Proceedings of the Technical Sessions, 25 (2009) 45-52
Institute of Physics - Sri Lanka

Comparison of Drying of Mixed Kitchen Garbage under Different Drying Conditions

O. K. Ranasingha and T. R. Ariyaratne

Centre for Instrument Development, Department of Physics, University of Colombo, Colombo 03, Sri Lanka.

ABSTRACT

The mixed kitchen garbage which is disposed from houses, hotels *etc.* mainly cause to lot of environment and hygienic problems. Mixed kitchen garbage generally contains higher moisture content. By drying, it is possible to convert them to some useful products while avoiding some of the problems arisen. This research investigates the drying behaviours of mixed kitchen garbage and its' constituents under three different methods namely drying in a low humid and high temperature, in an electrical oven and under the sun. Two-term exponential single layer drying model was found to be the best model to explain the behaviour of drying in a low humid, high temperature the drying chamber. The diffusion constants for the samples of tomato, rice , papaw, scraped coconut, cabbage, dry leaves, grass, mixed kitchen garbage 1, mixed kitchen garbage 2 and mixed kitchen garbage 3 were ; (2.026, 2.702, 2.871, 3.715, 2.702, 11.652, 9.625, 2.026, 2.026 and 2.702) x 10^{-9} m^2h^{-1} respectively. Newton single layer drying model was the best model to explain the behaviour where drying in an electrical oven. The respective diffusion constants for the samples of tomato, rice , papaw, scraped coconut, dry leaves, grass, mixed kitchen garbage 1and mixed kitchen garbage 2 were ;(3.040, 2.720, 5.066, 3.715, 2.533, 3.208, 3.715and 2.208) x10^{-9} m^2h^{-1} respectively. Henderson-Pabis single layer drying model was the best model which explain the drying under the sun. The corresponding diffusion constants for the samples of tomato, rice , papaw, scraped coconut, dry leaves, grass, mixed kitchen garbage 1and mixed kitchen garbage 2 were ;(0.338, 0.675, 0.675, 1.857, 1.520, 1.351, 0.507 and 1.013) x10^{-9} m^2h^{-1} respectively.

ABBREVIATIONS

A, A_1, A_2, a, b, c = Constants
k_1, k_2 = Drying constant (h^{-1})
MC = Moisture content at time t
MC_e = Equilibrium moisture content
RH = Relative Humidity
D =Diffusion Constant
a_w = Water activity = $RH/100$
L = Half of thickness of slab (m)
MC_0 = Initial moisture content
MR = Removable Moisture Ratio
t = Drying time (h)

1 INTRODUCTION

Organic and mixed kitchen garbage is a huge problem in all over the world. It consists of fruits, vegetables, left overs' of food, plant leaves *etc*. Sri Lanka also is a country which suffers from this problem, without a clear solution. Every home, office, restaurant and hotel *etc*. which people live in; releases at least some amount of mixed kitchen garbage to the environment. According to a book published in 2005 [1], around 3000 tons of Municipal Solid Waste (MSW) is collected in Sri Lanka per day. The interesting fact is approximately 75 % of MSW is biodegradable garbage *i.e.* mixed kitchen garbage.

Every municipal councils of Sri Lanka suffering this problem because they do not have enough lands for accommodate the huge collection of garbage. Within a few days these mixed kitchen garbage start biodegrade. As a result of this, a lot of problems will occur such as odour, epidemics and soil pollution etc. Important fact is that there is no method to destroy mixed kitchen garbage directly. Composting, making biodiesel, making bio gas and burning to generate energy are some of methods which reuse mixed kitchen garbage.

Burning is one of the energy recovering methods from mixed kitchen garbage. For a successful burning process; it needed to reduce the moisture content of mixed kitchen garbage to a certain critical level. And also for composting (10% in dry basis) [2], making biodiesel and making bio gas need low moisture content. Therefore high moisture content is a main problem in the energy recovering process, from mixed kitchen garbage. Drying is therefore, an essential process to recover the energy from mixed kitchen garbage. Even though energy is not recovered, from drying, the above mentioned problems can be reduced.

Drying is defined as a process of moisture removal due to simultaneous heat and mass transfer. The moisture can be either transported to the surface of the product and then evaporated, or evaporated internally at a liquid vapour interface and then transported as vapour to the surface. The transfer of moisture depends on the air temperature, relative humidity, air flow rate, exposed area of material and pressure. The physical nature of the material, including temperature, composition and in particular moisture content governs the rate of moisture transfer [3].

