World Applied Sciences Journal 23 (11): 1465-1470, 2013
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2013.23.11.535

Analysis Frying Constant of Pineapples Vacuum Frying

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Submitted: Jun 13, 2013; **Accepted:** Jul 22, 2013; **Published:** Jul 25, 2013

Abstract: Vacuum frying is frying process under a vacuum condition to prevent material object deterioration due to excessive heat caused by high temperature. This process is suitable to produce fruit chips. The objective of this research is to determine the frying constant of pineapple chips processing under vacuum condition. A 40mmx20mmx4mm sliced Pineapple were fried under equilibrium pressure at 10 kPa absolute (abs) and a temperature of 85±3°C. In this process, three feeding rate was chosen, which is a feeding of 50%, 75% and 100% of the vacuum fryer capacity. The water removal rate was observed during the process by measuring the condensate volume. Frying constant values (K) for a feeding rate of 50%, 75% and 100% were 0.078; 0.068 and 0.065 (minutes^{-1}) and the regression coefficient of 0.9677; 0.9668 and 0.9749 respectively. From the research done, it can be concluded that i) the frying constant (K) in pineapple vacuum frying could be determine by an exponential decay method. ii) The K value became greater at a smaller feeding rate.

Key words: Fruit chips · Frying constant · Vacuum frying · Water removal rate

INTRODUCTION

Frying is a simultaneous process of heat and mass transfer of water from the frying object, which is using edible oil as a media. Another opinion states that frying is a process of cooking and drying through contact with oil [1]. The purposes of frying is i) to increase the object digestibility, ii) to form the characteristic flavor, color and aroma and iii) to preserve the product, because heats will inactivate the microorganisms enzymes and would lower the water activity [2]. Heat transfer on a frying process is a combination of the heat convection from oil to the frying object and heat conduction within the material of the frying object. Since the entire surface of the frying object receive the same amount of heat, it would produce uniform color. Heat transfer coefficient of frying process reaches 2200 - 2650 W/m^2 K [1].

The temperature of a conventional frying under atmospheric pressure generally is not more than 160-190°C [2], sometimes temperatures could reaches to 205°C. At high temperature, the frying process time is shorter. Usually, after frying, the product would has an 8-25% dry basis (db) oil content. If low temperature is implemented in the atmospheric pressure frying, then the product would have a pale color, less flavor and a higher oil absorption. So, it is recommended that frying a heat sensitive material such as fruits and vegetables should use a low pressure (vacuum) frying and hence under a low temperature frying. Vacuum frying process with a water jet vacuum pump could be done at maximum pressure of 10 kPa abs, temperature 85-90°C, with the frying time of 60-100 minutes [3]. The vacuum frying pressure should be below 6.65 kPa absolute (abs) [4]. The beneficial with these frying condition would reduce the product oil content, maintain the product color and aroma, as well as reduce oil quality degradation. As state by other research, that at 100°C and 0.09 MPa abs. vacuum frying process would consume oil about 0.19 to 0.38 kg/kg db and reach an equilibrium moisture content about: 0.05 to 0.03 kg/kg db [5].

Temperature of the frying process can be lowered (around 85-90°C) by lowering the pressure. The advantage of this process is to minimize product and oil degradation quality.

The frying kinetics analogy equation based on the Newton's law of solid cooling is derived as follows:

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$$\frac{dT}{d\theta} = -K(T - T_{\infty}) \quad (1)$$

where, T = temperature, T = time, T_{∞} = temperature at equilibrium

When the temperature (T) is expressed in dry basis moisture content (M), the equation can be expressed:

$$\frac{dM}{d\theta} = -K(M - T_e) \quad (2)$$

where: M = the moisture content (% db), Me = the equilibrium moisture content (% db) and K = the constant evaporation of water (minutes^{-1}). Another form of the equation above is:

$$\frac{dM}{M - Me} = -Kd\theta \quad (3)$$

The third equation integration with the boundary conditions at initial time θ = 0 and the end period θ =θ is:

$$\frac{M - Me}{Mo - Me} = exp[-K\theta] \quad (4)$$

$$\theta = \frac{1}{K}\ln\frac{Mo - Me}{M - Me} \quad (5)$$

where $\frac{Mo - Me}{M - Me}$ *Moisture Ratio (MR)*

Frying constant (K) is an indicator of performance of the equipment that uses evaporation principles, such as evaporator, roaster and dryer. Research about K in the meantime much concentrated on drying process. However, research report on determining K for vacuum frying has not been found. Based on this condition, this study conducted experiments on vacuum frying of pineapple under the recommended temperature and capacity to analyze the value K, other research states that to produce a chip on a 6kg vacuum fryer capacity a temperature of 85°C is employed [6].

