Through-Circulation Drying of Particulate Natural Rubber I. Heveacrumb

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The rate of through-circulation drying of Heveacrumb, a 'new presentation' particulate natural rubber, has been investigated. The effects of temperature, air velocity and rate of loading on drying rate have been correlated and found to conform with theory to the extent that gas film mass transfer and activated diffusion are the controlling mechanisms involved, during the constant rate and the falling rate periods respectively. The combined effect of these factors on total drying time has also been studied. The static pressure loss has been correlated with air mass velocity.

Heveacrumb is a 'new presentation' natural rubber in crumb form, evolved by SEKHAR AND CHIN (1964) at the Rubber Research Institute of Malaya.

When natural rubber latex coagulum, either freshly prepared by normal methods or collected as field coagulum, is mixed with an incompatible oil such as castor oil and passed three or four times through crepeing rolls, it becomes a spongy mass of easily-separated granules. The preparation and properties of Heveacrumb have already been studied in detail (SEKHAR *et al.*, 1965, BATEMAN AND SEKHAR, 1965). Crumbs obtained from field latex as well as from naturally-coagulated cuplump are sold commercially under Standard Malaysian Rubber (SMR) grades with no mention of the source of coagulum. In this study, however, the former is designated as Heveacrumb WL and the latter is termed as Heveacrumb CL to enable comparative evaluation of their drying characteristics.

Through-circulation Drying

Drying of solids by through-circulation of hot air was successfully attempted many years ago in the case of granular, lumpy and flaky materials such as silica gel, aluminium hydrate, granular cellulose acetate, charcoal, bran flakes and straw (MARSHALL AND HOUGEN, 1942) seaweed (GARDNER AND MITCHELL, 1953) and brewers' spent grain, sugar beet, carrots and peas (MITCHELL AND POTTS, 1958a to d).

Pastes, sheets and lumps, not inherently suitable for through-circulation drying have been particulated either by mechanical and/or thermal means such as extrusion and steam-forming. The time required for through-circulation drying has been shown to be much less than that for cross-circulation drying by air flow across the surface of the particles (MARSHALL AND HOUGEN, 1942). A more general equation has also been developed for vaporisation of liquids other than water into gases other than air (GAMSON *et al.*, 1943).

Through-circulation drying is a rapid process because of the high surface area/weight ratio of granulated materials combined with a high velocity air flow over each particle.

Through-circulation drying has an advantage over tray cross-circulation drying since, in the latter case, the area of material exposed to drying is not changed by increasing the depth of the layer. In through-circulation drying, however, the area increases with the depth of loading, permitting the most efficient use of the air current. Thus, the throughput per square-foot of drying area is sizeably increased by through-circulation, which becomes a promising method for dealing with particulate natural rubber. The paper describes the investigations made to determine the drying characteristics of Heveacrumb by this method and the effect of the various factors involved.

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Drying of Heveacrumb

Drying techniques for Heveacrumb are very different from those used for convectional sheet rubbers, which are suspended over poles mounted on trolleys and dried either by natural convection or by forced-draught air circulation. The temperature in the process rarely exceeds 60°C, above which the wet sheets tend to sag under their own stress (RUBBER RESEARCH INSTITUTE OF MALAYA, 1962). Drying time under such conditions varies between three and four days. In the case of crumb rubbers, there is no problem due to sagging, since the granules are placed in trays. Temperatures can also be higher (120°C)—a major advance in the drying of natural rubber.

Evaluations of the drying of Heveacrumb WL and Heveacrumb CL reported here are based on through-circulation convection drying at atmospheric pressure, where the air conveys the heat while also removing the moisture. The effect of temperature, humidity, air velocity, bed depths and pressure drop on drying characteristics have also been studied, to assess the optimum conditions for the most efficient drying of crumb rubbers.

EXPERIMENTAL

Raw Material

Heveacrumb rubbers used in this study were made from field latex and from cuplump obtained from the Institute's Experiment Station. The crumbling procedures adopted were:

Heveacrumb WL. Castor oil (0.7% w/w of dry rubber) was added to undiluted field latex (d.r.c. approximately 30% w/w), with efficient stirring. The mixture was coagulated with formic acid (pH 5) and the coagulum formed was stood overnight and then passed four times through crepeing rolls with a clearance of 0.002 inch. The fine crumb obtained was soaked in water for 5 minutes to remove serum solids before it was loaded in the drier trays.

Heveacrumb CL. Estate cuplump free from tree lace was pre-creped to 4 mm thickness and smeared with castor oil (1% w/w of dry rubber). The material was then passed through the crepeing rollers, the procedure being similar to Heveacrumb WL, and the crumbs obtained were soaked in water for 15 minutes to standardise the removal of dirt before loading into drier trays. The sizes of particles in the crumbs obtained finally in both cases were found to vary slightly but the crumbs were not separated by size.

Equipment

Figure 1 shows the schematic view of the experimental drier used in the study, comprising a centrifugal fan to blow the air over a bank of electric heater elements into four vertical ducts in which the drying trays rest on high temperature—resistant soft rubber gaskets. The trays, each measuring one square-foot in cross-sectional area, are of sheet aluminium, with 1/16″ diameter perforations in the base.

Dry bulb thermometers are fitted at the air inlet immediately below and on top of the drier bed. The wet bulb thermometer is placed on top of the drying bed. The inlet dry bulb temperature is regulated by a Sunvic controller. Extra heating elements are fitted in the ducts to vary the temperatures of the vertical ducts independently (*Figure 1*). These elements are divided into base and variable loads, to control temperatures to within ±2°C of the set temperature.

Air velocity was varied by throttling the inlet air dampers. In the early experiments it was measured by a low air speed vane anemometer, while later, an electronic type direct reading vane anemometer was used to find the effect of air velocity in the constant rate period, the instrument being kept very close to the rubber surface; the variation across the measuring area was however found to be negligible.

A static pressure-tube mounted just below the trays in the inlet duct was connected by pressure tubing to a sensitive inclined water manometer with a range of 1.5 in. water reading to 0.02 in.

