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# Development of a Permeability Model for Palm Fruit Cake

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**Abstract:** Investigation was carried out on the effect of processing conditions such as temperature, pressure and porosity on permeability of palm fruit cake. It was observed that increasing the temperature of the crude palm oil from 30 to 75°C, pressure from 2.88 to 3.82 kPa and porosity from 9.2 to 27.3% increases the permeability of the palm fruit cake. The statistical analysis of the effects of the processing factors on permeability indicates that temperature and porosity are significant at 99.99% while pressure was significant at 95%. A permeability model applicable to the practical palm oil expression was also developed in the study.

**Key words:** Palm fruit cake, permeability, modeling, processing conditions

## INTRODUCTION

Permeability is defined that property of a porous material which characterizes the ease with which a fluid may be made to flow through the material by an applied pressure gradient. The equation, which gives permeability in terms of measurable quantities, is the Darcy's equation, given as (Mohsenin, 1978):

$$k = \frac{q\mu}{A\left(\Delta P / L\right)} \quad (1)$$

where:

- k is the permeability in m/s ;
- q is the flow rate in $m^3/s$;
- μ is the fluid viscosity in $kg\ m^{-1}s^{-1}$ ;
- ΔP is the pressure difference across the length of the pack in$N/m^2$ ;
- L is the length of presses pack in the direction of flow in m; and
- A is the cross-sectional area of flow in $m^2$

The unit of permeability in length squared indicates that it is a measure of mean square per diameter in the material. Mohsenni (1978) reported that in an anisotropic media, permeability has a directional quality and varies when measured with flow perpendicular to each face of a cube of the porous material. Permeability also varies with compaction and structural changes of the material due to mechanical forces.

Permeability is measured by establishing a steady state flow through a sample of the material in a flow apparatus (perm eater). Attempts have been made to predict permeability for various porous media in order to improve on the several experimental materials which have varied from rather straight forward measurements to more sophisticated approaches e.g., mercury porosimetry, electrical conductivity, nuclear magnetic resonance and acoustic properties of the medium (Koponen *et al*., 1996). Koponen *et al.* (1996) stated further that theoretical work often involves models with simplified pure geometries, which allows an analytical solution of the microscopic flow patterns. Also more sophisticated models based on statistical methods have been used.

In theoretical and experimental research on fluid flow in porous media, it is typically attempted to find functional correlations between the permeability and some other macroscopic properties of the porous medium. Among the most important of such properties are the porosity (ϵ) are the specific surface area (s) and for tortuosity (τ). Tortuosity has been introduced to account for the complexity of the actual microscopic flow paths through the substance. Tortuosity is defined as the ratio of an average length of microscopic flow paths to the length of the system in the direction of the macroscopic flux (Koponen *et al*., 1996, 1997).

In simulation experiment models of porous media are usually constructed by placing solid substances in a two-or three-dimensional test volume with the properties of the medium determined by the shape, size and the number of obstacles as well as the distribution of the obstacles within the volume. However, the application of these models validated by mere simulation experiments to permeability models becomes cumbersome owing to the difficulty in measuring some parameters in the model particularly the specific surface area Kamst *et al.* (1997)

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also reported that there is no general model for permeability of particulate beds as none of these models could describe the experiments adequately. Empirical models are thus preferred. Barneds (1994) suggested the following equations:

$$k = k_o e^{d(\epsilon - \epsilon o)} \quad (2)$$

where:

$k_o$ = Permeability at porosity $\epsilon_o$

d = Empirical parameter

Kamst *et al.* (1997) investigated the permeability of palm oil filter cake at room temperature and reported that the specific cake resistance (a function of permeability) is not a function of the porosity alone. The specific cake resistance was found to increase faster during the experiment than would be expected from the results of different experiments. This is because there was decreasing flow at a barely increasing volume of function of solids. Kamst *et al.* (1997) reported further that the increasing resistance may probably be caused by migration of the fines (fine particles of the cake), towards the filter or the blocking of the filter catch by fines as a result of longer duration of permeability measurement than the duration of normal expression experiment. The researchers (Kamst *et al.*, 1997) therefore concluded that it may therefore be advisable to shorten permeability measurement time and to include other factors that affect permeability. In their own study the temperature of the fluid was fixed at room temperature. However palm oil expression takes place at a temperature well above room temperature, as it is necessary to reduce the viscosity of the crude palm oil to enable oil flow easily. Therefore the permeability model obtained with such experiment may not represent the true practical situation.