The objective of this research is to determine the rate constant of water evaporation (K) in pineapple vacuum frying processes using exponential decay method.

MATERIALS AND METHODS

The raw material used in this study, is a pineapple with maturity level between 85% and 95% from a pineapple field in Blitar, East Java, Indonesia. After harvested before being processed, the pineapple should be stored in a cooling storage with a 10°C temperature. The aim of this process to minimize any physical properties changes, such us fermentation etc. The first process is peeling and was the pineapple and cut in small sizes with a dimension of 40mm x 20mm and thickness 4 mm. The pineapple slices thickness would be controlled precisely with a thickness gauge. After that, the pineapple slices would be fried with maximum pressure of 10 kPa abs and the temperature 85±3°C. This condition was repeated with a feeding rate variation of 50%, 75% and 100% of the vacuum fryer capacity.

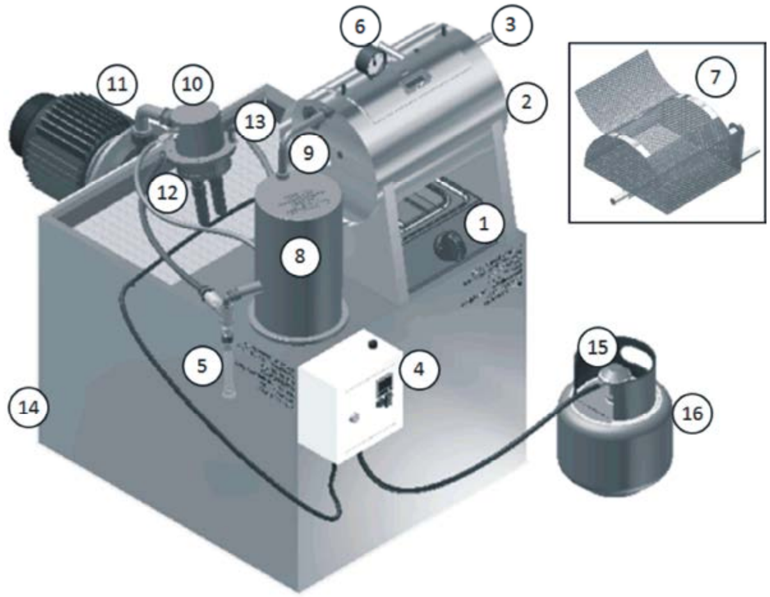
A water jet vacuum fryer with a maximum capacity of 6 kg of input / process was used in this experiment. The schematic and its parts is shown in Figure 1. The vacuum fryer has a diameter 450 mm and length of 800 mm and an evaporation area of 0.45 m x 0.8 m which is equal to 0.36 m^2. The oil volume and weight ratio of the pineapple chips is 7.5:1 to 15:1.

To determine the frying rate, the vacuum fryer is equipped with a condensate reservoir. Condensate water sample was taken from the condensate reservoir with a certain period time interval (Figure 1, Part 5). Changes in moisture content are determined by the initial moisture content and the amount of evaporated water according to the mass balance based on the evaporation process.

This research was done at Lastrindo Engineering Laboratory, Jl. Rajekwesi No.11, Malang, Indonesia. To determine the frying constant, the experiments was conducted at the recommended temperatures in the previous study [8]. The sum of raw material feeding was done at three levels: 50%, 75% and 100% of the recommended scale (Full capacity 6 kg / processes).