Procedure

Fresh crumb was loaded into the drying trays to the required experimental depths and the trays were left outside the drier for 30 minutes to drain off excess surface water, and thus minimise the variation in the initial moisture

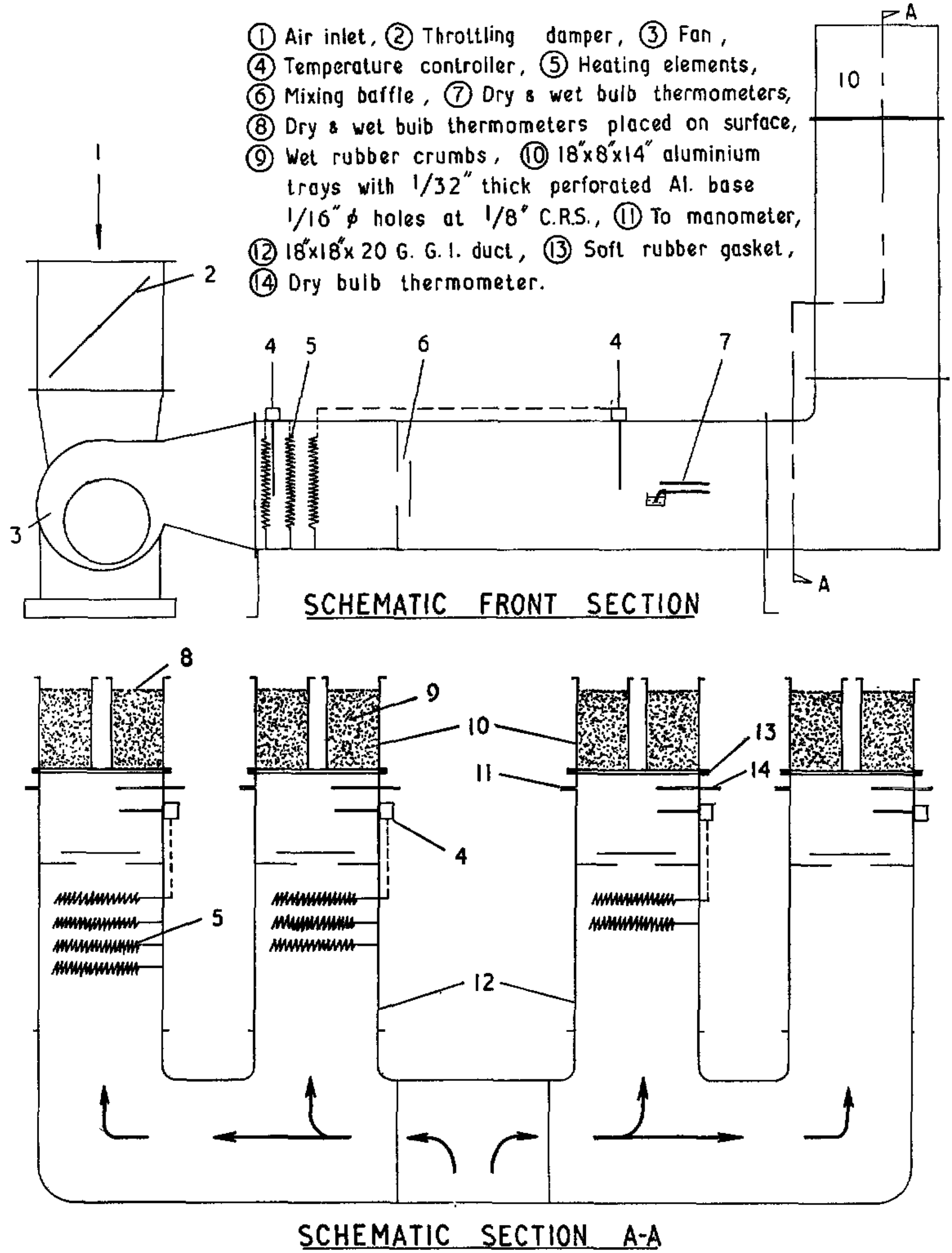

Figure 1. Schematic view of the experimental through-circulation drier used for the drying of Heveacrumb.

content. The fan and the heaters were switched on 15 minutes before the trays were loaded into the drier, to allow conditions to settle down. Temperatures and pressures were read at regular intervals, as were air speed levels. The trays were removed, weighed and replaced in the drier at intervals of 5 minutes initially and at intervals of fifteen minutes thereafter.

The experiment was concluded when the loss in weight for a given period was nil (weighing with an accuracy of 2–5 g on the 1–5 kg samples). For high temperatures (⩾100°C) and high air velocities (⩾100 ft/min) the criterion was no detectable loss over 15 minutes and for low temperatures (<100°C) and low air velocities (<100 ft/min), the criterion for termination was no loss over 30 minutes. After drying, the rubber was allowed to cool and random samples were weighed. These samples were further dried overnight in an electric oven at 70°C and equilibrated over activated alumina (GALE, 1959) for determining the 'bone dry' weight.

DRYING CHARACTERISTICS

Figure 2 shows the drying curves for Heveacrumb WL and Heveacrumb CL dried at 100°C/atmospheric humidity 100 ft/min air velocity and 2″ loading depth. The typical variation of dry and wet bulb temperatures of inlet and outlet air while drying Heveacrumb WL is shown in *Figure 3*.

In *Figure 2*, drying of Heveacrumb rubbers appears to be taking place in approximately three stages (AB, BC and CD) representing constant rate, first and second falling rate periods respectively. The first critical moisture content lies in the region of 10% and the second about 1.5%. For comparison of Heveacrumb dried under various conditions, however, it is convenient to consider the drying rate curve as divided into two stages: constant rate covering initial to 10% moisture content and falling rate covering 10% to dryness.

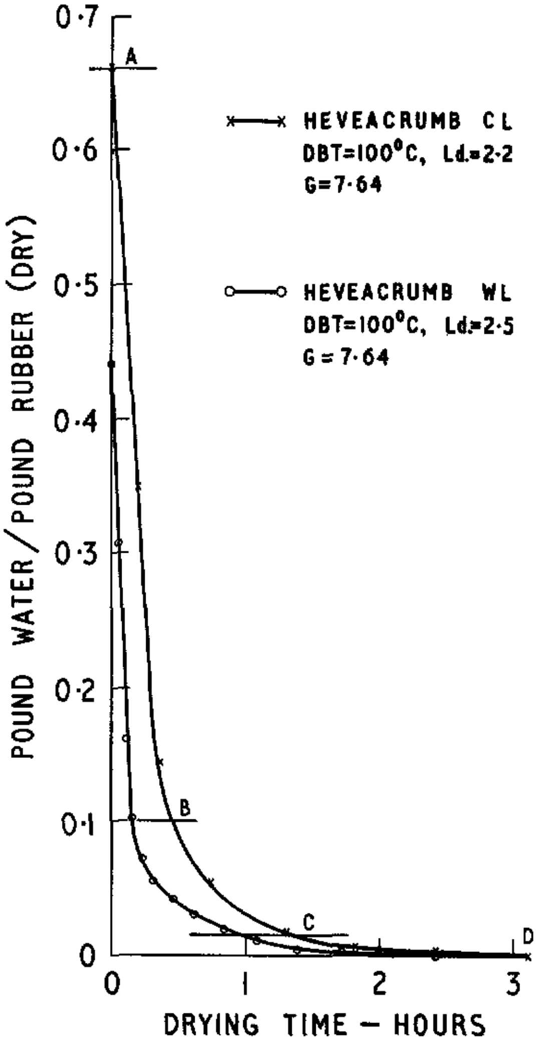

Figure 2. Typical drying curves for Heveacrumb WL and CL.

