0.78	0.83	0.74
480	47.06	55.88	41.18	0.74	0.80	0.69
540	43.75	53.13	37.50	0.68	0.76	0.63
600	40.00	50.00	33.33	0.63	0.71	0.56
660	37.93	46.43	31.03	0.59	0.66	0.52
720	35.71	42.31	28.57	0.52	0.60	0.48
780	33.33	37.50	25.93	0.48	0.54	0.43
840	30.77	34.78	23.08	0.44	0.50	0.38
900	28.00	31.82	20.00	0.39	0.45	0.33
960	25.00	28.57	16.00	0.33	0.41	0.27
1020	21.74	28.57	16.00	0.28	0.41	0.27
1080	18.18	25.00	16.00	0.28	0.36	0.27
1140	18.18	25.00	13.04	0.22	0.36	0.22
1200	14.29	21.05	13.04	0.22	0.30	0.22
1260	14.29	21.05	13.04	0.22	0.30	0.22
1320	14.29	21.05	9.09	0.16	0.30	0.15
1380	10.00	16.67	9.09	0.16	0.24	0.15
1440	10.00	16.67	9.09	0.16	0.24	0.15
1500	10.00	16.67	9.09	0.16	0.24	0.15
1560	10.00	11.76	4.76	0.08	0.17	0.08
1620	5.26	11.76	0.00	0.08	0.17	0.00
1680	0.00	11.76	------	0.00	0.17	------
1740	------	6.25	------	------	0.09	------
1800	------	0.00	------	------	0.00	------

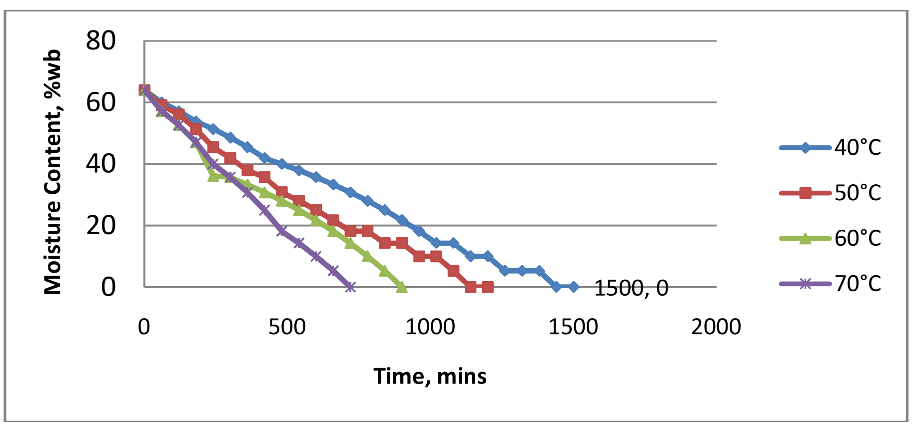

Fig. 6. Effect of temperature on moisture content against time for oven dried cattle hide

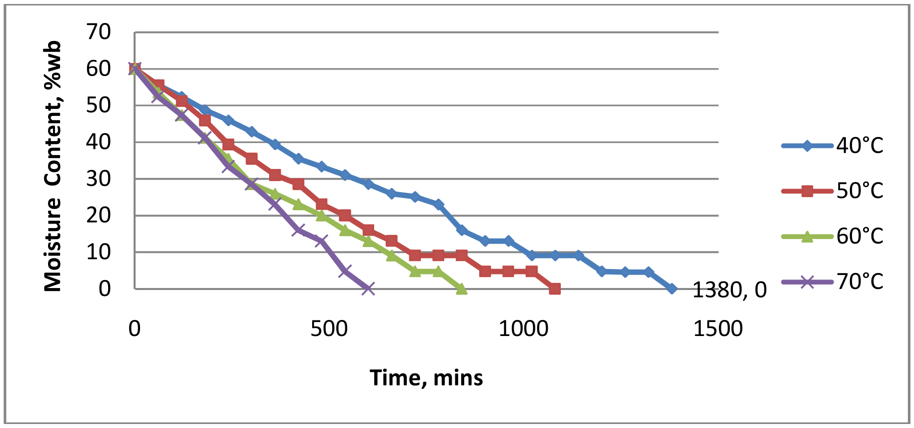

Fig. 7. Effect of temperature on moisture content against time for oven dried sheep skin

