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PRELIMINARY STUDIES ON THE BAKING OF 'CHAPATTIES'*

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ABSTRACT

Assuming that the degree of baking is determined by percentage loss of moisture content, and that conduction of heat is the predominant factor in the baking of 'Chapatties', an equation has been derived on the basis of a few simplifying assumptions, expressing the percentage moisture loss as a function of baking time and thickness of chapatties. The limitations of the equation have been discussed in the light of some preliminary observations taken under laboratory conditions, and the equation has been modified accordingly, in order to represent the experimental data with reasonable accuracy.

Introduction

The physical process of drying of food materials has, for a long time, attracted the attention of food scientists, and a considerable amount of valuable work has been carried out in this field (1,2). The baking process, apart from associated chemical changes, may be considered essentially as a physical process of drying at a high temperature. In fact, the degree of baking of chapatties has been found to be determined by the percentage loss of total moisture during baking. The moisture loss in this case is mainly influenced by conduction of heat, and to a certain extent, by diffusion of moisture. From the practical stand point, it was considered useful to collect some preliminary data which would enable us in a rough way to express the moisture loss as a function of the baking time and the thickness of chapatties. The present piece of work was undertaken with this end in view.

THEORETICAL CONSIDERATIONS

If T be the baking time for each chapatti of a given cross-section and thickness L, it can be assumed for the practical range of thickness, that $T \propto L^n$ .... (i), where n is a positive number to be determined. Again, if N be the number of chapatties in a given weight, then $N \propto \frac{1}{L}$ ....(ii) Hence the total baking time NT for given weight of chapatties will be given as

$$N\,T \propto L^{n-1} \quad \text{.......................(iii)}$$

Now if $n = 1$, NT will be independent of the thickness. Where as if $n > 1$, NT will increase with increasing thickness, and if $n < 1$, Nt will decrease with increasing thickness of chapatties.

In order to get an idea of the magnitude of the number n, it may be useful to consider a very simple problem from the theory of linear heat flow in a semi-infinite solid medium (3). If the boundary $x = 0$ is kept at a constant temperature V, and the initial temperature is zero, then v, the temperature as function of x and time t, will be

* Chapatti is a sort of pan-cake made out of dough prepared from wheat flour of about 98 per cent. extraction.

given by $\frac{v}{V} = erfc \frac{x}{2\sqrt{kt}}$ ....(iv) where k is the thermal diffusivity of the medium. Now if we assume v to be the temperature above which water cannot, under the practical conditions, exist except in the vapour form, and if the temperature of the heater plate is kept constant, then the ratio $\frac{v}{V}$ becomes constant, and in that case, we have,

$$x = a\sqrt{t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(v)$$

where x is the distance penetrated by the temperature v in time t, and 'a' is a constant depending on the thermal diffusivity of the material and the ratio v/V. In other words, x is the thickness of the layer from which moisture has been eliminated in time t. It has to be noted in this connection, that in the practical case of baking, some heat is lost as latent heat of vaporisation of moisture. The equation (v) is, however, not affected thereby. The loss of heat can be taken care of by increasing the value of v in equation (iv) by the requisite amount.

If m be the initial moisture content per unit volume, α the cross-section, then moisture loss M upto time t will be given by $M = m\,\alpha\, x = m\,\alpha\, a\sqrt{t}$. For a chapatti of thickness L, the initial moisture content $W_0 = m\alpha L$ or $m = \frac{W_0}{\alpha L}$, so that we have finally

$$\frac{M}{W_0} = a\sqrt{\frac{t}{L^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(vi).$$

Thus the percentage moisture loss in time t should vary directly as the square root of 't' and inversely as the thickness L.

For properly baked chappaties, M^1W_0 should be a constant, and if T be the baking time, we have,

$$T \propto L^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(vii).$$

From the simple consideration outlined above, we have, comparing (i) and (vii), n = 2. It follows from relation (iii) that the total baking time NT should be proportional to L, the thickness. If that be the case, thinner chapatties should be more economic than thicker ones, so far as total baking time and fuel are concerned.

The above picture is, however, oversimplified. The actual state of affairs is complicated by several factors, the most important being,—

(1) Chapatties are of finite thickness.