Constant Rate Period

(i) *Temperature and humidity.* For experiments on the effect of temperature and humidity only the dry bulb temperature (DBT) was controlled so that the absolute humidity of the dry air was that of the atmosphere. The difference between the saturation humidity corresponding to the wet bulb temperature of the hot inlet air, Hs, and humidity of atmospheric air, H_a, is expressed as humidity gradient ($\triangle$H). The loading depth and air mass velocity used in this series were kept constant as 2″ and 7.64 lb dry air/ft²/min.

The plot of constant drying rate versus $\triangle$H

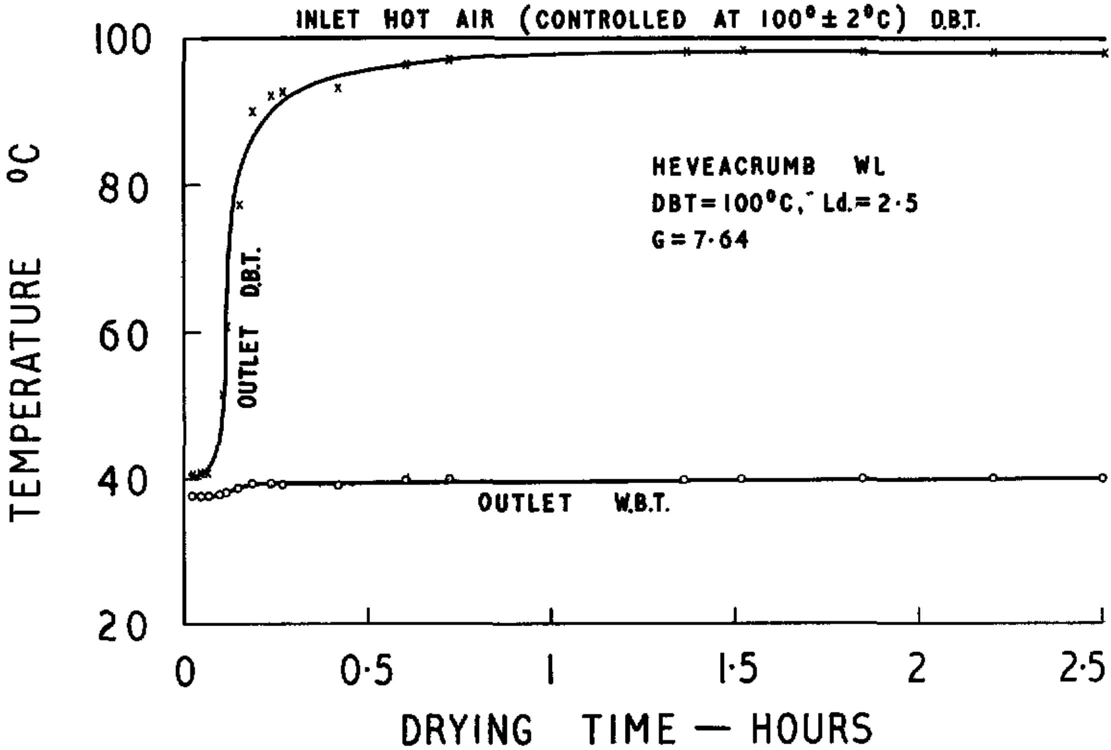

Figure 3. Typical variation of dry and wet bulb temperatures while drying Heveacrumb WL.

gives a straight line passing through the origin (*Figure 4*) for Heveacrumb WL and may be expressed by the Equation:

$$(dW/d\theta)_c = 94.52 \triangle H \qquad ...(1)$$

(ii) *Air velocity.* The air mass flow rate used ranged from 3 to 20 lb/ft^2/min. The depths of loading and dry bulb temperature were kept constant.

The plot of constant drying rate versus air mass velocity on logarithmic co-ordinates is a straight line for both Heveacrumb WL and Heveacrumb CL (*Figure 5*). The slope of the best straight line was 0.5968 for Heveacrumb WL and 0.784 for Heveacrumb CL. The constant drying rate may be expressed by the Equations:

For Heveacrumb WL at 100°C:

$$(dW/d\theta)_c = 0.3394 \; G^{0.5968} \qquad ...(2)$$

For Heveacrumb WL at 60°C:

$$(dW/d\theta)_c = 0.1461 \; G^{0.5965} \qquad ...(2a)$$

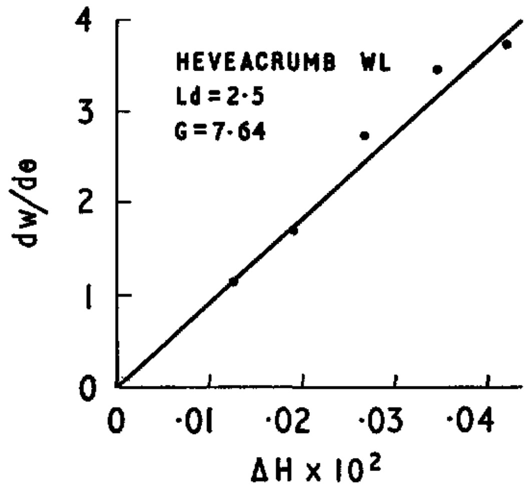

Figure 4. Effect of temperature and humidity on the drying of Heveacrumb WL during the constant rate period.

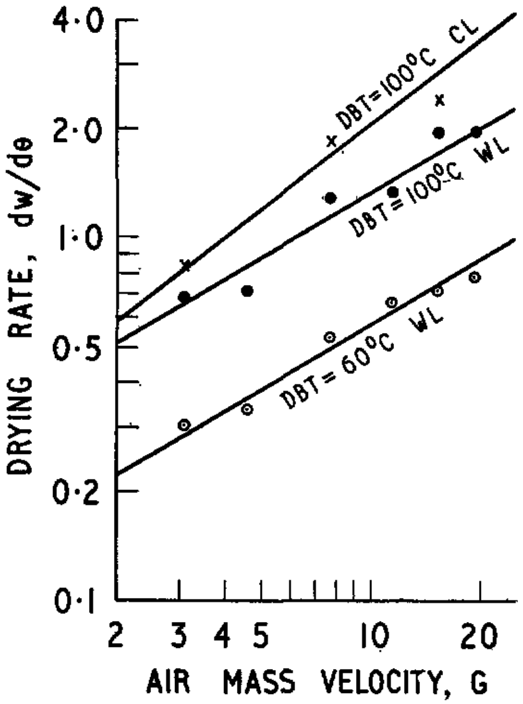

Figure 5. Effect of air mass velocity on drying of Heveacrumb WL and CL during the constant rate period. ($L_d = 2.5$).

