PART 2

Drying of Specific Fruits and Vegetables

An Introduction to the Dehydration and Drying of Fruits and Vegetables

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PART 2: DRYING OF SPECIFIC FRUITS AND VEGETABLES

1. Introduction:

The following pages contain information about the drying of specific fruits and vegetables. Most of these are typically grown in tropical locations.

This is not meant to be an exhaustive treatment of all available food materials. However, the examples presented here should serve to provide information suitable for establishing appropriate drying conditions for most of the more common fruits and vegetables.

Each fruit or vegetable is covered in a separate section describing its kinetics of water loss etc. They are arranged alphabetically according to their common names, with the pages numbered in a similar manner.

2. Experimental Methods:

All experiments summarized here were obtained using a Model UOP-8 laboratory-scale tray dryer manufactured by Armfield Limited of Ringwood, England. A photo of the dryer appears as Figure 1.

Figure 1: Armfield Laboratory-Scale Tray Dryer (Model UOP-8)

Prior to the actual drying trials, the dryer was adjusted to provide the desired air temperature and linear velocity. In most cases, 50^{0}C and 0.5 metres per second were used for the drying temperature and linear velocity, respectively.

Once the desired conditions were achieved, the material to be dried was placed on a wire mesh rack suspended from a digital balance positioned on top of the drying chamber. The balance with its suspension mechanism is shown in Figure 2 along with the digital thermometer indicating the temperature inside the drying chamber. When this photo was taken, there was no material inside the dryer and the dryer was not operating.

Figure 2: Balance and digital thermometer display on tray dryer

Figure 3 shows the wire mesh rack inside the dryer supported by the two metal rods which go through the upper portion of the dryer to the balance assembly above.

Figure 3: Wire mesh rack suspended inside tray dryer

The weight of the sample could then be monitored as moisture was removed throughout the drying process. Both the air temperature and sample weight were recorded at one-minute intervals using a time-lapse camera which photographed the displays of the balance and digital thermometer. Air velocities were checked on a regular basis using a hand-held vaned anemometer, sometimes called a “windmill anemometer”. In Figure 4, the anemometer is shown after taking an air velocity reading of 0.48 m/s. Once the trigger on the side of the anemometer is released, the reading is held in the digital display area.

Figure 4: Hand-held vaned anemometer for measuring air velocities

Initial moisture contents of each material being dried were determined using a Sartorius Model MA50 electronic moisture balance as shown in Figure 5.

Figure 5: Sartorius Model MA50 moisture balance

Temperatures and relative humidities of the ambient room air were also recorded periodically using a digital thermometer / hygrometer as seen in Figure 6. These readings had no real impact on the drying kinetics since they remained relatively constant throughout the entire set of trials which were done in our temperature-controlled lab.

Figure 6: Digital thermometer and relative humidity indicator

Once a drying run was completed, sample weights and temperatures for fifteen (15) minute intervals were entered into an Excel Spreadsheet program set up to calculate the dry basis moisture at each time. These calculations were based on the moisture content and weight of the sample at the start of the drying trials. Plots of the dry basis moisture versus time were then obtained. The built-in curve fitting features of the Excel package were then used to determine the exponential equation for the drying curves along with the correlation coefficients (i.e., R^2 values).

It should be emphasized that the Armfield Tray Dryer is an excellent laboratory tool for studying the drying kinetics of various materials. Temperature fluctuations were very small (usually ± 1 C^0) since the temperature within the laboratory was held quite constant. For all but a few materials, three replicate trials were conducted and the averages were then taken to obtain the overall drying kinetics curve equations.

Results obtained here should be reproducible in any dryer capable of delivering air to the drying chamber at these set temperatures and linear velocities. Those using counter-top food dehydrators designed for in-home use may find their results vary due to the preset air velocities of these dryers - even when used at temperatures comparable to those used here.

3. Laboratory Drying Results:

The following pages contain the results of drying trials on a variety of fruits and vegetables typically found in tropical countries. It is hoped that the information presented here will provide guidance to anyone wishing to dry these or similar materials in a forced-air dryer.

Results are organized in alphabetical order using the common name of the material. Comments regarding the preparation of samples have been included along with calculations using the rate equations obtained from the drying data.

The write-up for each fruit or vegetable is designed to stand on its own, without referring to any other part of this section. I have also tried to maintain the same layout for each of these descriptions. As a result, there is a certain necessary degree of repetition.

APPLE RING DRYING

Selection and Preparation of the Material:

The apples you select should be free from blemishes and surface contamination. Do not use windfall apples which are found lying on the ground since these may have been exposed to droppings from animals grazing in the area.

Thoroughly wash the apples, peel them, and core them. Then slice the apples into rings about 5 to 6 mm thick. If you want to try preventing the apples from becoming brown during drying, you can dip them into lemon juice. Be sure to shake the excess lemon juice from the apples before placing them in the dryer. The slight amount of moisture left on the surface of the apples will have very little effect on the overall drying of the apples.

Some people prefer to leave the skins on the apples. However, the skins become quite leathery when dried and have a tendency to stick in your teeth, which is rather unpleasant.

Fresh apple

Fresh apple rings in the dryer

Drying Conditions:

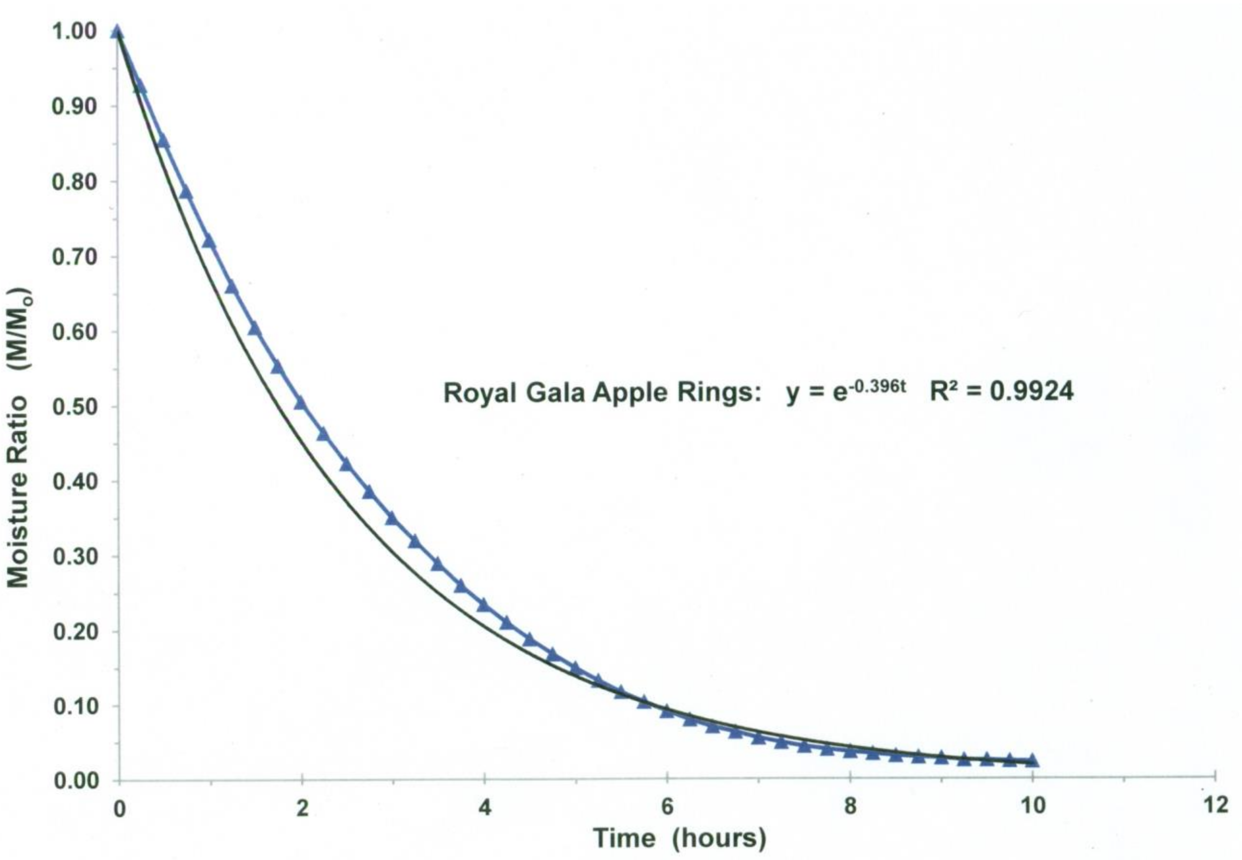
A temperature of about 50^{0}C, with a linear air velocity of 0.5 metres per second, works well for apple rings. Be sure that the pieces have a small amount of space between them to ensure the drying air contacts all surfaces.

Test for Dryness:

Once the apple rings are dry, they will be leathery, but there will still be some flexibility and cushiness to them.

Dried apple rings in the dryer

Drying Kinetics:



Graph of reduced moisture versus time for Royal Gala apple rings

Based on the curve above, the general kinetic equation for the drying of apple rings is given by:

$$\mathbf{y = e^{-0.396t}} \quad \text{(Eq'n 1)} \quad \text{where: y is the moisture ratio } M/M_o$$

t is the drying time in hours

Re-writing this equation:

$$\mathbf{M/ M_o = e^{-0.396t}} \quad \text{(Eq'n 2)} \quad \text{where: M is the dry basis moisture at time t}$$

M_o is the initial dry basis moisture

or: $$\mathbf{M = M_o\, e^{-0.396t}} \quad \text{(Eq'n 3)}$$

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$\mathbf{-0.396t = \ln(M/M_o)} \qquad \text{(Eq'n 4)}$$

Equation 4 then becomes: $$\mathbf{t = -\frac{\ln(M/M_o)}{0.396}} \qquad \text{(Eq'n 5)}$$

$$\mathbf{t = \ln(M_o/M) / 0.396} \qquad \text{(Eq'n 6)}$$

<u>Calculation of Drying Times</u>:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 85.4% on a wet basis (i.e., 5.84 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} \mathbf{t} &= \mathbf{\ln(M_o/M) / 0.396} \\ &= \mathbf{\ln(5.84/0.111) / 0.396} \\ &= \mathbf{\ln(52.61) / 0.396} \\ &= \mathbf{3.96 / 0.396} \\ &= \mathbf{10.0\ hours} \qquad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the apple rings under these conditions should take about 10 hours.

Application of the Drying Model:

For the Royal Gala apples dried in these tests at 50^{0}C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

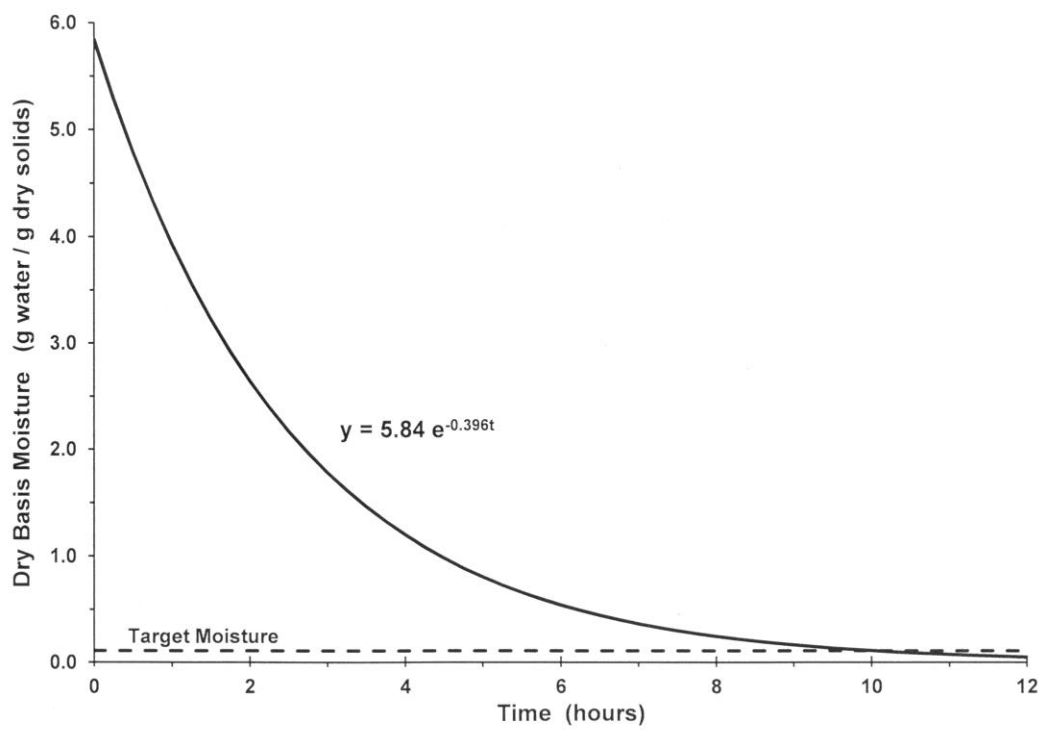
$$\mathbf{M = M_o\, e^{-0.396t}} \quad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 5.84 grams of water per gram of dry solids (i.e., approximately 85.4% wet basis moisture), this equation becomes:

$$\mathbf{M = 5.84\, e^{-0.396t}} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of Royal Gala Apple Rings

It can be seen that the apple rings reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 10 hours as calculated in Equation 7.

BANANA DRYING

Selection and Preparation of the Material:

Select the highest quality bananas available. It is best to use firm bananas for drying.

Peel and cut the banana into slices about 5 to 6 mm thick. To reduce the amount of browning during drying, you can dip the banana slices into lemon juice. Be sure to shake the excess lemon juice before placing them in the dryer. The slight amount of moisture left on the surface will have very little effect on the overall drying of the banana slices.

Fresh bananas

Thick slices of dried banana in the dryer

Drying Conditions:

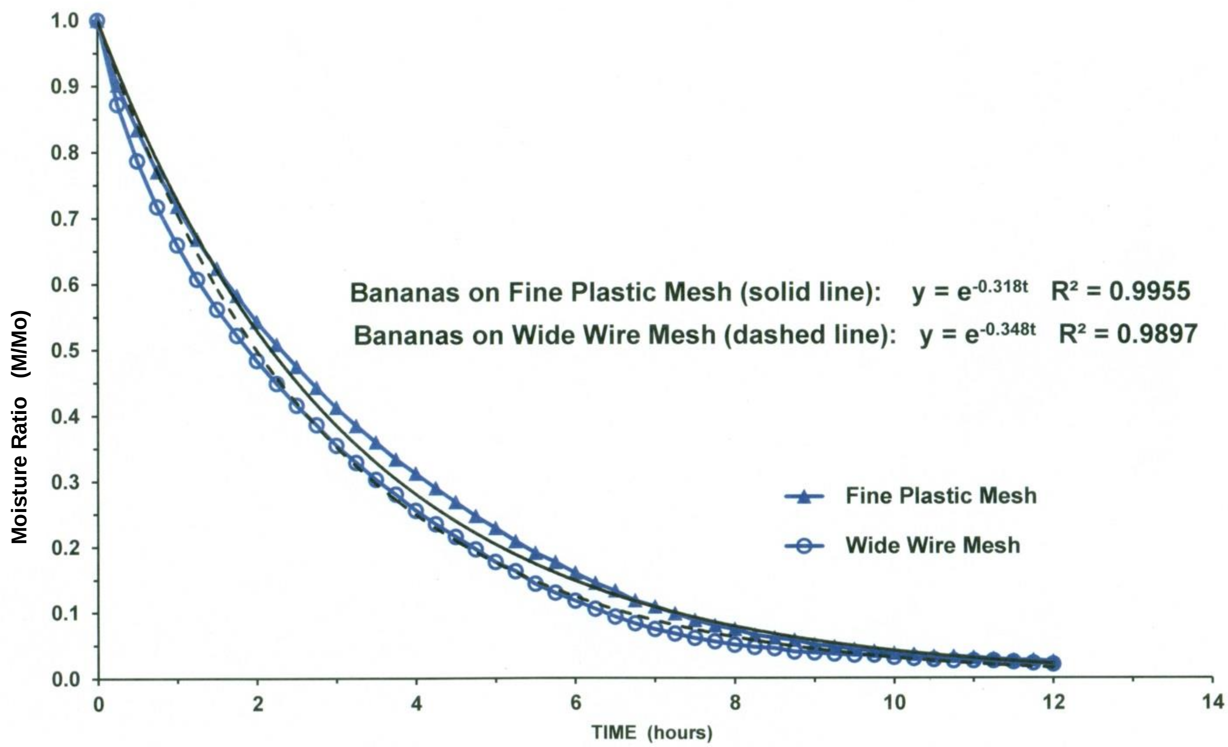
A temperature of about $50^{0}C$, with a linear air velocity of 0.5 metres per second, works well for banana slices. Be sure that the pieces have a small amount of space between them to ensure the drying air contacts all surfaces.

One problem with drying bananas is that they tend to stick to the wire mesh racks in the dryer. For this reason, it is best to use a flexible plastic mesh on which to place the banana slices (see the photograph above).

Test for Dryness:

When the banana slices are dry, they will be leathery and flexible. Since they are usually sticky, it is best to remove them from the plastic mesh material while they are still warm and have not had a chance to stick firmly to the mesh.

Drying Kinetics:



Moisture ratio versus time for bananas dried with and without plastic mesh on dryer racks

In the graph shown above, we can compare the effects of having a plastic mesh supporting the banana slices to the case where only the wire mesh racks were used. There is a slight increase in the drying rate on the wire racks since the bottoms of the slices are more exposed to the drying air when no plastic mesh is used. However, the banana slices stuck so badly to the wire mesh that they could not be removed from the dryer and were ruined. Therefore, we will use the data for the plastic mesh drying arrangement.

Based on the curve above, the general kinetic equation for the drying of banana slices is given by:

$$y = e^{-0.318t} \quad \text{(Eq'n 1)}$$

where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$$M/M_o = e^{-0.318t} \quad \text{(Eq'n 2)}$$

where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $$M = M_o e^{-0.318t} \quad \text{(Eq'n 3)}$$

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$-0.318t = \ln(M/M_o) \quad \text{(Eq'n 4)}$$

Equation 4 then becomes: $$t = -\frac{\ln(M/M_o)}{0.318} \quad \text{(Eq'n 5)}$$

$$t = \ln(M_o/M) / 0.318 \quad \text{(Eq'n 6)}$$

Calculation of Drying Times:

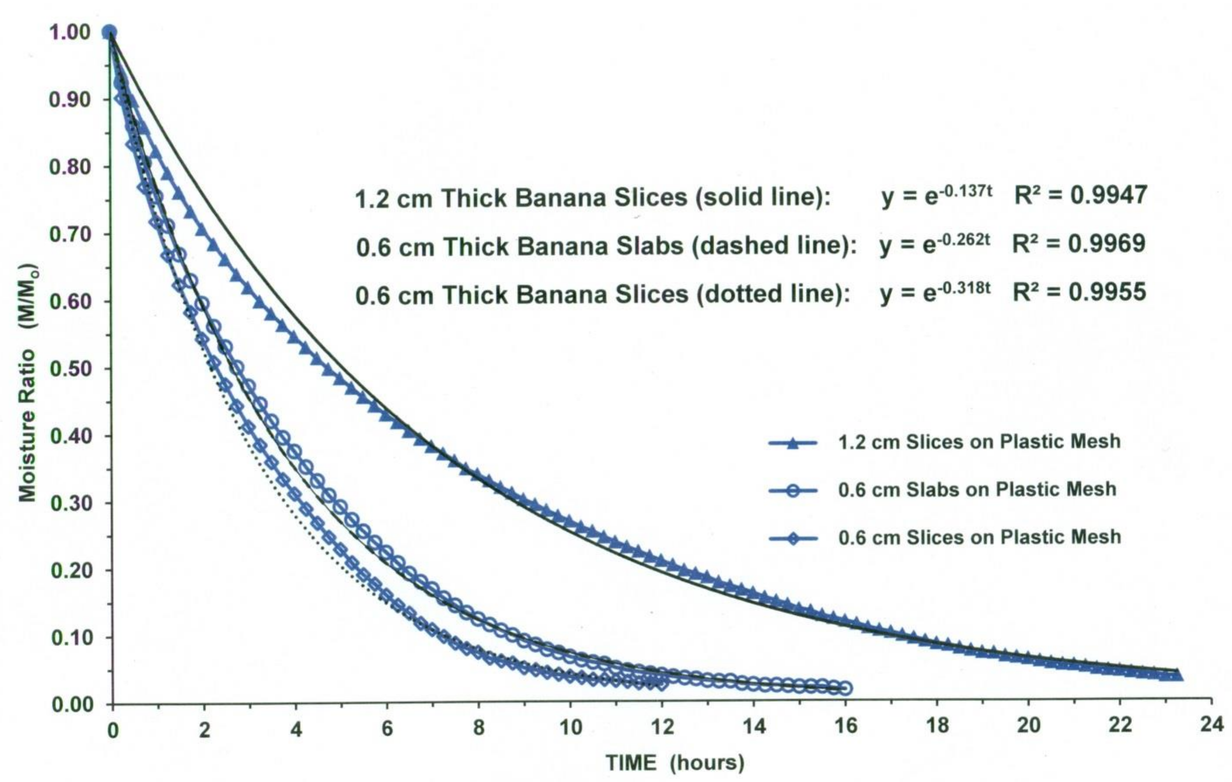
To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 73.7% on a wet basis (i.e., 2.80 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.318 \\ &= \ln(2.80/0.111) / 0.318 \\ &= \ln(25.22) / 0.318 \\ &= 3.23 / 0.318 \\ &= 10.2 \text{ hours} \qquad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the banana slices under these conditions should take about 10.2 hours.

Alternate Preparations of Bananas for Drying:

Let's take a look at what happens with alternate preparations of bananas for drying.



Moisture ratio versus time for various configurations of bananas

Here, we can see what happens when the bananas are sliced 0.6 cm (i.e., 6 mm) thick compared to when they are cut 1.2 cm thick (i.e., 12 mm).

For the thinner slices which we examined previously, the drying rate equation is:

$$\mathbf{y = e^{-0.318t}} \qquad \text{(Eq'n 1 from above)}$$

With the 1.2 cm thick slices, the rate equation is: $\mathbf{y = e^{-0.137t}}$ (Eq'n 8)

A third way of preparing the bananas was to cut them lengthwise into 0.6 cm thick pieces which I have called "slabs" to differentiate them from the round slices.

The rate equation for drying these slabs was: $\mathbf{y = e^{-0.262t}}$ (Eq'n 9)

To dry the thick slices would take about 23.6 hours. This is because the diffusion of the moisture from inside of the thick slices is quite slow.

To dry the slabs would take about 12.3 hours compared to 10.2 hours for the 0.6 cm thick slices since the effect of the plastic mesh obstructing the removal of moisture has a more pronounced effect than with the smaller diameter slices.

Application of the Drying Model:

For the 0.6 cm thick banana slices dried in these tests at 50^0C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

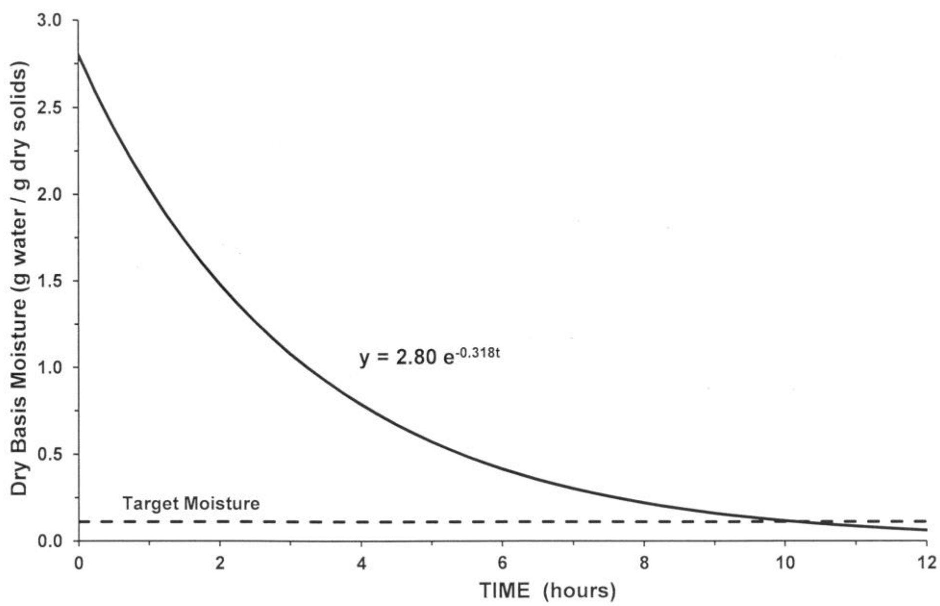
$$\mathbf{M = M_o\, e^{-0.318t}} \quad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 2.80 grams of water per gram of dry solids (i.e., approximately 73.7% wet basis moisture), this equation becomes:

$$\mathbf{M = 2.80\, e^{-0.318t}} \quad \text{(Eq'n 10)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of 0.6 cm thick banana slices

It can be seen that the slices reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 10 hours as calculated in Equation 7.

BEET DRYING

Selection and Preparation of the Material:

Beets can be dried cooked or uncooked. However, cooked beets tend to dry better than if they are not cooked. They also have better rehydration characteristics when used in stews etc. if they are cooked.

Cook the beets in boiling water until they are soft. This may take about half-an-hour or so. In order to cool them quickly, immediately place the hot beets into cold water. Once they are cool enough to handle safely, cut them into slices about 5 to 6 mm thick. This is a messy job, so be careful not to stain your clothes and work surfaces.

Fresh beets

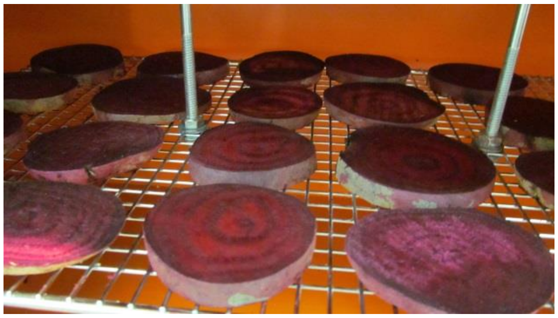
Fresh beets being boiled

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for beet slices. Be sure that the pieces have a small amount of space between them to ensure the drying air contacts all surfaces.

Test for Dryness:

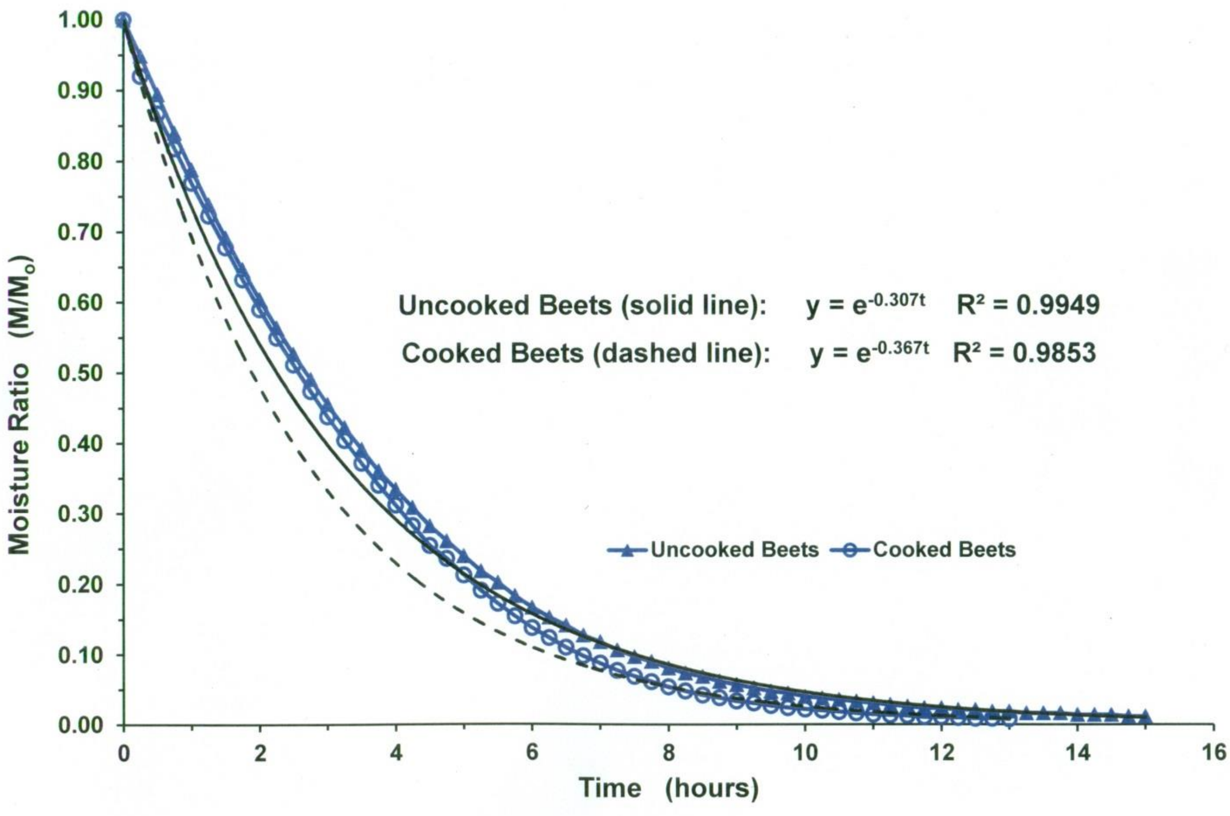
When the beet slices are dry, they will be leathery and flexible.



Fresh beet slices in the dryer

Dried beet slices in the dryer

Drying Kinetics:



Moisture ratio versus time for drying of cooked and uncooked beet slices

As can be seen from the graph shown above, the sliced cooked beets tend to dry faster than the sliced uncooked beets. The rate equation for the cooked beets does not fit the experimental data all that well for about the first seven hours of drying. However, after this time, there is very close agreement between the predicted and actual behaviour of the drying process. Since this is where we will need to be monitoring the moisture of the sliced beets most closely, it will be safe to use the equation obtained in the graph.

Based on the curve above, the general kinetic equation for the drying of cooked beet slices is given by:

$$\mathbf{y = e^{-0.367t}} \quad \text{(Eq'n 1)}$$

where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$$\mathbf{M/M_o = e^{-0.367t}} \quad \text{(Eq'n 2)}$$

where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $$\mathbf{M = M_o\, e^{-0.367t}} \quad \text{(Eq'n 3)}$$

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$\mathbf{-0.367t = \ln(M/M_o)} \quad \text{(Eq'n 4)}$$

Equation 4 then becomes: $$\mathbf{t = -\frac{\ln(M/M_o)}{0.367}} \quad \text{(Eq'n 5)}$$

$$\mathbf{t = \ln(M_o/M) / 0.367} \quad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 86.4% on a wet basis (i.e., 6.36 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.367 \\ &= \ln(6.36 / 0.111) / 0.367 \\ &= \ln(57.30) / 0.367 \\ &= 4.05 / 0.367 \\ &= 11.0 \text{ hours} \qquad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the beet slices under these conditions should take about 11.0 hours.