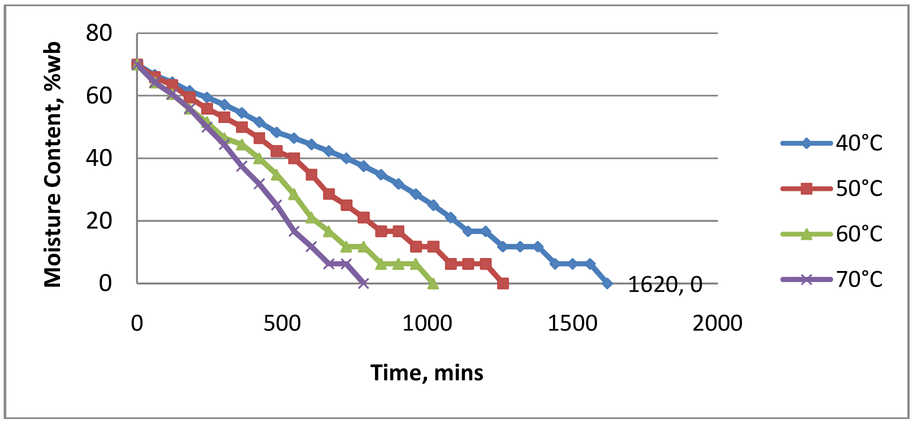

Fig. 8. Effect of temperature on moisture content against time for oven dried donkey hide

the surface stiff and hence limits the shrinkage [26]. To achieve minimized shrinkage, low-temperature drying should be employed so that moisture gradients throughout the products will be minimized. Moisture gradient occurring inside the hide/skin during drying generates stresses in the cellular structure of the hide/skin resulting in the structural collapse which response to the physical changes of shape and dimension or the volume change of material [27]. However, solar dried hide/skin showed a closer shrinkage pattern when compared with other drying techniques whereas oven dried hide/skin showed a wider shrinkage pattern making them shrink faster.

3.5 Effect of Air Speed and Temperature on Effective Moisture Diffusivity

The result of the effective moisture diffusivity was determined using the Solar dryer while the variation of temperature with the effective moisture diffusivity was investigated using the oven dryer, these are presented in Table 5. It shows the effects of air speed (m/s) on the values of the effective diffusion constant for SDCH, SDSS and SDDH. It was observed that the coefficient of determination was high indicating that there is a good correlation. The result revealed that the effective moisture diffusivity of Donkey hide is generally greater than that of Sheepskin and the later greater than Cattle hide. The moisture diffusion constant ranged from 1.1213 x 10^{-8} m^2/s to 2.2797 x 10^{-8} m^2/s, 1.0128 x 10^{-8} m^2/s to 1.5046 x 10^{-8} m^2/s and 1.34815 x 10^{-8} m^2/s to 1.7326 x 10^{-8} m^2/s for SDDH, SDSS and SDCH respectively as the air speed increased from 2.0 to 4.0 m^2/s. This is because there is the greater absorption of moisture from the sample surface at higher air speed. It leads to an increase in the moisture content gradient of the sample and hence an increase in the effective moisture diffusivity. Motevali et al. [28] and Mohsen [29] reported a similar trend of direct variation of velocity and effective moisture diffusivity in the thin-layer drying of jujube and apple slices respectively. Also, the range of values obtained in this work is similar to the values of 4.54 x 10^{-10} m^2/s to 1.08 x 10^{-9} m^2/s obtained in the solar drying of basil leaves by Shahi et al. [30].