This study investigates the permeability of crude palm oil by taking into consideration the influence of temperature among other factors in order to obtain the appropriate equation applicable to expression models.

## MATERIALS AND METHODS

**Material:** The materials used for the experiment include palm fruit cake and crude palm oil obtained form the Nigerian Institute for Oil Palm Research Benin City, Nigeria. The equipment consist of a falling head permeameter available in the Department of Agricultural Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria (Fig. 1).

**Methodology:** The determination of permeability of palm fruit cake involves the determination the properties of the

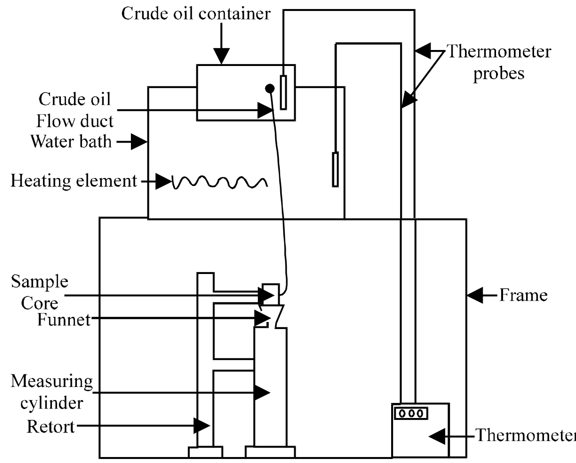


Fig. 1: Falling head permeameter

palm fruit cake such as average mass, bulk density and true density and then determining the permeability of the material using a permeameter.

**Determination of the properties of the palm fruit cake:** The determination of the properties of the palm fruit cake was carried out using the method adopted by Maduako and Faborode (1990). In determining the average mass of the palm fruit cake, a cone to be used for determining the permeability was filled randomly with the palm fruit cake and weighed on a weighing scale. The difference between the weight of the cone and the sample and that of the cone gives the weight of the cake as given by the equation below:

$$W_p = W_b - W_c \quad (3)$$

where:

$W_b$ is the weight of core + sample;

$W_c$ is the weight of the core only ; and

$W_p$ is the weight of the palm fruit cake.

This was replicated twenty times.

The bulk density of the cake was determined by determining the volume of the cone used above. The weight of the sample was divided by the volume of the core to give the bulk density of the material. i.e.,

$$\rho_b = \frac{W_p}{V_p} \quad (4)$$

Where,

$V_p$ is the volume of the palm fruit material (volume of the core) in $m^3$;

$W_p$ is the weight of the palm fruit material in kg; and

$\rho_b$ is the bulk density of the palm fruit material.

The experiment was also replicated twenty times.

To determination true density of the palm fruit cake, each of the samples of the palm fruit material was wrapped in water tight cellophane and lowered (using a sinker) into a measuring cylinder containing water of known volume. The final volume of water was recorded. The ratio of the mass of the sample as given above and the displaced volume gives the true density of the material as given below:

$$\rho_t = \frac{W_p}{V_D} \quad (5)$$

Where:
$\rho_t$ is the true density of the material palm fruit cake;
$W_p$ is the weight of the palm fruit cake; and
$V_D$ = Volume of water displaced by the palm fruit cake.
The experiment was replicated twenty times.

The porosity of the material was determined using the bulk density and true density obtained I above as:

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad (6)$$

where:
$\rho_t$ and $\rho_b$ are as defined earlier above and $\varepsilon$ is the porosity of the material.
This was also replicated twenty times.