For Heveacrumb CL at 100°C:

$$(dW/d\theta)_c = 0.3421\ G^{0.7840} \qquad \ldots(3)$$

(iii) *Bed depths.* The bed depths used range from 2″ to 14″ which correspond to 2 to 16 lb dry rubber/ft². The drying temperature and air mass velocity were kept constant at 100°C and 7.64 lb dry air/ft²/min respectively.

The constant drying rate plotted against the reciprocal of dry loading rate is a straight line passing through the origin (*Figure 6*) as from the Equations:

For Heveacrumb WL at 100°C:

$$(dW/d\theta)_c = \frac{6.5}{L_d} \qquad \ldots(4)$$

For Heveacrumb WL at 60°C:

$$(dW/d\theta)_c = \frac{5.1}{L_d} \qquad \ldots(4a)$$

The combined effect of temperature, humidity, air velocity and depth on constant drying rate is found to be:

For Heveacrumb WL:

$$(dW/d\theta)_c = \frac{67.7\ G^{0.5968}\ \triangle H}{L_d} \qquad \ldots(5)$$

For Heveacrumb CL:

$$(dW/d\theta)_c = \frac{25.7\ G^{0.7840}\ \triangle H}{L_d} \qquad \ldots(6)$$

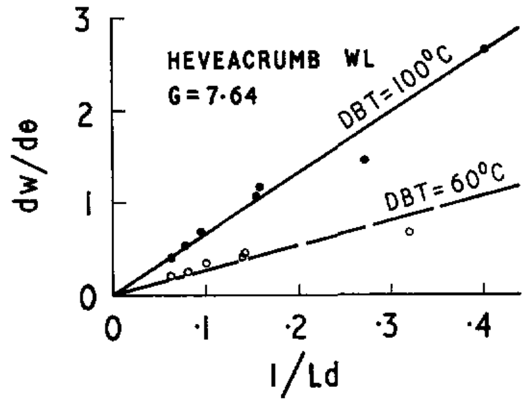

Figure 6. Effect of loading rate on drying of Heveacrumb WL during the constant rate period.

Falling Rate Period

As already described, 10% moisture content (dry basis) was selected as the first critical moisture content for drying of Heveacrumb rubbers. Therefore for the following study of the effect of major factors on drying characteristics during the falling rate period, the overall drying times for reducing the water content from 10 to 0.1% moisture content have been considered.

(i) *Temperature and humidity.* The variation of falling rate drying time with drying temperature is shown in *Table 1*. In this series of experiments the dry bulb temperature used was between 60 and 140°C.

TABLE 1. DRYING TIME VS DBT (FALLING RATE)

DBT,°C	Drying time (minutes)	
	Heveacrumb WL	Heveacrumb CL
140	36	—
120	98	111
100	124	170
80	318	—
60	754	1099

(ii) *Air velocity.* The effect of air velocity used, i.e. 3 to 20 $lb/ft^2/min$, on drying time during the falling rate period, are shown in *Figure 7.*

(iii) *Bed depths.* The effect of loading rate, which ranged from 2 to 16 lb/ft^2, on drying time during the falling rate period is shown in *Figure 7.*

Static Pressure Drops

Plots of static pressure drop ($\triangle P$) versus air mass velocity (G) on logarithmic co-ordinates give a straight line relationship (*Figure 8*) for various depths of loading (wet and dry), using air at room temperature.

The straight lines in *Figure 8* may be represented by the equation $\triangle P = CG^N$ where C and N are constants. The exponent N varies from 0.661 to 1.08 for wet rubber and from 1.28 to 1.71 for dry rubber.

The empirical equations for pressure drops of wet and dry Heveacrumb WL have been derived from the average value of the exponents and the value for the constant from the deepest beds and are as follows:

For Heveacrumb WL (Wet)

$$\triangle P = 0.1375\ G^{0.899} \qquad ...(7)$$

For Heveacrumb WL (Dry)

$$\triangle P = 0.0944\ G^{1.46} \qquad ...(8)$$

DISCUSSION

In an ideal situation, the weighing of the drying trays should be made continuously without removing the samples from the drier but this requires corrections for factors like variation

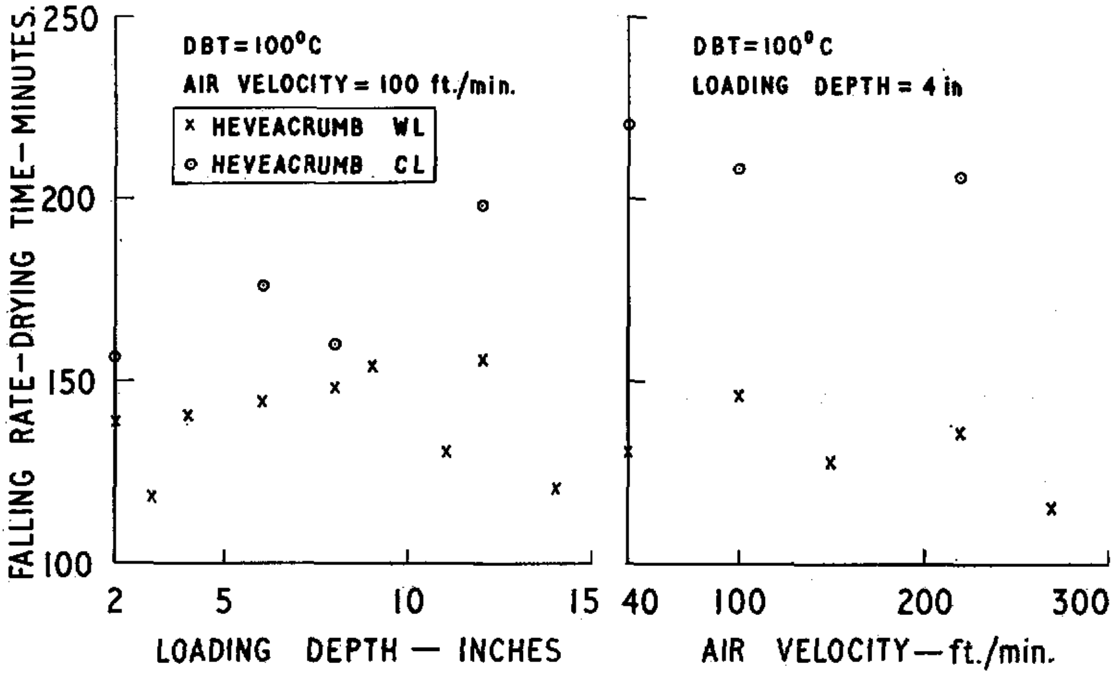

Figure 7. Effect of loading depth and air velocity on the falling rate drying time.