Application of the Drying Model:

For the 0.6 cm thick beet slices dried in these tests at $50^{o}C$ with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

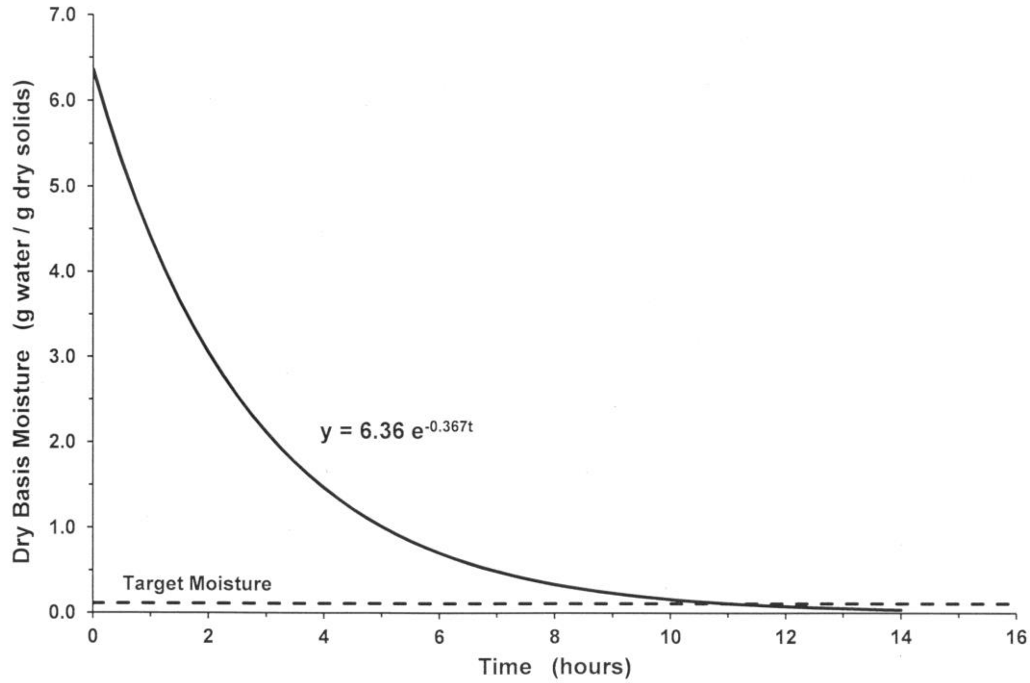
$$M = M_o\, e^{-0.367t} \quad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 6.36 grams of water per gram of dry solids (i.e., approximately 86.4% wet basis moisture), this equation becomes:

$$M = 6.36\, e^{-0.367t} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time “t” during the drying process

Plotting the dry basis moisture “M” versus time “t” gives the following graph:



Dry basis moisture versus time for the drying of sliced cooked beets

It can be seen that the beet slices reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 11 hours as calculated in Equation 7.

CANTALOUPE DRYING

Selection and Preparation of the Material:

You need to start with a high quality ripe cantaloupe. Try to avoid getting one that is overly ripe and soft. Cut the cantaloupe in half and scoop out the seeds. You can then cut each half cross-wise into crescent-shaped slices about 5 to 6 mm thick. Remove the outer skin with a paring knife and the slices are ready to be dried.

Fresh whole cantaloupe

Fresh cantaloupe slices in the dryer

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for cantaloupe slices. Be sure that the pieces have a small amount of space between them to ensure the drying air contacts all surfaces. You may have to cut the slices into smaller sections to optimize their placement in the dryer.

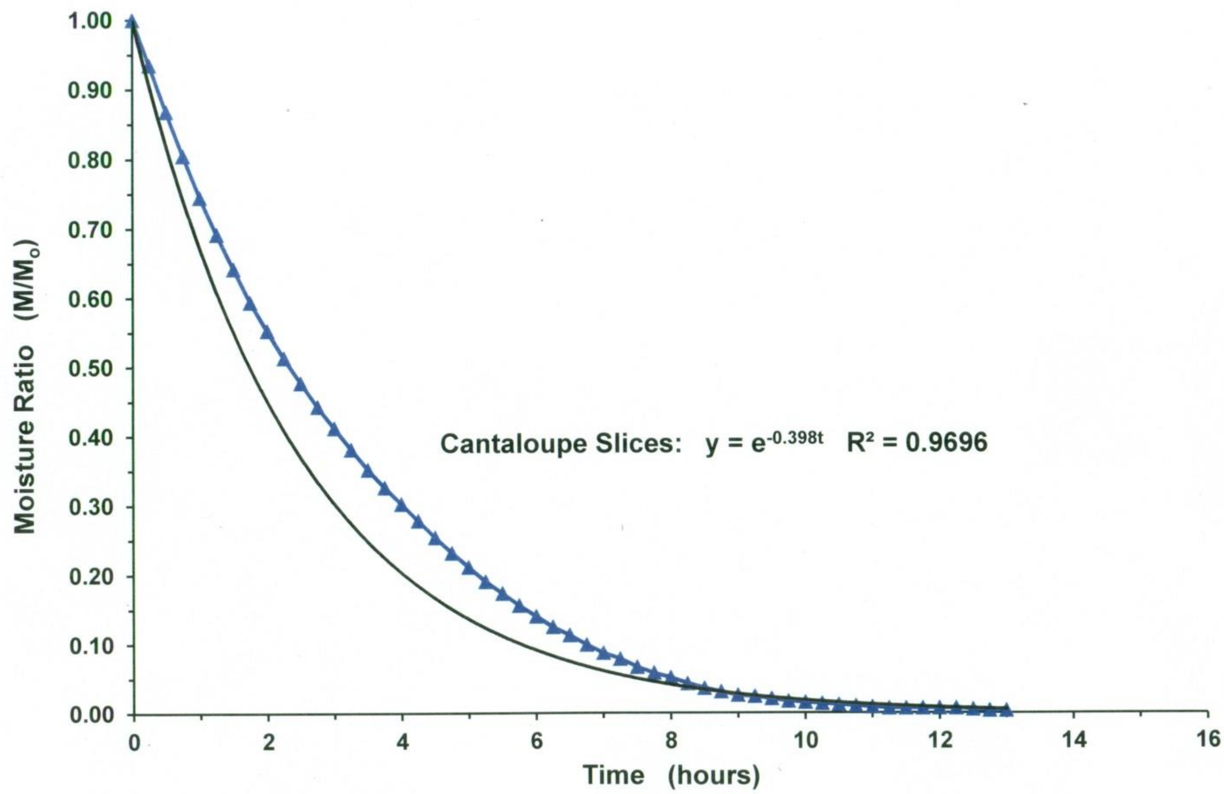
Test for Dryness:

When the cantaloupe slices are done, they will feel dry and will be leathery but flexible.

Dried cantaloupe slices in the dryer

Drying Kinetics:

In the graph shown below, there is a major disagreement between the experimental data and the mathematical equation that was derived by the spreadsheet program. However, during the first eight hours when this departure is occurring, the cantaloupe slices are still too wet to stop the drying. After eight hours, there is very close agreement between the mathematical equation and the experimental data. This allows the equation to be used after eight hours of drying when it fits the data.



Moisture ratio versus time for drying of cantaloupe slices

Based on the curve above, the general kinetic equation for the drying of cantaloupe slices is given by:

$$\mathbf{y = e^{-0.398t}} \quad \text{(Eq'n 1)}$$

where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$$\mathbf{M/ M_o = e^{-0.398t}} \quad \text{(Eq'n 2)}$$

where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $$\mathbf{M = M_o\, e^{-0.398t}} \quad \text{(Eq'n 3)}$$

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$-0.398t = \ln(M/M_o) \qquad \text{(Eq'n 4)}$$

Equation 4 then becomes: $$t = -\frac{\ln(M/M_o)}{0.398} \qquad \text{(Eq'n 5)}$$

$$t = \ln(M_o/M) / 0.398 \qquad \text{(Eq'n 6)}$$

<u>Calculation of Drying Times</u>:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 88.1% on a wet basis (i.e., 7.40 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.398 \\ &= \ln(7.40 / 0.111) / 0.398 \\ &= \ln(66.67) / 0.398 \\ &= 4.20 / 0.398 \\ &= 10.6 \text{ hours} \qquad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the cantaloupe slices under these conditions should take about 10.6 hours.

<u>Application of the Drying Model</u>:

For the 0.6 cm thick cantaloupe slices dried in these tests at 50^0C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

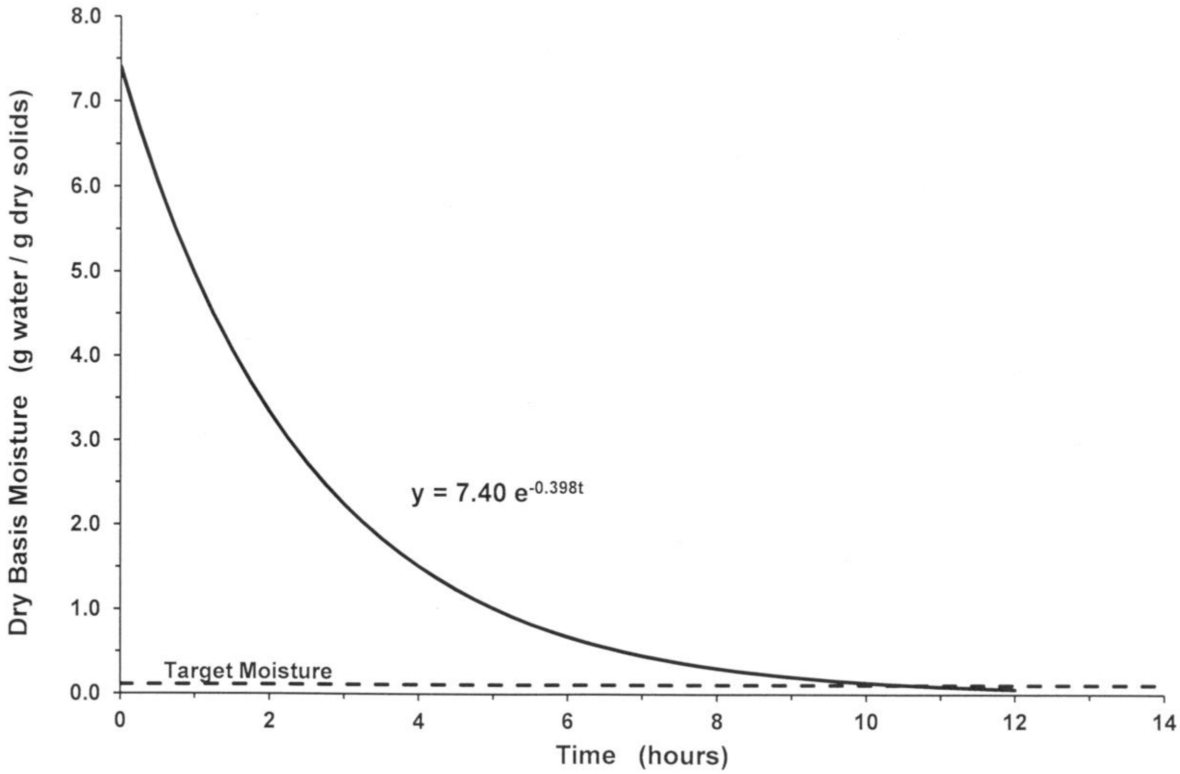
$$M = M_o\, e^{-0.398t} \qquad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 7.40 grams of water per gram of dry solids (i.e., approximately 88.1% wet basis moisture), this equation becomes:

$$M = 7.40\, e^{-0.398t} \qquad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture “M” versus time “t” gives the following graph:



Dry basis moisture versus time for the drying of sliced cantaloupe

It can be seen that the cantaloupe slices reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 10 to 11 hours as calculated in Equation 7.

CARROT DRYING

Selection and Preparation of the Material:

Carrots offer a variety of options as to how they may be prepared for drying. We will focus on drying slices of carrot about 5 to 6 mm thick. Once this is done, we will take a look at a couple of other less attractive drying options.

Selected carrots that are fresh and crisp, peel them, and cut them into 5 to 6 mm thick slices. They will now look like orange disks. Before drying, it is best to blanch the carrot slices by placing them in boiling water for two to three minutes. A strainer can be used to remove the carrots from the blanching water. They should be cooled immediately by placing them in cold water. Once they are cool enough to handle, the blanched carrot slices should be drained to remove as much surface water as possible.

Carrot slices before and after drying

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for carrot slices. Be sure that the pieces have a small amount of space between them to ensure the drying air contacts all surfaces. You may need to use a piece of plastic mesh to prevent the carrot slices from falling through the wire mesh rack as they dry.

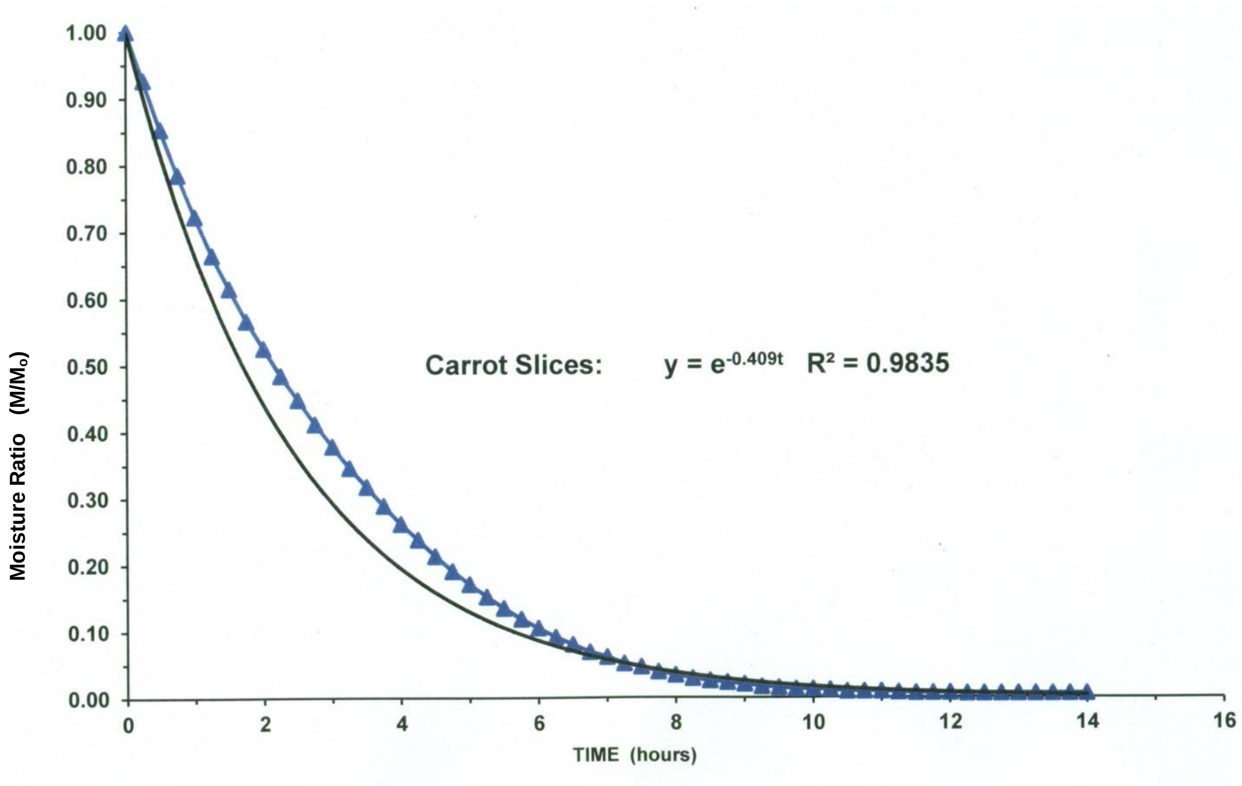
Test for Dryness:

When the carrot slices are done, they will feel dry and be quite leathery, or even crisp. One interesting feature of dried carrot slices is how the edges curl up in a distinctive wavy pattern.

Dried carrot slices

Drying Kinetics:

In the graph shown below, there is a lack of correlation between the experimental data and the mathematical equation during the first stages of the drying process. After about six hours of drying, when the moisture content is approaching the desired low levels, agreement between the mathematical equation and the experimental data is quite good, which makes the equation suitable for use as a predictive tool.



Based on the curve above, the general kinetic equation for the drying of carrot slices is given by:

$\mathbf{y = e^{-0.409t}}$ (Eq'n 1) where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$\mathbf{M/ M_o = e^{-0.409t}}$ (Eq'n 2) where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $\mathbf{M = M_o\, e^{-0.409t}}$ (Eq'n 3)

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$\mathbf{-0.409t = \ln(M/M_o)} \qquad \text{(Eq'n 4)}$$

Equation 4 then becomes: $$t = -\frac{\ln(M/M_o)}{0.409} \qquad \text{(Eq'n 5)}$$

$$t = \ln(M_o/M) / 0.409 \qquad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 89.0% on a wet basis (i.e., 8.10 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.409 \\ &= \ln(8.10 /0.111) / 0.409 \\ &= \ln(72.97) / 0.409 \\ &= 4.29 / 0.409 \\ &= 10.5 \text{ hours} \qquad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the carrot slices under these conditions should take about 10.5 hours.

Alternate Preparations of Carrots for Drying:

The best method for drying carrots is to cut them cross-wise into thin slices, as we have already examined. This exposes a great deal of surface area to the effects of the heated air blowing across them in the dryer. Carrots also have small capillaries which are like "tubes" running along their length to transport water. The thin sliced approach to drying tends to maximize the use of these capillaries in removing moisture.

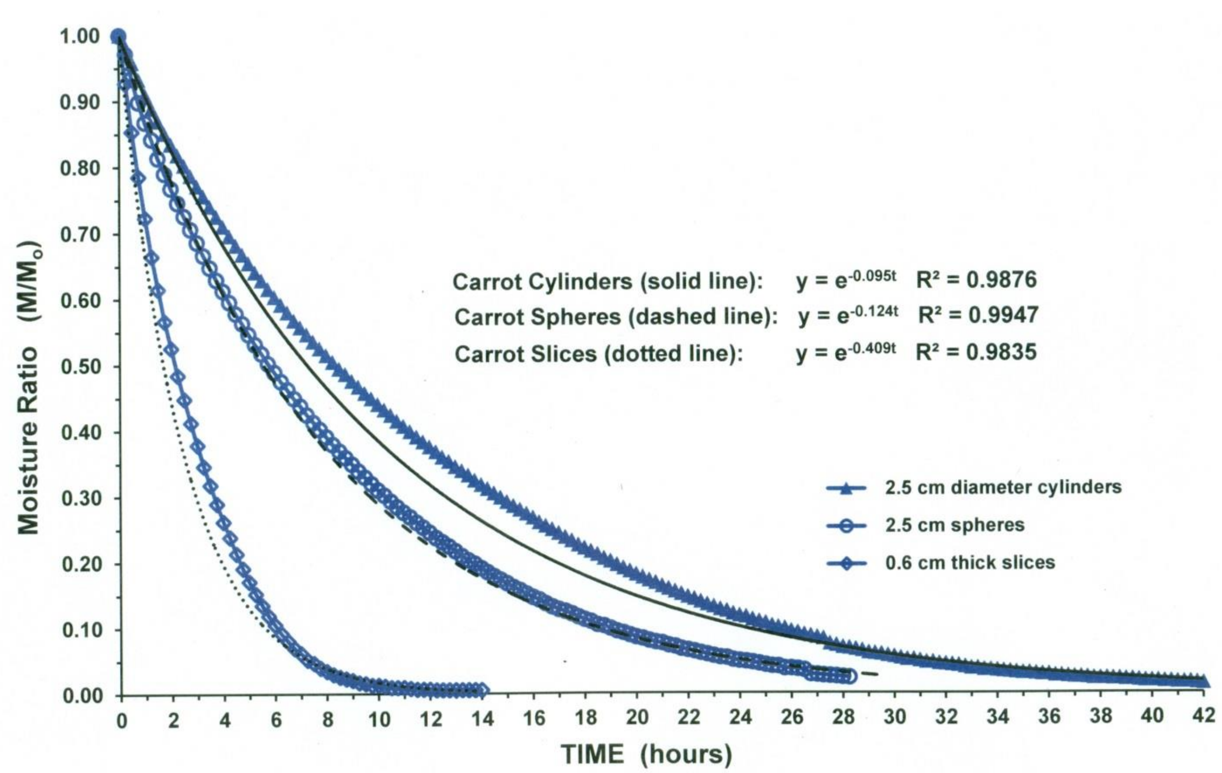
In an earlier chapter, we looked at how solids could approximate the shapes of flat slabs, spheres, and cylinders in the drying process.

Thin carrot slices (about 6 mm or 0.6 cm thick) would behave like flat slabs during drying. They have a large top and bottom surface to facilitate the loss of moisture. Any water at the centre of the carrot slices would have to travel only half the thickness of the slice to reach the surface and be removed by the drying air. The effects of the small amount of side area on the slices would not be nearly as great as the top and bottom surfaces.

If the carrots were to be cut into thick slices where their thickness became close to their diameter, they would approximate the behaviour of a sphere during the drying process. Let's consider what would happen if the diameter and thickness of the carrot slices were both about 2.5 cm (or 1 inch). Water in the carrots tends to travel lengthwise through the material. This means that it travels longitudinally, rather than outwards along the radius of the carrot slices to the surface. In a 2.5 cm thick slice, the water at the centre would then have to travel 1.25 cm to reach one end or the other of the carrot slice. If the water were to travel in a radial direction, it would still have to travel 1.25 cm to reach the outer surface. This distance is far greater than in a thinner slice and would slow the drying process.

Carrots cut into long pieces (for example 10 cm long) would approximate the behaviour of a cylinder. Moisture inside the cylinder would have to travel in a radial direction to reach the outer edge of the carrot. Similarly, if the moisture loss was in the lengthwise longitudinal direction, the water would have to travel 5 cm from the middle to reach either end of the carrot. This presents an even greater challenge to water removal than when the 2.5 cm thick slices were used.

The graph below compares the drying rate kinetics of 0.6 cm thick carrot slices with those of 2.5 cm thick slices and 10 cm long carrot cylinders.



Comparison of moisture ratios versus time for various carrot configurations

Earlier, we calculated the time to dry 0.6 cm thick carrot slices from an initial moisture content of 89.0% on a wet basis (i.e., 8.10 grams of water per gram of dry solids) to a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids). This turned out to be about 10.5 hours.

Using a similar mathematical treatment and substituting the exponents of the drying curves into the mathematical equations developed earlier, we can find the drying times of the "spheres" and "cylinders".

For the "slices": $\mathbf{t = 10.5}$ **hours** (from Eq'n 7)

For the "spheres": $\mathbf{t = \ln(M_o/M) / 0.124 = \ln(8.10 / 0.111) / 0.124}$

$\mathbf{t = 34.6}$ **hours** (Eq'n 8)

For "cylinders": $\mathbf{t = \ln(M_o/M) / 0.124 = \ln(8.10 / 0.111) / 0.095}$

$\mathbf{t = 45.2}$ **hours** (Eq'n 9)

From these results, it should be quite clear that the manner in which the material is prepared has a pronounced effect on its drying kinetics.

Fresh thick carrot slices resembling "spheres" (top), and after drying (bottom)

10 cm length of fresh carrot resembling “cylinder” (top), and after drying (bottom)

If care is not taken to thoroughly remove the water, the carrot “spheres” and “cylinders” may show signs of mold growth after a short time in storage.

Application of the Drying Model:

For the 0.6 cm thick carrot slices dried in these tests at 50^0C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

$$\mathbf{M = M_o\ e^{-0.409t}} \quad \text{(restating of Eq'n 3)}$$

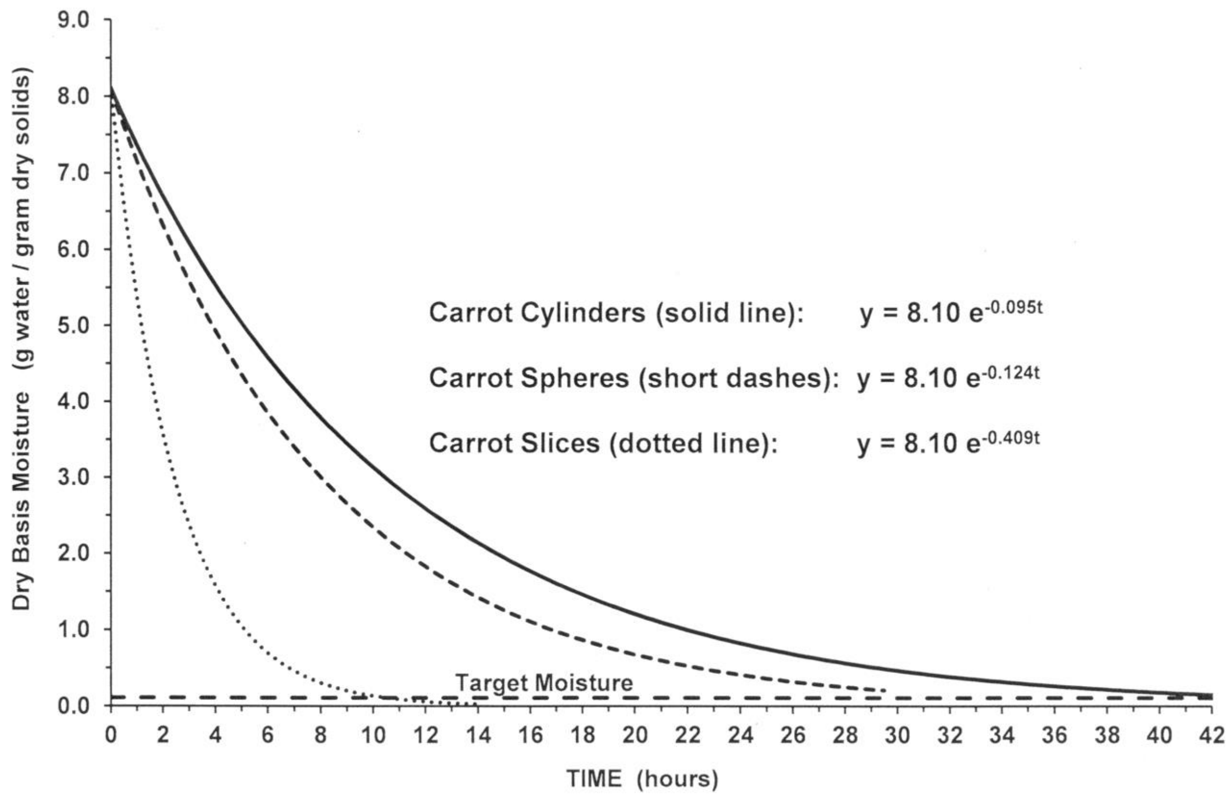
With an average initial dry basis moisture (M_o) of 8.10 grams of water per gram of dry solids (i.e., approximately 89.0% wet basis moisture), this equation becomes:

$$\mathbf{M = 8.10\ e^{-0.409t}} \quad \text{(Eq'n 10)}$$

where: M is the dry basis moisture at any time “t” during the drying process

The same can be done for carrots as spheres and cylinders.

Plotting the dry basis moisture “M” versus time “t” gives the following graph:



Dry basis moisture versus time for the drying of carrots

It can be seen that the carrot slices reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 10 to 11 hours as calculated in Equation 7.

Similarly, the times for the spherical and cylindrical configurations can be found from this graph.

CASSAVA DRYING

Selection and Preparation of the Material:

Before drying cassava, it is necessary to boil them. This accomplishes a number of things, including gelatinizing the starches and softening the cassava flesh. Once peeled, the cassava was cut into slices about 4 to 5 cm thick and boiled in water for approximately 30 minutes. After draining to remove the excess water from the pot, the cassava was mashed with a hand-held potato masher.

Cassava prior to peeling

Peeled cassava

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for drying mashed cassava.

The mashed cassava needs to be spread as evenly as possible on plastic mesh inside the dryer. Be careful not to make the layer of cassava too thick, or this will slow the drying process.

It should be noted that there can be more inherent variability in the drying of materials where more is involved than simply cutting the material and placing it in the dryer. You may need to practise a few times to establish a method that will give uniform drying results.

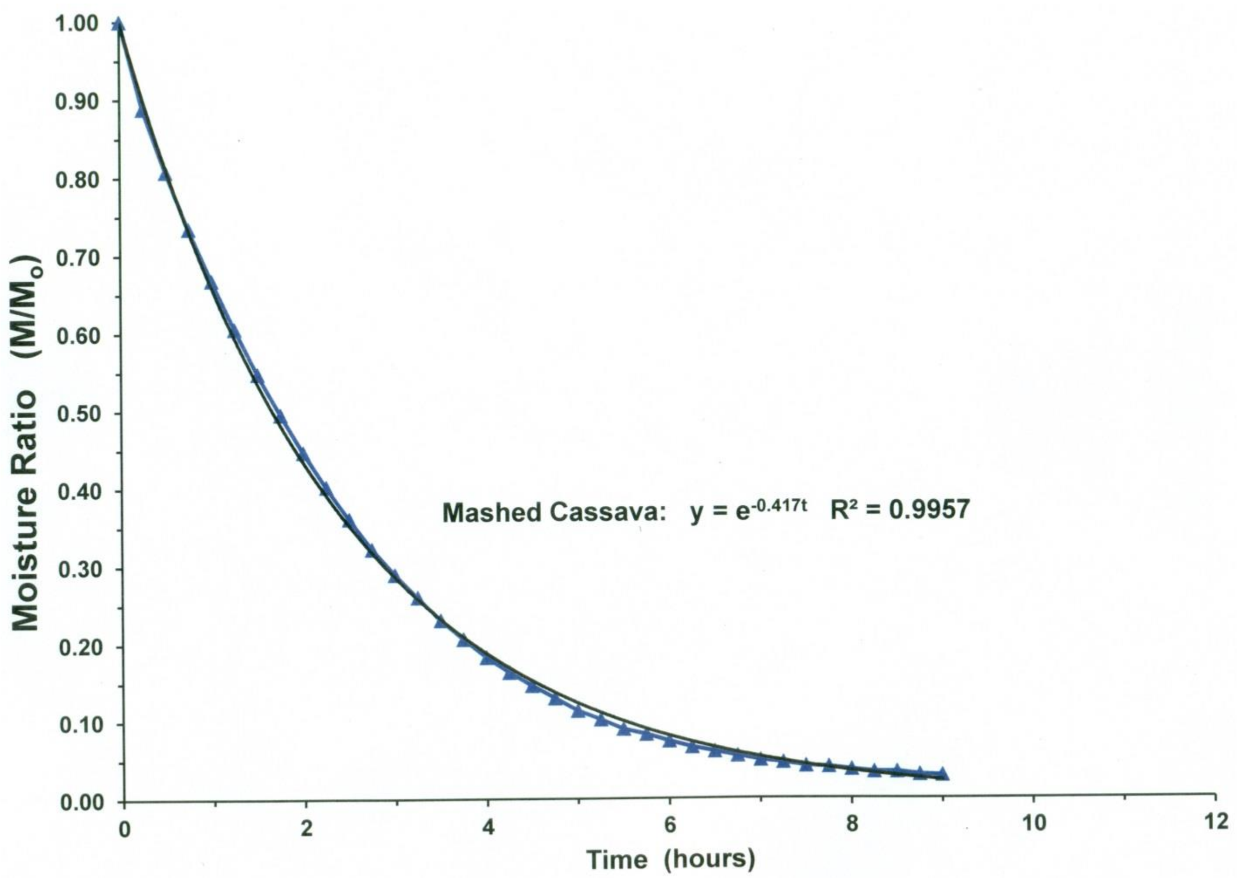
Test for Dryness:

When the mashed cassava is dried and cooled, the pieces will feel quite brittle and will break apart when crushed between your fingers.