**Permeability:** The 5cm core was filled with about 15.6g of palm fruit cake (as determined above) and set up in a variable-head permeameter (Fig. 1) as adopted by Osunbitan and Adekalu (2001). The crude palm oil was allowed to flow freely though the attached pipe into the cake column. The volume of the filterate after a certain period of time was recorded. Darcy's law for flow in porous media holds and is applied to determine the permeability.

$$Q = \frac{AkH_l}{L} \quad (7)$$

where,
Q is rate of flow of the crude oil through the medium in $m^3/s$;
V is the volume of filterate in $m^3$;
A is the = cross-sectional area of the medium in $m^2$;
k is the permeability in m/s;
$H_L$ is the pressure head of the crude palm oil; and
L is the length of the core

A $3^3$ factorial experimental design (Table 1) was used for the study.

Table 1: $3^3$ factorial experimental design for the permeability experiment

| Factor | Level | | |
|---|---|---|---|
| Temperature (°C) | 30.00 | 50.00 | 75.00 |
| Pressure ( kPa) | 2.88 | 3.35 | 3.82 |
| Porosity (%) | 9.2 | 19.20 | 27.30 |

The three levels of the pressure head was obtained by raising the overhead reservoir of crude oil by 50 mm (5 cm) interval. The crude oil is heated to the required temperature using a water bath which carries the overhead crude palm oil reservoir. A digital thermometer equipped with six terminals or probes was used to confirm the temperature. The porosity of the medium was varied by using a piston to compact the initial height of the cake (50 mm) to heights of 45 and 40 mm to give porosities of 27.3, 19.2 and 9.2%, respectively. The experiment was replicated twice.

The permeability graphs were obtained using Microcal origin 60 computer package.

## RESULTS AND DISCUSSION

**True density, bulk density and porosity of palm fruits cake:** The average mass of the palm fruitcake was found to be 15.63 g. The minimum and maximum true densities were 211.70 and 392.80 kg $m^{-3}$, respectively. The average true density was also found to be 296.27 kg $m^{-3}$. The maximum and minimum bulk densities were 337.20 and 49.30 kg $m^{-3}$ while the average bulk density was 215.30 kg $m^{-3}$. The minimum, maximum and average porosities were observed to be 10.46, 46.28 and 27.35%, respectively. The average values of these parameters of (true density, bulk density and porosity) were used in the permeability experiment.

Figure 2-4 shows the effect of temperature, porosity and pressure on the permeability of plam fruit cake for $3^3$ factorial experiment conducted

**Permeability of palm fruit cake:** From Fig. 2-4 it could be observed that permeability of the palm fruit cake increases by increasing the temperature of the crude palm oil from 30 to 75°C. This increase in the permeability could be attributed to the reduction of viscosity of the crude palm oil as a result of increase in temperature. Reduction of fluid viscosity normally increases the velocity of flow.

Also the permeability of the palm fruit cake reduces with reduction in porosity. This result may be explained in terms of induced restriction to flow due to reduction in pore spaces caused by decrease in porosity. Similar results were observed by Osunbitan and Adekalu (2001) in permeability of soil. Furthermore, permeability increases generally with increase in pressure.