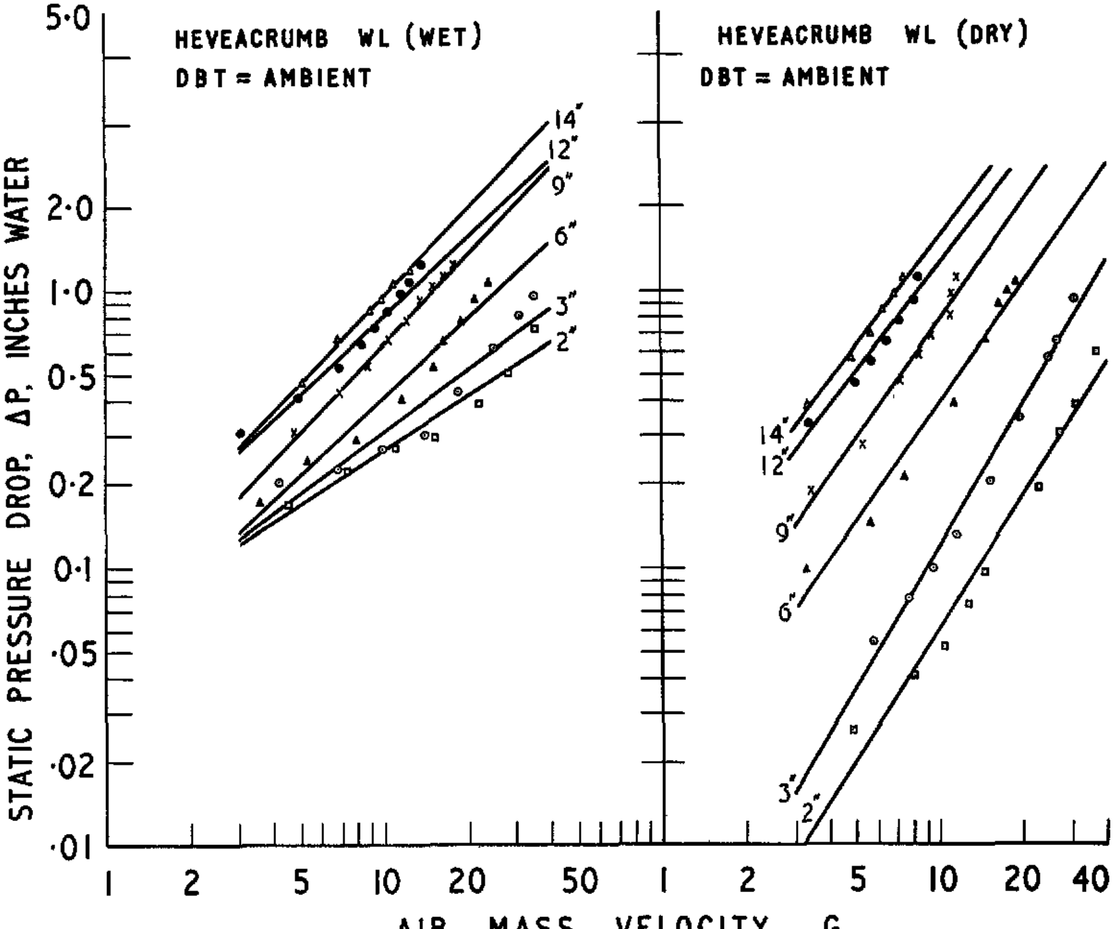

Figure 8. Variation of static pressure drop with air mass velocity and loading depth.

in air flow and upthrust of air. In the present study the trays were removed, weighed and replaced in the drier at pre-determined intervals. In most cases, the weighing took less than 15 seconds and the interruption of the steady conditions of drying by cooling and the time lost were found to be insignificant. Correction for this interruption was therefore considered unnecessary, as was previously inferred by GAMSON *et al.* (1943), who found that the time lost when the sample was removed from the drier for weighing had no effect on the rate of drying of catalyst pallets. GARDNER AND MITCHELL (1953) had a similar experience on drying of sea weed.

Although dry loading provides the more fundamental basis for expressing loadings, the system was considered inconvenient for industrial use because of the difficulty of making frequent estimations of water content. It was seen from the study that the initial water content of one type of material remains constant within reasonably close limits provided excess surface water is drained off the wet crumbs prior to drying.

Heveacrumb particles were discrete when wet, but their natural tack returned during the drying. In all cases, when drying was complete the entire bed became a semi-coherent mass which could be lifted and handled as a block.

Dry spots appeared on the surface at approximately 10% moisture content.

The drying-rate and temperature curves (*Figures 2* and *3*) suggest that the drying of Heveacrumb takes place in approximately three states: constant rate, first falling rate and second falling rate.

Constant rate. In this period, drying proceeds by diffusion of vapour from the saturated surface of the material across a stagnant air film into the environment. Moisture movement within the solid is rapid enough to maintain a saturated condition at the surface and the rate of drying is controlled by the rate of heat transfer to the evaporating surface. The rate of mass transfer balances the rate of heat transfer and the temperature of the saturated surface remains constant and is equal to the wet bulb temperature when the heat is transferred solely by convection. The time-temperature curve for Heveacrumb is in close agreement with this concept, as the dry bulb temperature of the outlet air is found to be constant and is almost equal to the wet bulb temperature of the outlet air (*Figure 3*).

Since during the constant rate period only the gas film is involved in mass transfer, the mass transfer Equation

$$w = KgAV\Delta p \quad \ldots(9)$$

can be modified to give the rate of transfer, on the basis of 1 lb of dry material, as follows:

$$w' = \frac{MKgA}{60\ \rho_s} \Delta p \quad \ldots(10)$$

For air water-water vapour mixtures encountered in air drying at atmospheric pressure, GAMSON *et al.*, (1943) have substituted the representative values and derived the following Equation

$$w' = \frac{0.0786A\ (G)^{0.59}\ \Delta H}{\rho_s\ D_p^{0.41}} \quad \ldots(11)$$

This equation is in a special and less exacting form than the general equation for gas film controlled mass transfer (Equation 9) with property constants inserted to give the rate of air drying of a solid by through circulation drying during the constant rate period.