Variation of temperature with the effective moisture diffusivity was investigated using the oven dryer and shown in Table 5. The results ranged from 4.9678 x 10^{-9} m^2/s to 1.08697 x 10^{-8} m^2/s for ODCH, ODSS and ODDH. The coefficients of determination were higher than 0.95 implying that there is a good fit correlation. These values are in the range reported by various authors and researchers. Minaei et al. [31] reported effective moisture diffusivity of pomegranate arils in the range of 3.43 x 10^{-10} m^2/s to 32.05 x 10^{-10} m^2/s for microwave drying. Tulek [32] equally reported moisture diffusion constant between 9.619 x 10^{-10} m /s to 1.556 x 10^{-10} m /s in drying mushroom slices at the same temperature of 40℃ to 70℃ used in this work. The table also indicated that increase in temperature increases the effective moisture diffusivity for ODCH, ODSS and ODDH. This trend is in agreement with the effects reported by various authors for agricultural products such as melon seeds [33], kale [34] and red chillies [35]. This outcome can be attributed to the fact there is an increase in the activity of water molecules and a decrease in water viscosity as the temperature increases.

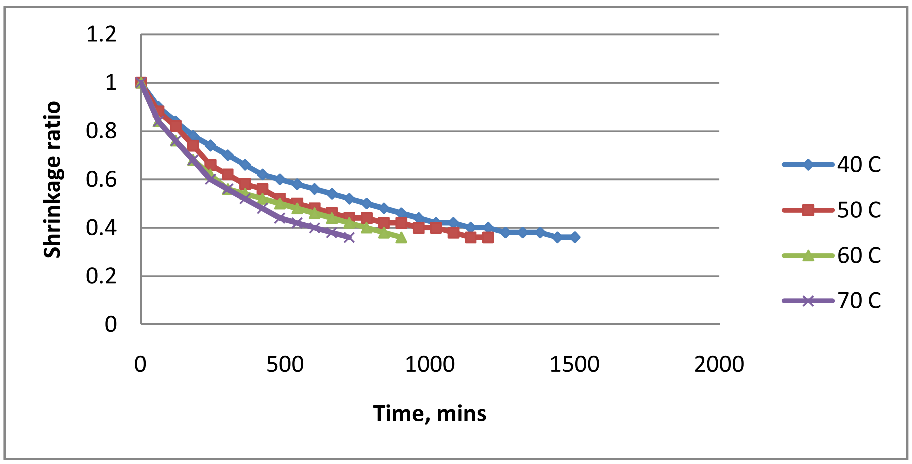

Fig. 9. Plot of Shrinkage ratio against time at different temperature for oven dried cattle hide

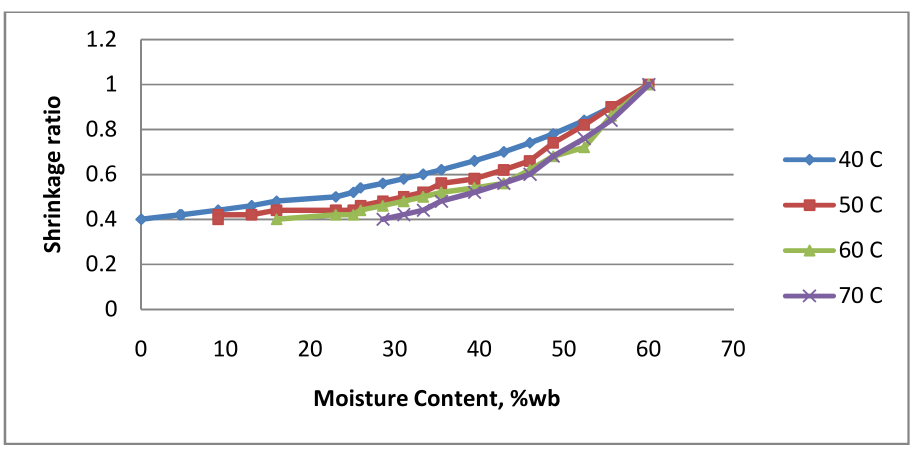

Fig. 10. Plot of Shrinkage ratio against moisture content at different temperatures for oven dried sheep skin

