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Microwave Drying of Hevea Rubber Latex and Total Solid Content (TSC) Determination

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ABSTRAK

Kertas ini membicarakan pengeringan mikrogelombang bagi lateks getah hevea. Ia menggariskan secara teori dan eksperimen kesan jumlah berat bahan (5 gm hingga 15 gm), paras kuasa mikrogelombang (3W/cm^3 hingga 10.6W/cm^3) dan kandungan pepejal awal (25% hingga 60%) terhadap kadar pengeringan serta jumlah masa pengeringan. Suatu siri graf (jisim lawan masa pengeringan) dilakarkan dan keadaan optimum pengeringan ditentukan. Perhubungan yang baik di antara teori dan eksperimen telah diperolehi. Kadar pengeringan dan jumlah masa pengeringan untuk jisim bahan 5 gm hingga 15 gm dengan TSC= 39.2% pada kuasa 9.3 W/cm^3 masing-masing lebih kurang 0.07 gm/saat dan 4 minit. Jisim bahan > 20 gm, dielak bagi menghalang berlakunya letupan dan rencikan semasa proses pengeringan. Dicadangkan jisim dan kuasa optima pengeringan masing-masing adalah 10 gm dan 9.3 W/cm^3. Keputusan eksperimen menunjukkan dengan jelas bahawa pengeringan mikrogelombang amat efisen bagi pengeringan lateks getah hevea jika dibandingkan dengan kaedah biasa yang memerlukan 1 hingga 2 jam.

ABSTRACT

This paper deals with the microwave drying of the hevea rubber latex. It outlines the theoretical and experimental aspects on the effect of sample weight (5 gm to 15 gm), microwave power levels (3W/cm^3 to 10.6W/cm^3) and initial TSC (25% to 60%) to the drying rate and final drying time. A series of drying curves (mass versus drying times) was generated and optimum conditions for drying were determined. A close relationship between theory and experiment has been found. The drying rate and final drying time for 5 to 15 gm samples with TSC = 39.2% at 9.3 W/cm^3 is approximately 0.07 gm/sec and 4 minutes respectively. A large amount of sample > 20 gm is avoided to prevent any explosion and sputtering of the sample during drying process. It is suggested that the optimal mass and power level are 10 gm and 9.3 W/cm^3 respectively. The experimental results clearly showed that microwere drying is very efficient for drying of fresh hevea latex as the conventional drying method needs 1 to 2 hours.

INTRODUCTION

Microwave heating and drying processes have been well developed in various industrial applications and the most popular application is in the use of microwave ovens for domestic and commercial heating.

The main advantages of micro drying are short time required for drying, uniform drying, convenience and controllability of the process and high heating efficency. The latter is due to direct heating whereby surrounding air and equipment remain cool.

In the rubber industry, microwave heating and drying found extensive application in processing of rubber products (Shute, 1971) Microwave power is used in several processes such

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as rubber moulding, extrusions curing and belting preheater. Vosilakos *et al.* (1984) investigated experimentally the microwave drying characheristics of various polymers such as polyisoprene rubber, polyolefin, polypropylene, polyethylene etc, with all initial moisture content about 40%. They showed that there was a good potential in the application of microwave drying.

However, until now, only limited work has been carried out on microwave dyring of the fresh hevea rubber for determination of TSC. This quantity is a prime factor in determining the quality of the hevea rubber latex.

The basic components of fresh hevea other than water (about 50%-80%) are 18% to 45% dry rubber content (DRC) and approximately 2% to 5% non-rubber constituens or total solid content of about 20% to 50% (Chin, 1979) (*Fig. 1*). Non rubber solids such as proteinous substances, resionous substances, carbohydrates, inorganic matter and others constitute about 4% (Cook, *et al,* 1953). Therefore the knowledge of the TSC can be used to determine dry rubber content of the latex.