(2) There will be diffusion of moisture due to concentration gradient set up in the baking process, and the distribution of concentration along the thickness, will also vary with time.

(3) The lower surface of the chapatti in contact with the heater plate cannot be considered to be at the same temperature as the heating surface. Its temperature will vary with the pressure of contact, which in turn will depend on the weight of the chapatti and hence on its thickness.

(4) The lower surface of the chapatti does not attain its maximum temperature instantaneously.

A detailed discussion of all these factors, though important from the theoretical point of view, is beyond the scope of the present paper, its main purpose being to find a suitable working formula, reasonably accurate for most practical purposes. So far as the diffusion of moisture is concerned, its contribution under the practical conditions of baking, may be considered to be relatively far less important than that of heat conduction.

Experimental

For experimental purposes, the situation was simplified as follows. The dough was prepared by adding the requisite amount of water to a known weight of atta. Chapatties of the same average diameter and thickness were prepared by rolling equal weights of the dough. For heating, an electric heater was used in conjunction with a variable transformer, the top of the heater being a steel plate. The temperature of the plate could be adjusted by varying the transformer voltage, and temperatures were measured with an ordinary copper-constantan thermo couple, standardised in the laboratory.

The chapatti was kept on the heater plate for a known interval of time and was then quickly transferred to the left-hand pan of an ordinary balance (sensitivity 0·01 gm), the right-hand pan being balanced with a known weight, such that the pointer was deflected considerably to the right. The position of the pointer was noted with time. The graph of the deflection against time was practically expotential, so that it was possible to extrapolate the weight of the chapatti at the instant of its removal from the heater plate. The experiment was repeated with different chapatties of the same dimensions for different durations of heating. Similar series of observations were taken on chapatties of different thicknesses.

Observations

Total moisture content of the dough including moisture content of dry atta, when correctly prepared, was found to be a practically constant fraction of the total weight of the dough. For example, observations were taken in the month of June, when moisture content of dry atta was found to be 8·1 per cent. on the average. One pound of this atta required nearly 295 c.c. of water for the preparation of the dough. The total moisture content, on calculation, came out to be about 44 per cent. of the weight of dough. Similar observations were repeated during the latter part of the month of July, when the average moisture content of dry atta was 12·0 per cent. In this case, about 255 c.c. of water was required per pound of dry atta. This also yields a value of about 44 per cent. for the moisture content of the dough.

The temperature of the heater-plate was adjusted to about 140°C, by keeping the heater voltage fixed at 118 volts. It was found that above about 160°C charring of the atta takes place rather quickly, thereby affecting the accuracy of observations. For normal baking also, observations show that no useful result is derived by raising the temperature of the heating-surface much above 160°C, because in that case, the surface of the chapatti is charred much before the whole mass is baked properly.

Average diameter being maintained at 4″, the thickness of unbaked chapatties was found to be 1 mm. per 10 gms. of the dough. three different thicknesses were used, namely, 0.2 cm, 0.4 cm, and 0·8 cm, which required for each chapatti, 20 gms, 40 gms and 80 gms of the dough respectively.

The observations are given in table I in which the following symbols have been used.

W_0 = initial moisture content of each unbaked chapatti, including that of atta, in gms.

M = loss of moisture in gms.

t = time of heating in minutes.

L = thickness of unbaked chapatti, in cms.

TABLE I

L cms	W_0 gms	t minutes	M gms
0·2	8·8	0·25	0·48
		1·00	1·49
		3·00	2·94
		8·00	4·62
		12·00	5·72
0·4	17·6	0·50	0·42
		2·00	1·57
		4·00	2·63
		12·00	6·62
		18·00	8·85
		32·00	12·20
		40·00	13·20
0·8	35·2	1·00	0·55
		4·00	2·20
		8·00	3·60
		16·00	7·19
		32·00	12·45
		90·00	22·38
		130·0	27·70

Discussions

In order to test the validity of equation (vi), M/W_0 was plotted against $\sqrt{\frac{t}{L^2}}$ as shown in Fig. 1. Points for the same thickness are found to be almost on a straight line, except near the origin. But we get three distinct lines for the three thicknesses, with slopes increasing with increasing thickness. Plotting M/W_o against $\sqrt{\frac{t}{L}}$ reverses this order as is evident from Fig. 2. This shows that L under the root sign should have an index between 2 and 1 in order that all the points may fall on a single curve. As a trial, therefore, M/W_0 was plotted against $\sqrt{\frac{t}{L^{3/2}}}$ and the result is shown in Fig. 3

Within the range of experimental errors, all the points may be reasonably supposed to be on a straight line, bending near the origin, since the origin must be a point on the curve.