Table 4. Variation of shrinkage ratio with moisture content and time for conventional and solar dried donkey hide

Time (mins)	Moisture content (%)	Conventional dryer Shrinkage ratio (70℃)			Solar dryer Shrinkage ratio		
		2 m/s	3 m/s	4 m/s	2 m/s	3 m/s	4 m/s
0	70.00	1.00	1.00	1.00	1.00	1.00	1.00
60	63.41	0.82	0.82	0.80	0.84	0.84	0.84
120	59.46	0.74	0.72	0.70	0.76	0.76	0.72
180	54.55	0.66	0.62	0.60	0.68	0.68	0.68
240	50.00	0.60	0.56	0.54	0.60	0.60	0.62
300	46.43	0.56	0.50	0.50	0.54	0.54	0.54
360	42.31	0.52	0.46	0.44	0.48	0.48	0.48
420	37.5	0.48	0.42	0.40	0.44	0.44	0.44
480	31.82	0.44	0.38	0.36	0.40	0.40	0.36
540	25.00	0.40	0.36	0.34	0.36	0.36	0.36
600	21.05	0.38	0.34	0.32	0.36	0.36	0.34
660	16.67	0.36	0.34	0.30	0.34	0.34	0.34
720	11.76	0.34	0.32	-----	0.34	0.34	0.32
780	11.76	0.34	0.32	-----	0.34	0.32	0.32
840	6.25	0.32	0.30	-----	0.32	0.32	0.30
900	6.25	0.32	-----	-----	0.32	0.30	-----
960	6.25	0.32	-----	-----	0.32	-----	-----
1020	0.00	0.30	-----	-----	0.30	-----	-----

Table 5. Result of drying air speed and temperature on the effective moisture diffusivity

Air speed (m/s)	$D_{eff}(m^2/s)$	R^2	Temperature (℃)	$D_eff(m^2/s)$	R^2
Cattle Hide					
2.0	1.3482 x 10^{-8}	0.989	40	6.2332 x10^{-9}	0.988
3.0	1.5367 x 10^{-8}	0.989	50	6.9978 x10^{-9}	0.993
4.0	1.7326 x 10^{-8}	0.990	60	8.234 x 10^{-9}	0.989
			70	9.0095 x 10^{-9}	0.981
Sheep Skin					
2.0	1.0128 x 10^{-8}	0.969	40	8.7617 x 10^{-9}	0.989
3.0	1.3299 x 10^{-8}	0.961	50	9.0723 x 10^{-9}	0.995
4.0	1.5046 x 10^{-8}	0.955	60	9.6781 x 10^{-9}	0.992
			70	1.0870 x 10^{-8}	0.992
Donkey Hide					
2.0	1.1213 x 10^{-9}	0.989	40	4.9678 x 10^{-9}	0.993
3.0	1.8214 x 10^{-9}	0.990	50	5.8142 x 10^{-9}	0.995
4.0	2.2797 x 10^{-9}	0.990	60	6.0017 x 10^{-9}	0.992
			70	6.5291 x 10^{-9}	0.989

3.6 Variation of Drying Rate in the Hot-air Dryer

The hot-air conventional dryer shows the combined effects of air speed and temperature on the drying rates of CDDH (Tables 6). The air speed used in the dryer ranged from 2.0 m/s to 4.0 m/s while the temperature was between 50℃ and 70℃. It is seen that there is more significant difference as the temperature changes from 50℃ to 70℃ than when the air speed increased from 2.0 to 4.0 m/s. When thin-layer drying is considered, the effect of temperature on drying time is more significant relative to the air speed [27,36]. The drying activity that occurs at higher air speed and the higher temperature reached the equilibrium moisture content more quickly than others.