Drying under the sun and oven drying are two well known methods used for drying fruits, vegetables, wood and etc. To drying under the sun requires a long time period to reduce the moisture content, in order to burn it. To properly dry tomatoes, 12 days of sun shine is approximately needed [4], and also this method totally depend on the whether conditions such long times would also lead to biodegradation and hence environment pollution. On the other hand, from oven drying, it is possible to achieve high temperature levels, but due to the lack of removal of moisture from the system, the maximum drying efficiency cannot be achieved from this method.

When considering the drying process, relative humidity and temperature are the key parameters. With the increasing temperature or the decreasing relative humidity, the rate of drying will increase. However it has been shown that the increase of the temperature is more effective than the reduction of the relative humidity of the drying environment [5]. Under this study, the drying characteristics of the drying of kitchen garbage under three different conditions drying under the sun, oven drying and drying inside a low humid and high temperature chamber were investigated.

2 THEORY

In drying the rate of diffusion is governed by the moisture content gradient. The Fick’s second law of diffusion is widely used to model the drying behaviour for this period [6]. There are many single layer drying models have been formulated for vegetables and fruits, based on the Fick’s second law of diffusion.

A well known analytical solution for the Fick’s second law has been reduced for a long drying time by R.H. Perry and D.W. Green, [7] as,

$$MR = \frac{MC - MC_e}{MC_0 - MC_e} = {}^{8}\!/_{\pi^2} \left[exp\left\{ -Dt \left({}^{\pi^2}\!/_{4L^2} \right) \right\} \right] \quad \text{-------------------} \quad 1$$

$$Moisture\ Contetnt(Dry\ Basis) = \left[\frac{Initial\ weight - Oven\ dry\ weight}{Oven\ dry\ weight}\right]$$

Equation 1 can be rewritten as

$$MR = Ae^{-Kt} \quad \text{--------------------------------} \quad 2$$

Moisture diffusivity constant (D) can be found from the gradient of the graph of “ln (MR) Vs t”.

There are several variations have been suggested for the equation 2. In this research, experimental data were fitted in to following single layer drying models to find the best model for drying of mixed kitchen garbage. [8]

Table 1 – Single layer drying models

Name	Model Equation
Two-term exponential	$MR = A_2\,exp(-k_1 t) + A_2 exp(-k_2 t)$
Henderson and Pabis	$MR = Aexp(-kt)$
Newton	$MR = exp\ (-kt)$
Logarithmic	$MR = A_1 + A_2 exp\ (-kt)$
Wang and Singh	$MR = A_1 t + A_2 t^2 + 1$

The following equation is the Henderson-Thompson empirical equation was used for calculating equilibrium moisture content [9].

$$MC_e = [\ln{(1 - a_w)}/(-a * (T + c))]\text{^}(1/b) \quad \text{--------------} \quad 3$$

3 MATERIALS AND METHODS

3.1 Preparation of test samples

Kitchen garbage samples were turned in to small pieces (approximately 1 cm). The static pressing system (hydraulic power) was used to remove the approximately 5 % of initial water content.

3.2 Designing the drying chamber

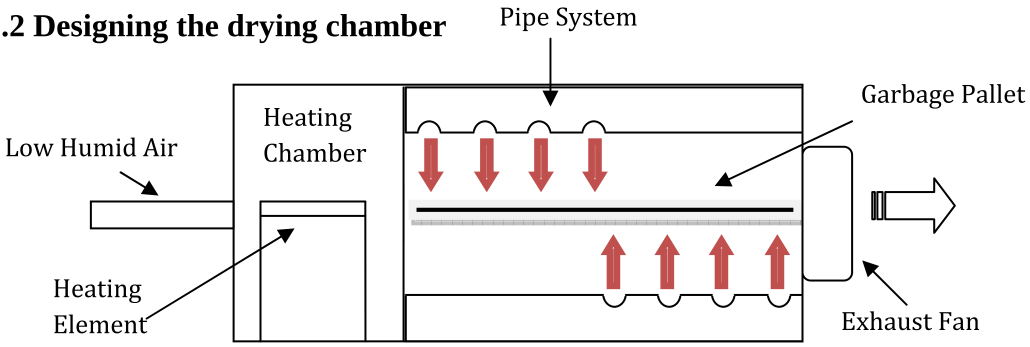

Figure 1 - Illustration of the drying chamber

The drying chamber consists of three 808.5 W heating elements, two metal pipe systems which contain a special holes structure, and it was insulated using three layers of asbestos and a layer of insulating foil on top. Low humid air flows through this heater system. The garbage palette was made out of a metallic mesh, having dimensions 172 cm × 73 cm × 2.5 cm and it consists of 2.5 mm × 2.5 mm holes and the pallet was placed in between the two pipe systems, at the middle as figure (1). An exhaust fan was used to remove the air which has absorbed the moisture from the garbage, from the drying chamber.