The frying constant determination in the vacuum frying process uses the analogous method by other research [9], the steps to determine frying constants are as follows:

- Measure the sample at any given time without disturbing the process.
- Transforming the weight data to the moisture content (% dry basis).
- Determinate equilibrium moisture content M_e Based on the frying conditions temperature.
- Calculate the level Moisture Ratio (MR) of free water, which is the ratio of free moisture content at time t to the free moisture content at the time to *0* as $\frac{Mo - Me}{M - Me}$
- Plot the data on a semi-log curve based on the equation of *exponential decay* and then determine the K based on the curve slope.



1.Burner
2.Frying Chamber
3.Mixing Handle
4.Thermo Controller
5.Condensate reservoir
6.Pressure Gauge
7.Basket (inside frying chamber)
8.Condensor
9.Suction Pipe
10.Water Jet
11.Circulation Pump
12.Cooling Water Pipe (Water in)
13.Cooling Water Pipe (Water out)
14.Chasis
15.LPG/ Gas Regulator
16.LPG

Fig. 1: Perspective and Schematic diagram of Vacuum fryer [7]

RESULTS AND DISCUSSION

The determination of the frying constant during the pineapple vacuum frying process with an exponential decay method has been applied to various feeding rate (capacity). A fresh pineapple has a moisture content of 83.87% wb (wet basis) which equal to 520% db. After of frying process completion, the pineapple chips product has moisture content of 4.76% wb equal to 4.99 % db equilibrium. Based on measurement, the ratio between the yield and raw material (feeding) is 18.98%. According to mass balance (based on 1 kg raw material), the output consist of 0.1613 kg solid and 0.0080kg water, so total output is 0.1693kg. Therefore, it means the difference between measurement and calculation (0.1898-0.1693=0.0205) considered as oil content as stated by Song *et al*. [8].

The vacuum frying performance test was conducted at maximum capacity of 6 kg/ process, under a temperature of 85±3°C and maximum pressure 10 kPa abs. The total volume of the frying chamber and cooking oil volume are 115 liters and 45 liters respectively. The results of the experiment are as follows.

Changes of Pressure and Moisture Content: During the vacuum frying process, the pressure inside the frying chamber decreases. The pattern of the pressure drop follows an exponential model (Figure 2), where the smaller amount of feeding the faster the pressure decreased.

The time required to reach 90% pressure difference, caused by a vacuum pump (in this case, 10 kPa abs) was 15 minutes, this is the critical period. This period can be used to indicate of humidity conditions in the frying chamber. The humidity situation inside the vacuum fryer could be seen on a small window glass on top of the vacuum fryer chamber, which will show a fog situation on the glass if the moisture is still high and would shows a clear view if moisture is reduced significantly. This phenomenon still needs to be studied more deeply, especially about the relationship between humidity and moisture content of materials along the frying process.

In the following period, the pressure did not drop fast, because the water present in the material was stronger bounded water, this phenomenon occurs because of free moisture content (Mo-Me) diminished. From equation (4), so the time to reduce moisture content