Wet mashed cassava after being placed on plastic mesh in the dryer

Dried mashed cassava pieces in the dryer

Drying Kinetics:



Moisture ratio versus time for the drying of mashed cassava

Based on the curve above, the general kinetic equation for the drying of mashed cassava is given by:

$$\mathbf{y = e^{-0.417t}}$$ (Eq'n 1) where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$$\mathbf{M/ M_o = e^{-0.417t}}$$ (Eq'n 2) where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $$\mathbf{M = M_o\, e^{-0.417t}}$$ (Eq'n 3)

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$-0.417t = \ln(M/M_o) \qquad \text{(Eq'n 4)}$$

Equation 4 then becomes: $t = -\dfrac{\ln(M/M_o)}{0.417}$ (Eq'n 5)

$$t = \ln(M_o/M) / 0.417 \qquad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 65.4% on a wet basis (i.e., 1.89 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.417 \\ &= \ln(1.89 /0.111) / 0.417 \\ &= \ln(17.02) / 0.417 \\ &= 2.83 / 0.417 \\ &= 6.8 \text{ hours} \qquad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the mashed cassava under these conditions should take about 6.8 hours.

Application of the Drying Model:

For the mashed cassava dried in these tests at 50^0C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

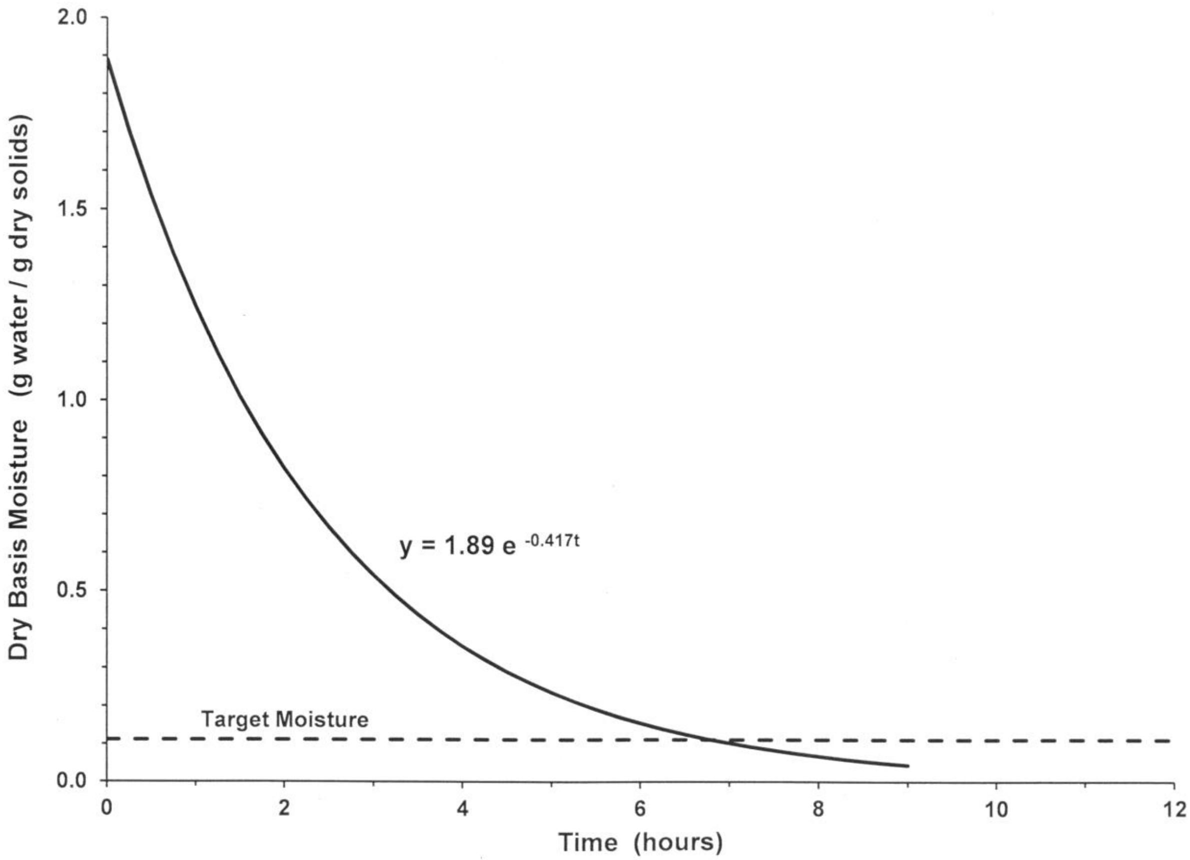
$$M = M_o\, e^{-0.417t} \qquad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 1.89 grams of water per gram of dry solids (i.e., approximately 65.4% wet basis moisture), this equation becomes:

$$M = 1.89\, e^{-0.417t} \qquad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture “M” versus time “t” gives the following graph:



Dry basis moisture versus time for the drying of mashed cassava

It can be seen that the mashed cassava reaches a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 7 hours as calculated in Equation 7.

CELERY DRYING

Selection and Preparation of the Material:

Fresh, non-wilted celery stalks should be selected. There is little preparation required before drying celery. Simply wash the celery thoroughly and shake off the excess water before cutting the stalks cross-wise into about 1 cm thick slices. Some people like to blanch the pieces of celery in boiling water, but this is not really necessary.

Fresh celery stalks prior to washing

Slices of celery before and after drying

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for drying celery slices.

You will definitely need to use a fine plastic mesh in the dryer to prevent the small pieces of celery from falling through the wider wire mesh rack that is usually found in many dryers. It is difficult to spread the celery pieces evenly without having them touch each other. The important thing is to do the best you can in spreading the pieces. In my experiments, the pieces were manually positioned on the plastic mesh before placing them into the dryer, which was a time consuming task. However, this assured that they would not be touching each other.

Test for Dryness:

The small pieces of dried celery should feel crisp or brittle when done (see photo above).

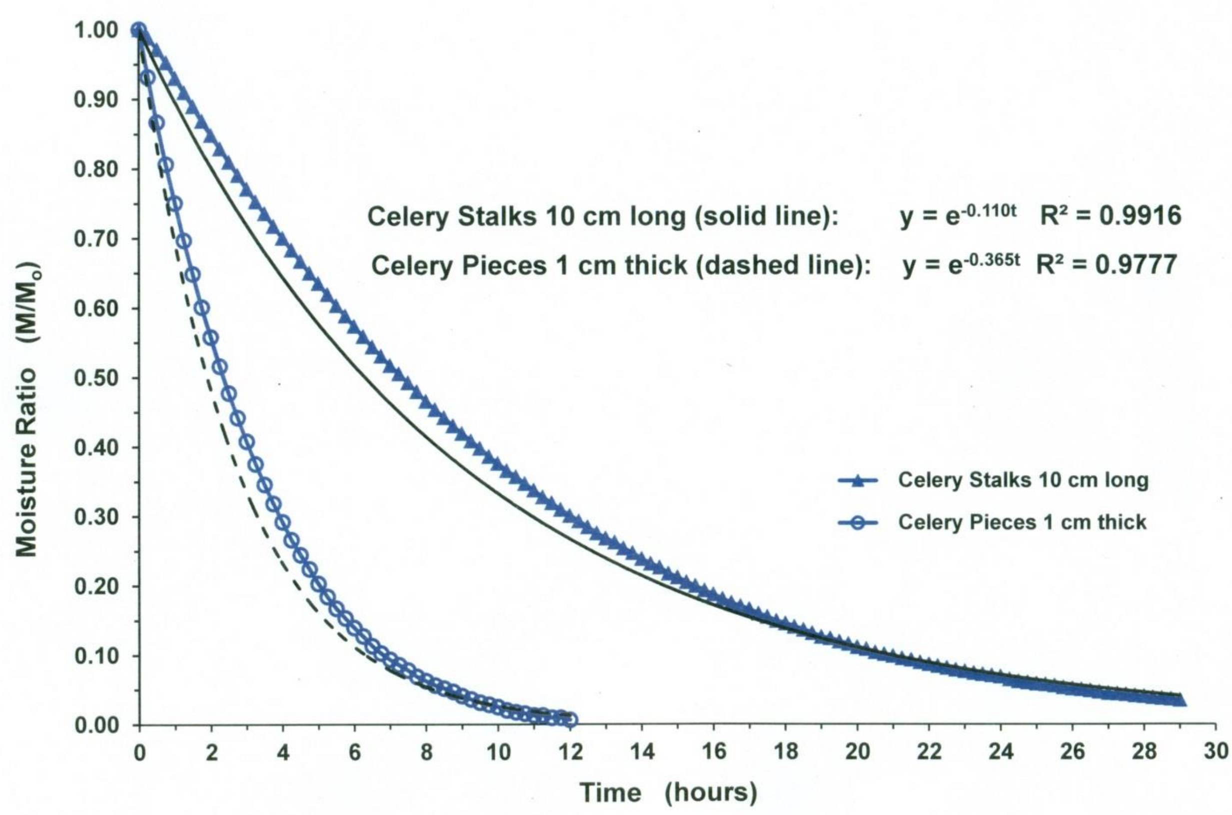
You may want to dry celery at a slightly higher temperature to increase the drying rate and lower the time taken. 55ºC is quite acceptable.

10 cm long celery stalks before and after drying

The 10 cm long celery “stalks” do not dry very well and are not useful in food preparations. Their inclusion here is primarily for academic consideration. In the photo above, we can see the difference between a fresh stalk and some dried samples.

Drying Kinetics:

In the graph below, 10 cm long “stalks” of celery have been included to show the impact of size when compared to the drying of 1 cm thick slices of celery. Both drying curves differ from the experimental values in the early stages of drying, but agree closely when the moisture levels become lower, later in the drying runs.



Moisture ratio versus time for the drying of celery slices and 10 cm long stalks

Based on the curve above, the general kinetic equation for the drying of 1 cm thick celery slices is given by:

$\mathbf{y = e^{-0.365t}}$ (Eq'n 1) where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$\mathbf{M/ M_o = e^{-0.365t}}$ (Eq'n 2) where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $\mathbf{M = M_o\, e^{-0.365t}}$ (Eq'n 3)

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$-0.365t = \ln(M/M_o) \qquad \text{(Eq'n 4)}$$

Equation 4 then becomes:

$$t = -\frac{\ln(M/M_o)}{0.365} \qquad \text{(Eq'n 5)}$$

$$t = \ln(M_o/M) / 0.365 \qquad \text{(Eq'n 6)}$$

<u>Calculation of Drying Times</u>:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 95.37% on a wet basis (i.e., 20.6 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.365 \\ &= \ln(20.6 / 0.111) / 0.365 \\ &= \ln(185.6) / 0.365 \\ &= 5.22 / 0.365 \\ &= 14.3 \text{ hours} \qquad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the 1 cm thick celery slices under these conditions should take about 14.3 hours.

Looking at the 10 cm long celery "stalks", the drying process would take about 47.5 hours.

$$\begin{aligned} t &= \ln(M_o/M) / 0.110 \\ &= \ln(20.6 / 0.111) / 0.110 \\ &= \ln(185.6) / 0.110 \\ &= 5.22 / 0.110 \\ &= 47.5 \text{ hours} \qquad \text{(Eq'n 8)} \end{aligned}$$

Application of the Drying Model:

For the celery slices dried in these tests at 50^{0}C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

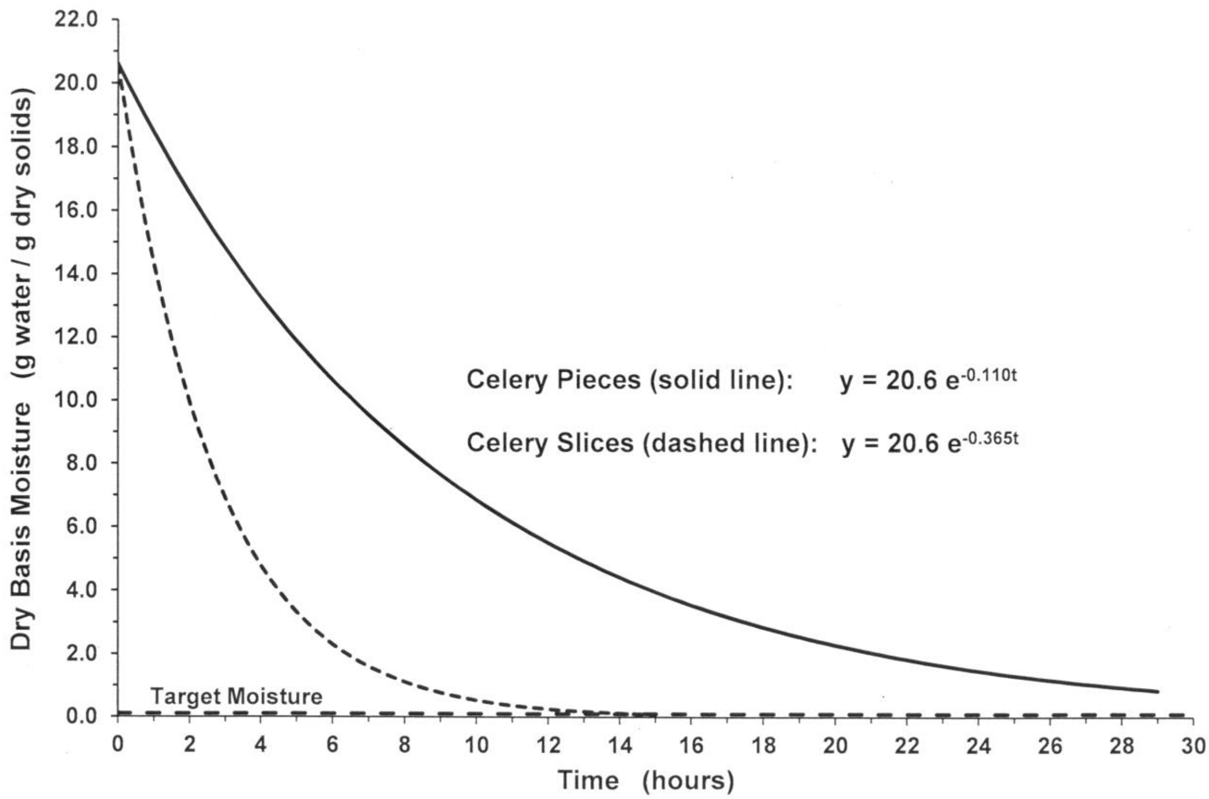
$$\mathbf{M = M_o\ e^{-0.365t}} \quad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 20.6 grams of water per gram of dry solids (i.e., approximately 95.4% wet basis moisture), this equation becomes:

$$\mathbf{M = 20.6\ e^{-0.365t}} \quad \text{(Eq'n 9)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of celery slices and stalks

It can be seen that the celery slices reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 14 hours as calculated in Equation 7. The stalks take appreciably longer (the time is off the graph shown here).

EGGPLANT DRYING

Selection and Preparation of the Material:

After selecting an eggplant that is free from blemishes, you simply need to wash it and peel it before cutting it lengthwise and then cross-wise into slices about 5 to 6 mm thick. Some people like to blanch the sliced eggplant in boiling water for a short time, but this is not really necessary.

Whole eggplant prior to peeling and slicing

Halved eggplant

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for drying eggplant slices. Place the slices in the dryer so that they are not touching.

Test for Dryness:

The slices of dried eggplant will feel quite leathery but will still retain a degree of flexibility.

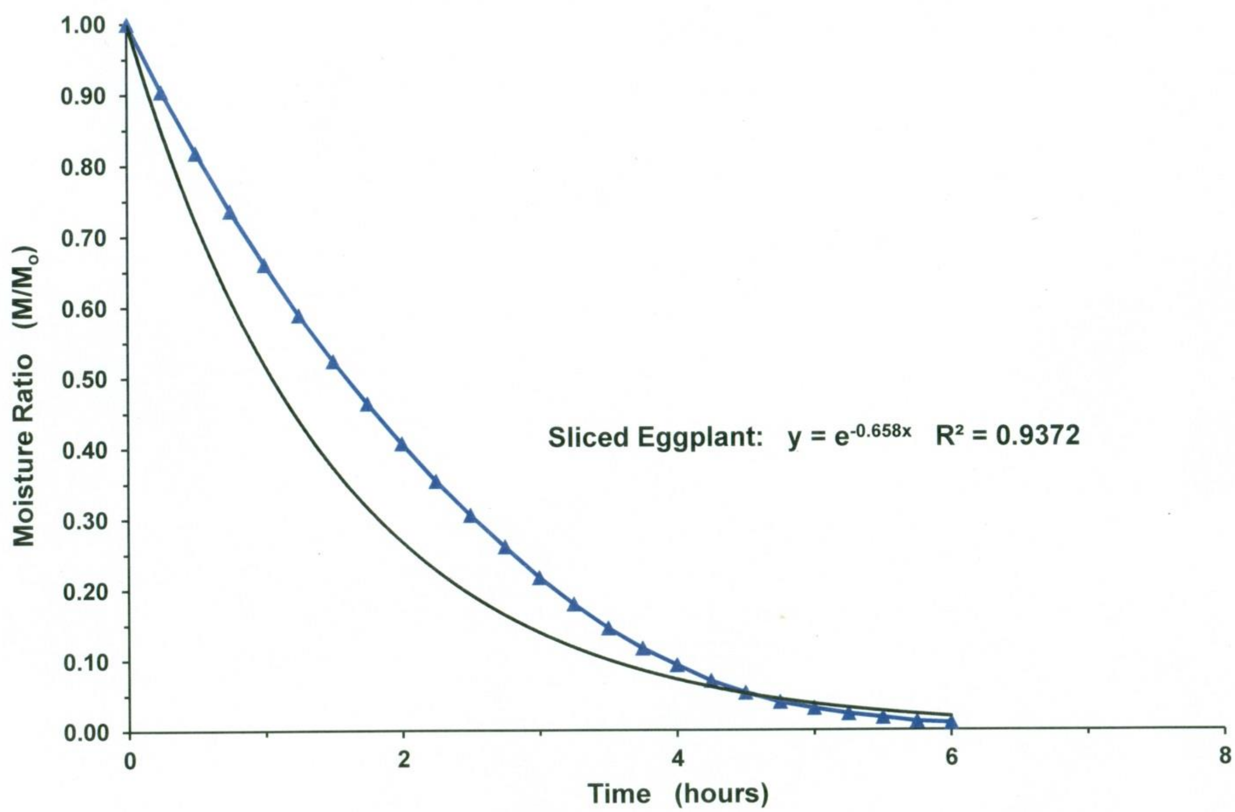
Fresh eggplant slices in dryer

Dried eggplant slices in dryer

Drying Kinetics:

This is probably one of the worst fitting mathematical equations that I had in this study. Notice how the R^2 value is quite low compared to the others we have seen. One of the reasons could be the rapidity with which the water is lost from such a high moisture material. It would be easy to switch the format of the curve from the usual exponential form which we have been using. However, I feel that it is important not to confuse things by introducing a different modelling format. Therefore, we will use this approach for the sake of convenience.

Fortunately, the agreement between the experimental data and the mathematical equation is reasonably close in the late stages of drying which will allow us to predict when the drying is nearing completion.



Moisture ratio versus time for the drying of eggplant slices

Based on the curve above, the general kinetic equation for the drying of 6 mm thick eggplant slices is given by:

$$y = e^{-0.658t} \quad \text{(Eq'n 1)}$$

where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$$M/M_o = e^{-0.658t} \quad \text{(Eq'n 2)}$$

where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or:

$$M = M_o e^{-0.658t} \quad \text{(Eq'n 3)}$$

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$-0.658t = \ln(M/M_o) \quad \text{(Eq'n 4)}$$

Equation 4 then becomes:

$$t = -\frac{\ln(M/M_o)}{0.658} \quad \text{(Eq'n 5)}$$

$$t = \ln(M_o/M) / 0.658 \quad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 92.9% on a wet basis (i.e., 13.0 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.658 \\ &= \ln(13.0 / 0.111) / 0.658 \\ &= \ln(117.1) / 0.658 \\ &= 4.76 / 0.658 \\ &= 7.2 \text{ hours} \quad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the 6 mm thick eggplant slices under these conditions should take only about 7.2 hours.

Application of the Drying Model:

For the eggplant slices dried in these tests at 50^{0}C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

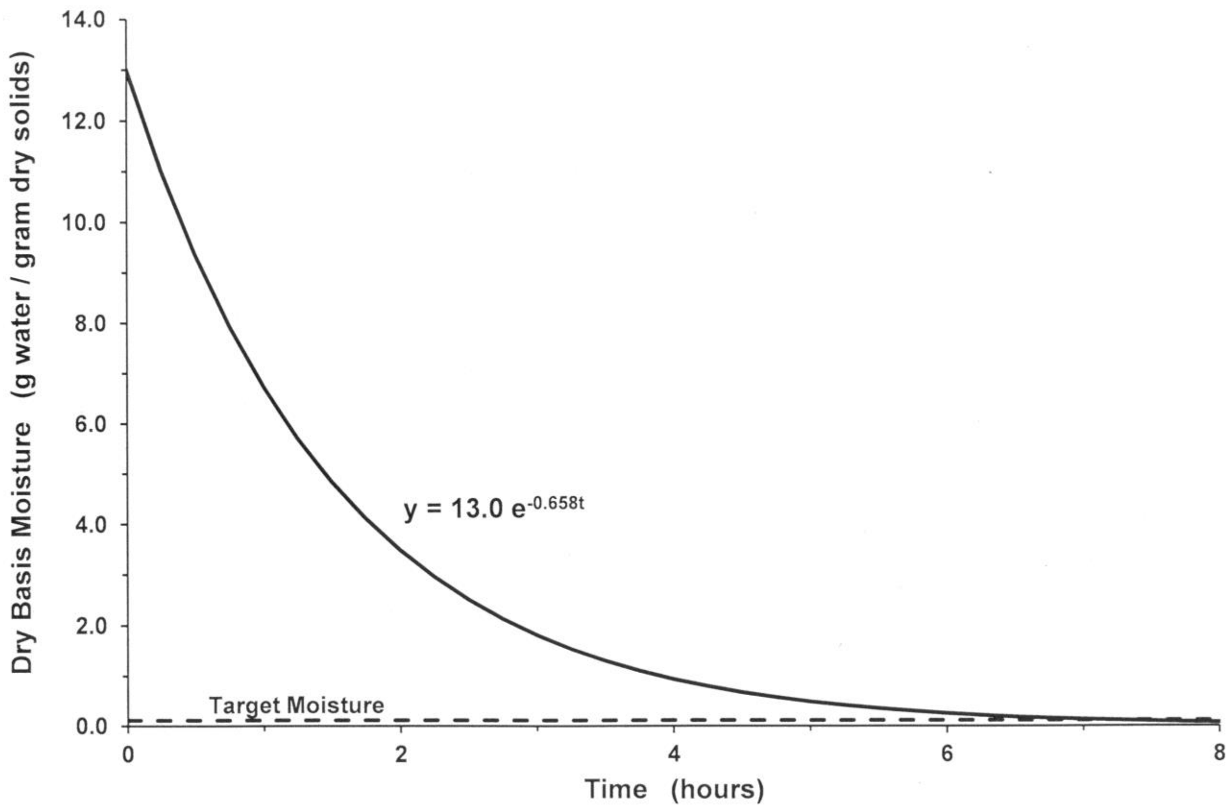
$$\mathbf{M = M_o\ e^{-0.658t}} \quad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 13.0 grams of water per gram of dry solids (i.e., approximately 92.9% wet basis moisture), this equation becomes:

$$\mathbf{M = 13.0\ e^{-0.658t}} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of eggplant slices

It can be seen that the eggplant slices reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 7 hours as calculated in Equation 7.

GINGER ROOT DRYING

Selection and Preparation of the Material:

The ginger root should be peeled before proceeding to any further preparation.

Whole ginger root prior to peeling

Once peeled, you have the option of cutting the pieces cross-wise into 5 to 6 mm thick slices or grating the ginger root using a kitchen grater. You may also prefer to cut the slices thinner if this serves your needs better. It will also help speed up the drying process.

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for drying ginger root slices or grated ginger root. There is the most pleasant aroma in the room while the drying process is proceeding. You will need to use plastic mesh under the ginger root to support it during drying.

Test for Dryness:

After drying, the ginger root will feel dry to the touch and be somewhat leathery or rubbery.

The following photographs show sliced and grated ginger root being dried.

Fresh sliced ginger root in the dryer

Dried slices of ginger root in the dryer

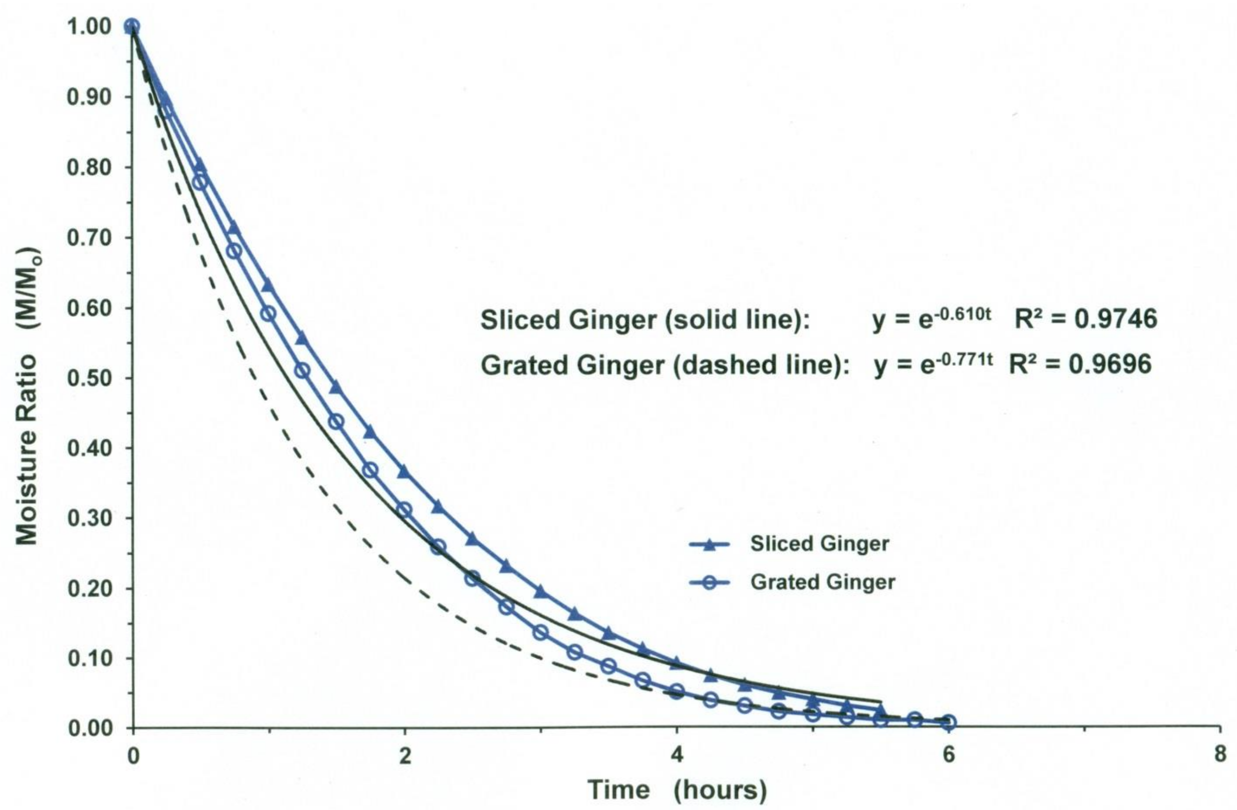
Fresh grated ginger root in the dryer

Dried grated ginger root in the dryer

Drying Kinetics:

The graph below shows how fast moisture is lost from both grated and sliced ginger root. As is often the case with high moisture products that lose their moisture rapidly, using an exponential equation to model the drying does not give a good fit to the experimental data during the first portion of the run. Fortunately, the curves fit the observed data late I the drying runs and can be used as a predictive tool at these times.

The exponential coefficients for moisture loss were among the fastest seen in any of this drying work.



Moisture ratio versus time for sliced and grated ginger

Based on the curve above, the general kinetic equation for the drying of 6 mm thick ginger root slices is given by:

$\mathbf{y = e^{-0.610t}}$ (Eq'n 1) where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$\mathbf{M/ M_o = e^{-0.610t}}$ (Eq'n 2) where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $\mathbf{M = M_o\, e^{-0.610t}}$ (Eq'n 3)

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$-0.610t = \ln(M/M_o) \quad \text{(Eq'n 4)}$$

Equation 4 then becomes:

$$t = -\frac{\ln(M/M_o)}{0.610} \quad \text{(Eq'n 5)}$$

$$t = \ln(M_o/M) / 0.610 \quad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 89.7% on a wet basis (i.e., 8.71 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.610 \\ &= \ln(8.71 / 0.111) / 0.610 \\ &= \ln(78.5) / 0.610 \\ &= 4.36 / 0.610 \\ &= 7.1 \text{ hours} \quad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the 6 mm thick ginger root slices under these conditions should take only about 7.1 hours.

Now, looking at the grated ginger root:

$$\begin{aligned} t &= \ln(M_o/M) / 0.771 \\ &= \ln(8.71 / 0.111) / 0.771 \\ &= \ln(78.5) / 0.771 \\ &= 4.36 / 0.771 \\ &= 5.7 \text{ hours} \quad \text{(Eq'n 8)} \end{aligned}$$

Therefore, drying the grated ginger root under these conditions should take only about 5.7 hours.

Application of the Drying Model:

For the sliced ginger dried in these tests at 50^{o}C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

$$M = M_o\, e^{-0.610t} \quad \text{(restating of Eq'n 3)}$$

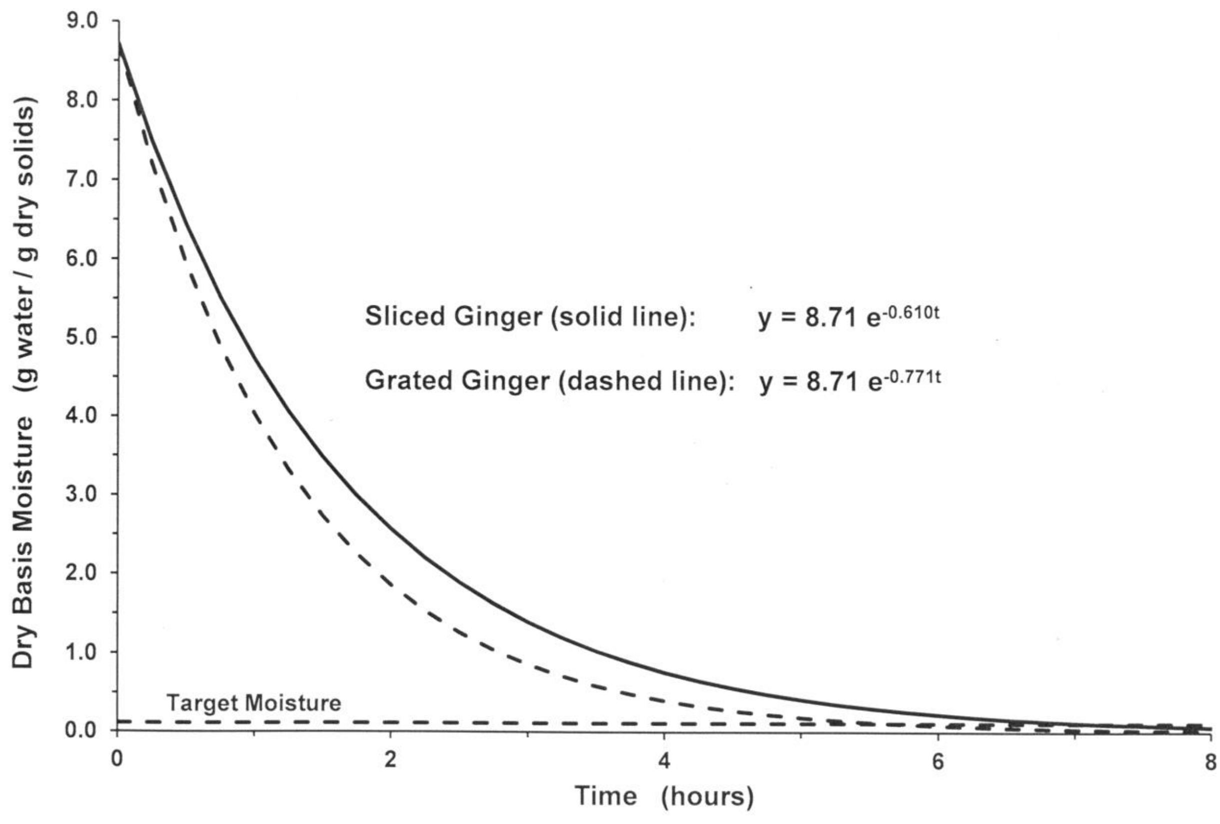
With an average initial dry basis moisture (M_o) of 8.71 grams of water per gram of dry solids (i.e., approximately 89.7% wet basis moisture), this equation becomes:

$$M = 8.71\, e^{-0.610t} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time “t” during the drying process

A similar curve can be plotted for the grated ginger as well.

