Experimental Validation on Drying Behaviour of AC Exhaust Dried Pumpkin Slices

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Abstract - *with the rich content of carotene, vitamins, minerals and pectin along with the antioxidants makes it important in human consumption and industry usage, but it is prone to microbial spoilage, even under refrigerated conditions. This perishable nature of pumpkin limits its utilization. To improve its shelf life, it is dried. Drying of food material involves simultaneous heat and mass transfer where water is transferred by diffusion from inside the food to the air-food interface and to the air stream by convection. Drying is the most commonly used method of food preservation which involves the removal of moisture from a material to a level at which microbial and enzymatic activities are greatly minimized. The mechanism responsible for this process in fruits and vegetables is diffusion, which is due to the simultaneous heat and mass transfer that occurs in the material during a falling rate period. The rate of the heat and mass transfer depends on the drying conditions of temperature, relative humidity, air velocity and material thickness. A controlled environment is recommended in order to process a uniform dry product with high acceptability. The objective of this paper is to understand the drying behavior of pumpkin in open solar drying and ac exhaust air drying in order to select a suitable model that will estimate the effects of drying conditions on the drying kinetics and show the effect of drying on the dimensional changes of pumpkin in open solar drying and ac exhaust air drying.*

***Key Words*: AC exhaust air drying, Solar drying, Pumpkin drying, improved shelf life, high acceptability, uniform dry product, dimensional change, drying kinetics**

1. INTRODUCTION

Pumpkin is a cultivar of the squash plant with round, smooth, slightly ribbed skin and deep yellow to orange colouration. The three most common varieties are Cucurbita pepo, Cucurbita maxima and Cucurbita moschata. Pumpkin is also rich in carotene, vitamins, minerals and pectin.

Just as in most fruits, pumpkins are very sensitive to microbial spoilage, even under refrigerated conditions. Thus, it is best if they are preserved in order to increase shelf life. This is especially true as the perishable nature of pumpkin tends to limit its utilisation, hence the need to be processed by drying. The use of solar energy is the oldest form of natural, atmospheric drying of grains, fruits and vegetables. Sun drying has several problems other than the fact that sunshine is uncertain sometimes even during the day season. Sun dried food products are often of low quality as a result of slow drying, insect damage and contamination from air-borne dust. A controlled environment is recommended in order to process a uniform dry product with high acceptability.

1.1 Drying

Drying is concerned with the process of removing the moisture from a product and can be implemented in two stages. In first stage, the moisture inside the product is brought to the surface and dried in air at a constant rate as water vapour. The second stage involves a slow drying rate, and its process is related to the properties of the materials to be dried. Drying of different materials, namely, gases, liquids or solids can be accomplished by different methods.

Drying of food material involves simultaneous heat and mass transfer where water is transferred by diffusion from inside the food to the air-food interface and to the air stream by convection. The drying rate is influenced by the following factors: nature of the food material, initial moisture content, mass of the food material per unit exposed area, drying air temperatures, humidity of the drying chamber and drying air velocity. Moisture removal processes and their dependence on these factors are expressed in terms of drying kinetics; hence, the determination of the drying rate is essential for the development of reliable process model. By and large the drying phenomena can be described using thin layer models mainly to estimate the drying time and moisture content of the food materials at any time after they are subjected to a known temperature and relative humidity.

1.2 Drying Models

Thin layer drying curve models are often employed to evaluate the drying process of food products and may be categorized into three groups, namely; theoretical, semi-theoretical and empirical models. The semi-theoretical and empirical models have been applied and found best at describing the drying process and predicting the drying kinetics of numerous agricultural foods. These categories of models provide a greater extent of drying curve fitting and better prediction of drying behaviours. the semi-theoretical models, which are generally derived from Fick's second law, Newton's laws of cooling and Newton's law of fluid momentum, provide better understanding of the transport processes and show a better fit to the experimental data than other categories of models. Thus, the semi-theoretical models can provide an appropriate estimation of the drying kinetics for agricultural and food products.

The objective of this paper is to understand the drying behaviour of pumpkin in open solar drying and ac exhaust air drying in order to select a suitable model that will estimate the effects of drying conditions on the drying kinetics. In addition, the study intends to show the effect of drying on the dimensional changes of pumpkin in open solar drying and ac exhaust air drying.