Relative humidity and temperature of five different places along the chamber were measured by interfacing Sensirion SHT75 sensors to a PIC16F877A microcontroller. A PC is connected via the serial port to the microcontroller based data acquisition system, in order to record data. The five sensors were connected to a special circuit which is capable of tolerating high temperatures, and the circuit was placed inside the drying chamber.

3.3 Drying the samples

Pressed samples were separated into three apparently equal points and weighed. One portion was dried inside the low humid and high temperature and the other two samples were dried under the sun and in the electrical oven, to compare the drying process. The slab size was maintained as 1 cm for each sample.

After the sample was placed in the drying chamber, and the temperature inside the chamber was increased by switching on the heating elements and low humid air was flushed into the chamber continuously. Weight of the sample was measured in time intervals of 15 minutes, (for 1 or 2 hours). Temperature and relative humidity were recorded in the PC.

4 ANALYSIS

4.1 Drying inside the constructed chamber

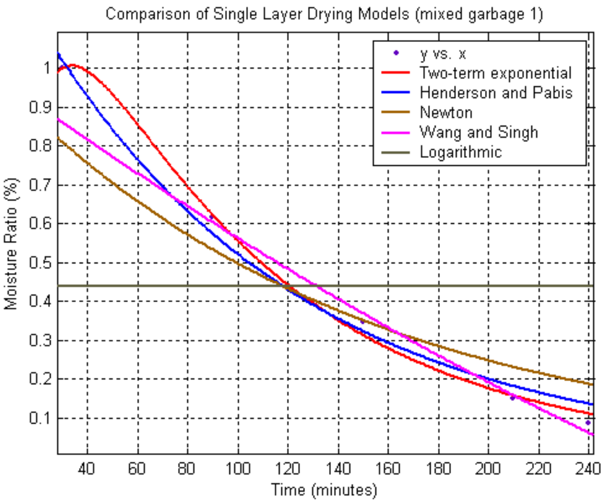

Figure 2 - Five single layer drying models for drying in a drying chamber

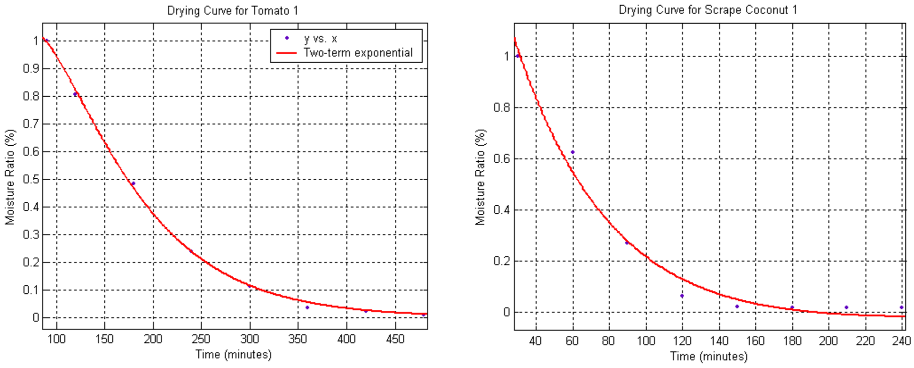

Figure 3 – Drying curves for tomato and scraped coconut drying in a chamber

Of the five single layer drying models applied (figure 2), the two-term exponential model was the most suitable, since it shows the lowest standard deviation and mean squared deviation and highest correlation coefficient for drying inside the drying chamber. The Two-term exponential single drying model was applied for all other constituents and mixed kitchen garbage samples and identified two drying constants k_1 and k_2.

Table 2 Drying constants and moisture diffusion constants for drying in the drying chamber

Sample	k_1 (h^{-1})	k_2 (h^{-1})	D $\times 10^{-9}$ (m^2h^{-1})
Tomato	0.013	0.023	2.026
Rice	0.011	0.098	2.702
Papaw	0.018	0.047	2.871
Scraped Coconut	0.017	0.014	3.715
Cabbage	0.016	0.142	2.702
Dry leaves	0.021	0.026	11.652
Grass	0.080	0.072	9.625
Mixed Kitchen Garbage 1	0.011	0.072	2.026
Mixed Kitchen Garbage 2	0.019	0.062	2.026
Mixed Kitchen Garbage 3	0.066	0.014	2.702

The materials arranged to the ascending order of their diffusion coefficients are as follows. In the case of individual materials the order is consistent with what one would expect naturally.