Plotting the dry basis moisture “M” versus time “t” gives the following graph:



Dry basis moisture versus time for the drying of sliced and grated ginger

It can be seen that the sliced ginger reaches a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 7 hours as calculated in Equation 7.

The grated ginger dries more rapidly and reaches the desired final moisture in about 5 to 6 hours as calculated in Equation 8.

HERB DRYING: (Sage and Oregano)

Selection and Preparation of the Material:

From a personal point of view, I prefer fresh herbs whenever possible. However, these are not always available, so dried herbs offer a suitable alternative.

Leafy herbs retain a lot of surface moisture when they are washed. You may find it necessary to blot the leaves dry to remove any excess moisture which can add to the water removal demands on the dryer and slow the entire process. The leaves can be removed from the stems and dried loose, or small clusters of leaves can be left on the stems and dried in that manner.

Fresh oregano in the dryer

Fresh sage in the dryer

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for drying herbs, but it may actually be a bit too warm. Even though the drying will be a bit slower, you may want to reduce the temperature to 45ºC, or even 40ºC.

Keep in mind that while the room may smell wonderful while you are drying your herbs, all this aroma is actually an indication that you are losing many of the quality attributes of your materials.

Test for Dryness:

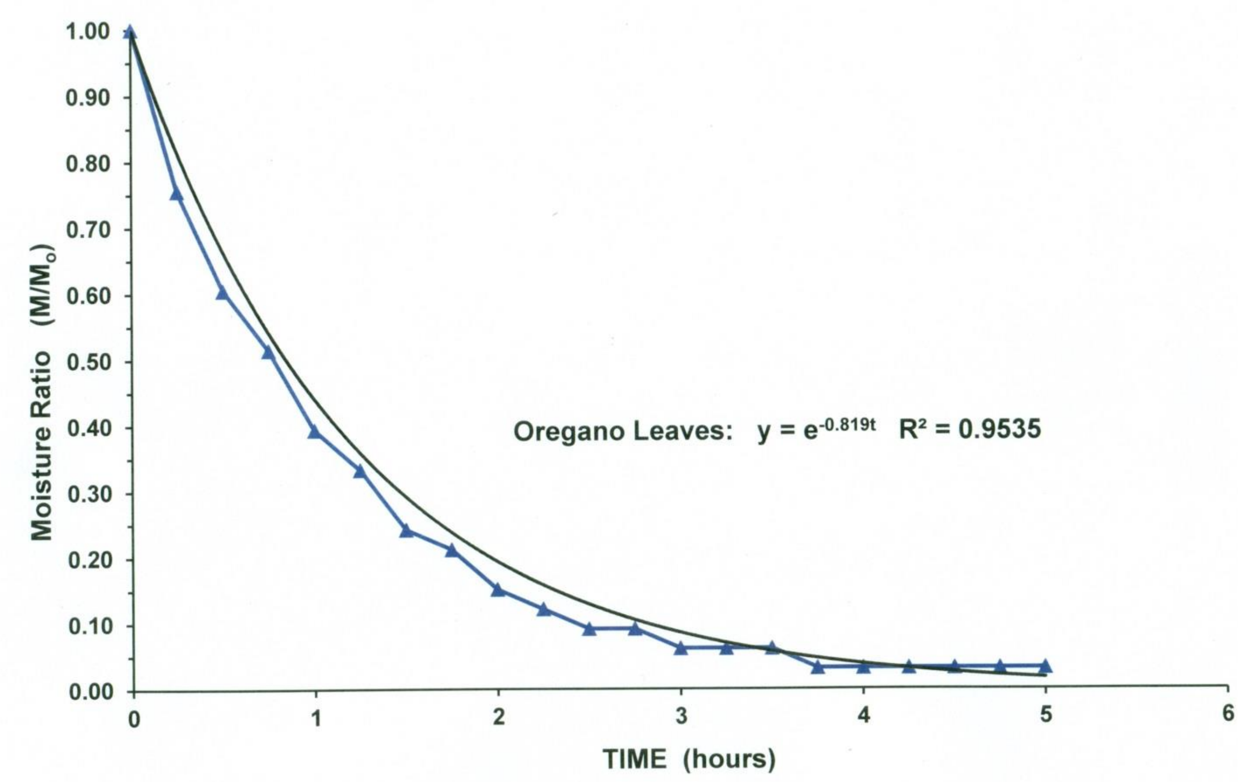
Once properly dried, the leaves should be quite brittle and crumble in your fingers.

The following photographs show oregano and sage after they have been dried.

Dried oregano in the dryer

Dried sage in the dryer

Drying Kinetics for Oregano:



Moisture ratio versus time for drying of oregano

Based on the curve above, the general kinetic equation for the drying of oregano leaves is given by:

$$\mathbf{y = e^{-0.819t}} \quad \text{(Eq'n 1)}$$

where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$$\mathbf{M/ M_o = e^{-0.819t}} \quad \text{(Eq'n 2)}$$

where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $$\mathbf{M = M_o\, e^{-0.819t}} \quad \text{(Eq'n 3)}$$

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$-0.819t = \ln(M/M_o) \qquad \text{(Eq'n 4)}$$

Equation 4 then becomes: $$t = -\frac{\ln(M/M_o)}{0.819} \qquad \text{(Eq'n 5)}$$

$$t = \ln(M_o/M) / 0.819 \qquad \text{(Eq'n 6)}$$

Calculation of Drying Times for Oregano:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 87.0% on a wet basis (i.e., 6.7 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.819 \\ &= \ln(6.70 / 0.111) / 0.819 \\ &= \ln(60.4) / 0.819 \\ &= 4.10 / 0.819 \\ &= 5.0 \text{ hours} \qquad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the oregano leaves under these conditions should take only about 5.0 hours.

Application of the Drying Model for Oregano:

For the oregano dried in these tests at 50^0C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

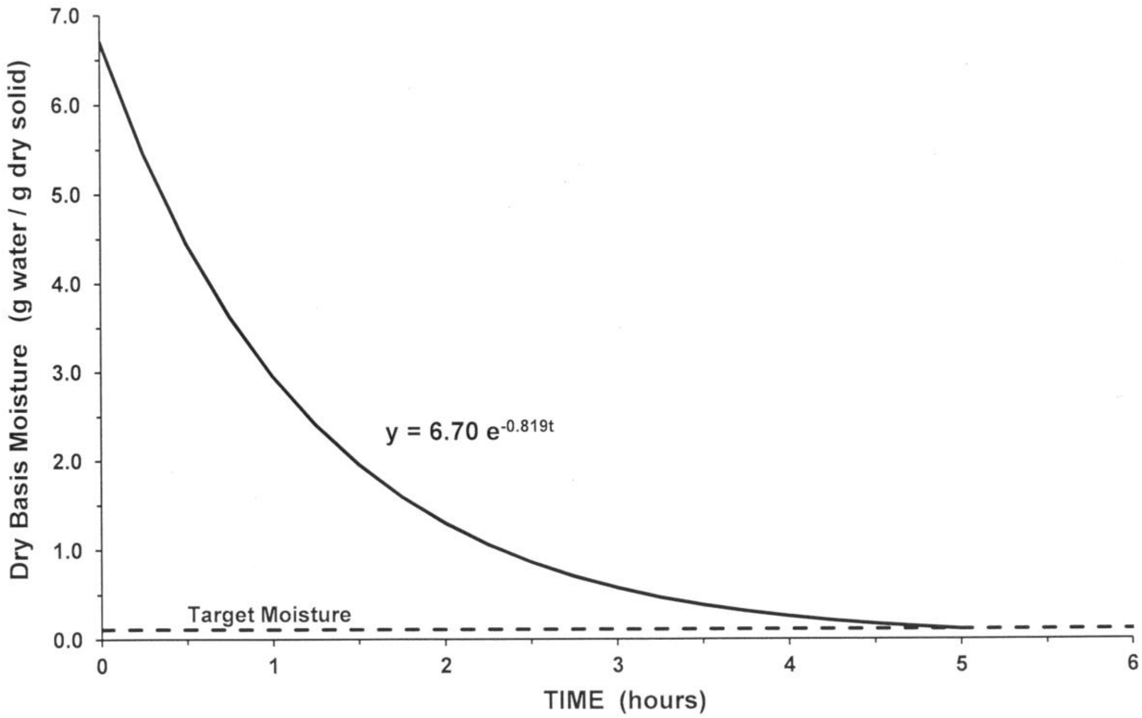
$$M = M_o\, e^{-0.819t} \qquad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 6.70 grams of water per gram of dry solids (i.e., approximately 87.0% wet basis moisture), this equation becomes:

$$M = 6.70\ e^{-0.819t} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

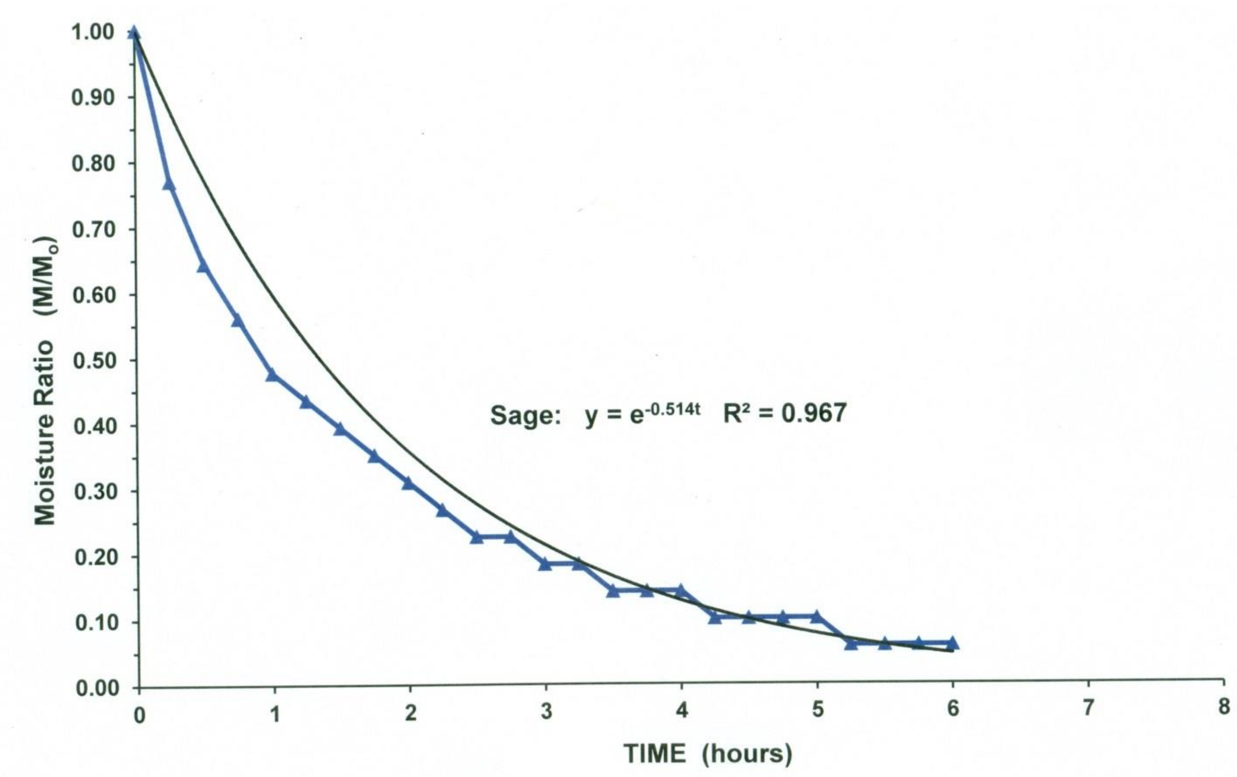
Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of oregano

It can be seen that the oregano reaches a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 5 hours as calculated in Equation 7.

Drying Kinetics for Sage Leaves:



Moisture ratio versus time for the drying of sage

Based on the curve above, the general kinetic equation for the drying of sage leaves is given by:

$$y = e^{-0.514t}$$ (Eq'n 9) where: y is the moisture ratio M/M_o
t is the drying time in hours

Calculation of Drying Times for Sage:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 76.2% on a wet basis (i.e., 3.2 grams of water per gram of dry solids), we can follow the same procedure as was used for oregano.

$$t = \ln(M_o/M) / 0.514$$
$$= \ln(3.20 / 0.111) / 0.514$$
$$= \ln(28.8) / 0.514$$
$$= 3.36 / 0.514$$
$$= 6.5 \text{ hours} \qquad \text{(Eq'n 10)}$$

Therefore, drying the sage leaves under these conditions should take about 6.5 hours.

Application of the Drying Model for Sage:

For the sage dried in these tests at 50^0C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

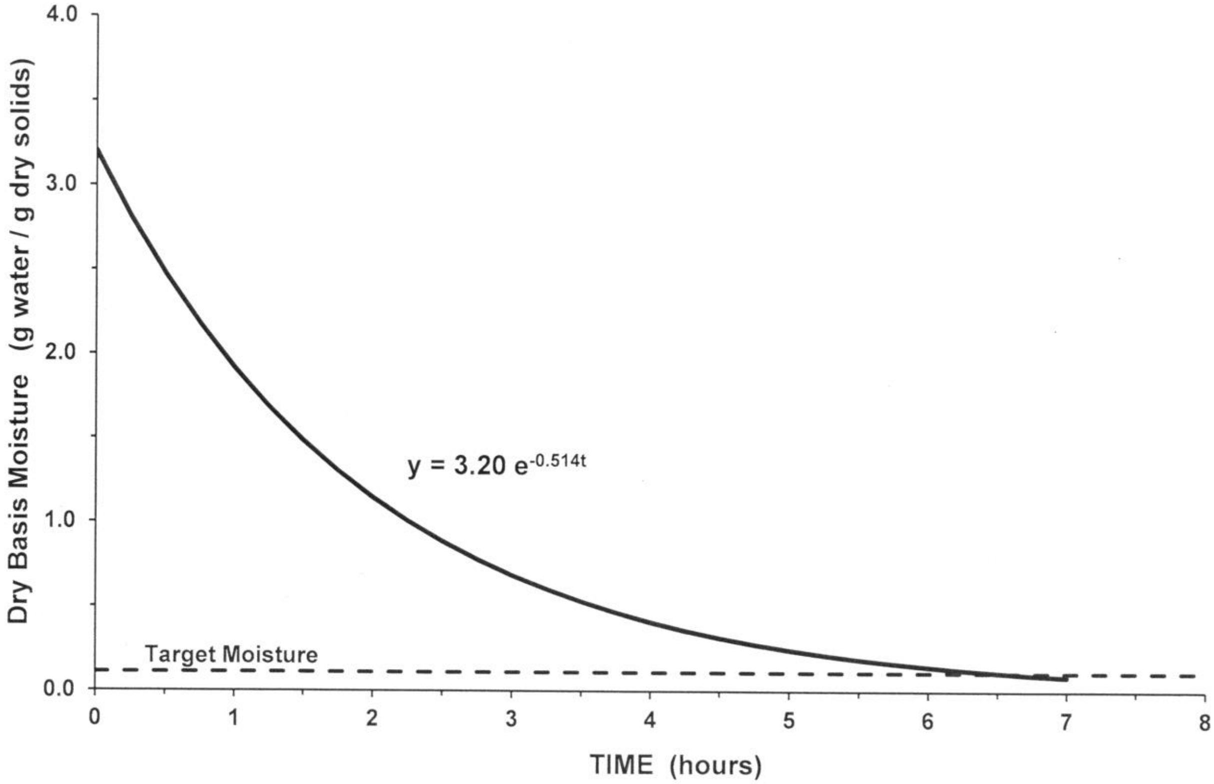
$$y = e^{-0.514t} \qquad \text{(restating of Eq'n 8)}$$

With an average initial dry basis moisture (M_o) of 3.20 grams of water per gram of dry solids (i.e., approximately 76.2% wet basis moisture), this equation becomes:

$$M = 3.20\, e^{-0.514t} \qquad \text{(Eq'n 11)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of sage

It can be seen that the sage reaches a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 6.5 hours as calculated in Equation 10.

JALAPENO PEPPER DRYING

Selection and Preparation of the Material:

The jalapeno peppers you select should be free from blemishes and be of appropriate ripeness. They should be firm and have a smooth waxy surface, which is typical of most peppers.

> **CAUTION**: For hot peppers, it is a good idea to wear rubber gloves to prevent the transfer of the “heat” to your fingers. If you happen to rub your eyes or get the juice of the peppers in a small cut, it can be quite painful. Wash the affected area well.
>
> Peppers are hot due to the presence of an oily chemical compound called “capsaicin”. It triggers a burning sensation when it contacts the sensory nerves in our bodies.
>
> Extreme care should be taken when handling hot peppers.

Thoroughly wash the whole peppers and remove the excess water by blotting them dry with a paper towel, or allow the surface to dry in the room air for a short period of time.

Slice the peppers lengthwise. You can then remove the seeds and cut off the stem section at the top of each piece.

Cut each of the two halves in half lengthwise once again so that the pepper is now quartered. If the pepper is large, you may wish to cut it into narrower slices to speed the drying process.

Fresh jalapeno peppers

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for pepper slices.

Lay the pepper slices on the dryer rack with the skin side down (i.e., touching the rack). The fleshy portion should be pointing upwards. This will increase the exposure of the moist, porous inner surface of the peppers to the drying air, and improve the overall efficiency of the drying process.

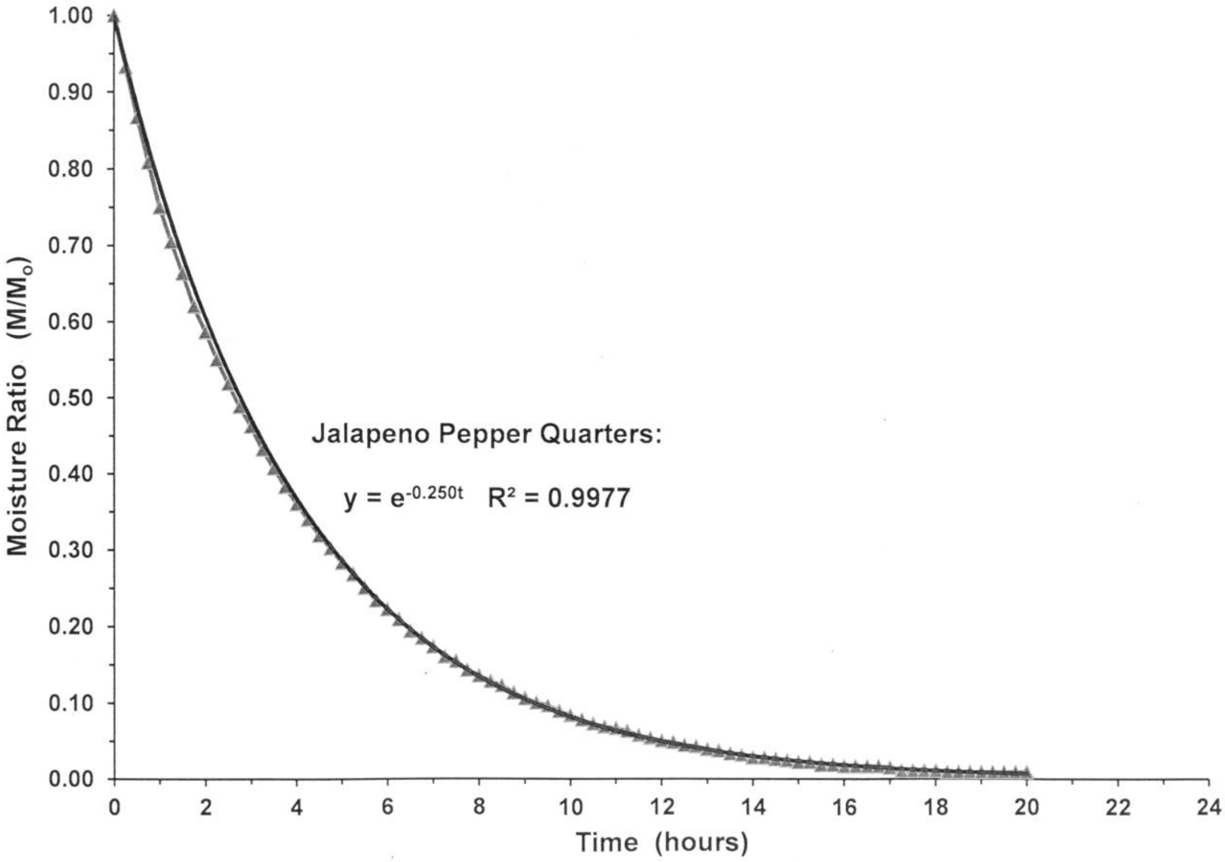
Be sure that the pieces have a small amount of space between them to ensure the drying air contacts all surfaces. Don't be too worried if the edges of the peppers are toughing slightly since they will shrink during drying.

Test for Dryness:

Once the pepper slices are dry, they will tend to be crisp. There should be no signs of moisture in the dried slices. It's a good idea to wear rubber gloves even when handling the dried peppers if you are particularly sensitive to the "heat" from the capsaicin oil.

The long slices tend to curl inwards during drying, so be sure to check the inner surfaces for any remaining moisture.

Drying Kinetics:



Moisture ratio versus time for the drying of jalapeno pepper slices (quarters)

Based on the curve above, the general kinetic equation for the drying of jalapeno pepper slices is given by:

$\mathbf{y = e^{-0.250t}}$ (Eq'n 1) where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$\mathbf{M/ M_o = e^{-0.250t}}$ (Eq'n 2) where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $\mathbf{M = M_o\, e^{-0.250t}}$ (Eq'n 3)

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$\mathbf{-0.250t = \ln(M/M_o)} \qquad \text{(Eq'n 4)}$$

Equation 4 then becomes: $$\mathbf{t = -\frac{\ln(M/M_o)}{0.250}} \qquad \text{(Eq'n 5)}$$

$$\mathbf{t = \ln(M_o/M) / 0.250} \qquad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 93.9% on a wet basis (i.e., 15.53 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} \mathbf{t} &= \mathbf{\ln(M_o/M) / 0.250} \\ &= \mathbf{\ln(15.53/0.111) / 0.250} \\ &= \mathbf{\ln(139.9) / 0.250} \\ &= \mathbf{4.94 / 0.250} \\ &= \mathbf{19.8\ hours} \qquad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the jalapeno pepper slices under these conditions should take about 20 hours.

Application of the Drying Model:

For the jalapeno pepper slices dried in these tests at 50^{0}C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

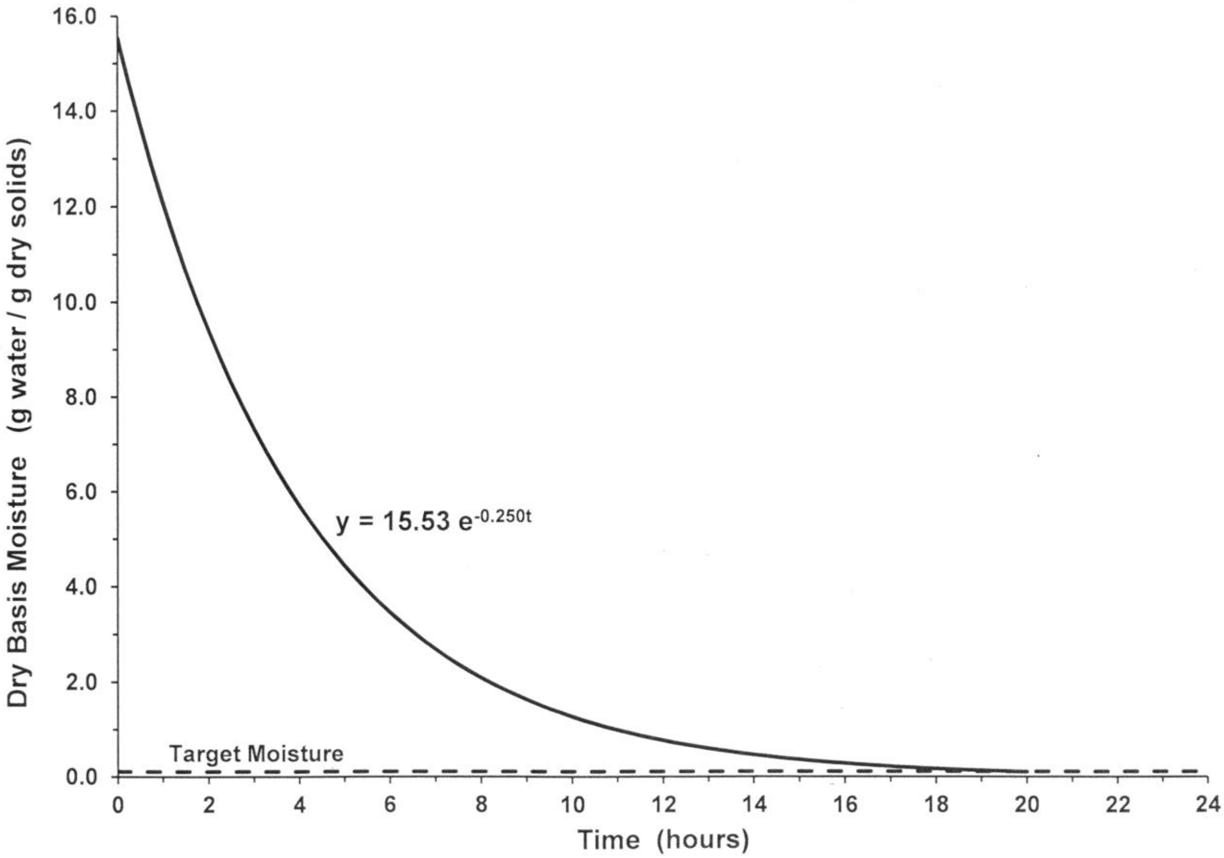
$$\mathbf{M = M_o\, e^{-0.250t}} \qquad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 15.53 grams of water per gram of dry solids (i.e., approximately 93.9% wet basis moisture), this equation becomes:

$$M = 15.53\ e^{-0.250t} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of jalapeno pepper slices (quarters)

It can be seen that the jalapeno pepper slices reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 19 to 20 hours as calculated in Equation 7.

MANGO DRYING

Selection and Preparation of the Material:

Select fresh mangoes that are ripe enough to have their fully developed flavour and sweetness. After peeling the mango, cut off slices that are about 5 to 6 mm thick. It is best to cut the first slices parallel to the flat side of the large stone in the middle of the mango. You can then cut smaller slices (still about 5 to 6 mm thick) off the stone once you have obtained the larger slices from the sides. Mangoes can become very slippery to hold, so exercise caution when cutting them.

Fresh whole mango

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for mango slices. Be sure that the pieces have a small amount of space between them to ensure the drying air contacts all surfaces. You may have to cut the slices into smaller sections to optimize their placement in the dryer.

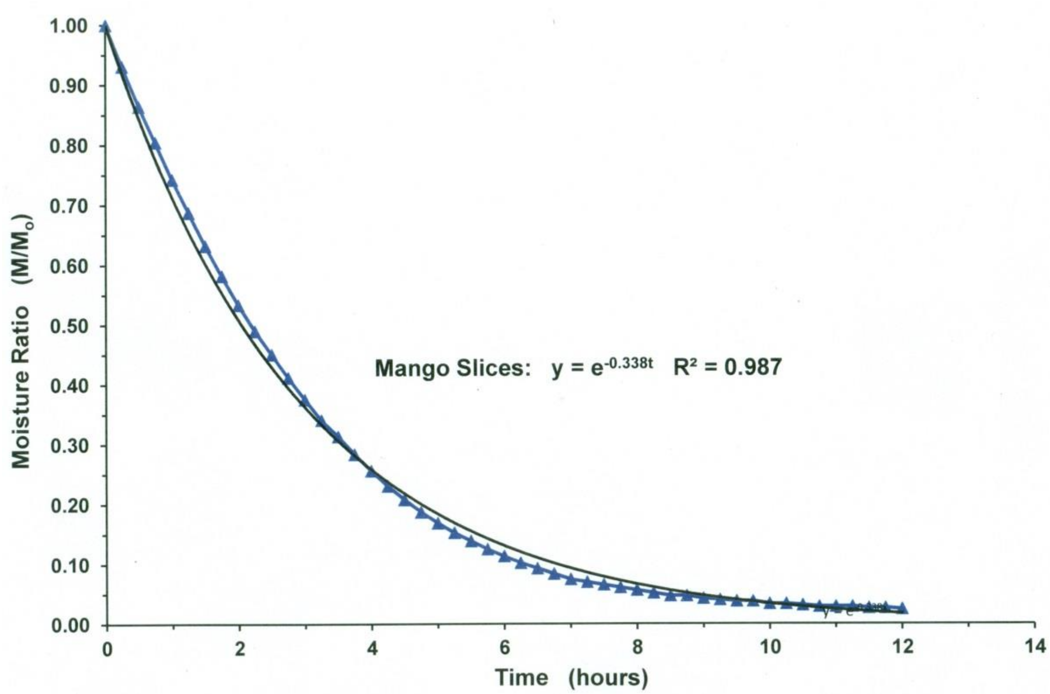
Test for Dryness:

When the mango slices are done, they will feel dry and will be leathery but still flexible.

Dried mango slices

Drying Kinetics:

In the graph shown below, the agreement between the experimental data and the mathematical equation is quite good for the entire duration of the drying process.



Moisture ratio versus time for drying of sliced mangoes

Based on the curve above, the general kinetic equation for the drying of mango slices is given by:

$$\mathbf{y = e^{-0.338t}} \quad \text{(Eq'n 1)}$$

where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$$\mathbf{M/ M_o = e^{-0.338t}} \quad \text{(Eq'n 2)}$$

where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $$\mathbf{M = M_o\, e^{-0.338t}} \quad \text{(Eq'n 3)}$$

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$\mathbf{-0.338t = \ln(M/M_o)} \quad \text{(Eq'n 4)}$$

Equation 4 then becomes: $$\mathbf{t = -\frac{\ln(M/M_o)}{0.338}} \quad \text{(Eq'n 5)}$$

$$\mathbf{t = \ln(M_o/M) / 0.338} \quad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 85.7% on a wet basis (i.e., 5.97 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned}\mathbf{t} &= \mathbf{\ln(M_o/M) / 0.338}\\ &= \mathbf{\ln(5.97 /0.111) / 0.338}\\ &= \mathbf{\ln(53.78) / 0.338}\\ &= \mathbf{3.98 / 0.338}\\ &= \mathbf{11.8\ hours} \quad \text{(Eq'n 7)}\end{aligned}$$

Therefore, drying the mango slices under these conditions should take about 11.8 hours.