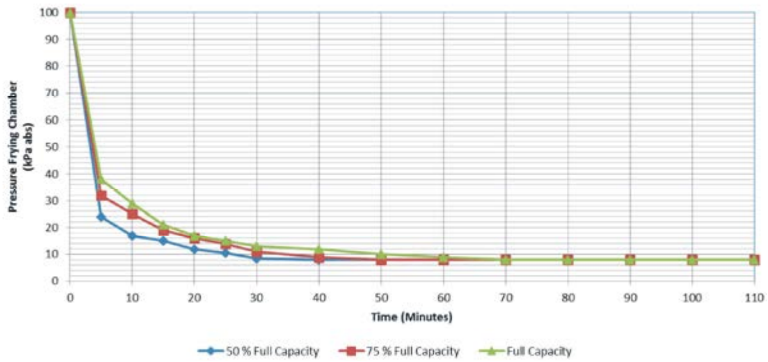


Fig. 2: Pattern of Pressure Changes In Vacuum Frying

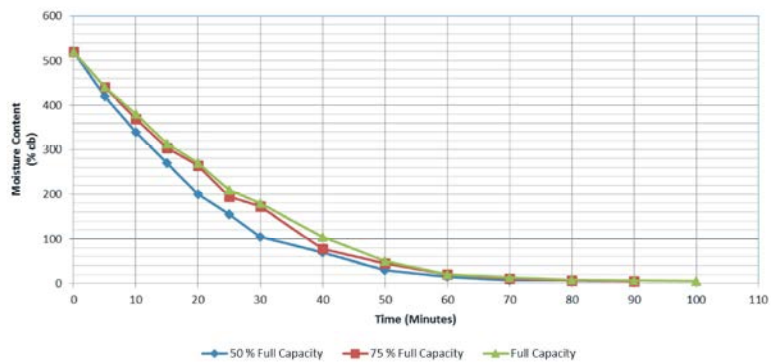


Fig. 3: Pattern Changes in Water Levels During Vacuum Frying

will longer. The evaporation process takes place under this conditions far above to the boiling point of pure water. This period is characterized by the oil temperature has reached the set point. Therefore evaporation process take place at constant temperature, so vacuum pump have an important role, in order to moisture transport faster.

On nearly the end of the frying process, the rate of evaporation reaches an equilibrium point compare with the rate of vacuum pump moister evacuation. On this situation the water content in the product object would very difficult to be evaporate. The evaporation process is controlled by different partial pressure of water in the product and on the oil surface. The success of this process depends on the strength of the vacuum pump, especially power and vacuum pumps type used, because high vacuum improves the rate of the moisture evaporation [10]. The pressure change pattern is an indicator of the vacuum frying parameters, such as the rate of evaporation, water content decrease and the frying constant. The following figure (Figure 3) shows similarity of water level changes during vacuum frying process.

Evaporation Rate: The evaporation rate in a vacuum frying is defined as the amount of water evaporated (kg), time (hours) and the heat transfer area (m^2). In other word, the evaporation rate states in unit: kg H_2O/ (kg db.h.m^2). The surface area of evaporation is the oil surface area in the frying chamber, which is multiplying the frying chamber diameter (0.45 m) by the length of the frying chamber (0.8 m). With this evaporation rate, found from this research, it is expected that this evaporation rate would be used as reference in evaluating a vacuum fryer performance, regardless the dimensions of the vacuum fryer machine.

Figures 4 and 5 show the evaporation rate pattern in pineapple vacuum frying. Figure 4 shows the evaporation rate based on dry basis (% db). Figure 5 shows the evaporation rate based on time. From on figures 4 and 5 it can be stated that the smaller the feeding number, the higher the evaporation rate. This was probably caused by the heat and vacuum supply that exceeds the recommended capacity (6 kg/process). The maximum rate was achieved at the beginning of the process of 33.3 kg H_2O/ (kgdb.h.m2). This value was quite large, because the convection coefficient of boiling water is large enough [1].

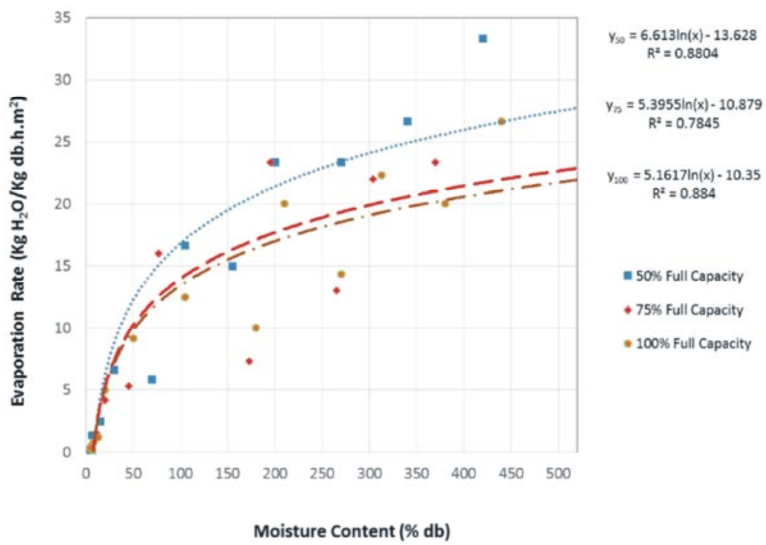


Fig. 4: Evaporation Rate in Pineapple Vacuum Frying Based Moisture Content % db.