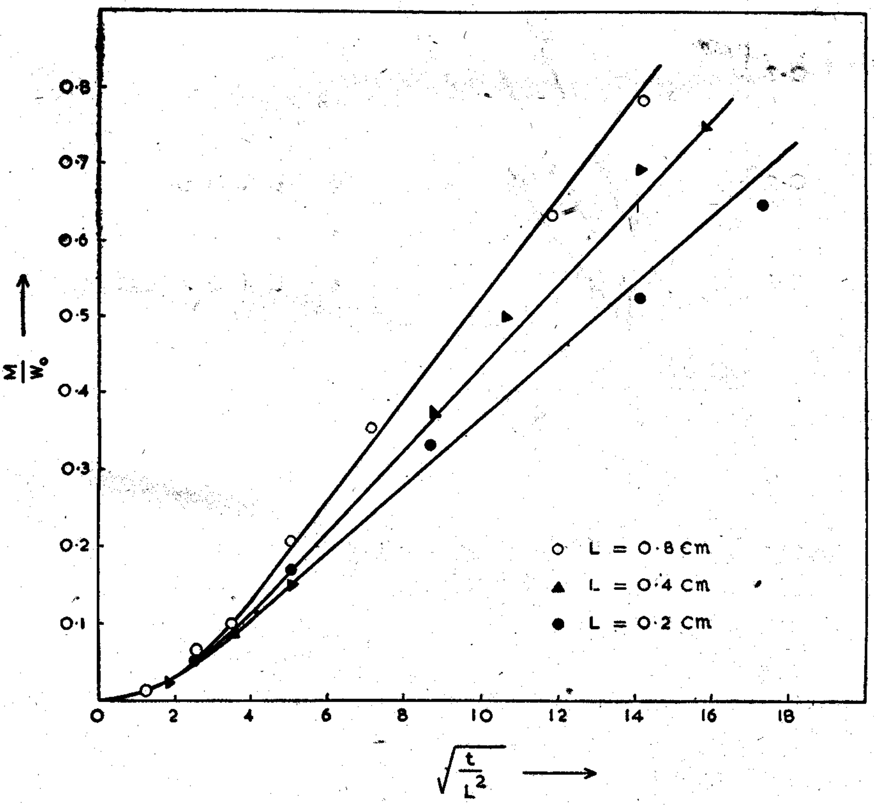

Fig. 1.—Relation between fractional moisture loss, time of heating and the thickness.