Application of the Drying Model:

For the mango slices dried in these tests at 50^{0}C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

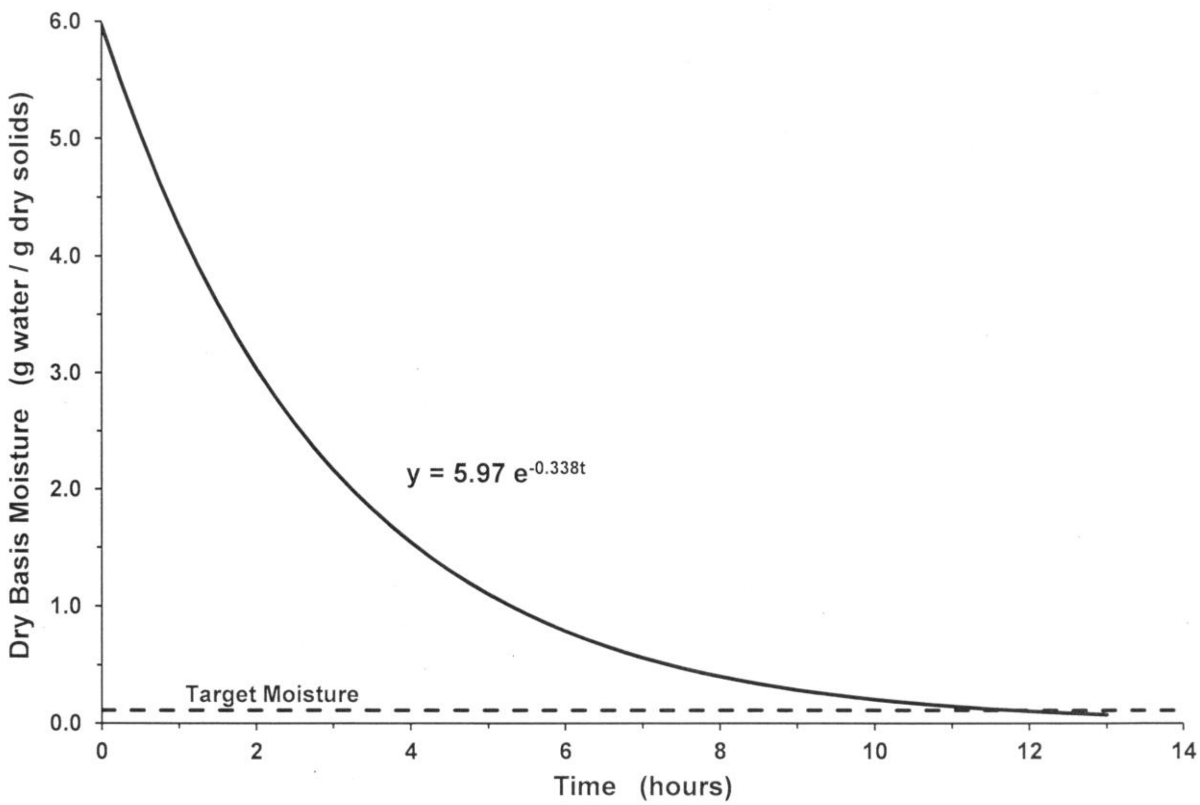
$$\mathbf{M = M_o\, e^{-0.338t}} \quad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 5.97 grams of water per gram of dry solids (i.e., approximately 85.7% wet basis moisture), this equation becomes:

$$\mathbf{M = 5.97\, e^{-0.338t}} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of mango slices

It can be seen that the mango slices reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 12 hours as calculated in Equation 7.

PAPAYA DRYING

Selection and Preparation of the Material:

Remove the outer skin and underlying layer with a knife while the papaya is still whole. You can cut it in half lengthwise in order to remove the seeds and the soft flesh that is attached to them.   Each half can be cross-wise into crescent-shaped slices about 5 to 6 mm thick.

Fresh whole papaya

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for papaya slices. Be sure that the pieces have a small amount of space between them to ensure the drying air contacts all surfaces. You may have to cut the slices into smaller sections to optimize their placement in the dryer.

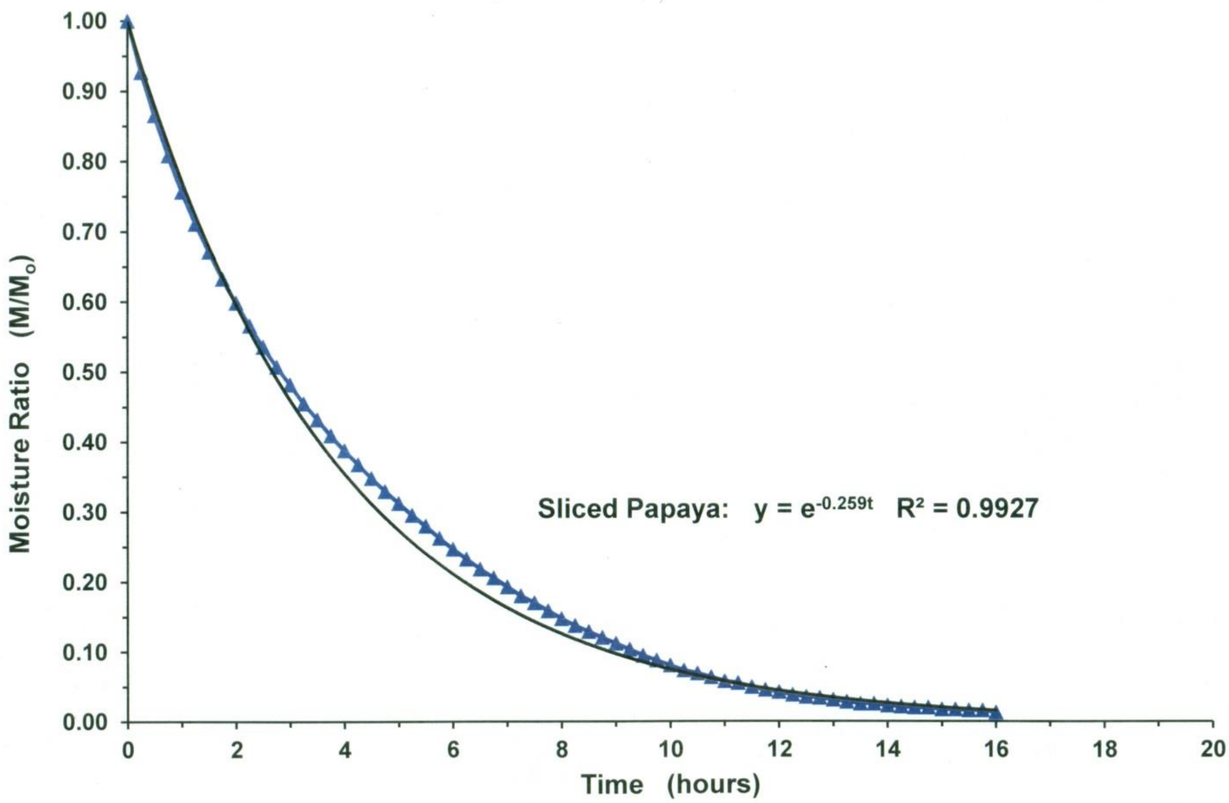
Test for Dryness:

When the papaya slices are done, they will feel dry and will be leathery but flexible.

Dried papaya slices in the dryer

Drying Kinetics:

In the graph shown below, the agreement between the experimental data and the mathematical equation is quite good.



Moisture ratio versus time for the drying of papaya slices

Based on the curve above, the general kinetic equation for the drying of papaya slices is given by:

$$y = e^{-0.259t} \quad \text{(Eq'n 1)}$$

where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$$M/M_o = e^{-0.259t} \quad \text{(Eq'n 2)}$$

where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $$M = M_o\, e^{-0.259t} \quad \text{(Eq'n 3)}$$

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$-0.259t = \ln(M/M_o) \quad \text{(Eq'n 4)}$$

Equation 4 then becomes:

$$t = -\frac{\ln(M/M_o)}{0.259} \quad \text{(Eq'n 5)}$$

$$t = \ln(M_o/M) / 0.259 \quad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 86.9% on a wet basis (i.e., 6.64 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.259 \\ &= \ln(6.64 /0.111) / 0.259 \\ &= \ln(59.82) / 0.259 \\ &= 4.09 / 0.259 \\ &= 15.8 \text{ hours} \quad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the papaya slices under these conditions should take about 15.8 hours.

Application of the Drying Model:

For the papaya slices dried in these tests at 50^{o}C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

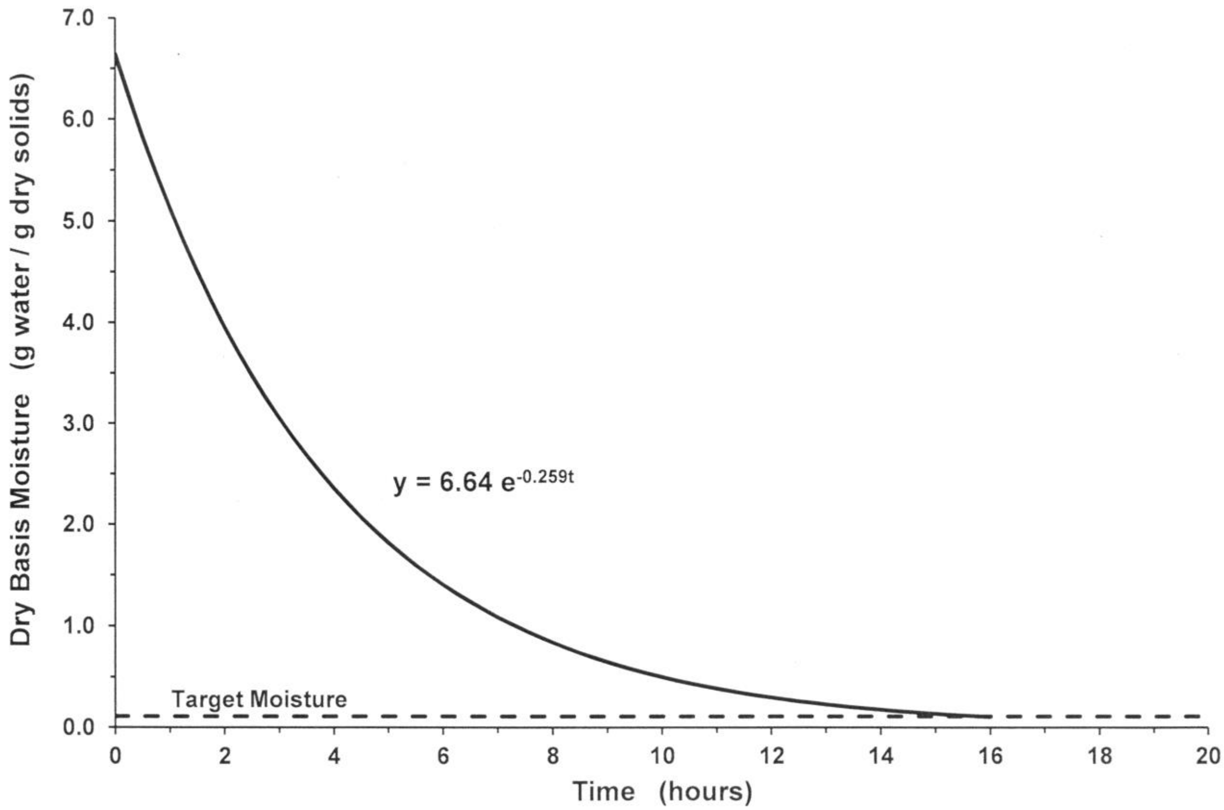
$$M = M_o\, e^{-0.259t} \quad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 6.64 grams of water per gram of dry solids (i.e., approximately 86.9% wet basis moisture), this equation becomes:

$$\mathbf{M = 6.64\ e^{-0.259t}} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of papaya slices

It can be seen that the papaya slices reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 16 hours as calculated in Equation 7.

PINEAPPLE DRYING

Selection and Preparation of the Material:

The pineapples selected should be as fresh as possible and be free of signs of infestation and degradation.

Remove the top and the outer "skin" from the pineapple. Then cut the pineapple in a cross-wise direction to obtain about 5 to 6 mm thick slices. The core can then be removed to create pineapple rings. Any serious blemishes should be cut out of the pineapple rings before drying. It may help with positioning the pineapple rings in the dryer if you cut the rings in half. (Note: You may find it more convenient to remove the core from the pineapple before slicing it, if you have the proper coring tool.)

Fresh pineapple Fresh pineapple rings in dryer (note the half rings)

Drying Conditions:

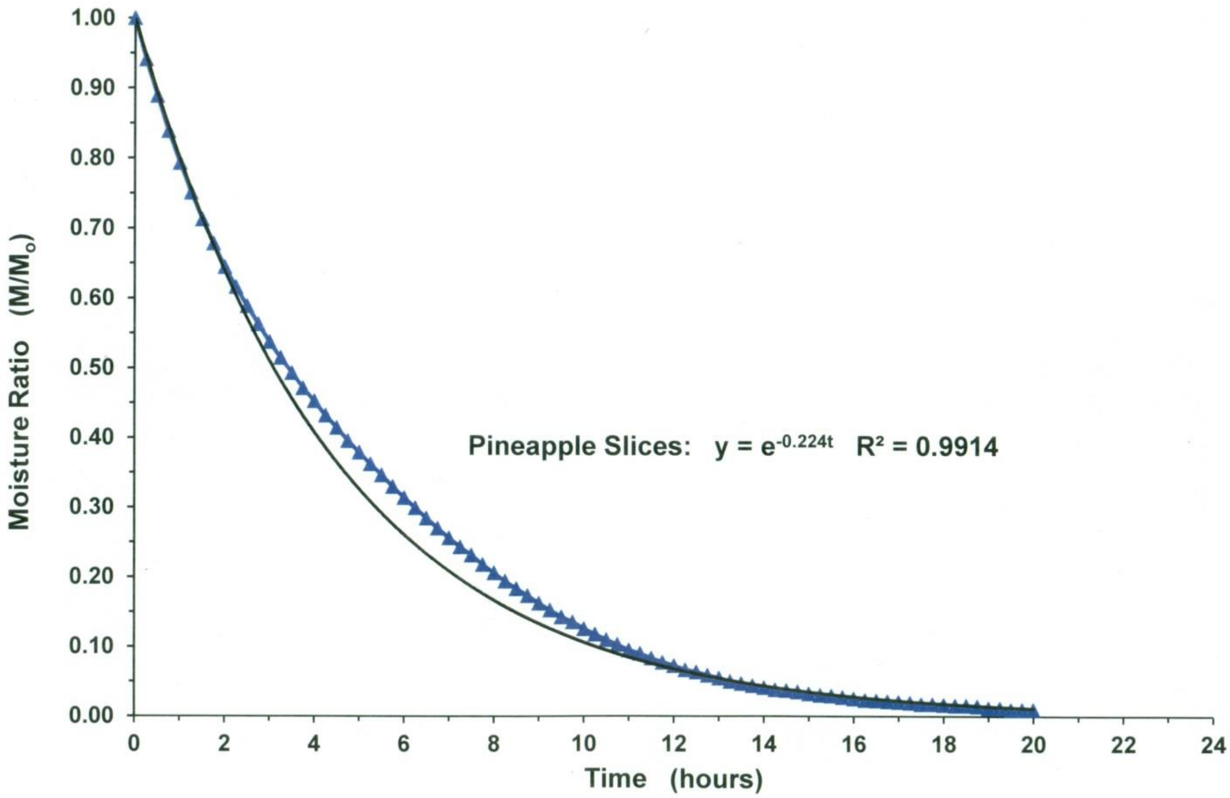
A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for pineapple rings. Be sure that the pieces have a small amount of space between them to ensure the drying air contacts all surfaces.

Test for Dryness:

Once the pineapple rings are dry, they will be leathery, but there will still be some flexibility to them due to the effects of the high concentration of sugar they contain.

Dry pineapple rings in the dryer

Drying Kinetics:



Moisture ratio versus time for drying of pineapple rings

Based on the curve above, the general kinetic equation for the drying of pineapple rings is given by:

$$y = e^{-0.224t} \quad \text{(Eq'n 1)}$$

where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$$M/ M_o = e^{-0.224t} \quad \text{(Eq'n 2)}$$

where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $$M = M_o\, e^{-0.224t} \quad \text{(Eq'n 3)}$$

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$-0.224t = \ln(M/M_o) \qquad \text{(Eq'n 4)}$$

Equation 4 then becomes: $$t = -\frac{\ln(M/M_o)}{0.224} \qquad \text{(Eq'n 5)}$$

$$t = \ln(M_o/M) / 0.224 \quad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 84.3% on a wet basis (i.e., 5.35 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.224 \\ &= \ln(5.35/0.111) / 0.224 \\ &= \ln(48.2) / 0.224 \\ &= 3.875 / 0.224 \\ &= 17.3 \text{ hours} \qquad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the pineapple rings under these conditions should take about 17 hours.

Application of the Drying Model:

For the pineapple rings dried in these tests at $50^{0}C$ with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

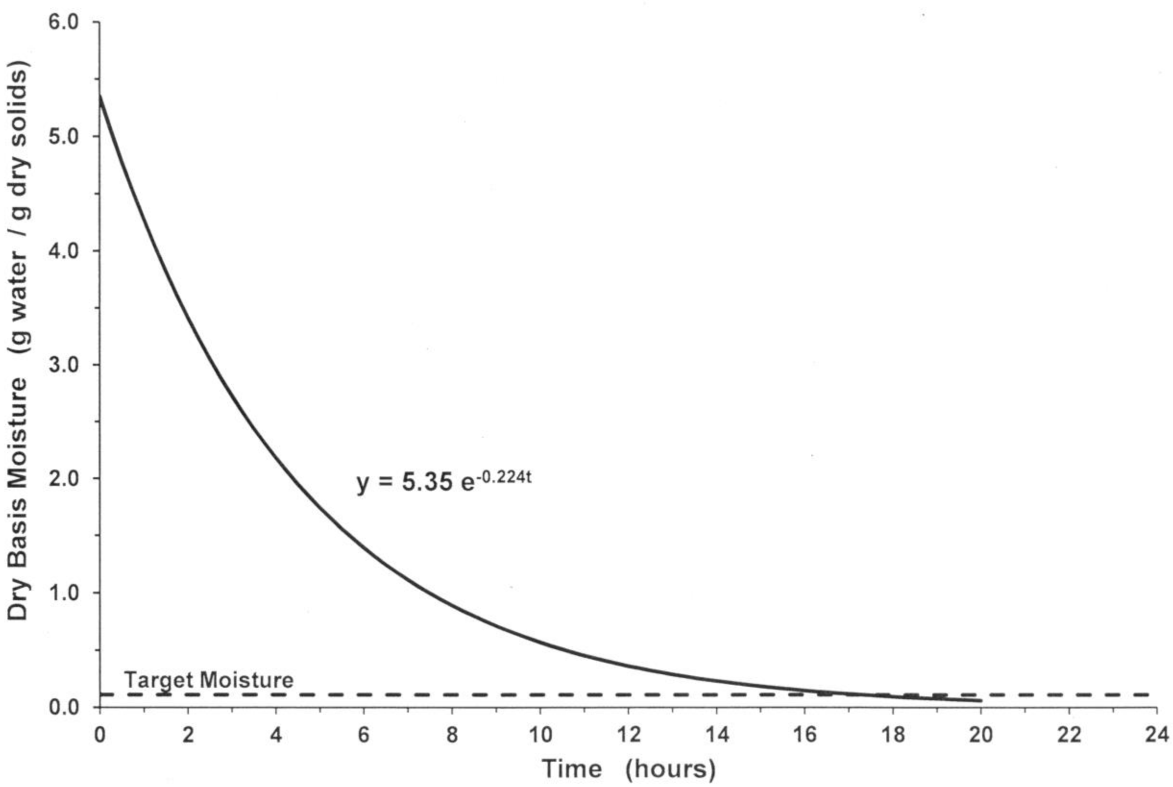
$$\mathbf{M = M_o\, e^{-0.224t}} \quad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 5.35 grams of water per gram of dry solids (i.e., approximately 84.3% wet basis moisture), this equation becomes:

$$\mathbf{M = 5.35\, e^{-0.224t}} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of pineapple rings

It can be seen that the pineapple rings reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 17 to 18 hours as calculated in Equation 7.

PITAYA DRYING

Selection and Preparation of the Material:

There are several variations on the spelling of “pitaya”, including “pitahaya”. It is also commonly referred to as “Dragon Fruit”. Cut the “dragon fruit” in half and remove the soft contents with a spoon. You can the cut each half into slices about 5 to 6 mm thick.

Fresh whole pitaya

Pitaya cut in half

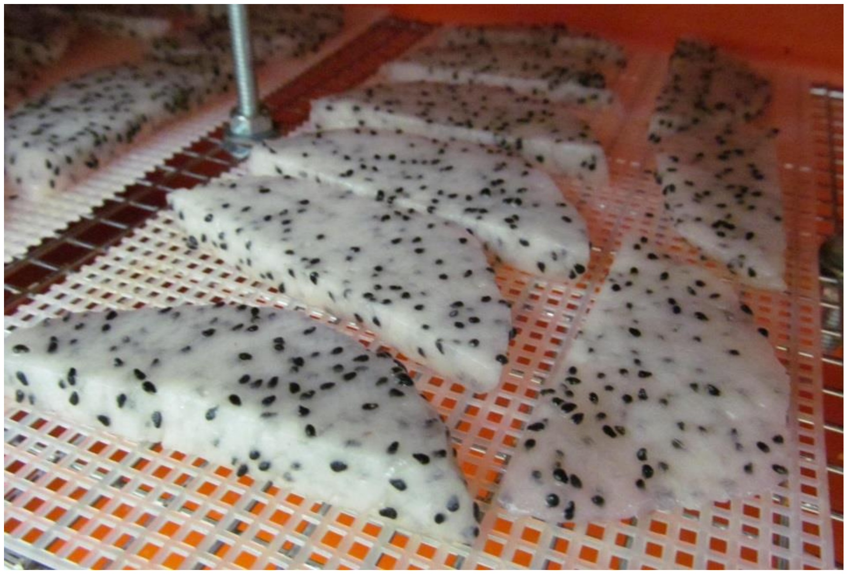
Fleshy portions of pitaya

Drying Conditions:

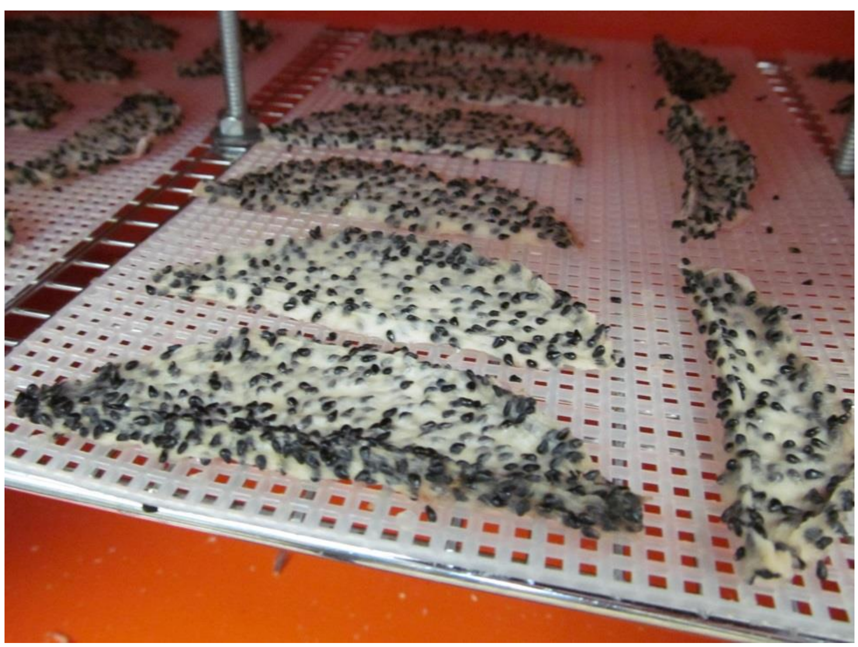
A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for sliced pitaya. Be sure that the pieces have a small amount of space between them to ensure the drying air contacts all surfaces. You may have to cut the slices into smaller sections to optimize their placement in the dryer. It is a good idea to place the pitaya slices on plastic mesh. This eliminates the problem of the material sticking to the wire mesh racks in the dryer.

Test for Dryness:

When the pitaya slices are done, they will feel dry and will be leathery but flexible.



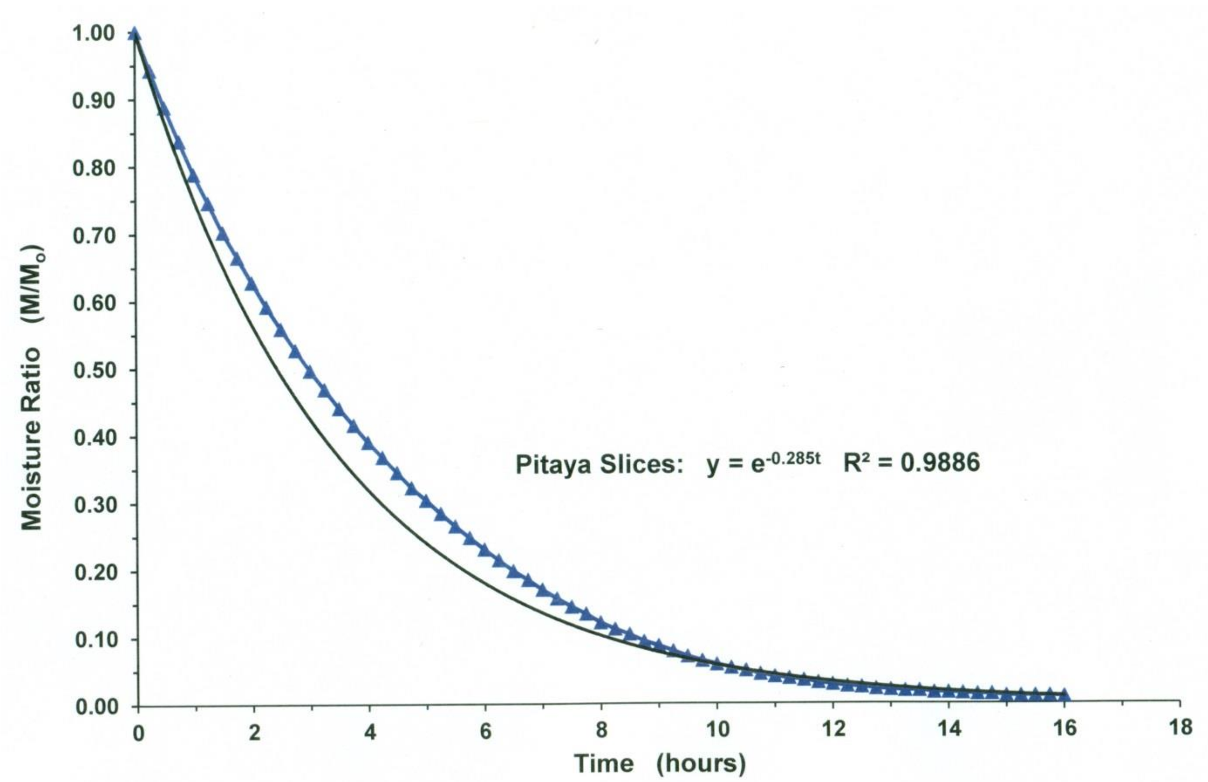
Fresh pitaya slices in dryer



Dried pitaya slices in the dryer

Drying Kinetics:

In the graph shown below, the agreement between the experimental data and the mathematical equation is quite good in the later stages of the drying process when it is important to monitor the moisture content of the material.



Moisture ratio versus time for drying of sliced pitaya

Based on the curve above, the general kinetic equation for the drying of pitaya slices is given by:

$$y = e^{-0.285t} \quad \text{(Eq'n 1)}$$

where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$$M/M_o = e^{-0.285t} \quad \text{(Eq'n 2)}$$

where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $$M = M_o\, e^{-0.285t} \quad \text{(Eq'n 3)}$$

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$\mathbf{-0.285t = \ln(M/M_o)} \qquad \text{(Eq'n 4)}$$

Equation 4 then becomes:

$$\mathbf{t = -\frac{\ln(M/M_o)}{0.285}} \qquad \text{(Eq'n 5)}$$

$$\mathbf{t = \ln(M_o/M) / 0.285} \qquad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 83.2% on a wet basis (i.e., 4.94 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} \mathbf{t} &= \mathbf{\ln(M_o/M) / 0.285} \\ &= \mathbf{\ln(4.94 / 0.111) / 0.285} \\ &= \mathbf{\ln(44.50) / 0.285} \\ &= \mathbf{3.80 / 0.285} \\ &= \mathbf{13.3\ hours} \qquad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the pitaya slices under these conditions should take about 13.3 hours.

Application of the Drying Model:

For the pitaya slices dried in these tests at 50^0C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

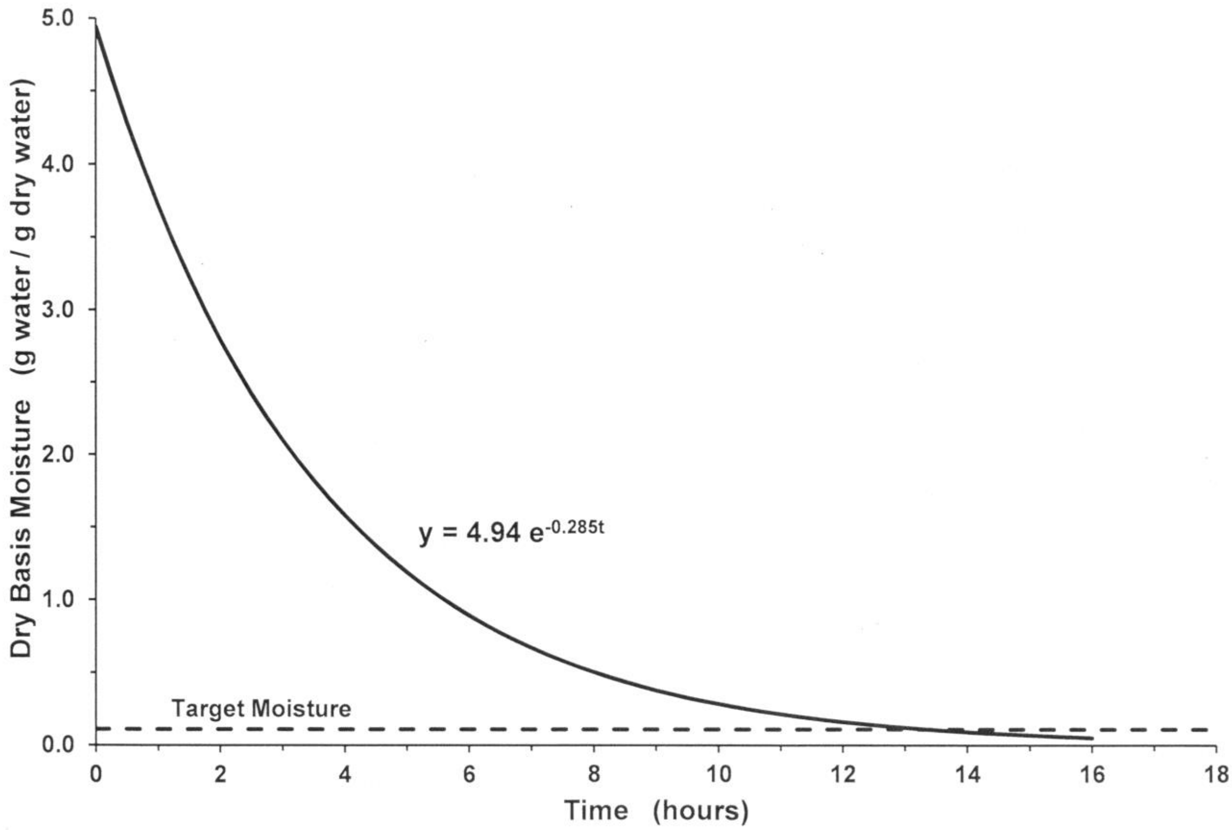
$$\mathbf{M = M_o\, e^{-0.285t}} \qquad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 4.94 grams of water per gram of dry solids (i.e., approximately 83.2% wet basis moisture), this equation becomes:

$$\mathbf{M = 4.94\ e^{-0.285t}} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time “t” during the drying process

Plotting the dry basis moisture “M” versus time “t” gives the following graph:



Dry basis moisture versus time for the drying of pitaya slices

It can be seen that the pitaya slices reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 13 to 14 hours as calculated in Equation 7.