2. Research Methodology

2.1 Moisture Content

Moisture content is determined by the weight loss of the samples during drying

$$MC = [(W_i-W_f)/W_i] * 100$$

2.1.1 Initial Moisture Content.

Natural Agricultural products are not completely dry. Some moisture content is always there in it. This moisture is represented as a percent moisture content for the product. Moisture content can be represented in 2 ways. These methods are wet basis (MC_{wb}) and dry basis (MC_{db}). It is the amount of moisture content present initially in the pumpkin sample. It is denoted as MC_i

2.1.2 Moisture Content During Drying

It is the amount of moisture content during the process of open solar drying and ac exhaust air drying. It is determined by the weight loss of the sample at every consecutive hour. It is simply represented as MC and it can be measured on dry basis and wet basis.

$$MC_{db} = [(W_i-W_f)/W_f] \times 100 \quad MC_{wb} = [(W_i-W_f)/W_i] \times 100$$

Use of the wet basis measurement is common in the grain industry where moisture content is typically expressed as percent wet basis. Wet basis method has one clear disadvantage. The total mass will change when moisture is removed. When the total mass is taken as the reference base for the moisture content, the reference condition will change when the moisture is removed. But, the dry matter remains constant. Thus, the reference condition for dry basis measurements does not change as moisture is removed. For a given product, the moisture content dry basis is always higher than the wet basis moisture content. The difference between the two bases is small at low moisture levels, but it increases rapidly at higher moisture levels.

2.1.3 Final Moisture Content

It is the amount of moisture content present at the end of the drying process. Usually the final moisture content should be zero or negligible to achieve complete drying of the pumpkin sample.

2.1.4 Equilibrium moisture content

A material held for a long time at a fixed temperature and relative humidity will eventually reach a moisture content that is in equilibrium with the surrounding air. This does not mean that the material and the air have the same moisture content. It simply means that an equilibrium condition exists such that there is no net exchange of moisture between the material and the air. This equilibrium moisture content is a function of the temperature, the relative humidity, and the product. It is the relative humidity for equilibrium between air and a specific product at a given temperature.

2.2 Drying Time

It is the time taken by the pumpkin samples to remove its entire moisture content. It is the time taken to make the final moisture content zero.

2.3 Moisture Ratio

Moisture ratio predicted is used to find the best fit model for the drying kinetics of pumpkin

$$MR = (W_f-W_e)/(W_i-W_e)$$

2.4 Root Mean Square and Chi-Square Values

They are used to statistically validate the drying behavior of the pumpkin slices. They are used to fit the model suitably which describes the drying kinetics of pumpkin

$$RMSE = [1/N\ \Sigma\ (MR_{pre} - MR_{exp})^2]^{1/2}$$

$$\chi^2 = \Sigma\ (MR_{exp} - MR_{pre})^2/(N-n)$$

2.5 Drying Curves

The drying curves are plotted between the moisture ratio and time to find the drying kinetics constants and coefficients. A curve plotted between the MR_{exp} and MR_{pre} shows the best fit model among the five proposed models.

2.6 Drying Models

Thin-layer equations are often used for a description of the drying kinetics for various types of porous materials. Thin-layer drying models that describe the drying phenomenon of biological materials fall mainly into three categories, namely, theoretical, semi-theoretical and empirical. The first takes into account only internal resistance to moisture transfer, while the other two consider only the external resistance to moisture transfer between the product and the air.

Table-1: Thin Layer Model

model	Equation
Newton	MR = exp (-kt)
Page	MR = exp ($-kt^n$)
Modified Page	MR = exp $(-kt)^n$
Henderson and Pabis	MR = a exp (-kt)
Wang and Singh	MR = $1+at+bt^2$

2.6.1 Newton Model

Newton model is a special case of Henderson and Pabis model where the intercept is unity. It is used to describe the drying of barley and grape seed. The model is expressed as follows

$$MR = \exp(-kt)$$

k denotes the constant in this equation, represents the slope of the curve plotted between natural logarithm of moisture ratio and time.

2.6.2 Page Model

The Page model is a modification of the Lewis model to overcome its short comings. This model has produced good fits in predicting the drying of grain and rough rice, shelled corn and barley. The equation representing this model is

$$MR = \exp(-kt^n)$$

The constant k in this equation is the slope of the curve plotted between ln (ln MR) and ln t.