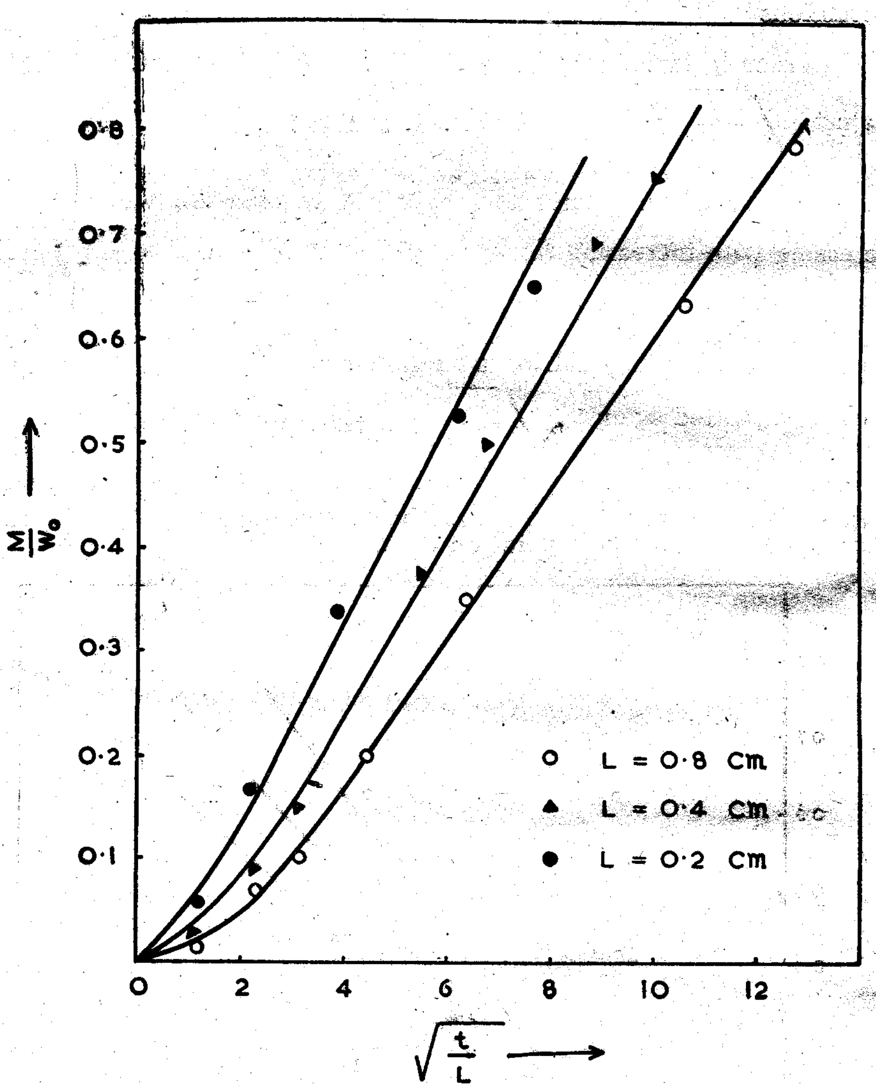

FIG 2.—Relation between fractional moisture loss, time of heating and the thickness.

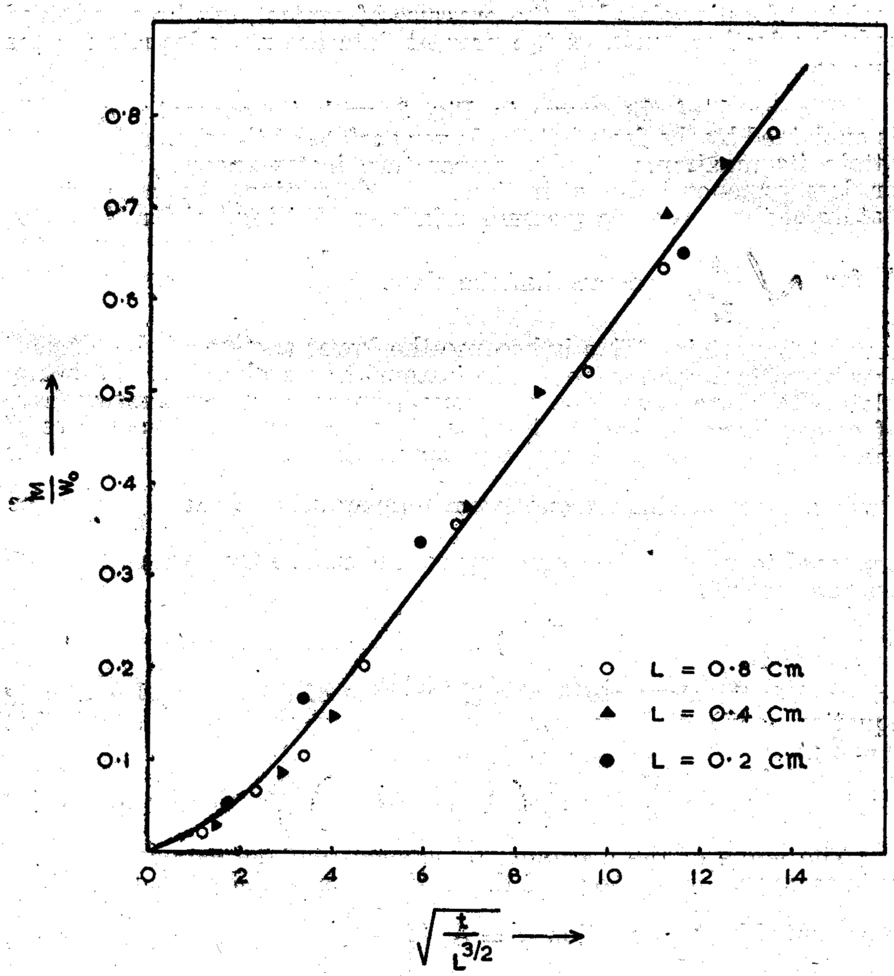

FIG 3.—Relation between fractional moisture loss, time of heating and the thickness.