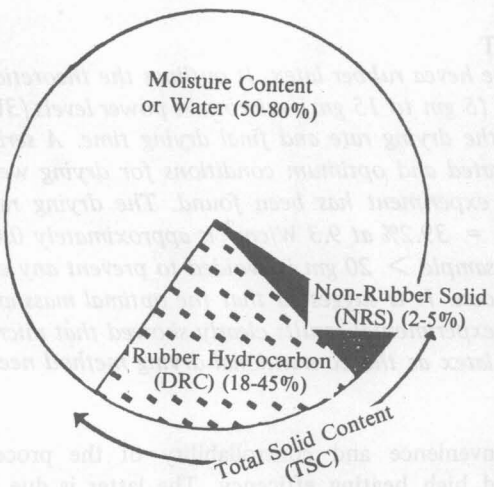


Fig. 1: Basic components of hevea rubber latex

The conventional oven has been widely used for TSC or DRC determination, but for a high accuracy level it takes 1 to 2 hours. The use of a low microwave power level for determination of TSC or moisture content of hevea rubber latex has successfully been done. (Khalid, 1982, Khalid 1983, Khalid 1987). Despite the complexity of the physical nature of the hevea latex, there exists a relationship between moisture content and attenuation of the microwave power. The accuracy of the measurement is less than 1% per unit moisture content.

In this paper the impact of microwave drying on increasing the efficiency and drying time of fresh hevea latex are studied. It includes theoretical and experimental investigations on the effects of initial mass, microwave power level and initial moisture content to the drying time. Optimization in the efficiency of the drying process will be discussed.

Physical Processes

The physical process which govern the removal of moisture from a liquid can be divided into two stages i.e. initial heating up period and drying process as shown in *Figure 2*.

In the initial heating up period process, the temparature of the material rises towards the boiling point of the liquid. The time taken for this process is given by

$$\Delta t = \left(\frac{\bar{P}}{V}\right)^{-1} h\Delta To \qquad (1)$$

where h is the specific heat of the material $\bar{P}/V$ average volumetric power absorption and, ΔT is the temperature rise and ρ is the density of the material.

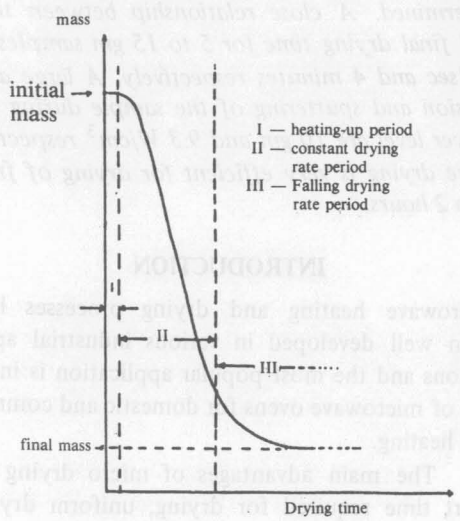


Fig. 2: Drying characteristics of a liquid

In the drying process, the rate of moisture evaporation of the liquid takes places under two distinct periods, ie. constant drying period and falling drying period.

During the constant drying rate period, the moisture content is very high and the evaporation will occur from the surface at a contant rate. Under steady state conditions, the heat transfered from microwave power is exactly balanced by the latent heat of water.

$$\Delta m/\Delta t = -\frac{1}{\lambda} \left(\frac{\bar{P}}{V}\right) V_s \qquad (2)$$

where λ is the latent heat

Δm is the mass of water evaporated during period Δt.

V_s is the volume of the sample.

During the falling rate period the drying process follows the conventional convective drying.

The average power absorbed per volume by a material exposed to electromagnetic fields as a result of dielectric losses is given by (Stuchly *et al* 1972).

$$\frac{\bar{P}}{\bar{V}} = \sigma E_i^2 = \varepsilon' \varepsilon_o E_i^2 \tan\delta \, 2\pi f \qquad (3)$$

where σ represents the conductivity, ε' is the relative permittivity, ε_o is the permittivity of vacuum, E_i is the rms electric field strength inside the material, $\tan\delta$ is the loss tangent and f is the frequency of the microwave radiation.

The magnitude of the E_i can be related to the magnitude of the electric field outside the volume of the sample, E_o. Von Hippel (1954) suggests that the standard result of a particular shape of a dielectric field is given by

$$E_o = E_i + w/\varepsilon_o (\varepsilon' - 1) E_i \qquad (4)$$

where w is the shape correction which is determined by the geometry of the polarized body. It can be calculated for spheres, cylinders and ellipsoids. The value of w for the case of the latex in the cylindrical beaker is given in the Appendix.