PLANTAIN DRYING

Selection and Preparation of the Material:

Plantain should be prepared in a method similar to that used for bananas. You just need to remove the peel and cut the plantain into slices about 5 to 6 mm thick. No pre-treatment steps are necessary prior to drying.

Fresh whole plantain

Fresh slices of plantain in dryer

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for sliced plantain. Be sure that the pieces have a small amount of space between them to ensure the drying air contacts all surfaces. Since plantain is initially drier than bananas and much less sticky, there is really no need to use a plastic mesh as was done in the case of bananas. However, if it makes things easier, then by all means use the plastic mesh.

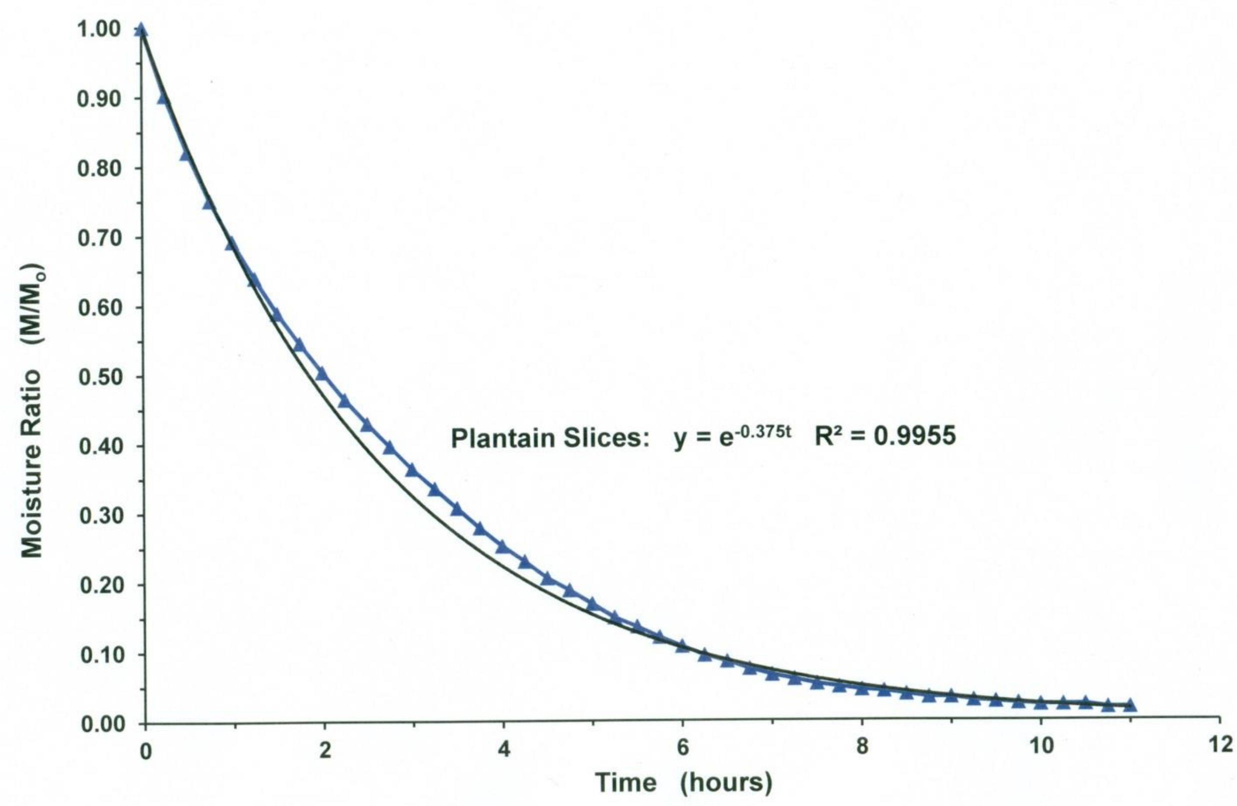
Test for Dryness:

When the plantain slices are done, they will feel dry and will be somewhat airy and almost chalk-like in texture. (see photo on next page)

Dried plantain slices in the dryer

Drying Kinetics:

In the graph shown below, the agreement between the experimental data and the mathematical equation is quite good. The R^2 value being so close to 1.000 is a good indication of the fit of the data to the line predicted by the mathematical equation.



Moisture ratio versus time for the drying of plantain slices

Based on the curve above, the general kinetic equation for the drying of plantain slices is given by:

$$y = e^{-0.375t} \quad \text{(Eq'n 1)}$$

where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$$M/M_o = e^{-0.375t} \quad \text{(Eq'n 2)}$$

where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $$M = M_o e^{-0.375t} \quad \text{(Eq'n 3)}$$

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$-0.375t = \ln(M/M_o) \quad \text{(Eq'n 4)}$$

Equation 4 then becomes: $$t = -\frac{\ln(M/M_o)}{0.375} \quad \text{(Eq'n 5)}$$

$$t = \ln(M_o/M) / 0.375 \quad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 60.5% on a wet basis (i.e., 1.53 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.375 \\ &= \ln(1.53 / 0.111) / 0.375 \\ &= \ln(13.78) / 0.375 \\ &= 2.62 / 0.375 \\ &= 7.0 \text{ hours} \quad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the plantain slices under these conditions should take about 7.0 hours.

Application of the Drying Model:

For the plantain slices dried in these tests at 50^0C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

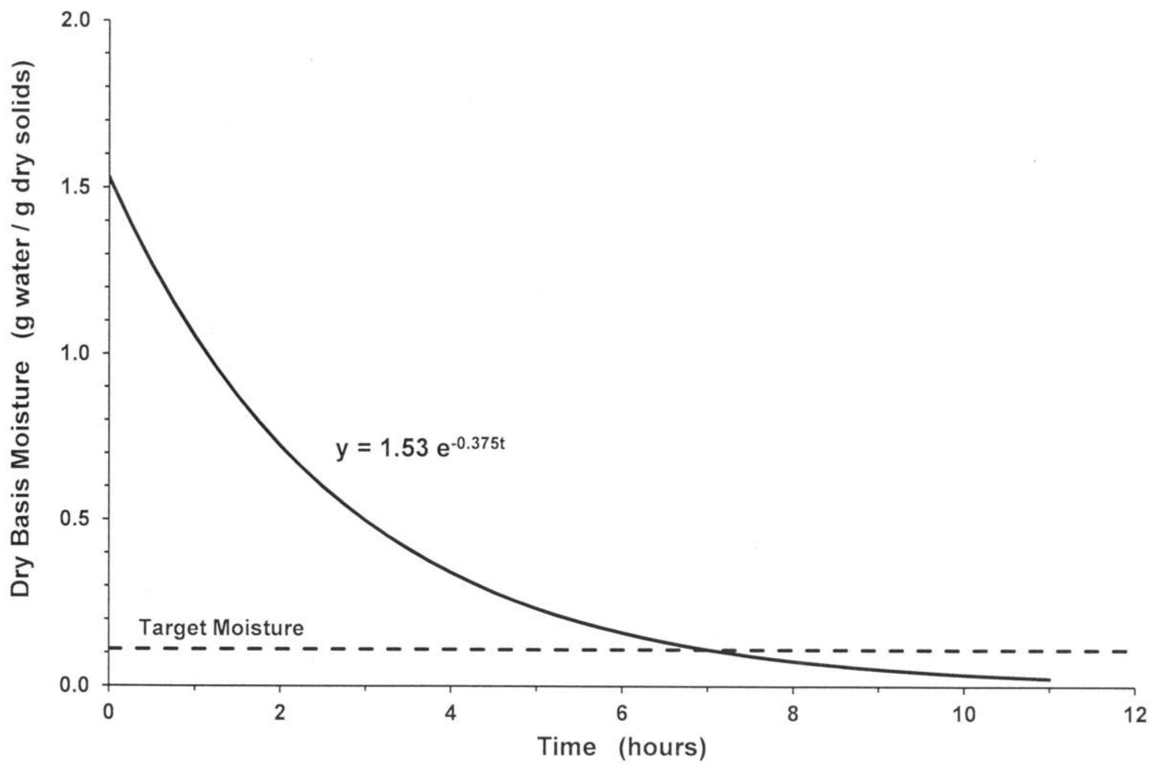
$$M = M_o \, e^{-0.375t} \quad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 1.53 grams of water per gram of dry solids (i.e., approximately 60.5% wet basis moisture), this equation becomes:

$$M = M_o \, e^{-0.375t} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of plantain slices

It can be seen that the plantain slices reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 7 hours as calculated in Equation 7.

RADISH DRYING

Selection and Preparation of the Material:

Radishes contain a surprisingly high amount of water (about 95% by weight on a wet basis). In order to dry them as quickly as possible, after you cut off the tops and bottoms of your radishes, slice the remaining portions of the radishes very thinly. About 3 mm is a convenient thickness to use.

Fresh whole radishes

Fresh slices of radish in dryer

Drying Conditions:

A temperature of about 50^{o}C, with a linear air velocity of 0.5 metres per second, works well for sliced radishes. Be sure that the pieces have a small amount of space between them to ensure the drying air contacts all surfaces. Because of their small size, radish slices tend to fall through the wire mesh drying racks. For this reason, it is a good idea to use plastic mesh to support your radish slices.

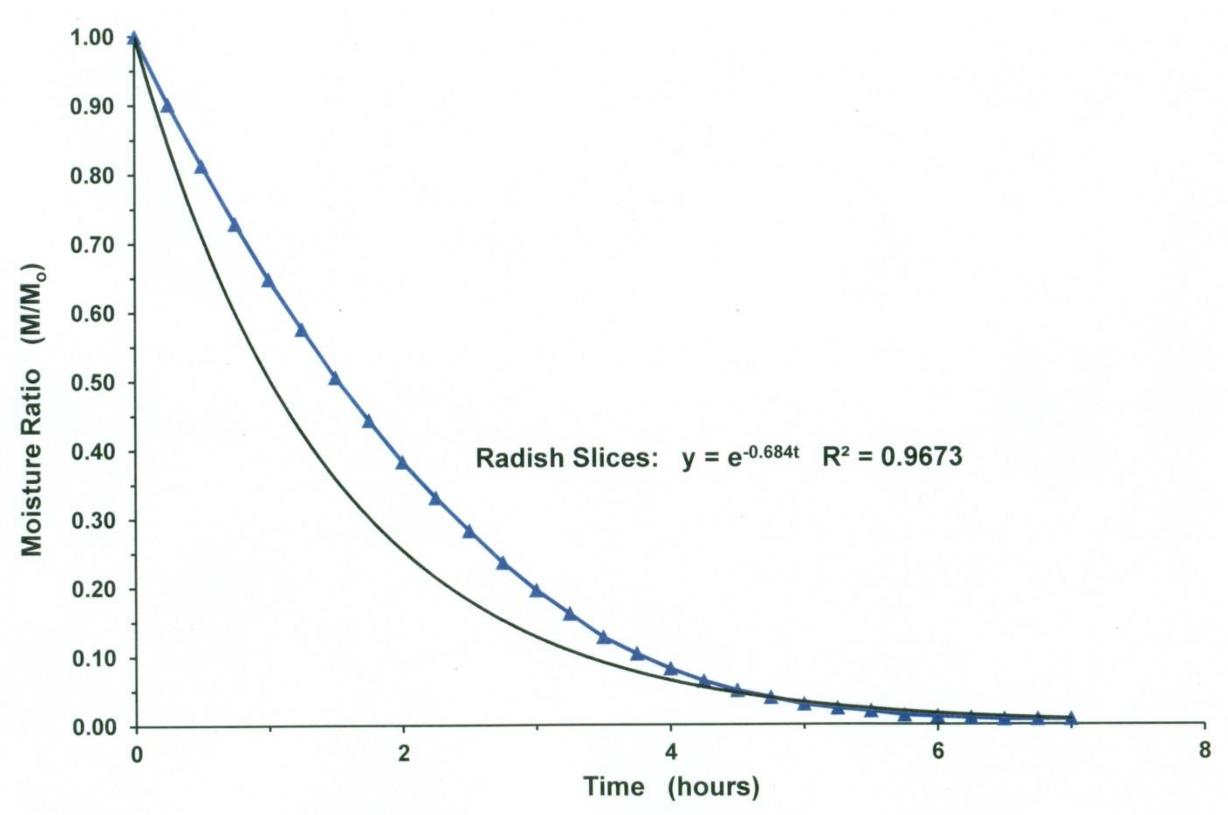
Test for Dryness:

When the radish slices are done, they will feel dry and be curled up to some extent. When broken apart, they will seem a bit crisp. (see photo on next page)

Dried radish slices in the dryer

Drying Kinetics:

In the graph shown below, the agreement between the experimental data and the mathematical equation is quite good after about four hours into the drying process.



Moisture ratio versus time for drying of radish slices

Based on the curve above, the general kinetic equation for the drying of radish slices is given by:

$$y = e^{-0.684t} \quad \text{(Eq'n 1)}$$

where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$$M/ M_o = e^{-0.684t} \quad \text{(Eq'n 2)}$$

where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $$M = M_o\, e^{-0.684t} \quad \text{(Eq'n 3)}$$

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$-0.684t = \ln(M/M_o) \quad \text{(Eq'n 4)}$$

Equation 4 then becomes: $$t = -\frac{\ln(M/M_o)}{0.684} \quad \text{(Eq'n 5)}$$

$$t = \ln(M_o/M) / 0.684 \quad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 95.2% on a wet basis (i.e., 19.82 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.684 \\ &= \ln(19.82 /0.111) / 0.684 \\ &= \ln(178.56) / 0.684 \\ &= 5.18 / 0.684 \\ &= 7.6 \text{ hours} \quad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the radish slices under these conditions should take about 7.6 hours.

Application of the Drying Model:

For the radish slices dried in these tests at 50^0C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

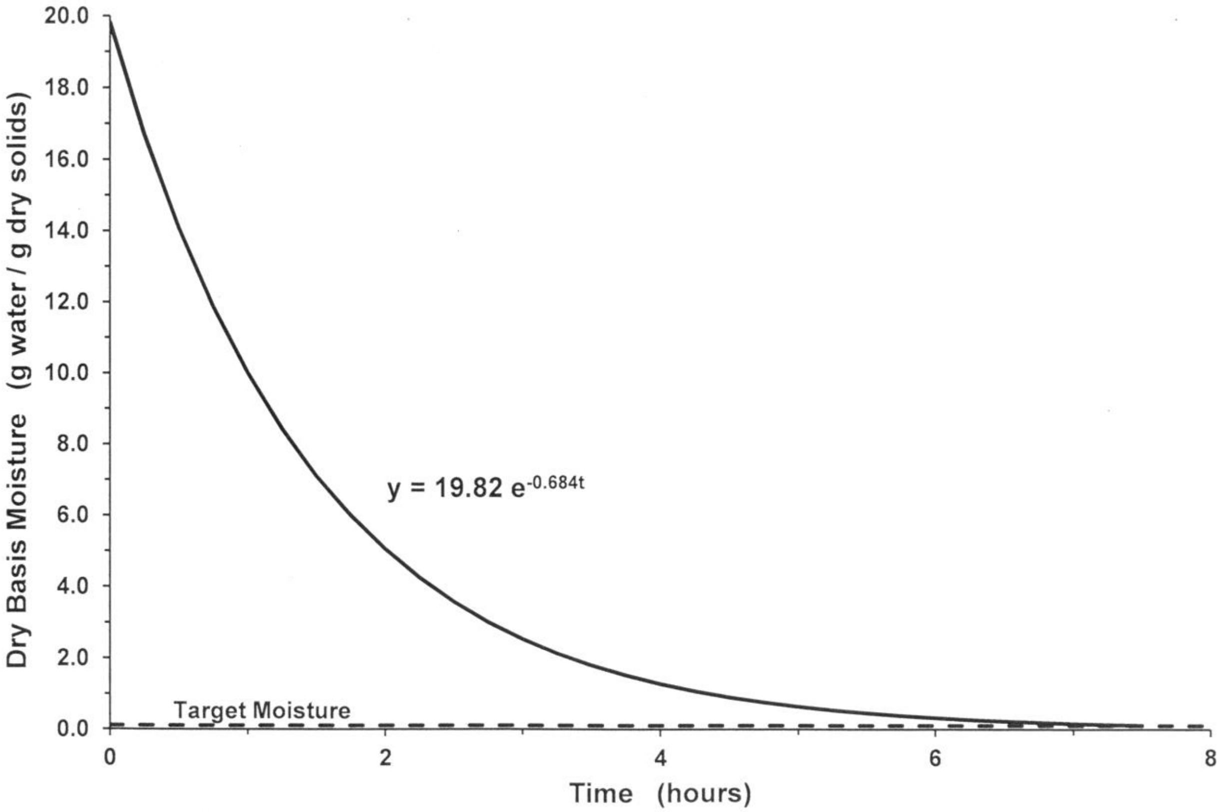
$$\mathbf{M = M_o\ e^{-0.684t}} \quad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 19.82 grams of water per gram of dry solids (i.e., approximately 95.2% wet basis moisture), this equation becomes:

$$\mathbf{M = 19.82\ e^{-0.684t}} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of radish slices

It can be seen that the radish slices reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 7.5 hours as calculated in Equation 7.

SCOTCH BONNET PEPPER DRYING

Selection and Preparation of the Material:

The Scotch Bonnet peppers you select should be free from blemishes and be of appropriate ripeness. They should be firm and have a smooth waxy surface, which is typical of most peppers. Scotch Bonnet peppers tend to look somewhat shrunken or wrinkled in appearance and look like a Scottish "tam" – hence their name.

CAUTION: For hot peppers, it is a good idea to wear rubber gloves to prevent the transfer of the "heat" to your fingers. If you happen to rub your eyes or get the juice of the peppers in a small cut, it can be quite painful. Wash the affected area well.

Peppers are hot due to the presence of an oily chemical compound called "capsaicin". It triggers a burning sensation when it contacts the sensory nerves in our bodies.

Scotch Bonnet peppers can be very hot. Exercise extreme caution when handling them.

Thoroughly wash the whole peppers and remove the excess water by blotting them dry with a paper towel, or allow the surface to dry in the room air for a short period of time.

Slice the peppers lengthwise. You can remove the seeds, but this might be difficult. Cut off the stem section at the top of each piece.

You can then cut each of the two halves in half lengthwise once again so that the pepper is now quartered. If the pepper is large, you may wish to cut it into narrower slices to speed the drying process.

Fresh Scotch Bonnet peppers

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for pepper slices.

Lay the pepper slices on the dryer rack with the skin side down (i.e., touching the rack). The fleshy portion should be pointing upwards. This will increase the exposure of the moist, porous inner surface of the peppers to the drying air, and improve the overall efficiency of the drying process. Using plastic mesh on the drying rack will prevent the small pieces from falling through the wider openings in the wire drying rack.

With Scotch Bonnet peppers, the slices may be small and be difficult to position on the drying rack. Some pieces will be positioned with the skin side pointing upwards, and the pieces will probably end up touching each other. You should spread the pieces as evenly as possible and stir the bed occasionally during the drying process.

Test for Dryness:

Once the pepper slices are dry, they will tend to be crisp. There should be no signs of moisture in the dried slices. You should definitely wear rubber gloves even when handling the dried Scotch Bonnet peppers.

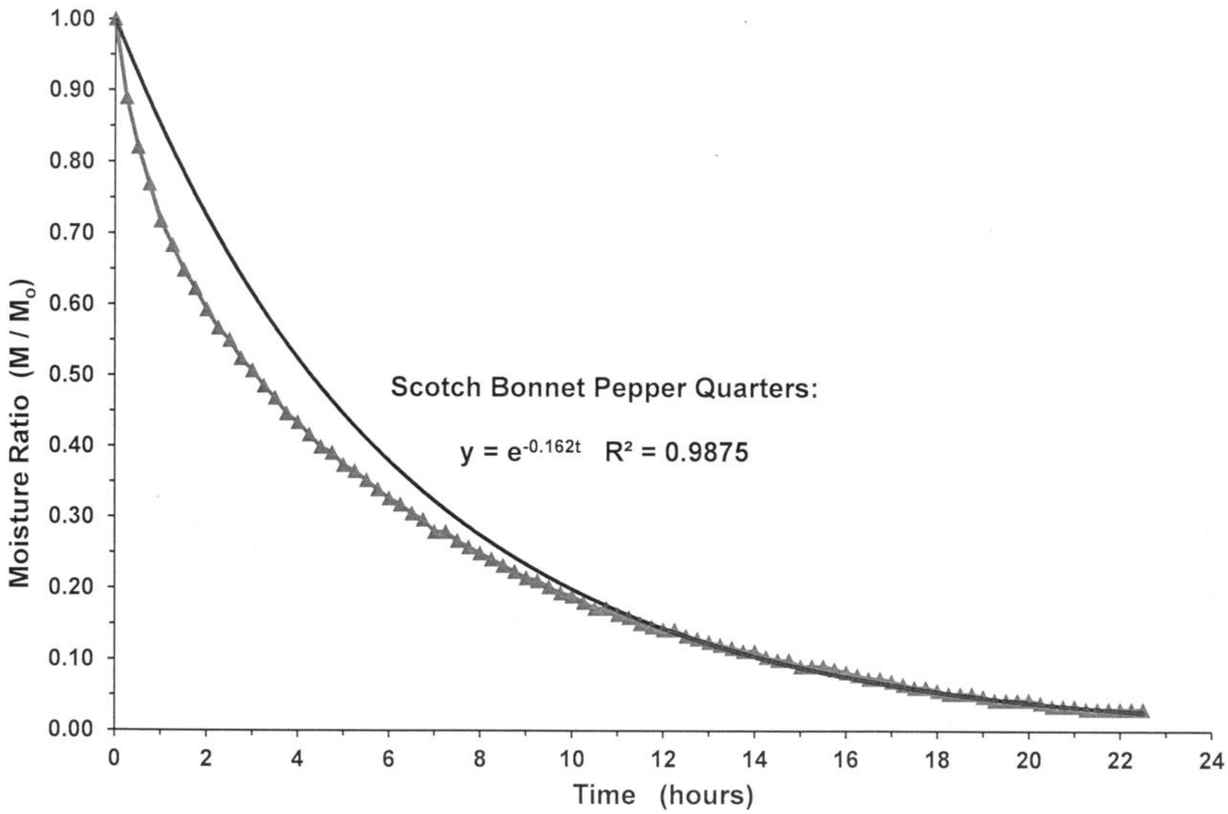
The Scotch Bonnet pepper pieces may tend to curl inwards during drying, so be sure to check the inner surfaces for any remaining moisture.

Fresh slices of Scotch Bonnet peppers

Dried slices of Scotch Bonnet peppers

Drying Kinetics:

The actual test results for the Scotch Bonnet pepper drying trials differed from the mathematical model during the initial ten hours. However, the predicted equation fits the experimental data quite well during the later periods of the drying process as the moisture content becomes lower.



Moisture ratio versus time for the drying of Scotch Bonnet pepper slices (quarters)

Based on the curve above, the general kinetic equation for the drying of Scotch Bonnet pepper slices is given by:

$$\mathbf{y = e^{-0.162t}} \quad \text{(Eq'n 1)}$$

where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$$\mathbf{M/M_o = e^{-0.162t}} \quad \text{(Eq'n 2)}$$

where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $\mathbf{M = M_o\, e^{-0.162t}}$ (Eq'n 3)

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$\mathbf{-0.162t = \ln(M/M_o)} \qquad \text{(Eq'n 4)}$$

Equation 4 then becomes: $$\mathbf{t = -\frac{\ln(M/M_o)}{0.162}} \qquad \text{(Eq'n 5)}$$

$$\mathbf{t = \ln(M_o/M) / 0.162} \qquad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 87.0% on a wet basis (i.e., 6.69 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} \mathbf{t} &= \mathbf{\ln(M_o/M) / 0.162} \\ &= \mathbf{\ln(6.69/0.111) / 0.162} \\ &= \mathbf{\ln(60.27) / 0.162} \\ &= \mathbf{4.10 / 0.162} \\ &= \mathbf{25.3\ hours} \qquad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the Scotch Bonnet pepper slices under these conditions should take about 25 hours.

Application of the Drying Model:

For the Scotch Bonnet pepper slices dried in these tests at 50^0C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

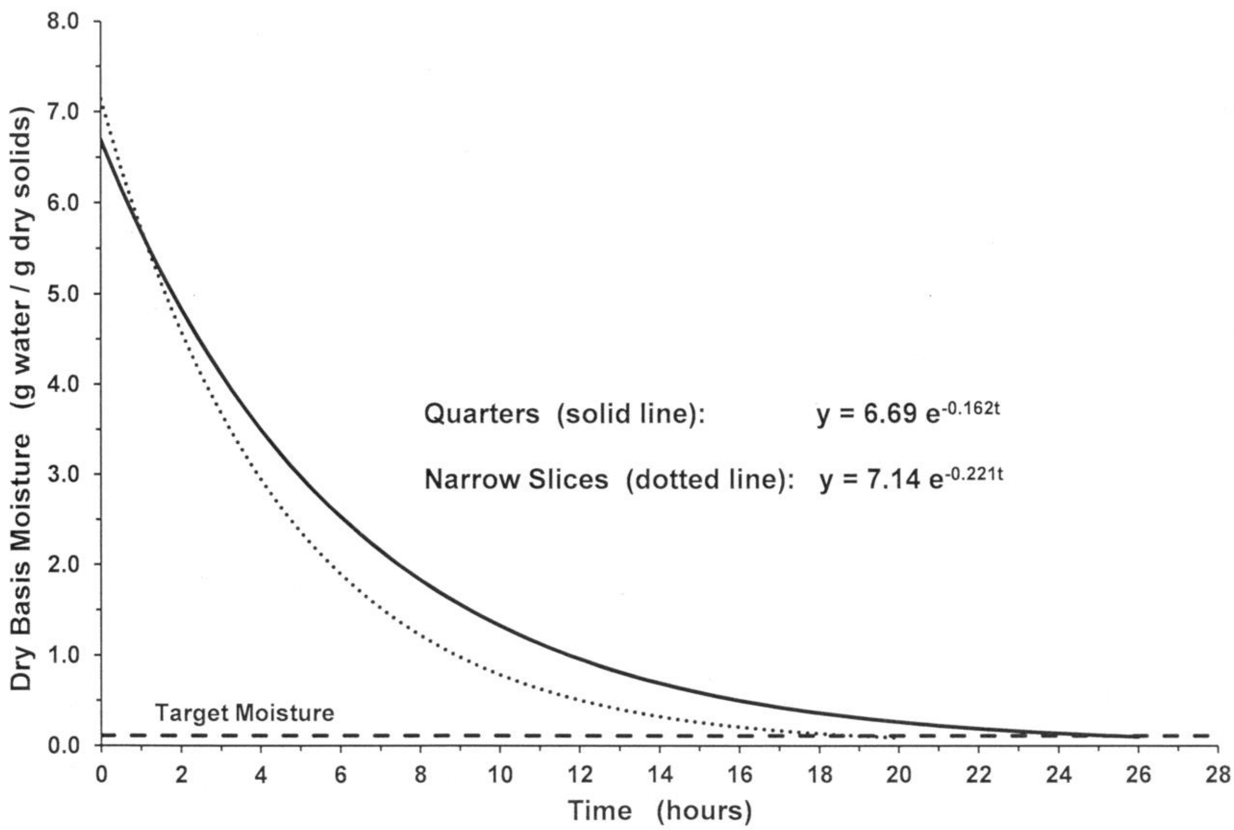
$$\mathbf{M = M_o\, e^{-0.162t}} \qquad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 6.69 grams of water per gram of dry solids (i.e., approximately 87.0% wet basis moisture), this equation becomes:

$$\mathbf{M = 6.69\ e^{-0.162t}} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of Scotch Bonnet pepper slices

It can be seen that the Scotch Bonnet pepper slices reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 25 to 26 hours as calculated in Equation 7.

In addition to the quartered Scotch Bonnet peppers, a second batch having a slightly higher moisture content was tested by cutting them into narrow slices. As can be seen from the graph above, these peppers dried faster and reached the desired finished moisture after about 19 hours of drying.

STAR FRUIT DRYING

Selection and Preparation of the Material:

Star fruit should be cut cross-wise into slices about 5 to 6 mm thick. The end sections will need to be discarded since they are composed mainly of thick waxy skin and lack the fleshy inner portions found in the main body of the fruit. Star fruit tend to darken during drying, so you may want to dip them in lemon juice prior to drying to reduce browning. Be sure to shake off the excess lemon juice before placing the slices in the dryer.

Fresh whole star fruit

Fresh slices of star fruit in dryer

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for sliced star fruit. Be sure that the pieces have a small amount of space between them to ensure the drying air contacts all surfaces.

Test for Dryness:

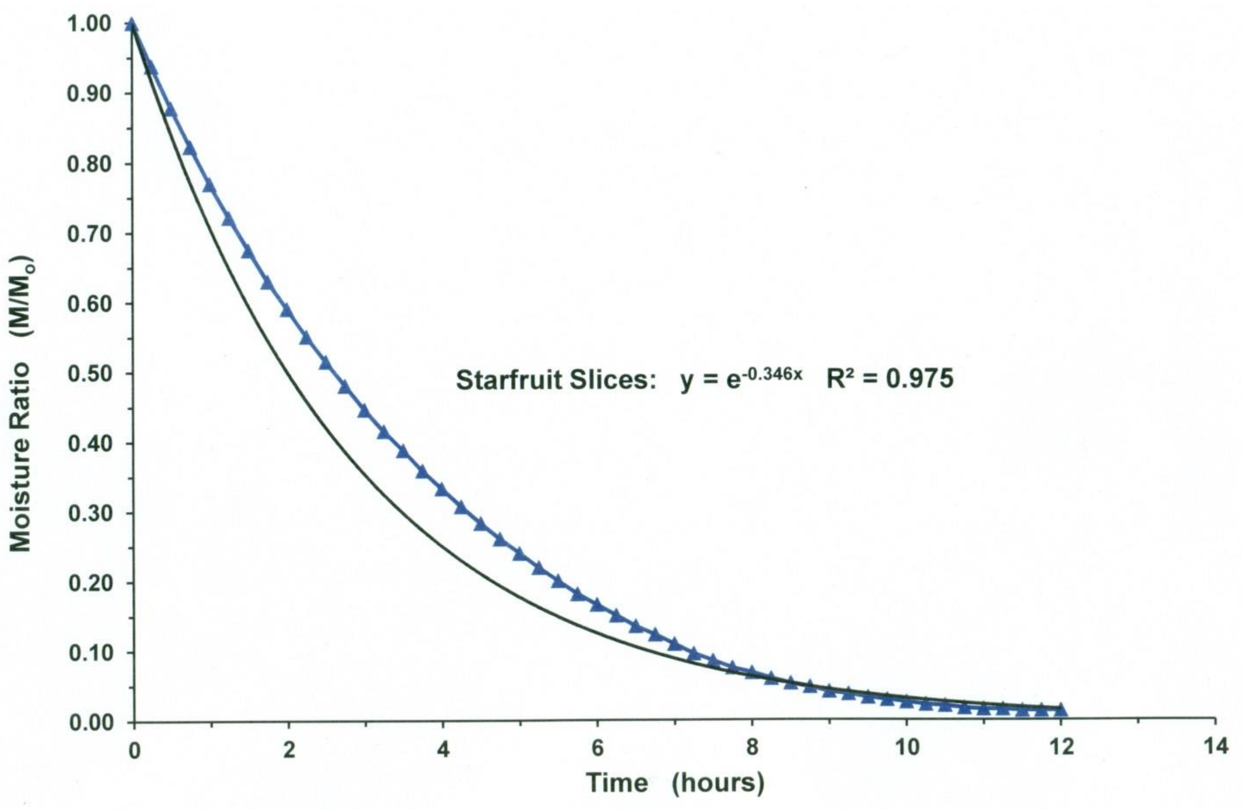
When the star fruit slices are done, they will feel brittle and may have darkened significantly. (See photos on the following page)

Dried star fruit slices in the dryer

Star fruit before and after drying

Drying Kinetics:

In the graph shown below, the agreement between the experimental data and the mathematical equation is quite good after about seven hours into the drying process.