2.6.3 Modified Page Model

The modified Page model has slight modifications in the equation of Page model. The equation of the modified Page model is as follows and the constant k is the slope of the curve plotted between ln (ln MR) and ln t.

$$MR = \exp(-kt)^n$$

2.6.4 Henderson and Pabis Model

The Henderson and Pabis model is the first term of a general series solution of Fick's second law. This model was used successfully for model drying corn, wheat and peanuts. The slope of this model, coefficient k, has relationship with effective diffusivity when the drying process takes place only in the falling rate period when the process is controlled by liquid diffusion. The equation for this model is

$$MR = a \exp(-kt)$$

2.6.5 Wang and Singh

The Wang and Singh model represents the moisture ratio as a polynomial function. The equation representing the Wang and Singh model is as follows

$$MR = 1+at+bt^2$$

2.7 Model Fitting

In the literature there are several criteria to evaluate the suitability of a model to experimental data. Among these, the correlation coefficient (r), the mean bias error (MBE), the reduced chi-squared ($\chi 2$) and root mean square error (RMSE) are the most widely used ones. In this study, the constants and coefficients of the best fitting model were determined by fitting the total model employed to the experimental drying curves involving drying variables. The effect of these variables on the constants and coefficients of the drying expression are also investigated by the multiple linear regression analysis. The goodness of the fit of the tested models to the experimental data is the coefficient of determination (r). The models with less RMSE and chi square values is found to best fit the drying kinetics of pumpkin slices.

2.8 Dimensional Changes

ImageJ software is used to determine the dimensional changes of the dried pumpkin samples like the changes in length, breadth and thickness. First the photograph of the samples was uploaded in the imageJ software window. Then the portion is selected to set a scale. Once the scale is set to known dimension, the various dimensions like length, breadth and height are all plotted in a tabular form as results.

3. Solar Dryer

Solar dryers utilize solar energy to dry food products and other substances. The basic principles employed in solar dryer are,

Black on the inside of a solar dryer will enhance the conversion of light into heat.

Isolation between the air inside the dryer and the air outside the dryer secures the heat inside the system. Clear solid setup will facilitate the light to enter, but once the light is absorbed and converted to heat, the clear solid will trap the heat inside. This ensures reaching similar temperatures on cold and windy days as on hot days.

Natural convection dryer along with forced convection dryer use the convection of the heated air to move the heat to the food.

3.1 Open Solar Drying

The most common drying method used in tropical and subtropical countries involves spreading the crop into thin layers on trays, covering the mats with shadow, and exposing the product to wind and sun. The classifications of sun drying, procedures are created based on the stage of processing, the location of drying, or the apprehension to solar radiation.

Fig -1: Open Solar Drying

The open drying process is not suitable for large amounts of products processed by large firms. Apart from the disadvantages of higher cost of labour, larger area requirement and decreased quality of products, it also involves a labor intensive process before the products can be ready for storage. Open sun drying depends on environmental conditions, such as solar radiation, wind, and other ambient conditions. It usually leads to the deterioration of the products because of many determinants, such as reduced quantity due to wind, wastage, rainfall, and animal and anthropological impedance. Storing the crop during the night and being subjected to rain under a shelter can remoistening. As the drying process is relatively slow, considerable losses occur, including insect infection, enzymatic reactions, growth of microorganisms, and augmentation of mycotoxin, which causes an ascertainable reduction in product quality.

Non-uniform drying also leads to the degeneration of the agricultural products during storage. Serious drying problems arise, particularly food products have to be dried during the rainy season.

Its many disadvantages have led sun drying to be replaced with mechanical dryers, which use fossil fuel to heat drying air and electricity to force dry air through the agricultural products. However, the advantageous application of solar energy to high- temperature solar drying systems is neither technically nor circumspectly feasible without lowering the capacity and the reliability.

4. AC Exhaust Dryer

The solar dryer setup considered in our project is simple and cheap. Here the pumpkin slices are placed on the tray of the drying chamber. Solar radiation is thus not incident directly on the samples. Our principle here is that, Black substance absorbs more heat than any other materials,

Warm air is always lighter than cold air and Air flows from high pressure to low pressure.