Tomato < Rice = Cabbage < Papaw < Scraped Coconut < Grass < Dry leaves
Mixed kitchen Garbage 1 = Mixed kitchen Garbage 2 < Mixed kitchen Garbage 3

4.2 Drying under the sun

The average temperature for sun drying was 32^0 C and the average relative humidity was 75 %. Using the same method identified the Henderson and Pabis single drying model as most suitable single layer drying model for drying under the sun. This is expected as sun drying taken longer times can be explained well with single term models. The table 3 represents the calculated diffusion constants.

Table 3 Diffusion Constants for drying under the sun

Sample	D $\times 10^{-9}$ (m^2h^{-1})
Tomato	0.338
Rice	0.675
Papaw	0.675
Scrape Coconut	1.857
Dry leaves	1.520
Grass	1.351
Mixed Kitchen Garbage 1	0.507
Mixed Kitchen Garbage 2	1.013

The materials arranged to the ascending order of their diffusion coefficients for drying under sun are as follows.

Tomato < Rice = Papaw < Grass < Dry leaves < Scraped Coconut
Mixed kitchen Garbage 1 < Mixed kitchen Garbage 2

4.3 Drying inside the electric oven

The temperature used for oven drying was 105^0 C. Using the same method identified the Newton single drying model as most suitable single layer drying model for drying under the sun. The table 4 represents the calculated diffusion constants.

Table 4 Diffusion Constants for oven drying

Sample	$D \times 10^{-9}$ (m^2h^{-1})
Tomato	3.040
Rice	2.720
Papaw	5.066
Scrape Coconut	3.715
Dry leaves	2.533
Grass	3.208
Mixed Kitchen Garbage 1	3.715
Mixed Kitchen Garbage 2	3.208

The materials arranged to the ascending order of their diffusion coefficients for oven drying are as follows.

Dry leaves < Rice < Tomato < Grass < Scraped Coconut < Papaw
Mixed kitchen Garbage 2 < Mixed kitchen Garbage 1

5 DISCUSSION

Inside the drying chamber, when nearly homogenous samples are kept the drying constants k_1 and k_2 become nearly equal for samples such as grass, dry leaves and scraped coconut. For tomato and papaw samples, $k_1 < k_2$. Therefore, it can be said that the whole drying process is a resultant of two different drying processes with k_1 and k_2 drying constants. When papaw and tomato samples are concerned, diffusion from stem, peel and radial arms cannot be expected as high as diffusion through the flesh. Since it can be identified as k_1 is a drying constant for flesh and k_2 is a drying constant for stem and hard peel. Also, the flesh of papaw is highly porous compared to that of tomato, hence D for tomato is lower than that of papaw.

The mixed kitchen garbage 1 and 2 samples had almost equal compositions, consisting of constituents like tomato, banana, rice and dried fish. Therefore the same values for the diffusion constants were identified. But mixed kitchen garbage 3 samples were mostly consisting of, scraped coconut, rice and papaw. This accounts for the higher diffusion constant, when compared to the other mixed kitchen garbage samples.

For the cabbage sample, $k_1 << k_2$. It is clear that the drying constant for the stems should be lower than the drying constant for cabbage leaves. The ultimate result leaves k_2 as the drying constant for the cabbage leaves and k_1 as the drying constant for the stems of cabbage.

When consider the drying under the sun, Tomato gives the lowest diffusion constant among these constituents as same as in the drying in the prototype chamber. Diffusion constants of rice and papaw were equal for the drying under the sun. Also, scraped coconut gives the higher diffusion constant than the grass and the dry leaves. Even though the compositions of mixed garbage 1 and 2 samples were almost equal, the diffusion constants for sun drying were different.

When consider the drying inside the electric oven, the shifting of the drying constants of the dry leaves and the grass can be seen clearly, compared to the results of the drying in the drying chamber and sun drying. The convection currents inside the oven are not at a good level. This must have affected the samples such as dry leaves and grass which have a relatively large surface area. The removed moisture must have not directly removed via the small outlet of the electric oven due to less convection currents. As result of this, a part of the moisture content must have accumulated in a small area around the sample. The surface area of mixed kitchen garbage 2 sample was greater than the mixed kitchen garbage 1 sample. Therefore mixed kitchen garbage 2 gave a lower diffusion constant than the mixed kitchen garbage 1 sample due to above mentioned effect. Rice and scraped coconut samples did not have large surface areas. Therefore the effect of the moisture accumulation in a small region did not affect these two samples. As a result of this, rice and scraped coconut gave equal diffusion constants for drying in the prototype chamber and the electric oven.