The drying time for each sample was calculated and corrected with the duty cycle of the microwave power. A simplified flow digram for the culculation of successive time increments is shown in *Figure 3.*

The moisture content (wet basis) at time t is determined by using the following expression:

$$M_t = X_{wt}/X_{st} \qquad (5)$$

where X_{wt} is the mass of water at time t.

X_{st} is the mass of sample at time t.

The dielectric properties of hevea rubber latex at a particular time t is determined by using Kraszewski model (Kraszewski, 1976).

$$\sqrt{\varepsilon_\ell} = V_t \sqrt{\varepsilon_H} + (1 - V_t) \sqrt{\varepsilon_R}$$

where $\varepsilon_\ell = \varepsilon'_\ell - j\varepsilon''_\ell$, ε'_ℓ is the relative dielectric constant of the latex and ε''_ℓ is the dielectric loss of the latex, $\varepsilon_H = \varepsilon'_H - j\varepsilon''_H$, ε'_H is the relative dielectric constant of the water and ε''_H is the dielectric loss of the water and $\varepsilon_R = \varepsilon'_R - j\varepsilon''_R$, ε'_R is the relative dielectric constant of the solid hevea rubber and ε''_R is the dielectric loss of the solid hevea rubber.

V_t is the volume fraction at time t and is related to the moisture content M_t.

$$V_t = M_t/(M_t + \frac{\gamma_w}{\gamma_d} (1 - M_t)) \qquad (7)$$

where γ_d and γ_w are relative density of the solid and water respectively and are considered to be constant with $\gamma_d = 0.94$ and $\gamma_w = 1.0$.

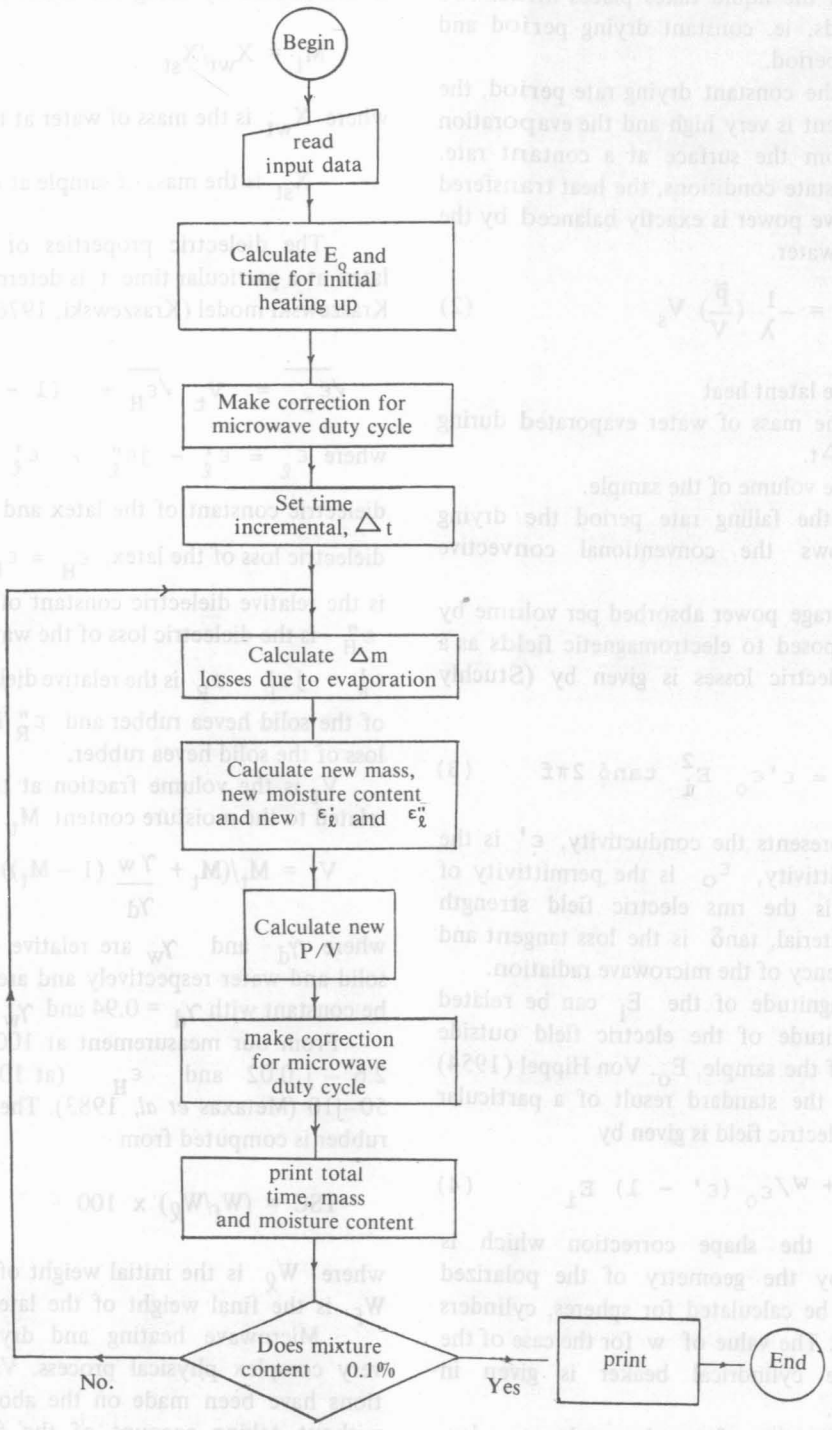
From our measurement at 100 C, ε_R is 2.6 – j 0.02 and ε_H (at 100 C) equals to 50–j10 (Metaxas *et al,* 1983). The TSC of hevea rubber is computed from