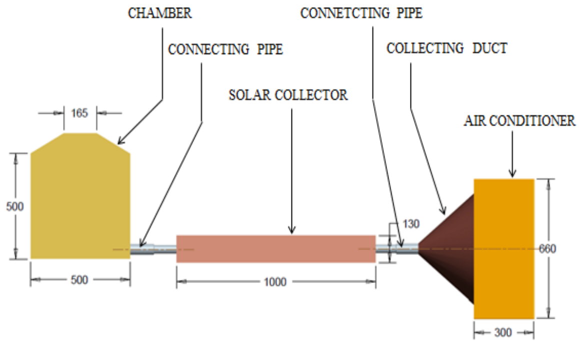

Fig -2: AC Exhaust Dryer Set-up

4.1 Air Conditioner

Air conditioners employs a fan to circulate the conditioned air to an air conditioned to improve thermal comfort of occupants and indoor air quality. The very same air coming from the AC exhaust is used for drying the pumpkin slices.

4.2 Connecting Duct

The collecting duct is conical in shape. It is used to collect the AC exhaust air. It is painted in black colour to absorb the solar radiation which increases the thermal capacity of the exhaust air.

4.3 Solar Collector

Solar collector is rectangular in shape. The lower layer is painted black. The middle layer consists of pebbles to trap the heat from the solar radiation. The top layer is transparent glass. When the solar light is incident on the collector, the air is low. When the air gets into the collector, it gets warmed and rises through the lower layer of shelves and exit from exhaust place near the roof of the dryer.

4.4 Drying Chamber

It is the main part of the dryer where the products are being placed and gets dried there. It consists of layer of shelves made up of completely dry materials (to reduce moisture) having tiny holes for the passage of the rising warm (heated) air from the bottom. When the dried air passes through the layers, pumpkin samples placed inside the dryer gets dried. This warm air will contain moisture when it reaches the top of the dryer. The dimensions of drying chamber are 500x500x500 mm. It is cubic structure made of sheet metal enclosed by thermocol to provide insulation. The inner surface is painted black in colour to enhance the drying rate. It has a door for the loading and unloading the samples at every consecutive hour.

4.5 Connecting Pipes

The different parts such as duct, solar collector, drying chamber are connected using connecting pipes to make the entire experimental set up. It is of circular cross section having 50 mm and 40 mm diameter. It is made up of PVC material. These pipes acts as a passage for the flow of ac exhaust air to the chamber. A reducer valve is used to connect the different diameter pipes.

5. Experimental Procedure

For the drying experiment, the pumpkins were stored in a cool and dry place. Then they were washed, maintained at the room temperature and then sliced for drying test.

5.1 Sample Preparation

After washing the pumpkin, its skin was peeled with a peeler. It is then followed by the seed removal process and then sliced into small cubes having dimensions of 25 x 10 x 5 mm. Roughly around 40 such cubes were prepared and spread on the trays of the drying chamber. Thus the pumpkin samples were prepared for drying.

5.2 Open Solar Drying

The samples were spread over the glass surface for open solar drying. The moisture loss has to be periodically measured for every consecutive hour. For calculating the moisture content, the weight of the sample must be noted using a weighing scale for every one hour. The moisture content is determined as follows

$$MC=[(W_i-W_f)/W_i]x100$$

5.3 AC Exhaust Air Drying

The prepared pumpkin samples were arranged in trays of the drying chamber. The AC exhaust air entering with a velocity of 5 m/s is collected by the duct which is fully painted in black to absorb the sun's radiation and to trap the heat. The exhaust air from the duct then enters into the solar collector which is filled with pebbles to retain the heat produced by the incident sunlight.

Finally, hot air with a velocity of 2 m/s from the solar collector then enters into the drying chamber where the samples are placed for drying.

5.4 Loading and Unloading of Samples

Approximately 60g of sample were used in drying. The samples were arranged in a single thin layer at the middle tray loaded by the door fitted at the backside of the chamber. The samples were then taken out with the help of the same door for every one hour. The weight of the samples was noted down from the weighing scale for every one hour. From the weight of the samples obtained, the moisture content of the samples can be calculated. The temperature at the inlet and outlet is measured by using a thermocouple. The velocity at the inlet and outlet is measured by anemometer. The radiation is measured with the help of pyrometer. Initially at the time of loading, the weight of each sample is 1.5g. At every consecutive hour, this weight reduces gradually due to the removal of moisture content.