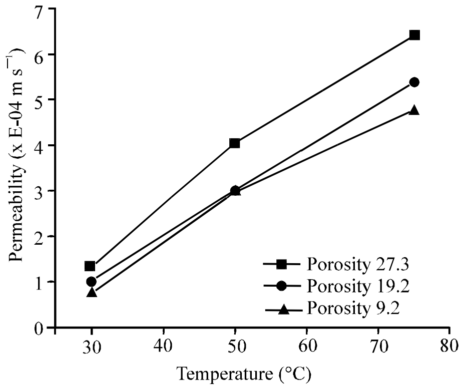


Fig. 2: Effect of temperature and porosity on permeability at pressure 3.82 kPa

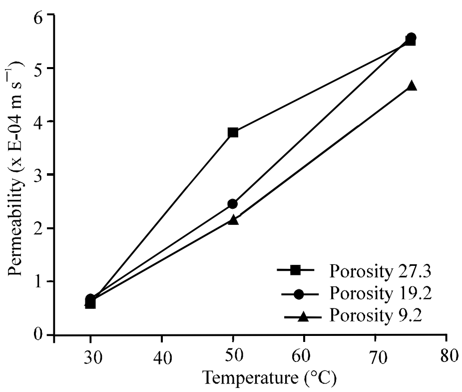


Fig. 3: Effect of temperature and porosity on permeability at pressure 3.35 kPa

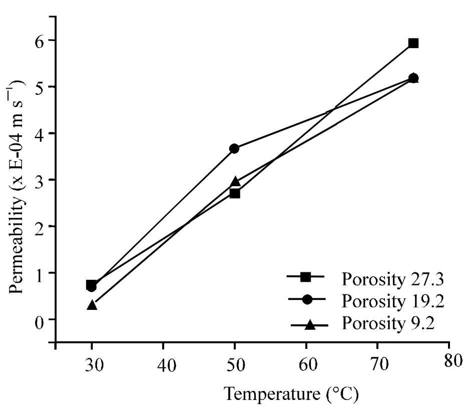


Fig. 3: Effect of temperature and porosity on permeability at pressure 2.88 kPa

Increase in pressure increases the velocity of flow which enables more fluid to be filtered at a faster rate through the medium.

From this Table 2, it could be observed that temperature has a higher effect followed by porosity and pressure. The effect of temperature and pressure were found to be significant as 99.99% while that of pressure was significant as 95%.

Table 2: Statistical analysis of the effect of processing conditions on permeability of palm fruit cake

| Variable | DF | Estimate | Error | t-value | Pr > 1t1 |
|---|---|---|---|---|---|
| Intercept | 1 | -3.74243 | 0.65711 | -5.70 | <.0001 |
| Temp | 1 | 0.09155 | 0.00333 | 27.52 | <.0001 |
| Porosity | 1 | 0.04261 | 0.00914 | 4.66 | <.0001 |
| Pressure | 1 | 0.00037274 | 0.00019470 | 1.91 | 0.0613 |

The regression analysis carried out using the statistical package (SAS, 1987) indicates that permeability and the processing factors can be represented by:

$$k = 3.67 \times 10^{-6} T + 9.84 \times 10^{-6} \epsilon + 1.29 \times 10^{-8} P \quad (8)$$

where:

k is the permeability in m/s
T is the temperature in °C
$\epsilon$ is the porosity
P is the pressure

The implication of these results is that palm fruit mash must be at high temperature for oil to flow easily out of the interkernel voids while the porosity should also allow this.

## CONCLUSIONS

Most of the theoretical permeability models have been found not to represent truly the practical situation owing the varying properties of the materials. Empirical models are thus still preferred. The empirical model developed in this study considered the effect of temperature among other factors and it was shown to be very significant when compared with other factors. With this result it is expected that the model will be more useful in palm oil expression model.

## NOTATIONS

A Cross-sectional area, $m^2$
d En empirical parameter
k Permeability, m/s
HL Pressure head of crude palm oil, m
L Length of presses or core, m
P Pressure, kPa
$\Delta P$ Pressure difference
Q, q Flow rate, $m^3/s$
T Temperature, °C
W Weight of material, kg
$W_b$ Weight of core and sample, kg
$W_c$ Weight of core alone, kg

$W_p$ Weight of palm fruit cake, kg
$V_p$ Volume of palm fruit cake, $m^3$
$V_D$ Volume of water displaced
$\rho$ Density, kg $m^{-3}$
$\rho_b$ Bulk density, kg $m^{-3}$
$\rho_t$ True density, kg $m^{-3}$
$\mu$ Fluid viscosity, kg $m^{-1}$ $s^{-1}$
$\varepsilon$ Porosity, %

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