Moisture ratio versus time for star fruit slices

Based on the curve above, the general kinetic equation for the drying of star fruit slices is given by:

$$\mathbf{y = e^{-0.346t}} \quad \text{(Eq'n 1)}$$

where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$$\mathbf{M/ M_o = e^{-0.346t}} \quad \text{(Eq'n 2)}$$

where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $$\mathbf{M = M_o\, e^{-0.346t}} \quad \text{(Eq'n 3)}$$

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$\mathbf{-0.346t = \ln(M/M_o)} \quad \text{(Eq'n 4)}$$

Equation 4 then becomes: $$\mathbf{t = -\frac{\ln(M/M_o)}{0.346}} \quad \text{(Eq'n 5)}$$

$$\mathbf{t = \ln(M_o/M) / 0.346} \quad \text{(Eq'n 6)}$$

<u>Calculation of Drying Times</u>:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 90.1% on a wet basis (i.e., 9.10 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned}
\mathbf{t} &= \mathbf{\ln(M_o/M) / 0.346} \\
&= \mathbf{\ln(9.10 /0.111) / 0.346} \\
&= \mathbf{\ln(81.98) / 0.346} \\
&= \mathbf{4.41 / 0.346} \\
&= \mathbf{12.7 \text{ hours}} \quad \text{(Eq'n 7)}
\end{aligned}$$

Therefore, drying the star fruit slices under these conditions should take about 12.7 hours.

Application of the Drying Model:

For the star fruit slices dried in these tests at 50^{0}C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

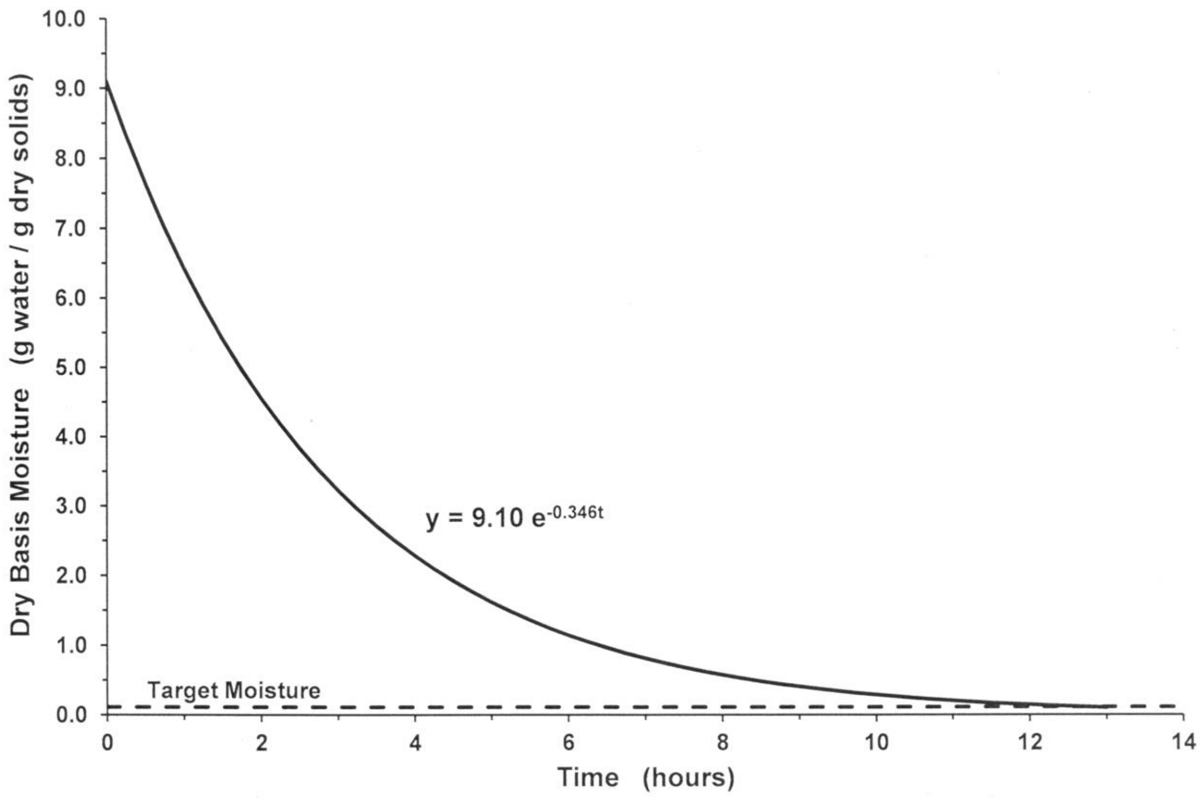
$$\mathbf{M = M_o\ e^{-0.346t}} \quad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 9.10 grams of water per gram of dry solids (i.e., approximately 90.1% wet basis moisture), this equation becomes:

$$\mathbf{M = 9.10\ e^{-0.346t}} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of star fruit slices.

It can be seen that the star fruit slices reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 12 to 13 hours as calculated in Equation 7.

SWEET GREEN PEPPER DRYING

Selection and Preparation of the Material:

The sweet green peppers you select should be free from blemishes and be of appropriate ripeness. They should be firm and have a smooth waxy surface, which is typical of most peppers.

Sweet green peppers are not “hot” and pose no problems in handling them.

Thoroughly wash the whole peppers and remove the excess water by blotting them dry with a paper towel, or allow the surface to dry in the room air for a short period of time.

Slice the peppers lengthwise. You can then remove the seeds and cut off the stem section at the top of each piece. Some people cut across the top and remove it first before slicing the peppers lengthwise. This may make it easier to remove the seeds and eliminates the need to cut the ends off the smaller individual pieces later.

You can then cut each of the two halves in half lengthwise once again so that the pepper is now quartered. Most sweet green peppers are fairly large, so it would be advisable to cut each of the quarters into three or four narrower slices to speed the drying process.

Fresh sweet green pepper

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for pepper slices.

Lay the pepper slices on the dryer rack with the skin side down (i.e., touching the rack). The fleshy portion should be pointing upwards. This will increase the exposure of the moist, porous inner surface of the peppers to the drying air, and improve the overall efficiency of the drying process.

Be sure that the pieces have a small amount of space between them to ensure the drying air contacts all surfaces. Don't be too worried if the edges of the peppers are toughing slightly since they will shrink during drying.

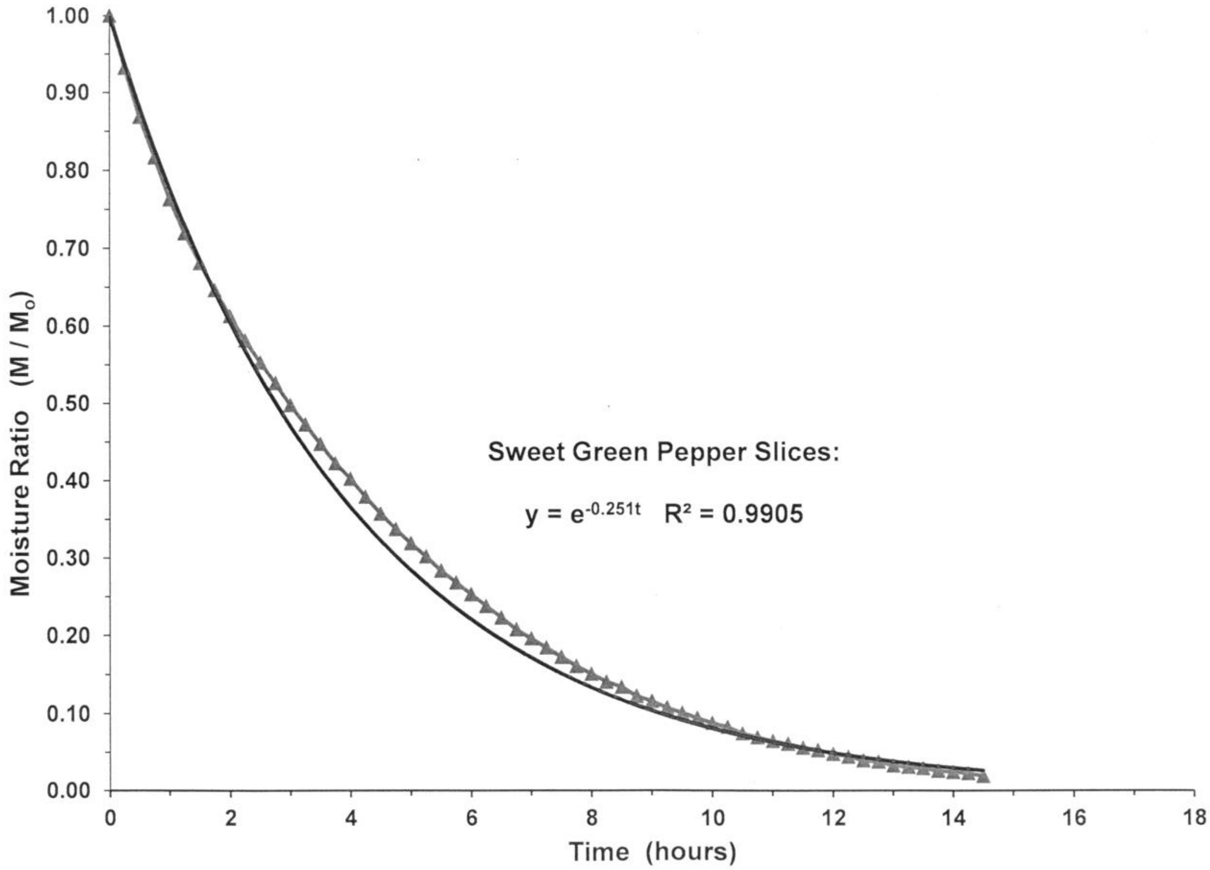
Test for Dryness:

Once the pepper slices are dry, they will tend to be crisp. There should be no signs of moisture in the dried slices.

The long slices tend to curl inwards during drying, so be sure to check the inner surfaces for any remaining moisture.

Fresh slices of sweet green peppers in dryer

Drying Kinetics:



Moisture ratio versus time for the drying of sweet green pepper slices (narrow slices)

Based on the curve above, the general kinetic equation for the drying of sweet green pepper slices is given by:

$\mathbf{y = e^{-0.251t}}$ (Eq'n 1) where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$\mathbf{M/ M_o = e^{-0.251t}}$ (Eq'n 2) where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $\mathbf{M = M_o\, e^{-0.251t}}$ (Eq'n 3)

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$-0.251t = \ln(M/M_o) \qquad \text{(Eq'n 4)}$$

Equation 4 then becomes:

$$t = -\frac{\ln(M/M_o)}{0.251} \qquad \text{(Eq'n 5)}$$

$$t = \ln(M_o/M) / 0.251 \qquad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 94.4% on a wet basis (i.e., 16.74 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.251 \\ &= \ln(16.74/0.111) / 0.251 \\ &= \ln(150.8) / 0.251 \\ &= 5.02 / 0.251 \\ &= 20.0 \text{ hours} \qquad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the sweet green pepper slices under these conditions should take about 20 hours.

Application of the Drying Model:

For the sweet green pepper slices dried in these tests at 50^{o}C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

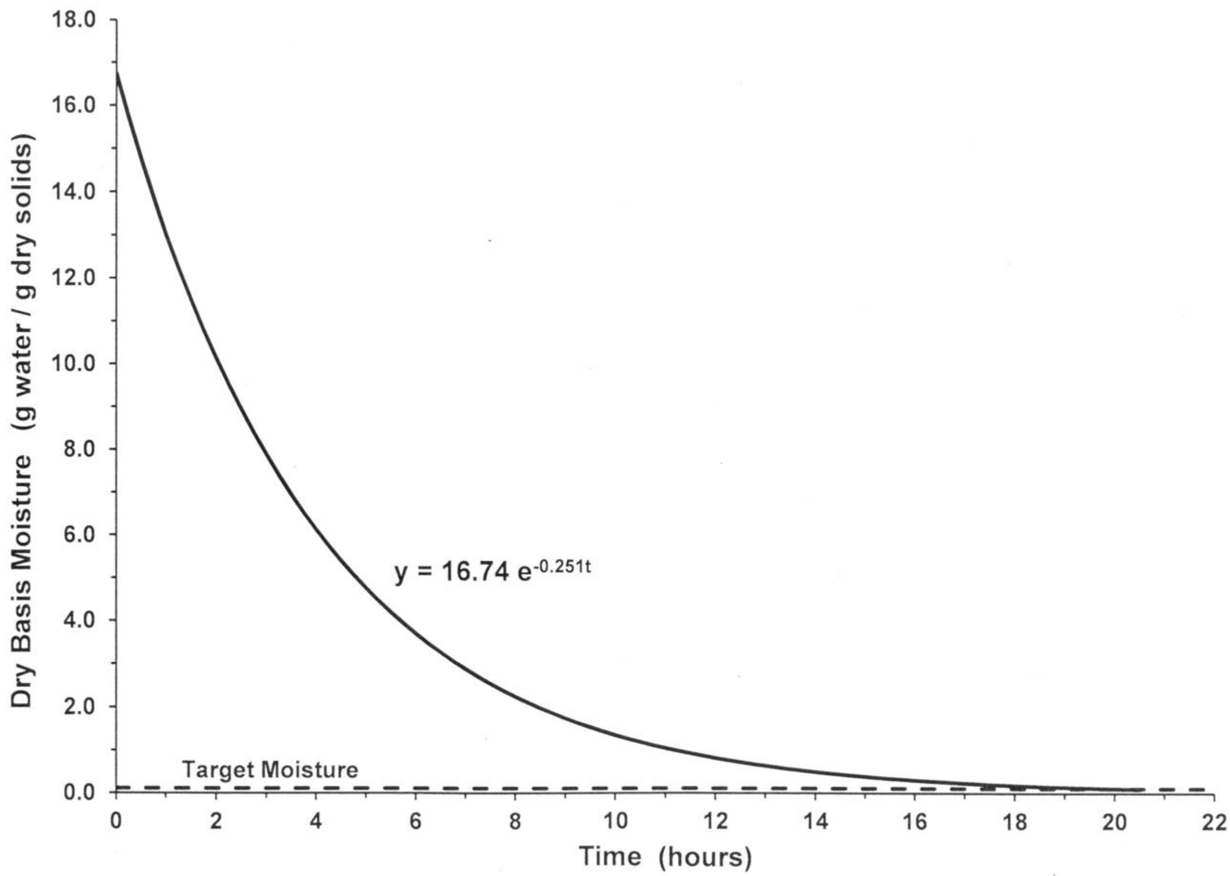
$$M = M_o\, e^{-0.251t} \qquad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 16.74 grams of water per gram of dry solids (i.e., approximately 94.4% wet basis moisture), this equation becomes:

$$\mathbf{M = 16.74\ e^{-0.251t}} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of sweet green pepper slices (quarters)

It can be seen that the sweet green pepper slices reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 20 hours as calculated in Equation 7.

TARO DRYING

Selection and Preparation of the Material:

Before drying taro, it is necessary to boil them. This accomplishes a number of things, including gelatinizing the starches and softening flesh. Once peeled, the taro was cut into long pieces and boiled in water for approximately 30 minutes. After draining to remove the excess water from the pot, the taro was mashed with a hand-held potato masher.

Taro before and after peeling

Taro being boiled

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for drying mashed taro.

The mashed taro needs to be spread as evenly as possible on plastic mesh inside the dryer. Be careful not to make the layer of taro too thick, or this will slow the drying process.

It should be noted that there can be more inherent variability in the drying of materials where more is involved than simply cutting the material and placing it in the dryer. You may need to practise a few times to establish a method that will give uniform drying results.

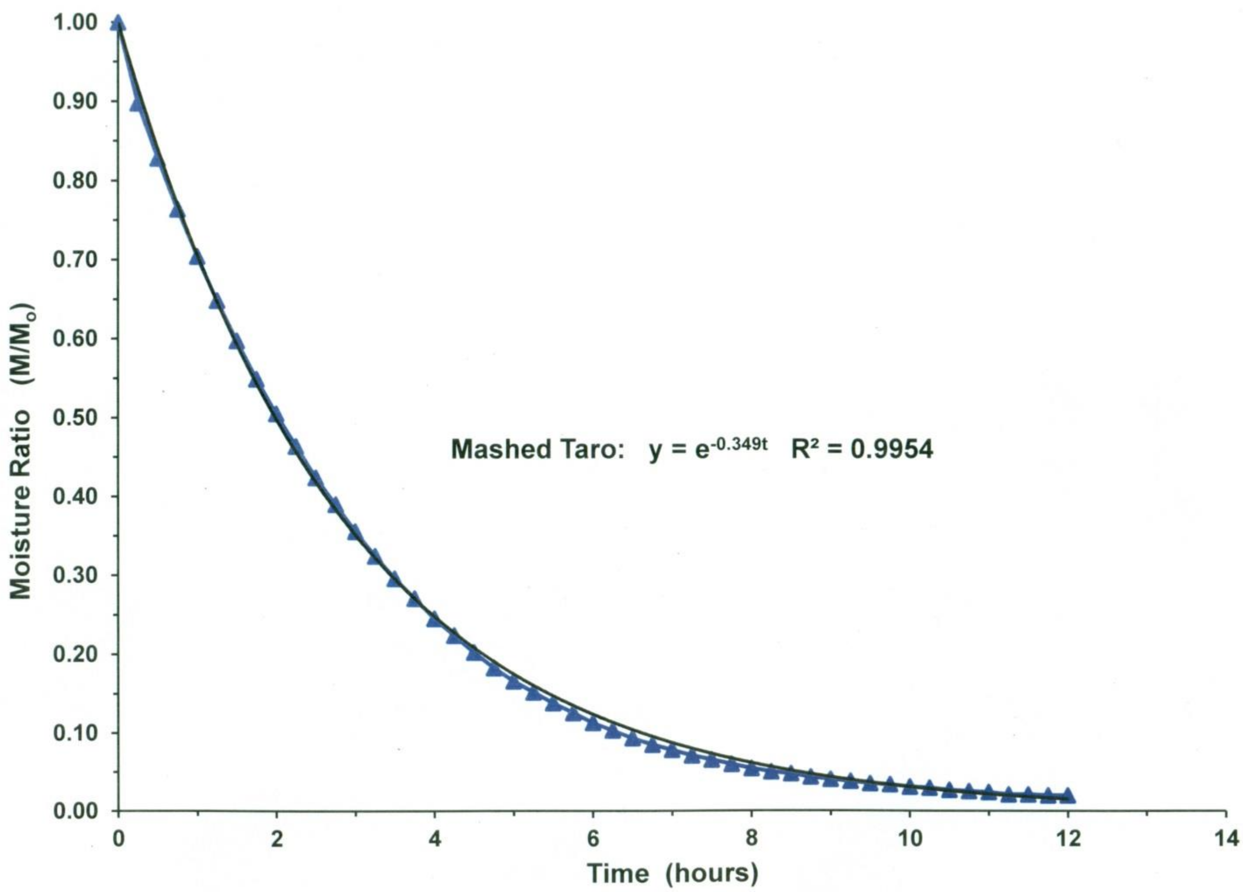
<u>Test for Dryness</u>:

When the mashed taro is dried and cooled, the pieces will feel quite brittle and will break apart when crushed between your fingers.

Wet mashed taro after being placed on plastic mesh in the dryer

Dried mashed taro pieces in the dryer

Drying Kinetics:



Moisture ratio versus time for drying of mashed taro

Based on the curve above, the general kinetic equation for the drying of mashed taro is given by:

$\mathbf{y = e^{-0.349t}}$ (Eq'n 1) where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$\mathbf{M/ M_o = e^{-0.349t}}$ (Eq'n 2) where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $\mathbf{M = M_o\, e^{-0.349t}}$ (Eq'n 3)

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$-0.349t = \ln(M/M_o) \qquad \text{(Eq'n 4)}$$

Equation 4 then becomes:

$$t = -\frac{\ln(M/M_o)}{0.349} \qquad \text{(Eq'n 5)}$$

$$t = \ln(M_o/M) / 0.349 \qquad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 67.6% on a wet basis (i.e., 2.09 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.349 \\ &= \ln(2.09 /0.111) / 0.349 \\ &= \ln(18.83) / 0.349 \\ &= 2.94 / 0.349 \\ &= 8.4 \text{ hours} \qquad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the mashed taro under these conditions should take about 8.4 hours.

Application of the Drying Model:

For the mashed taro dried in these tests at 50^{o}C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

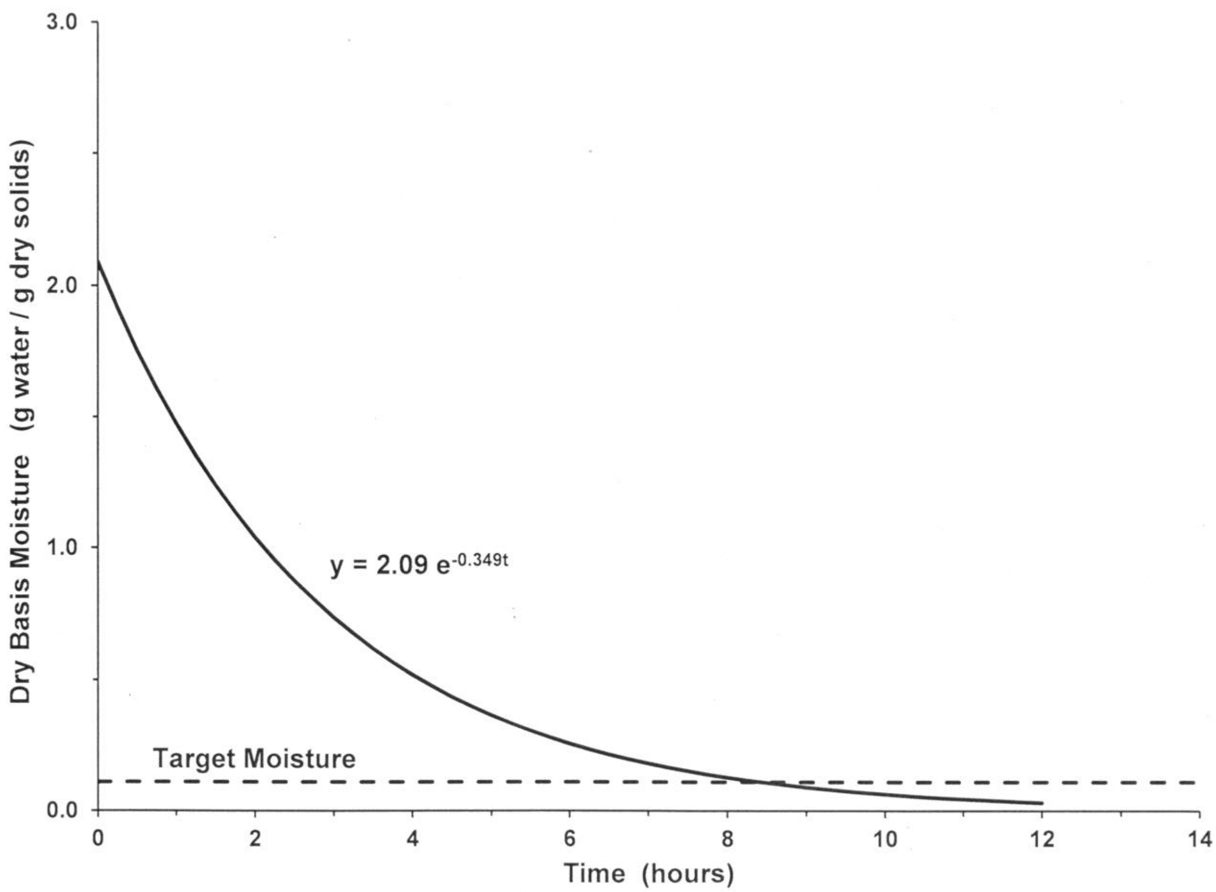
$$M = M_o\, e^{-0.349t} \qquad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 2.09 grams of water per gram of dry solids (i.e., approximately 67.6% wet basis moisture), this equation becomes:

$$\mathbf{M = 2.09\ e^{-0.349t}} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time “t” during the drying process

Plotting the dry basis moisture “M” versus time “t” gives the following graph:



Dry basis moisture versus time for the drying of mashed taro

It can be seen that the mashed taro reaches a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 8.5 hours as calculated in Equation 7.

TOMATO DRYING

Selection and Preparation of the Material:

Tomatoes are usually the first thing that comes to mind when people consider what they would like to dry. Unfortunately, because they contain so much water, tomatoes are one of the slowest things to dry. Roma tomatoes were originally developed to have a slightly lower moisture content than other types of tomatoes, which would make them better for use in sauces where the lower moisture content would help create a thicker consistency. However, in recent years, we have seen the gradual increase in moisture content of Roma tomatoes, so there is very little difference between their water content and that of other tomato varieties.

When preparing tomatoes for drying, it is usually best to cut the tomatoes into wedges. Roma tomatoes can be easily cut lengthwise into eight wedges.

Fresh Roma tomatoes

Tomato wedges ready for drying

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for tomato wedges. Place the tomato wedges on the dryer rack with the skin side down so that it will hold the fleshy part of the tomato in place. It is best to position the wedges so that they point towards the incoming air flow. In this way, the warm drying air can flow along each of the exposed sides of the wedges and increase the water removal efficiency of the drying operation.

Be sure that the pieces have a small amount of space between them to ensure the drying air contacts all surfaces.

Test for Dryness:

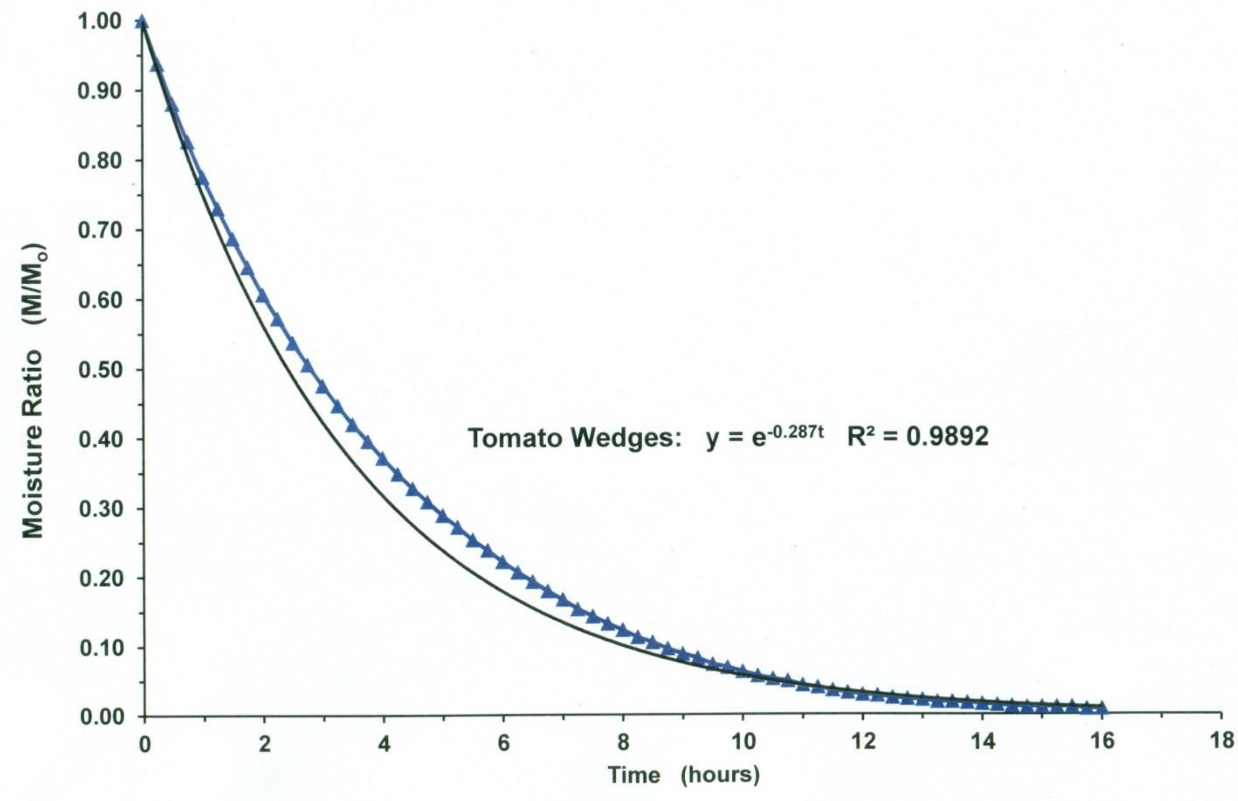
When the tomato wedges are done, they will feel rather tough and leathery. They may have darkened significantly. There should be no sign of moisture when you bend the dried wedges in your hands.

Fresh tomato wedges in the dryer
(the air flow is travelling from the left of the photo to the right)

Dried tomato wedges in the dryer

Drying Kinetics:

In the graph shown below, the agreement between the experimental data and the mathematical equation is quite good after about eight or nine hours into the drying process.



Moisture ratio versus time for the drying of tomato wedges

Based on the curve above, the general kinetic equation for the drying of tomato wedges is given by:

$$y = e^{-0.287t} \quad \text{(Eq'n 1)}$$

where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$$M/M_o = e^{-0.287t} \quad \text{(Eq'n 2)}$$

where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or:

$$M = M_o e^{-0.287t} \quad \text{(Eq'n 3)}$$

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$-0.287t = \ln(M/M_o) \qquad \text{(Eq'n 4)}$$

Equation 4 then becomes:

$$t = -\frac{\ln(M/M_o)}{0.287} \qquad \text{(Eq'n 5)}$$

$$t = \ln(M_o/M) / 0.287 \qquad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 93.8% on a wet basis (i.e., 15.08 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.287 \\ &= \ln(15.08 / 0.111) / 0.287 \\ &= \ln(135.9) / 0.287 \\ &= 4.91 / 0.287 \\ &= 17.1 \text{ hours} \qquad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the tomato wedges under these conditions should take about 17.1 hours.