From the data obtained, the experimental moisture ratio is calculated and it is used to fit the model for the drying kinetics of pumpkin samples.

5.5 Measured Parameters

The measurement method consists of fixing the values of the drying air velocity. The samples were kept inside the chamber for an hour for the variation of the weight of the product as a function of time. The time separating two successive measurements is about an hour. The parameters measured during the experiment are:

Temperature: It is measured by thermocouples. The diameter of thermocouple is 1 mm and the temperatures at the inlet and outlet of the experimental set up are measured.
Drying air velocity: It is measured by anemometer. The AC exhaust air enters with an inlet velocity of 5 m/s and leaves with the outlet velocity of 2 m/s in the experimental setup. The measurement of accuracy is 0.1m/s,

Mass of the sample: It is measured by a digital weighing scale apparatus with an accuracy of 0. 0001g.This weighing apparatus enables us to determine continuously the loss of mass of the sample due to moisture removal during the drying process.
Radiation: It is measured by pyrometer to determine the heat absorbed in the drying process.

5.6 Dimensional changes

During drying the samples loss their moisture content which leads to the reduction of mass. Due to the moisture removal, the samples get shrinked and structural changes had been observed. The dimensional changes are the changes in the length, breadth and thickness of the samples. ImageJ software is used to measure the dimensional changes of the samples. It shows the results of the dimensional changes in the pumpkin samples taken for each hour with the photograph of that samples.

5.7 Drying Model Development

The data acquired from open solar drying and ac exhaust drying were fitted into five models which are Newton model, Page model, Modified Page model, Henderson and Pabis model, Wang and Singh model. The moisture ratio was calculated to fit the drying model.

The drying rate constants and coefficients are determined using regression. The data required for model fitting are initial moisture content, moisture content during drying, equilibrium moisture content, drying time.

For model fitting, the moisture ratio is considered as dependent variable. The statistical validity of the models is evaluated and compared using the RMSE and chi square values

6. Results and Discussion

6.1 Moisture Removed

The moisture removed during drying is calculated and plotted with respect to time.

The graph shows that the moisture removed in AC exhaust air drying for instance during second hour, the moisture removed is 0.4524g which is higher compared with open solar drying where the moisture removed during second hour is 0.3764g. The moisture removal rate is higher in AC exhaust drying compared to that of open solar drying.

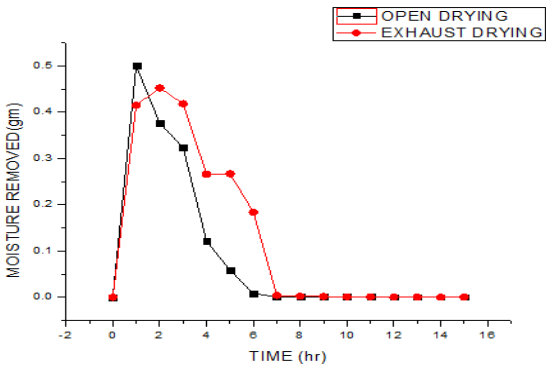

Fig -3: Moisture Removed from both open solar and AC exhaust air Drying

6.2 Fitting Models

The calculated RMSE and χ^2 values are tabulated as follows

Table -2: RMSE and χ^2 values of different models

MODEL	RMSE		χ^2	
	1	2	1	2
Newton	0.065	0.136	0.005	0.0200
Page	0.199	0.026	0.048	0.0008
Modified Page	0.017	0.267	0.001	0.0009
Henderson And pabis	0.038	0.077	0.002	0.0069
Wang and Singh	2.195	0.072	5.887	0.0060

1-open solar drying

2-AC Exhaust air drying

The model which has the lowest RMSE and χ^2 best fits the drying behavior of pumpkin slices.

The graphs plotted between MR(exp) and MR(pre) to obtain the best fit model are as follows.

The model for which the readings lie near the 45° line best fit the drying behavior of pumpkin slices.