Thus from the experimental observations, we are led to the conclusion that the percentage loss of moisture content is a function of $\sqrt{\frac{t}{L^{3/2}}}$ and not of $\sqrt{\frac{t}{L^2}}$ as could be expected from equation (vi) which was derived on the basis of a few simplifying assumptions. This discrepancy between the theoretical and observed results may be partly attributed to the fact that, in deriving equation (vi), the variability of the pressure of contract between the chapatti and the heater plate was not taken into account, whereas in actual practice, the pressure of contact should be proportional to the weight of chapatti, and hence to its thickness. The precise way in which the moisture loss is related to the pressure of contact, can be ascertained only by further work, as the present data are not adequate for the purpose.

The bend of the curve in Fig. 3, with its concavity upwards, is explained by the fact that the lower surface of the chapatti does not attain its maximum steady temperature instantaneously, but more or less exponentially with time. To determine the approximate nature of the curve, we proceed as follows. Writing 'y' for M/W_0 and θ for $\sqrt{\frac{t}{L^{3/2}}}$ we see that the slope $\frac{dy}{d\theta}$ of the curve must be zero at the origin. This is because the lower surface of the chapatti was at room temperature at the instant it was placed on the heater plate. Moisture losses due to evaporation at room temperature have of course, been ignored. The slope increases as the temperature of the lower surface increases, and approaches a steady value as the lower surface attains its maximum temperature. Thus $\frac{dy}{d\theta}$ may be supposed to vary in the same way as the surface temperature, so that we can assume,

$$\frac{dy}{d\theta} = A\left(1 - e^{-p\theta}\right) \qquad \text{(viii)}$$

where A is the slope of the straight portion of the curve. Integrating equation (viii) with respect to θ, with the initial condition that $y = o$ at $\theta = o$, we finally obtain,

$$y = A\left[\theta - 1/p\left(1 - e^{-p\theta}\right)\right] \qquad \text{(ix)}$$

The value of the constant 'p' is such that the exponential term quickly approaches zero; and the straight portion of the curve is then represented by the equation $y = A\left(\theta - \frac{1}{p}\right)$.....(x). The constants A and p were determined from the mean straight line drawn through the experimental points, the numerical values obtained being $A = 0{\cdot}0682$ and $p = 0{\cdot}62$. With these values of A and p, the graph of equation (ix) was drawn, and is shown by the smooth curve in Fig. 3.

The fitting is tolerably good, with due consideration of the inaccuracy inherent in the nature of the experiment, especially in rolling with hands, and in the method of weighing.

The percentage loss of total moisture content can be assumed to be a constant for properly baked chapatties, in which case θ also becomes a constant. The baking time T per chapatii is therefore, proportional to $L^{3/2}$ so that from relation (iii) we see that the total baking time for a given weight of chapattis should vary as the square root of the thickness, that is,

$$NT \propto L^{\frac{1}{2}} \qquad \text{(xi)}$$

Thus the total baking time increases with increasing thickness of chapattis, the total weight of chapattis being constant.

SUMMARY OF CONCLUSIONS

1. The total moisture content in the properly made dough, including that of dry atta, is found to be nearly 44 per cent. of the total weight of dough.

2. Within the experimental range, except for the initial thermal lag, the percentage loss of moisture is found very nearly to vary as the square root of the duration of heating, and inversely as $L^{\frac{3}{4}}$, L being the thickness of chapattis.

3. The total baking time for a given weight of chapattis is found to vary directly as the square root of the thickness.

4. No useful purpose is likely to be served by raising the temperature of the heater plate much above 160°C.

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