Table 6. Effect of air speed on drying rate against time and moisture content for CDDH at different temperature

50℃					60^{0}C					70^{0}C				
Time (mins)	Moisture content (%)	Drying rate (g/g.mins)			Time (mins)	Moisture content (%)	Drying rate (g/g.mins)			Time (mins)	Moisture content (%)	Drying rate (g/g.mins)		
		2 m/s	3 m/s	4 m/s			2 m/s	3 m/s	4 m/s			2 m/s	3 m/s	4 m/s
60	65.12	1.17	1.30	1.30	60	64.29	1.30	1.30	1.50	60	63.41	1.50	1.50	1.67
120	62.5	0.50	0.50	0.67	120	61.54	0.50	0.67	0.50	120	59.46	0.67	0.80	0.80
180	59.46	0.50	0.50	0.67	180	59.46	0.30	0.50	0.50	180	54.55	0.67	0.80	0.80
240	55.88	0.50	0.50	0.67	240	55.88	0.50	0.50	0.50	240	50.00	0.50	0.50	0.50
300	53.13	0.30	0.30	0.67	300	51.61	0.50	0.50	0.50	300	46.43	0.30	0.50	0.30
360	50.00	0.30	0.30	0.30	360	48.28	0.30	0.30	0.30	360	42.31	0.30	0.50	0.50
420	46.43	0.30	0.17	0.30	420	44.44	0.30	0.30	0.30	420	37.50	0.30	0.30	0.30
480	42.31	0.30	0.30	0.30	480	40.00	0.30	0.30	0.30	480	31.82	0.30	0.30	0.30
540	37.50	0.30	0.30	0.30	540	34.78	0.17	0.17	0.30	540	25.00	0.30	0.17	0.17
600	31.82	0.30	0.30	0.17	600	31.82	0.17	0.30	0.30	600	21.05	0.30	0.17	0.17
660	28.57	0.17	0.17	0.17	660	28.57	0.17	0.17	0.30	660	16.67	0.17	0.00	0.17
720	25.00	0.17	0.17	0.17	720	25.00	0.17	0.17	0.17	720	11.76	0.00	0.17	-----
780	21.05	0.00	0.17	0.00	780	21.05	0.00	0.17	0.00	780	11.76	0.17	-----	-----
840	21.05	0.17	0.17	0.17	840	16.67	0.17	0.00	0.17	-----	-----	-----	-----	-----
900	16.67	0.00	0.00	0.00	900	16.67	0.00	0.00	-----	-----	-----	-----	-----	-----
960	16.67	0.17	0.17	0.17	960	11.76	0.00	0.17	-----	-----	-----	-----	-----	-----
1020	11.76	0.00	0.00	0.17	1020	11.76	0.17	-----	-----	-----	-----	-----	-----	-----
1080	11.76	0.00	0.17	0.00	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1140	11.76	0.17	0.00	0.17	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1200	6.25	0.00	0.00	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1260	6.25	0.00	0.17	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1320	6.25	0.00	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
1380	0.00	0.17	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

4. CONCLUSION

To design the right industrial dryer, the properties of the material to dry have to be considered. Besides, requirements for quality, size, shape and moisture content of the final dried product have to be taken into consideration, as well as the production environment, permitted construction materials, energy consumption etc. This study focused on drying of animal's hide/skin which includes Cattle hide, Sheepskin and Donkey hide. Considering relevant design parameters, the study showed that drying of animal hides and skin can be achieved using the solar cabinet dryer, oven dryer, the hot air conventional dryer and the open sun drying though their drying properties differed. It was also found that the drying of Cattle hides, Sheepskin and Donkey hide occur mainly in the falling rate period. The drying time decreased with air-speed and temperature. The water activity is dependent on the moisture content and its value affects the estimated mold-free shelf life. The effective moisture diffusivity increased with air speed and temperature

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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