6.2.1 Open Solar Drying

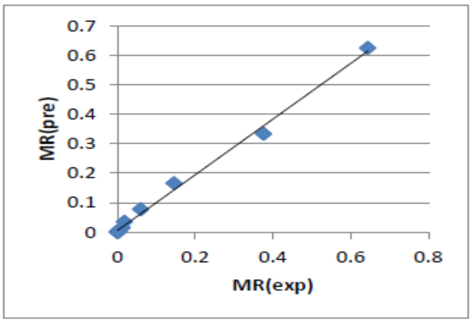

Chart -1: Modified Page model

6.2.2 AC Exhaust air drying

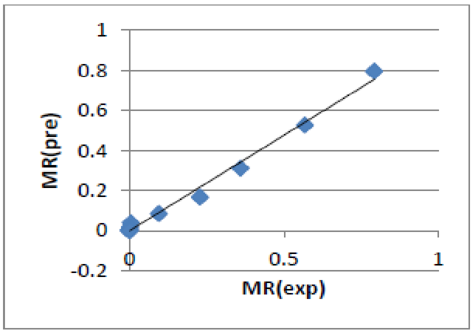

Chart -2: Page model

6.2.3 Dimensional Changes

The graphs are plotted to represent the dimensional changes. The graphs shows that the dimensional changes occur at a faster rate in AC exhaust drying due to faster moisture removal rate when compared to open solar drying.

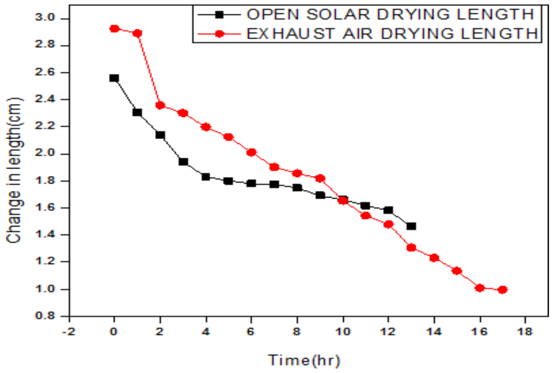

Chart -3: change in length

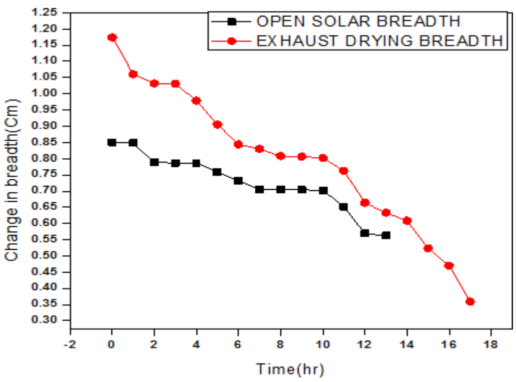

Chart -4: change in breadth

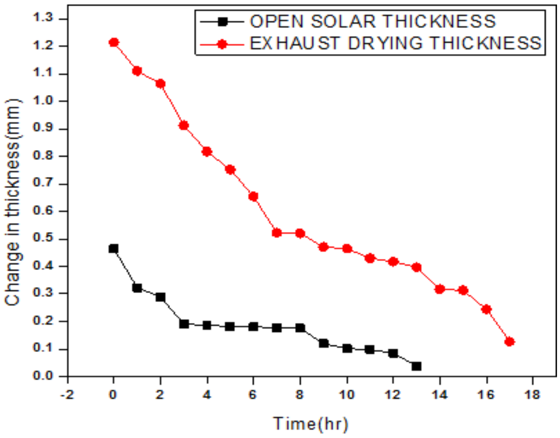

Chart -5: Change in thickness

7. CONCLUSIONS

The model that best fits the experiment data and describes the drying behavior of pumpkin slices is MODIFIED PAGE for open solar drying which has the lowest RMSE (0.0171) and χ^2(0.0004) and PAGE model for AC exhaust air drying which has the lowest RMSE (0.0263) and χ^2(0.0008) and the graphs plotted between MR(exp) and MR(pre) of these models lie near the 45^o line which shows that these models best fits the drying behavior of pumpkin slices.

The dimensional changes like the change in length, breadth and thickness occurs at a faster rate in AC exhaust air drying compared to that of open solar drying. As a result of this work, we conclude that the moisture removal rate is higher in AC exhaust air drying when compared to open solar drying and AC exhaust air drying can be employed to improve the shelf life of pumpkin to enhance its industrial and human consumption needs.

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