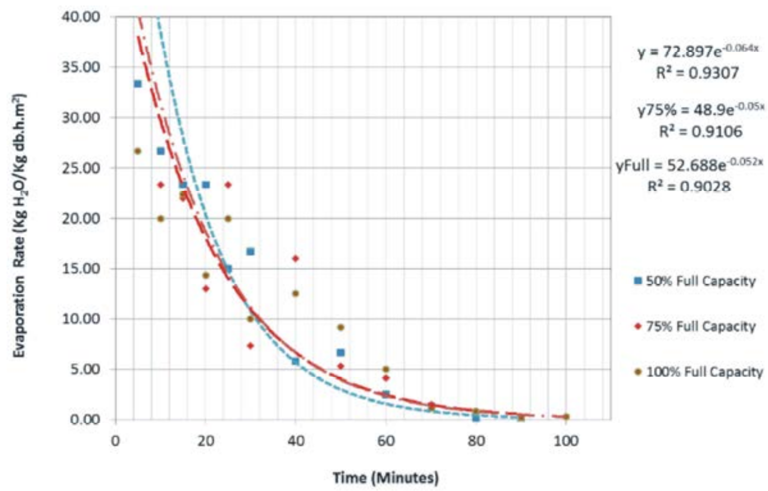


Fig. 5: Evaporation Rate in Pineapple Vacuum Frying Based on Time

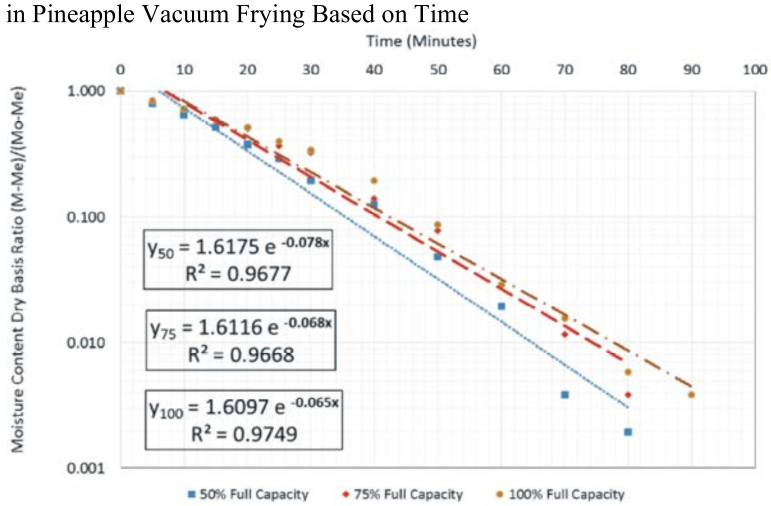


Fig. 6: The graph of Frying constant determination in Pineapple Vacuum Frying with feeding rate at 50%, 75%, 100% full capacity (6 kg/ process)

Frying Constant: Based on the evaporation rate equation derived from Newton's law of solids cooling it was obtained an exponential model (equation 4). By linearized this equation and then plot into semi-log graph for each treatment, then the values of frying constants and coefficients of determination on pineapple vacuum frying could be seen in Figure 6.

According to Figure 6, the K value became greater at smaller feeding recommended capacity. This means that the smaller the feeding rate the higher the evaporation rate in a frying process.

CONCLUSION

To determine the frying constant (K) in pineapple vacuum frying by implementing exponential decay methods on a variety of feeding, it is require changes in moisture content data and time. Moisture content during vacuum frying is determined based on condensate data. Furthermore, the value of K could be determined by using the equation 4. The estimates of the model parameters (50%, 75%, 100% Full Capacity) are presented in Figure 6. The model provided very good fits for all the conditions tested (R^2 between 0.967 and 0.975).

Based on the research result this it can be conclude that i) the method of exponential decay could be used to determine the frying constant in pineapple vacuum frying. ii) The K value would be larger at smaller feeding recommended capacity.

ACKNOWLEDGEMENTS

The implementation of this research is inseparable from the role of Supervisors and the Indonesian government which provides scholarships of BPPS in the period of 2008 to 2011, during my study in the Doctoral Program of Mechanical Engineering (PDTM) Faculty of Engineering, University of Brawijaya.

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