$$TSC = (W_f/W_\ell) \times 100 \qquad (8)$$

where W_ℓ is the initial weight of the latex and W_f is the final weight of the latex after drying.

Microwave heating and drying involves a very complex physical process. Various assumptions have been made on the above calculations without taking account of the following parameters or phenomena.

(i) reflection of the microwave radiation at the surface of the sample.



Note: E_o is determined by water-load method [Mae Latchy et. al 1980]

Fig. 3: A simplified flow diagram for calculation of the heating time

(ii) heat loss due to radiation and conduction during the constant drying rate period.

(iii) movement of moisture within the material from the surface during the falling drying period.

MATERIALS AND METHODS

A modified National (Model: NE-6760) commercial microwave oven operating at 2450 MHz with a maximum measured power output of 12 Watt/cm^3 was used in this experiment (*Fig. 4*). The oven features five different power settings (100%, 89%, 77%, 52% and 23% of maximum power). When one of these powers is set at any power setting other than high power, the variable power switch is energized intermittenly by signals from the variable power control circuit. The variable power control circuit controls the ON-OFF time of the variable power switch contacts within a specific duty cycle. One complete duty cycle of this oven is approximately, 22 seconds. ON-OFF cycle of magnetron can be detected simply by observing the dimming of the oven light. If the oven light dims the circuit is supplying high voltage to the magnetron and when the oven light goes bright, it indicates no voltage supply to the magnetron. The brightness of the oven light during the process can be detected by a photo detector. *Fig. 5* shows the relationship between the output power of a microwave oven and the corresponding duty ratio.

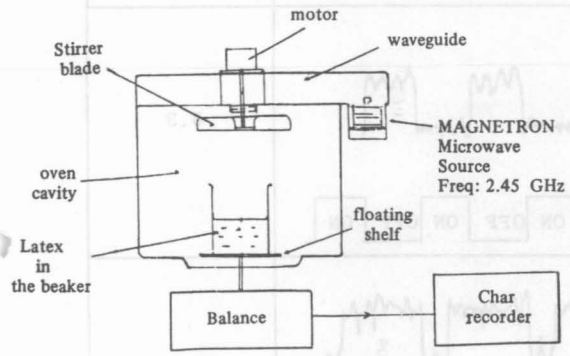


Fig. 4: A microwave oven cavity

The oven also incorporates a metalic fan to distribute the power evenly inside the oven cavity. *Fig. 6* shows the average temperature distribution within a 900 cm^2 of the central region of the cavity. This was determined using a beaker containing 100 ml of water and exposed to the microwave radiation for 1 minute. The temperature was measured using a Cu-Constantan thermocouple immediatly after exposure.