The empirical equations (Equations 5 and 6) derived for the combined effect of drying of Heveacrumb WL and CL, thus conform with the above theoretical equation to the extent that gas film mass transfer is the controlling mechanism during the constant rate drying period.

A check has also been made by plotting the values obtained for the constant drying rate using Equation 5 against the actual values obtained from the experiments for various drying conditions (*Figure 9*). Even though slightly scattered, the actual values are found to be in close agreement with the empirical relationship.

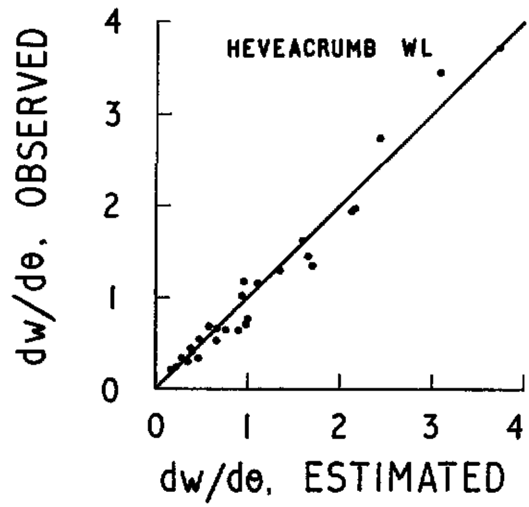

Figure 9. Verification of actual (observed) and estimated rate of drying during constant rate period—Heveacrumb WL.

For Heveacrumb CL, as the relationship between the constant drying rate and temperature, air velocity and loading rate was found to be similar to that of Heveacrumb WL, the empirical equation for constant rate have been derived only for the combined effect. The experimental values obtained for constant drying rate under various drying conditions were used for the above analysis. Equation 6 is thus a regression equation derived statistically, its validity being verified by plotting the actual against theoretical (*Figure 10*) values.

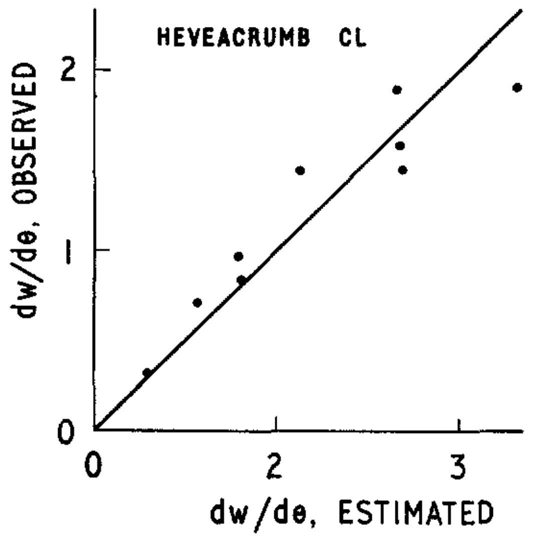

Figure 10. Verification of observed and estimated rate of drying during constant rate period —Heveacrumb CL.

For convenience, this equation has also been rearranged to give the drying time for a given constant rate period:

$$Q = (W_1 - W_2)/(dW/d\theta)_c$$

Falling rate. As stated earlier, the first and the second falling rate periods are considered together in this study.

Initiation of the falling rate period indicates that the rate of water movement from the interior of the material has become a controlling factor in the rate of drying. This is of steadily increasing significance as the moisture content is reduced with consequent reduction in evaporation rate. In the early stage of the falling rate period it is possible to visualise that the transport of water from within the particle to the surface—which is less than the rate of evaporation from the surface. During this period, the dry bulb temperature of outlet air rises rapidly to become equal to the dry bulb temperature of the inlet air. *Figure 3* confirms this concept for the drying of Heveacrumb rubbers. In the final stage of drying, however, internal water movement solely controls the rate of drying.

GALE (1962) has studied the internal water movement in sheet rubber and has suggested that it occurs by activated diffusion under the influence of differences in moisture concentration. He has also shown that drying rate during the diffusion-controlled period is inversely proportional to the sheet thickness raised to the power of approximately two and that the activation energy of diffusion is 17.2×10^3 B.Th.U./lb mole. It is believed, however, that the actual mechanism of diffusion of moisture within the particles of the Heveacrumb rubbers are not appreciably different from that of sheet rubber, as the process of making Heveacrumb is virtually comminution with consequent reduction of the effective thickness of the particle. Within the limits studied, the presence of castor oil has been found to have no effect on the drying rate. With this in view, the following equation for activated diffusion mechanism has been applied to express the effect of temperature at constant air velocity and the rate of loading on the falling period drying rate of Heveacrumb rubbers:

$$\theta = C.e^{(E/RT)} \qquad \ldots(13)$$

In evaluating sheet rubber (GALE, 1962), no satisfactory equation was developed to fit the drying curves at all temperatures and humidities and thus the approach was limited to a consideration of the effects of temperature and humidity on overall drying times for fixed water content intervals. A similar approach has been made for the evaluation of Heveacrumb drying and the interval studied was 10 to 0.1% moisture content (dry basis). The straight line relationship obtained when θ was plotted against the reciprocal of T on logarithmic coordinates (*Figure 11*) also confirmed the previous hypothesis and may be expressed by the Equation:

$$\theta = 1.074 \times 10^{-5}\, e\, \frac{(16.48 \times 10^3)}{RT}$$

for Heveacrumb WL ...(14)

$$\theta = 0.4295 \times 10^{-5}\, e\, \frac{(18.11 \times 10^3)}{RT}$$

for Heveacrumb CL ...(15)

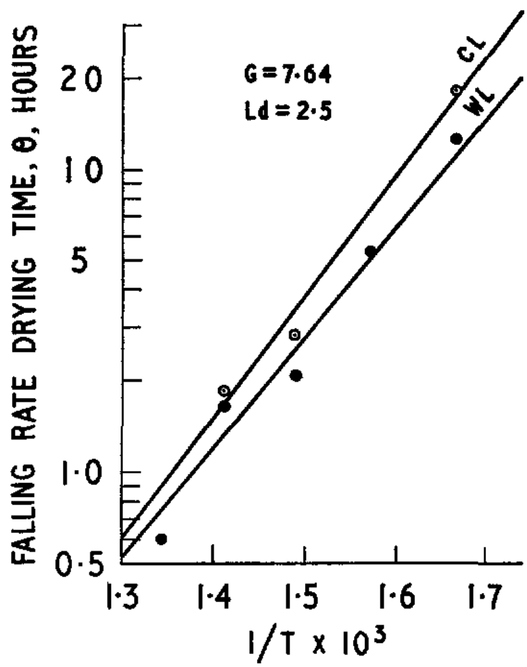

Figure 11. Correlation of drying temperature with falling rate drying time.