Actually sun drying is an uncontrollable and unpredictable drying process because drying conditions fluctuate drastically with time. When clouds cover the sun, the temperature and the relative humidity do not change. But the amount of solar radiation available for the drying process decrease during that time period. As a result of this, the drying process cannot be predictable as a function of time, for sun drying. Finally, it can be concluded that the drying chamber provides the most efficient and effective environment for drying compared to the sun drying or oven drying.

As far as the diffusion constants are concerned, it can be concluded that the sun drying is not suitable for the drying of mixed kitchen garbage. Oven drying method also does not facilitate for efficient drying due to lack of moisture removal method from the air inside the oven. Heated low humid air is allowed to flow at a rate of 12 kmh^{-1}, along the mixed kitchen garbage inside the constructed drying chamber. Dry leaves and grass show higher diffusion constant for drying chamber compared to that of oven.

6 CONCLUSION

When analyzing the drying data, the Two-term exponential single layer drying model was identified as the best model to explain the drying of mixed kitchen garbage, in the drying chamber. The diffusion constants for the samples of tomato, rice , papaw, scraped coconut, cabbage, dry leaves, grass, mixed kitchen garbage 1, mixed kitchen garbage 2 and mixed kitchen garbage 3 were found to be; (2.026, 2.702, 2.871, 3.715, 2.702, 11.652, 9.625, 2.026, 2.026 and 2.702) x 10^{-9} m^{2}h^{-1} respectively. When consider the diffusion constants, the samples of tomato, rice, cabbage and papaw can be separated as the constituents with low diffusion constants and the samples of scraped coconut, dry leaves and grass as the constituents with high diffusion constants. This resembles the real situation as well.

Newton single layer drying model was identified as the best model for drying of mixed kitchen garbage, in the electrical oven. The diffusion constants for the samples of tomato, rice , papaw, scraped coconut, dry leaves, grass, mixed kitchen garbage 1 and mixed kitchen garbage 2 were ;(3.040, 2.720, 5.066, 3.715, 2.533, 3.208, 3.715and 2.208) x10^{-9} m^2h^{-1} respectively. The drying behaviours inside the oven were affected by the low convection currents. Therefore it can be concluded that the surface area of a sample directly affects the drying process.

Henderson-Pabis single layer drying model was identified as the best model for drying of mixed kitchen garbage, under the sun. The diffusion constants for the samples of tomato, rice , papaw, scraped coconut, dry leaves, grass, mixed kitchen garbage 1 and mixed kitchen garbage 2 were ;(0.338, 0.675, 0.675, 1.857, 1.520, 1.351, 0.507 and 1.013) x10^{-9} m^2h^{-1} respectively.

ACKNOWLEDGMENT

Assistance given by the International Science Programs (ISP), Uppsala University, Sweden and National Research Council (NRC) is acknowledged.

REFERENCES

1. A.L.Juhaz, C.Megesan, R.Naidu, *Waste Management.* 2005.
2. H.S.Premachandra, *Household Waste Composting & MSW,* Asia 3R Conference, Tokyo, 2006.
3. E.Akpinar, A.Midilli, and Y.Bicer, *Single layer drying behavior of potato slices in a convective cyclone dryer and mathematical modeling,* Energy conversion and management, 44, 1689-1705, (2003)
4. *Sun or Oven Drying Tomatoes to Storage. Golden Harvest Organics.* [Online] December 1997. http://www.ghorganics.com/Sun%20Dried%20Tomatoes.htm#To%20Sun%20Dry
5. P. C.Panchariya, D.Popovic and A. L. Sharma, *Thin – layer modeling of black tea drying process,* Journal of food engineering, 52, 349-357 (2002).
6. M.H. Nguyen, W. E. Price, *Air-drying of banana: Influence of experimental parameters, slab thickness, banana matuarity and harvesting season,* Journal of food engineering, 79, 200-2007 (2006)
7. R.H. Perry, D.W. Green. *Perry's chemical engineers handbook.* New York : McGraw-Hill, 1998.
8. A. Cihan, K. Kahveci, O. Hacihafizoglu, *Modelling of intermittent drying of thin layer rough rice,* Journal of food engineering, 79(1), 293-298 (2006)
9. D. S. Cordeiro, W. P. Oliveira., *Drying Medical Plants: Equilibrium moisture content and mathematical modelling of "maytenus ilicifolia" leaves,* 2004