Application of the Drying Model:

For the tomato wedges dried in these tests at 50^0C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

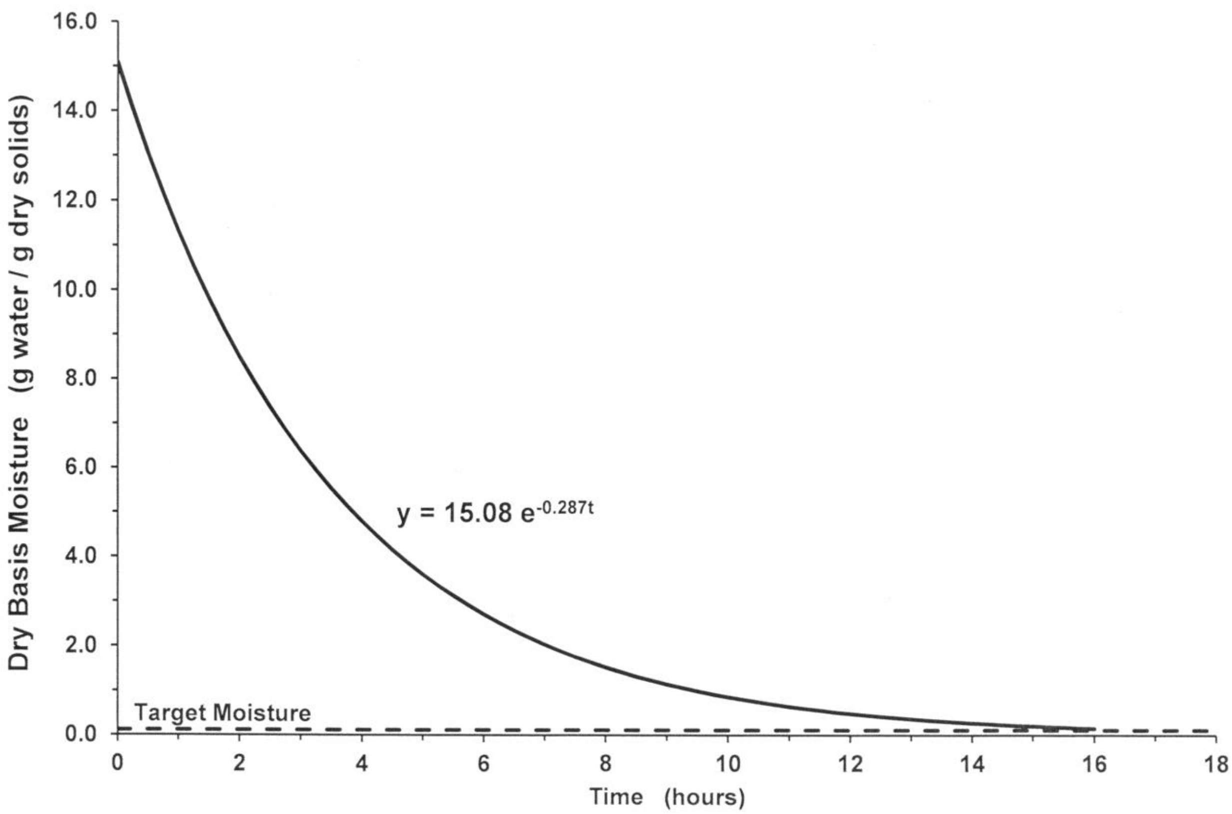
$$M = M_o e^{-0.287t} \qquad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 15.08 grams of water per gram of dry solids (i.e., approximately 93.8% wet basis moisture), this equation becomes:

$$\mathbf{M = 15.08\ e^{-0.287t}} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of tomato wedges

It can be seen that the tomato wedges reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 17 hours (by extrapolation) as calculated in Equation 7.

WATERMELON DRYING

Selection and Preparation of the Material:

Watermelon is not something that I would personally recommend drying. The end uses of dried watermelon slices are not at all plentiful and there is a lot of water that needs to be removed to obtain only a small amount of dried product. However, it has been included here as a bit of a curiosity.

When preparing the watermelon for drying, you can try cutting the melon into slices about 3 cm thick. Then you can remove the rind and cut the fleshy portion into pieces that are easy to handle and place in your dryer.

Whole watermelon

Fresh watermelon slices in dryer

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for watermelon slices. Be sure that the pieces have a small amount of space between them to ensure the drying air contacts all surfaces.

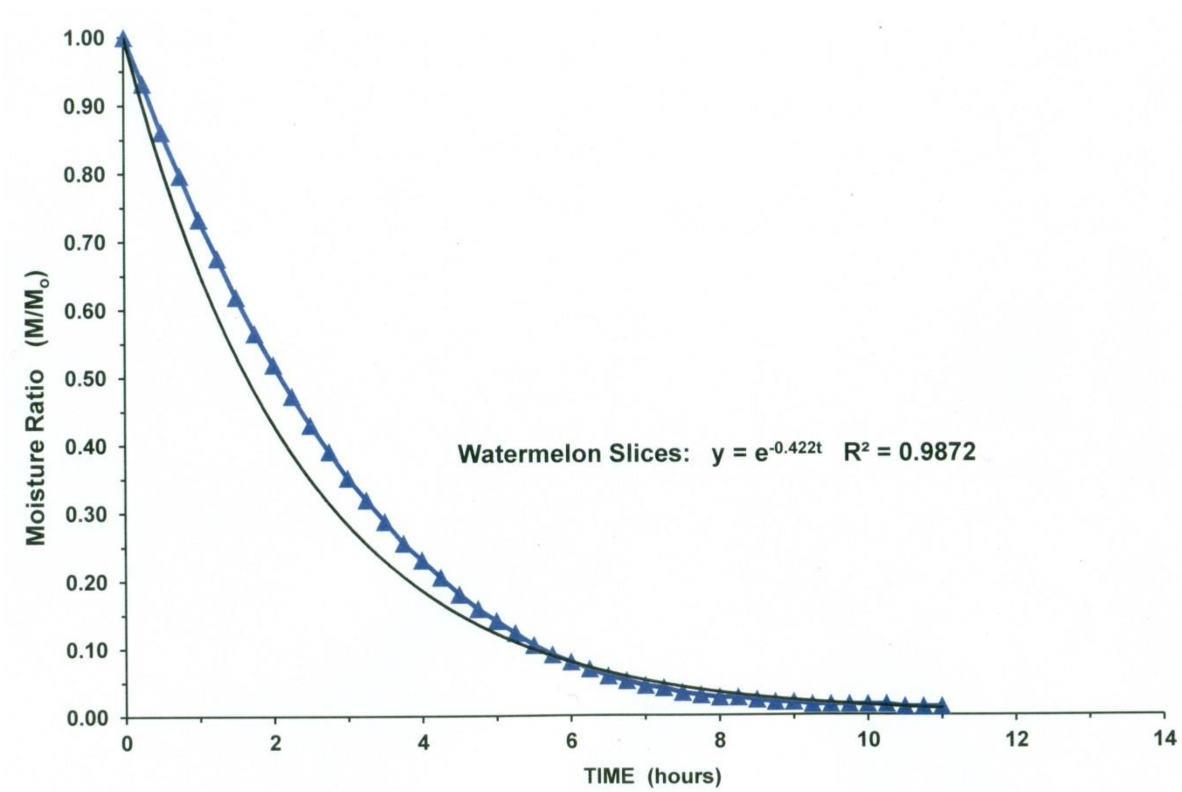
Test for Dryness:

When the watermelon slices are done, they will have shrivelled up noticeably. They should feel dry and be somewhat pliable. (see photos on next page)

Fresh watermelon slices in dryer Dried watermelon slices in dryer

Drying Kinetics:

In the graph shown below, the agreement between the experimental data and the mathematical equation is quite good after about five hours into the drying process.



Moisture ratio versus time for the drying of watermelon slices

Based on the curve above, the general kinetic equation for the drying of watermelon slices is given by:

$$\mathbf{y = e^{-0.422t}} \quad \text{(Eq'n 1)} \quad \text{where: y is the moisture ratio } M/M_o$$

t is the drying time in hours

Re-writing this equation:

$$\mathbf{M/ M_o = e^{-0.422t}} \quad \text{(Eq'n 2)}$$

where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $$\mathbf{M = M_o\, e^{-0.422t}} \quad \text{(Eq'n 3)}$$

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$\mathbf{-0.422t = \ln(M/M_o)} \quad \text{(Eq'n 4)}$$

Equation 4 then becomes: $$\mathbf{t = -\frac{\ln(M/M_o)}{0.422}} \quad \text{(Eq'n 5)}$$

$$\mathbf{t = \ln(M_o/M) / 0.422} \quad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 93.5% on a wet basis (i.e., 14.38 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} \mathbf{t} &= \mathbf{\ln(M_o/M) / 0.422} \\ &= \mathbf{\ln(14.38 /0.111) / 0.422} \\ &= \mathbf{\ln(129.5) / 0.422} \\ &= \mathbf{4.86 / 0.422} \\ &= \mathbf{11.5 \text{ hours}} \end{aligned} \quad \text{(Eq'n 7)}$$

Therefore, drying the watermelon slices under these conditions should take about 11.5 hours.

Application of the Drying Model:

For the watermelon slices dried in these tests at 50^{0}C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

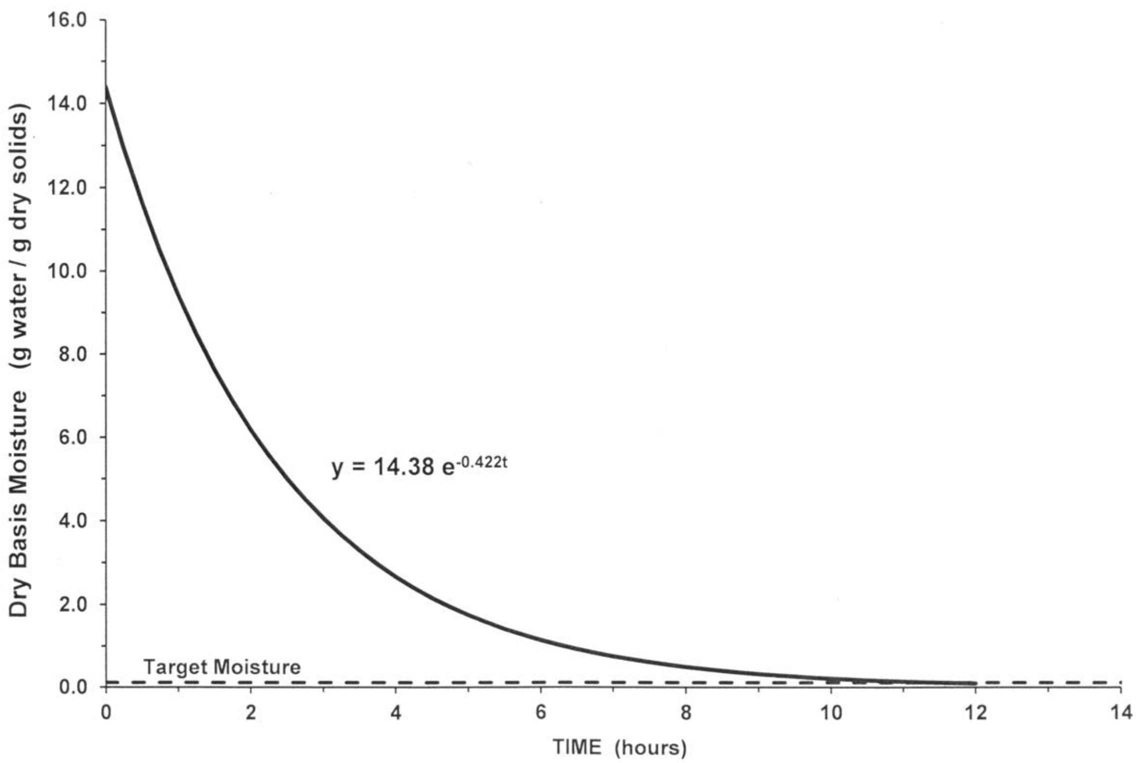
$$\mathbf{M = M_o\ e^{-0.422t}} \quad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 14.38 grams of water per gram of dry solids (i.e., approximately 93.5% wet basis moisture), this equation becomes:

$$\mathbf{M = 14.38\ e^{-0.422t}} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of watermelon slices

It can be seen that the watermelon slices reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 11 to 12 hours as calculated in Equation 7.

YAM DRYING

Selection and Preparation of the Material:

Before drying yams, it is necessary to boil them. This accomplishes a number of things, including gelatinizing the starches and softening flesh. Once peeled, cut the yam into slices about 4 to 5 cm thick and boil them in water for approximately 30 minutes. After draining to remove the excess water from the pot, the yam can be mashed with a hand-held potato masher.

Yam before peeling

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for drying mashed yams.

The mashed yams need to be spread as evenly as possible on plastic mesh inside the dryer. Be careful not to make the layer of yams too thick, or this will slow the drying process.

It should be noted that there can be more inherent variability in the drying of materials where more is involved than simply cutting the material and placing it in the dryer. You may need to practise a few times to establish a method that will give uniform drying results.

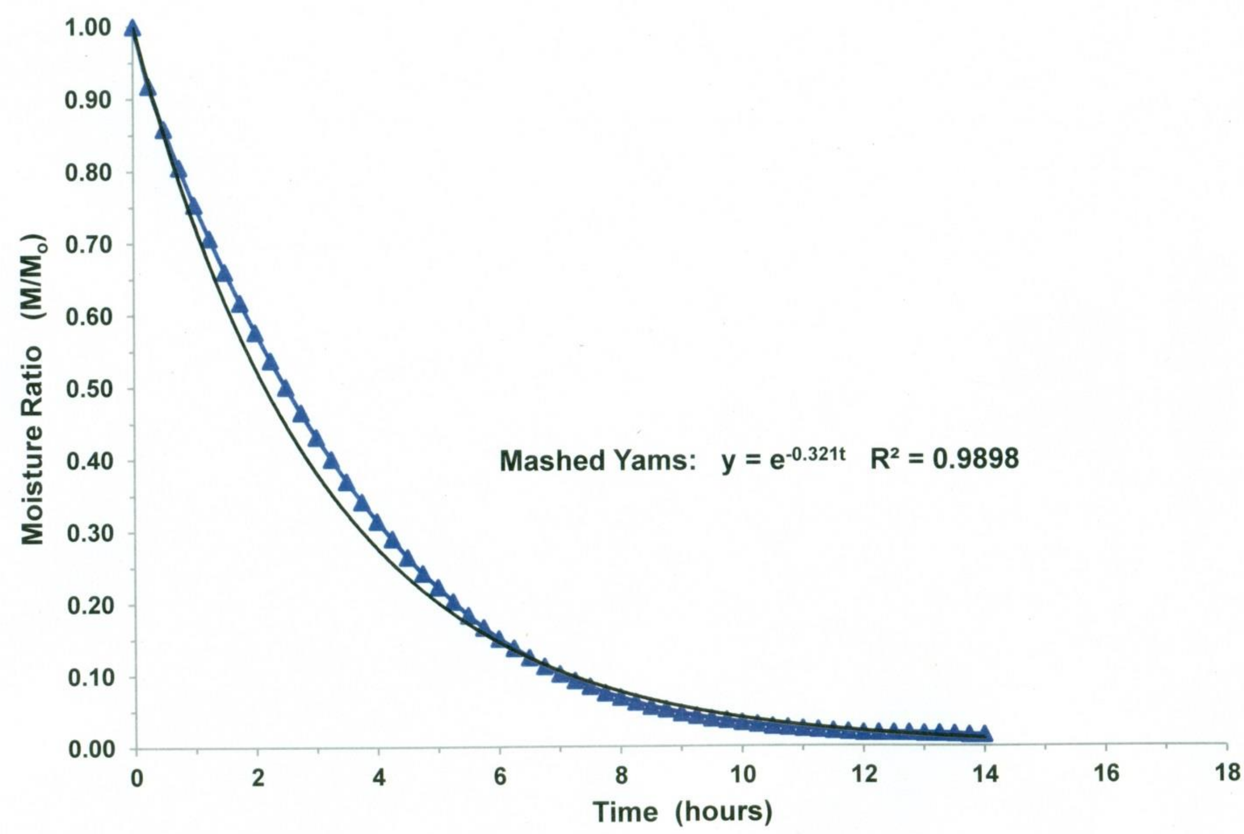
Test for Dryness:

When the mashed yams are dried and cooled, the pieces will feel quite brittle and will break apart when crushed between your fingers.

Wet mashed yams after being placed on plastic mesh in the dryer

Dried mashed yam pieces in the dryer

Drying Kinetics:



Moisture ratio versus time for drying of mashed yams

Based on the curve above, the general kinetic equation for the drying of mashed yams is given by:

$$\mathbf{y = e^{-0.321t}} \quad \text{(Eq'n 1)}$$

where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$$\mathbf{M/ M_o = e^{-0.321t}} \quad \text{(Eq'n 2)}$$

where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $$\mathbf{M = M_o\, e^{-0.321t}} \quad \text{(Eq'n 3)}$$

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$-0.321t = \ln(M/M_o) \qquad \text{(Eq'n 4)}$$

Equation 4 then becomes:

$$t = -\frac{\ln(M/M_o)}{0.321} \qquad \text{(Eq'n 5)}$$

$$t = \ln(M_o/M) / 0.321 \qquad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 69.1% on a wet basis (i.e., 2.24 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.321 \\ &= \ln(2.24 /0.111) / 0.321 \\ &= \ln(20.18) / 0.321 \\ &= 3.00/ 0.321 \\ &= 9.3 \text{ hours} \qquad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the mashed yams under these conditions should take about 9.3 hours.

Application of the Drying Model:

For the mashed yams dried in these tests at 50^0C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

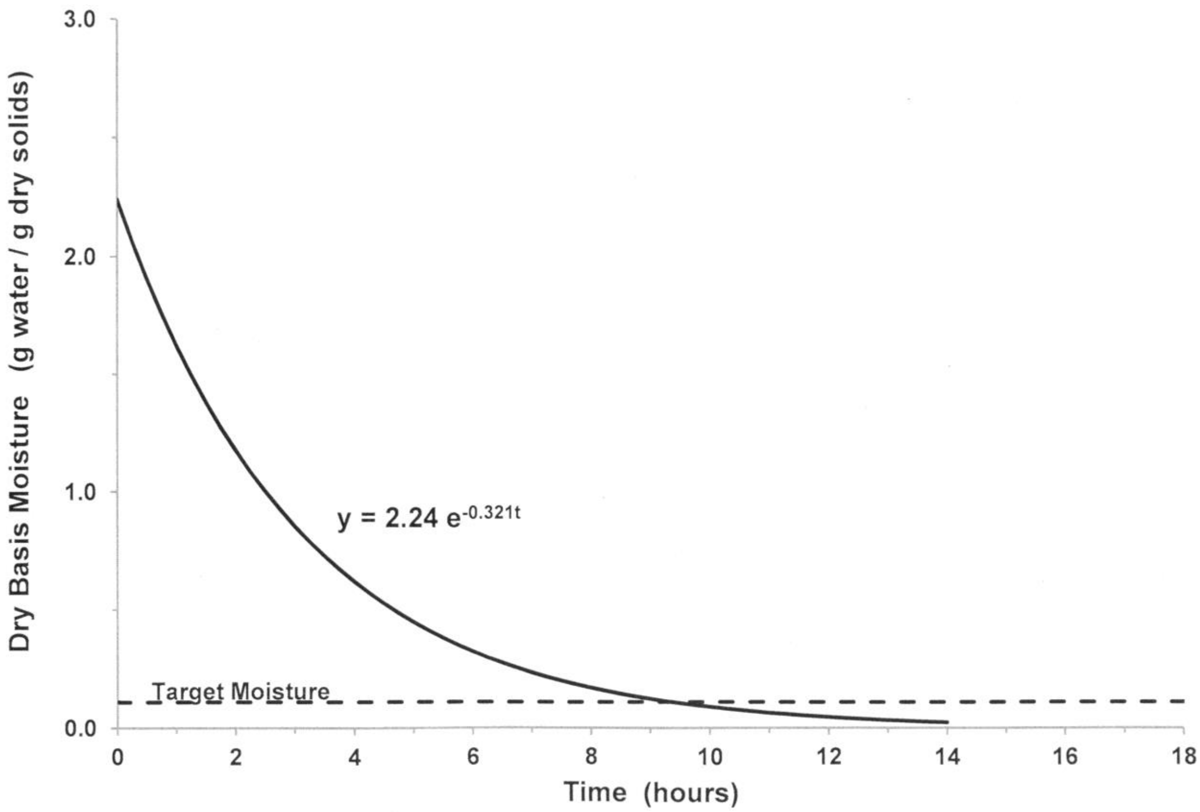
$$M = M_o\, e^{-0.321t} \qquad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 2.24 grams of water per gram of dry solids (i.e., approximately 69.1% wet basis moisture), this equation becomes:

$$M = 2.24\, e^{-0.321t} \qquad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture “M” versus time “t” gives the following graph:



Dry basis moisture versus time for the drying of mashed yams

It can be seen that the mashed yam reaches a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 9.5 hours as calculated in Equation 7.

YELLOW PEPPER DRYING

Selection and Preparation of the Material:

The hot yellow peppers you select should be free from blemishes and be of appropriate ripeness. They should be firm and have a smooth waxy surface, which is typical of most peppers.

CAUTION: For hot peppers, it is a good idea to wear rubber gloves to prevent the transfer of the "heat" to your fingers. If you happen to rub your eyes or get the juice of the peppers in a small cut, it can be quite painful. Wash the affected area well.

Peppers are hot due to the presence of an oily chemical compound called "capsaicin". It triggers a burning sensation when it contacts the sensory nerves in our bodies.

Extreme care should be taken when handling hot peppers.

Thoroughly wash the whole peppers and remove the excess water by blotting them dry with a paper towel, or allow the surface to dry in the room air for a short period of time.

Slice the peppers lengthwise. You can then remove the seeds and cut off the stem section at the top of each piece.

You can then cut each of the two halves in half lengthwise once again so that the pepper is now quartered. If the pepper is large, you may wish to cut it into narrower slices to speed the drying process.

Fresh hot yellow pepper

Drying Conditions:

A temperature of about 50ºC, with a linear air velocity of 0.5 metres per second, works well for pepper slices.

Lay the pepper slices on the dryer rack with the skin side down (i.e., touching the rack). The fleshy portion should be pointing upwards. This will increase the exposure of the moist, porous inner surface of the peppers to the drying air, and improve the overall efficiency of the drying process.

Be sure that the pieces have a small amount of space between them to ensure the drying air contacts all surfaces. Don't be too worried if the edges of the peppers are toughing slightly since they will shrink during drying.

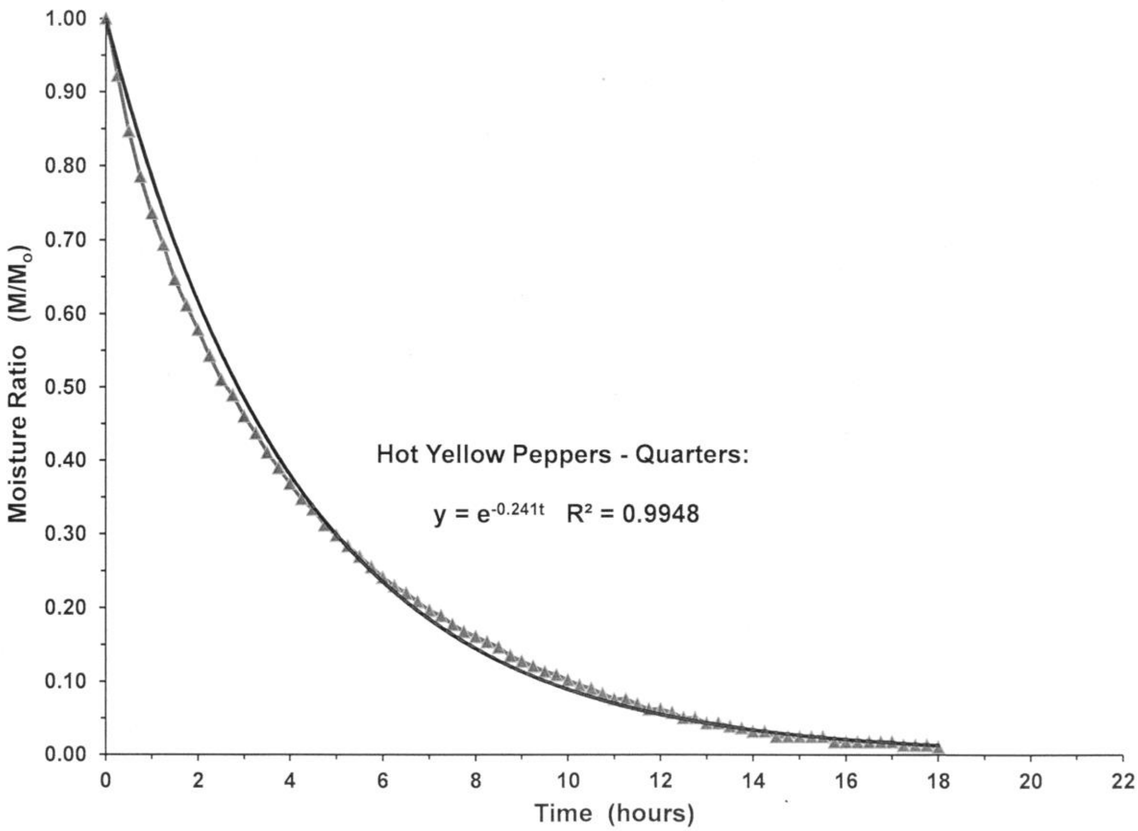
Test for Dryness:

Once the pepper slices are dry, they will tend to be crisp. There should be no signs of moisture in the dried slices. It's a good idea to wear rubber gloves even when handling the dried peppers if you are particularly sensitive to the "heat" from the capsaicin oil.

The long slices tend to curl inwards during drying, so be sure to check the inner surfaces for any remaining moisture.

Dried slices of hot yellow peppers

Drying Kinetics:



Moisture ratio versus time for the drying of hot yellow pepper slices (quarters)

Based on the curve above, the general kinetic equation for the drying of hot yellow pepper slices is given by:

$$\mathbf{y = e^{-0.241t}}$$ (Eq'n 1) where: y is the moisture ratio M/M_o
t is the drying time in hours

Re-writing this equation:

$$\mathbf{M/M_o = e^{-0.241t}}$$ (Eq'n 2) where: M is the dry basis moisture at time t
M_o is the initial dry basis moisture

or: $$\mathbf{M = M_o\, e^{-0.241t}}$$ (Eq'n 3)

This equation will allow you to calculate the dry basis moisture at any time t, if you know the starting dry basis moisture.

To find the time it takes to reach a desired final dry basis moisture, Equation 2 can be rearranged into the following form: (Note: "ln" indicates taking the natural logarithm)

$$-0.241t = \ln(M/M_o) \qquad \text{(Eq'n 4)}$$

Equation 4 then becomes:

$$t = -\frac{\ln(M/M_o)}{0.241} \qquad \text{(Eq'n 5)}$$

$$t = \ln(M_o/M) / 0.241 \qquad \text{(Eq'n 6)}$$

Calculation of Drying Times:

To reach a final moisture content of 10% wet basis moisture (i.e., 0.111 grams of water per gram of dry solids) from an initial moisture content of 92.9% on a wet basis (i.e., 13.02 grams of water per gram of dry solids), Equation 6 can be applied.

$$\begin{aligned} t &= \ln(M_o/M) / 0.241 \\ &= \ln(13.02/0.111) / 0.241 \\ &= \ln(117.30) / 0.241 \\ &= 4.76 / 0.241 \\ &= 19.8 \text{ hours} \qquad \text{(Eq'n 7)} \end{aligned}$$

Therefore, drying the yellow pepper slices under these conditions should take about 20 hours.

Application of the Drying Model:

For the hot yellow pepper slices dried in these tests at 50^0C with an air velocity of 0.5 metres per second, the following model can be applied based on Equation 3 presented above:

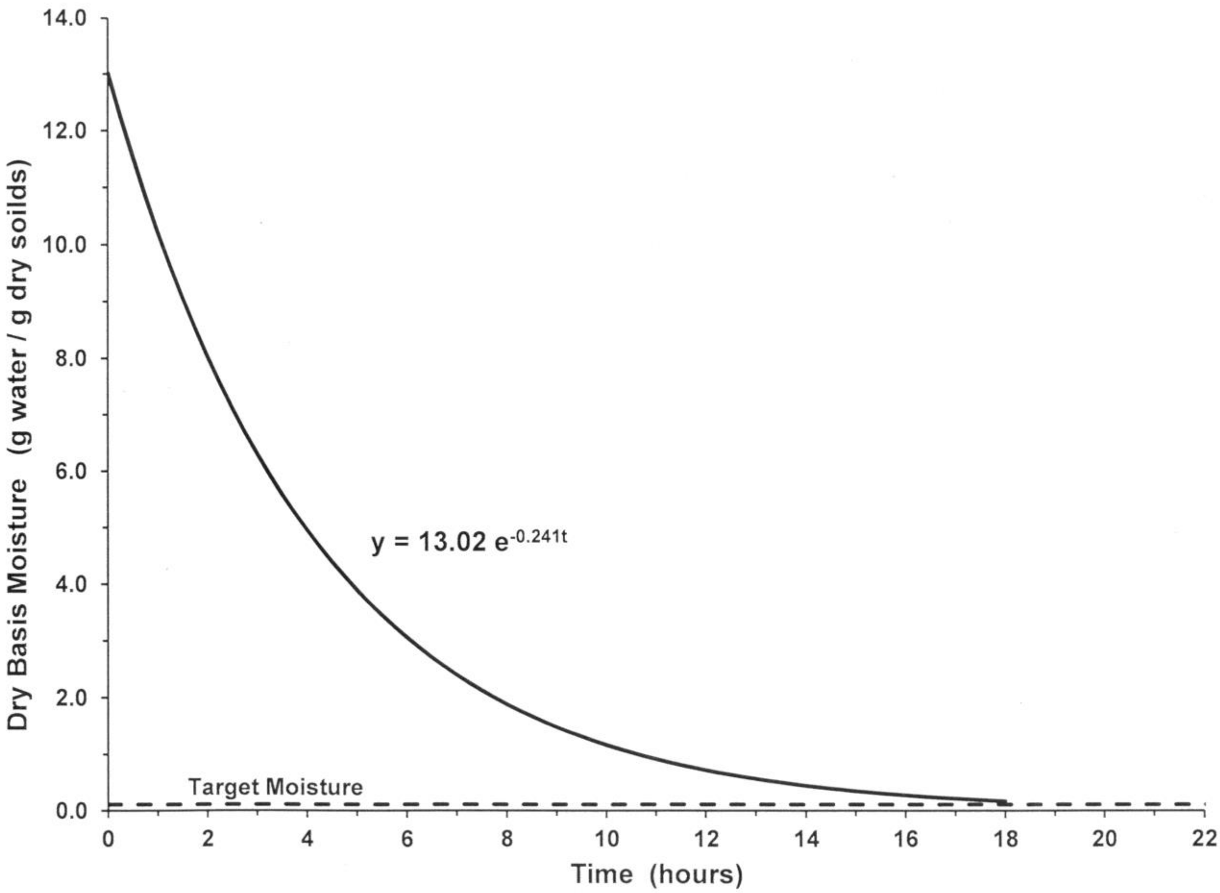
$$M = M_o\, e^{-0.241t} \qquad \text{(restating of Eq'n 3)}$$

With an average initial dry basis moisture (M_o) of 13.02 grams of water per gram of dry solids (i.e., approximately 92.9% wet basis moisture), this equation becomes:

$$\mathbf{M = 13.02\ e^{-0.241t}} \quad \text{(Eq'n 8)}$$

where: M is the dry basis moisture at any time "t" during the drying process

Plotting the dry basis moisture "M" versus time "t" gives the following graph:



Dry basis moisture versus time for the drying of hot yellow pepper slices (quarters)

It can be seen that the yellow pepper slices reach a dry basis moisture content of 0.11 grams of water per gram of dry solids in approximately 19 to 20 hours (by extrapolation) as calculated in Equation 7.