and the activation energy of diffusion (E) is as follows:

$$E = 16.48 \times 10^3 \text{ B.Th.U./lb mole}$$
(for Heveacrumb WL)

$$E = 18.11 \times 10^3 \text{ B.Th.U./lb mole}$$
(for Heveacrumb CL)

When the drying rate is controlled by activated diffusion the loading rate should ideally have no effect on drying during the falling rate period. This has been largely confirmed by the scatter of points in the plot of drying time against loading rate (*Figure 7*), which shows no correlation. The drying time to reduce the moisture content from 10 to 0.1 % when drying at 100°C and at 100 ft/min (air velocity, varying the bed depth from 2 to 14", is found to be 136 ±18 minutes, the value obtained at this temperature from the above empirical equation also being 136 minutes.

Air velocity during the falling rate period like that of bed depth would be expected to have no effect on drying rate. However, the plot of overall drying time versus air velocity showed a slight reduction in drying time as the air speed increases (*Figure 7*). This could possibly be explained as due to better temperature distribution at higher air velocities and shorter drying time during the first falling rate period, i.e. curve BC in *Figure 2*.

Within the range studied in this work, however, the effect of rate of loading and the air velocity on drying time during the falling rate period was found to be not significant for practical purposes.

To assess the combined effect of temperature, air velocity and depth of loading on the drying of Heveacrumb WL during both the constant rate and the falling rate periods, the total drying time from 40 % initial moisture content to dryness has been estimated and the values obtained are plotted in *Figure 12*. The empirical equations derived for the rate of drying during the constant-rate period have been used for determining the drying time up to 10%. From 10% to dryness, the relationship based on activated diffusion for the effect of temperature during the falling-rate period has been used; the drying time during the falling-rate period has been taken as being independent of air velocity and the rate of loading.

As indicated earlier, the effect of oil on the surface of Heveacrumb WL has also been studied, to ascertain whether it influences the drying characteristics in any way. Comparison of overall drying time obtained for various percentages of oil added to field latex before coagulation is shown in *Figure 13*. It is, of course, not possible to make a direct comparison between crumbs with and without oil, since in the latter case the rubber does not crumble on milling.

If it may be assumed that increasing the amount of oil added to the latex before coagulation increases the actual amount of oil remaining in the crumbs, the oil on the surface seems to have no effect on drying time. As 1.5 % oil is already more than twice the amount recommended for effective crumbling (RUBBER RESEARCH INSTITUTE OF MALAYA, 1964), the effect of oil on the surface of Heveacrumb on drying time may be taken as insignificant.

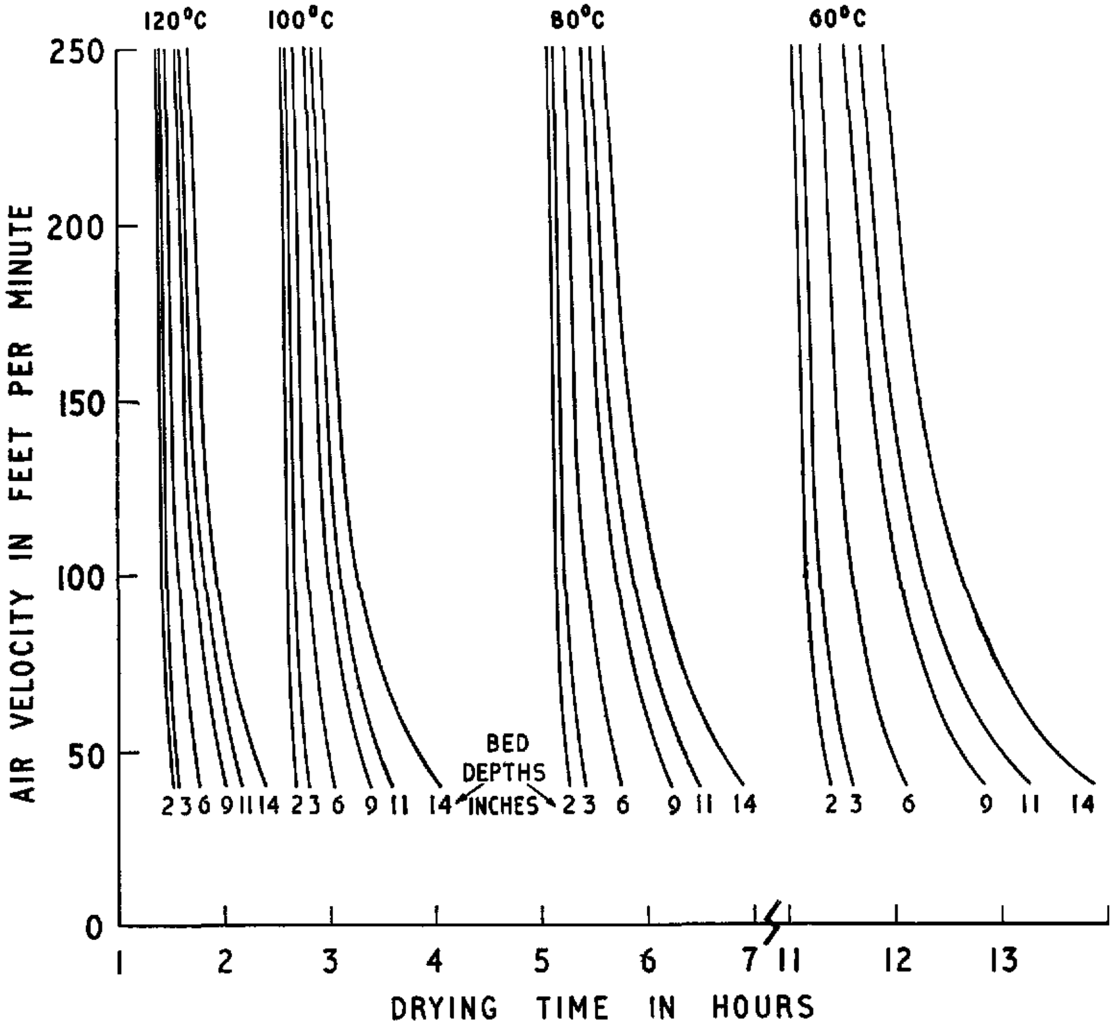

Figure 12. Summary of the effect of temperature, the loading rate and the air velocity on total drying time of Heveacrumb WL.

Static pressure drops across the drying bed are found to vary exponentially with air mass velocity. Other workers (ALLERTON, *et al.*, 1949; CARMAN, 1937; LEVA AND CRUMATER, 1947) have presented more theoretical consideration for the correlation of static pressure drop data in terms of parameters such as bed porosity, particle diameter, gas velocity and bed height. It is difficult to attempt the same type of relationship with crumb rubber, since the bed is not made of definitely formed particles as in other experiments.

CONCLUSIONS

The study has shown that the drying of Heveacrumb by through-circulation method is not only feasible but is also of promise as regards its practical application and value to the producers of crumb rubbers.

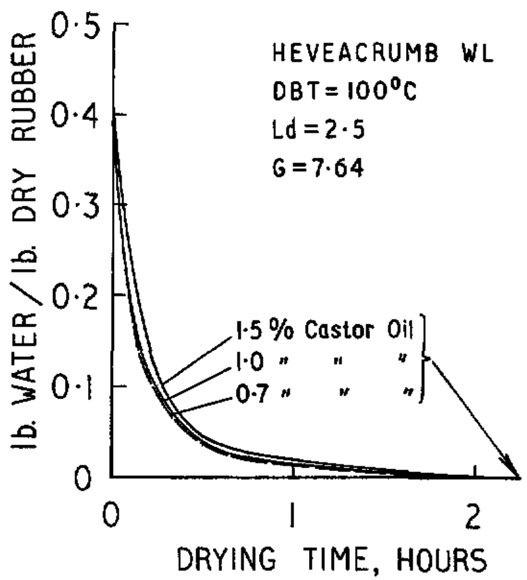

Figure 13. Drying curves for Heveacrumb WL with various concentrations of castor oil.

Drying of Heveacrumb has been effectively studied in two stages: the constant-rate period and the first and second falling rate periods, the critical moisture content is about 10%. During the constant rate period, the rate of drying (expressed as pounds of water evaporated per pound of dry rubber) has been found to vary directly with humidity gradient, exponentially with air velocity and reversely with the rate of loading (see Equations 5 and 6). The study has further confirmed the theory that gas film mass transfer is the controlling mechanism in the above period.

During the falling rate period, the rate of drying of Heveacrumb (as with sheet rubbers) is controlled by activated diffusion mechanism, the activation energy of diffusion (E) being:

16.48×10^3 B.Th.U./lb mole
for Heveacrumb WL, and
18.11×10^3 B.Th.U./lb mole
for Heveacrumb CL.

The rate of loading and air velocity during the above period have been found to be insignificant.

Data for the combined effect of temperature air velocity and the rate of loading have been presented (*Figure 12*).

Doubling the amount of castor oil used for crumbling the coagulum was found to have no effect on total drying time.

The static pressure drops of wet and dry Heveacrumb WL were found to vary exponentially with air mass velocity (Equations 7 and 8).

ACKNOWLEDGEMENT

The author wishes to express his thanks to Mr B.C. Sekhar, Director of the Rubber Research Institute of Malaya, and Mr D.J. Graham, Group Leader, Advisory and Development Section, R.R.I.M., for their keen interest on the work described, to Mr G. Chidambara Iyer for advice on statistical analysis of the results. Thanks are also due to Messrs G. Muthu and Lai Kong Jee for their assistance in experimental work. This work forms part of the programme of research and development on drying of natural rubber undertaken by the Rubber Research Institute of Malaya.

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Kuala Lumpur *July 1967*

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APPENDIX

Calculations

Rate of loading. The rates of loading (Ld) in all experiments were calculated by dividing the total dry weight of rubber by the cross sectional area of the drying tray.

Air velocity. The mass flow of air instead of linear air velocity was used in the present evaluation. The mass flow was calculated from the area of the trays and standard air density and expressed as pounds of dry air per minute per square foot of cross sectional area of the bed. The correction of the effect of density on the anemometer reading was neglected as it was found to be usually small (PERRY, 1950).

Temperature humidity. Humidity of the inlet air was calculated on the basis of psychrometric chart readings corresponding to the dry and wet bulb temperatures of atmospheric air taken just before and during the experiment. An average value of inlet humidity was used in conjunction with the psychometric chart to determine the wet bulb temperature of the hot inlet air. The saturation humidity was based on the above wet bulb temperature of the hot inlet air.

Rate of drying. The bone-dry weight of the rubber crumb was calculated from the final weight of the rubber in the dryer after determining its equilibrium water content. The water content (dry basis) of the rubber crumb at each weighing were then calculated using the bone-dry weight and the percentage moisture content (dry basis) was plotted against time (*Figure 2*).

To enable the rate of drying during constant rate period to be calculated accurately the appropriate part of the graph was redrawn on a large scale and the best straight line was drawn during the data. The slope of this straight line represented the rate of drying during the constant rate period.

Static pressure drops. Static pressure drop, expressed as inches of water was calculated from the readings taken from the sensitive inclined water manometer when the bed of rubber was in position by deducting the corresponding value taken similarly with the empty basket placed in position at the same air flow.

NOMENCLATURE

A	= Effective surface area/unit vol./ft^2/ft^3.
C	= Proportionality constant.
C.L.	= Cuplump coagulum.
d.r.c.	= Dry rubber content, % (w/w).
D_p	= Effective particle diameter, ft.
DBT	= Dry bulb temperature, °C.
E	= Activation energy of diffusion, B.Th.U./lb mole.
e	= Base of natural logarithm.
G	= Air mass velocity, lb (dry)/ft^2/min.
H	= Humidity, lb water/lb dry air.
H_s	= Saturation humidity, corresponding to the wet bulb temperature of hot inlet air, lb water/lb dry air.
H_a	= Atmospheric humidity of inlet air, lb water/lb dry air.
K_g	= Mass transfer coefficient of gas film, lb mole/h/ft^2/atm.
L_d	= Rate of dry rubber loading, lb/ft^2 of drying area.

M = Molecular weight.
$\triangle P$ = Static pressure drop, inches water.
$\triangle p$ = Partical pressure difference, atm.
R = Gas constant (1.986 B.Th.U./lb mole °R).
R.H. = Relative humidity.
T = Temperature, °R.
w = Molar rate of mass transfer, lb mole/h.
w′ = lb water/lb dry solid/min.
W_1 = Initial moisture content, lb water/lb dry rubber.
W_2 = First critical moisture content, lb water/lb dry rubber.
W.B.T. = Wet bulb temperature °C.
W.L. = Whole field latex (undiluted).
$(dW/d\theta)_c$ = Drying rate during constant rate period, lb water/lb dry air/h.
ρ_s = Bulk density of solid, lb/ft^3.
θ = Drying time, h.