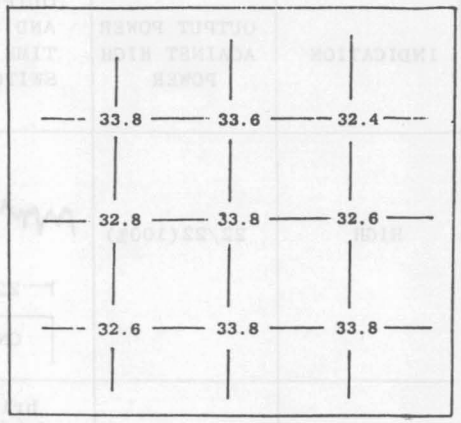


Fig. 6: Temperature distribution in central region of cavity, 3 cm x 3 cm.

The oven has a balance placed at the bottom as seen in *Fig. 4*. The variation of mass with time of heating is automatically recorded on the chart recorder. An electric balance Gibertini (Model E415) with readability 0.0001 gm and precision of $\hat{=}$ 0.0005 gm was used to weigh the sample before and after drying.

In a typical experiment, a sample of hevea latex under investigation was spread on a 500 ml cylindrical beaker, weighed and then placed into the oven.

Before the initial amount of the sample was chosen, various samples with initial masses of 40 gm, 30 gm, 25 gm and 15 gm were tested. The results of this testing is shown in *Fig. 7* with average microwave power of 10.6 W/cm^3. For initial masses greater than 25 gm, the samples exploded and the latex sputtered. This effect is more serious for an initial mass greater than 40 gm and it happened soon after the heating up period, and was repeated several times with the duty cycle of the microwave radiation. The same effect has been seen for different levels of microwave power. From this testing, a sample weight smaller than 20 gm was chosen.

A series of solutions from hevea rubber latex were prepared ranging in dilution from 40% to 100% moisture content (wet basis). The hevea latex used in this experiment came from concentrated hevea rubber latex (supplied by

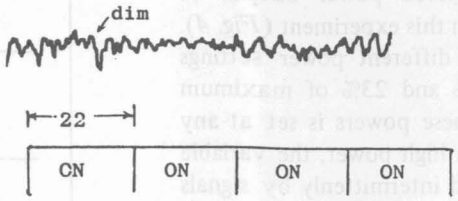
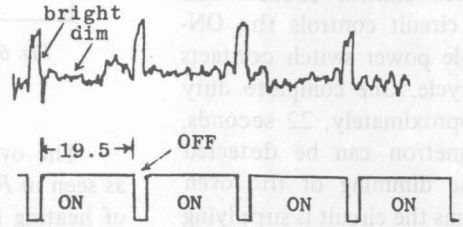
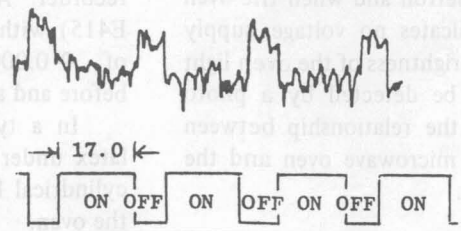
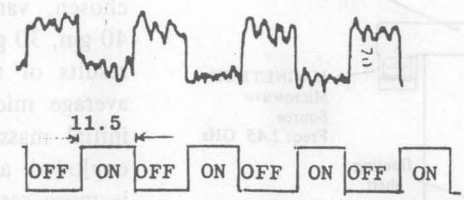
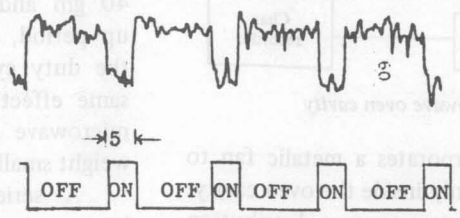
INDICATION	OUTPUT POWER AGAINST HIGH POWER	OUTPUT VOLTAGE OF PHOTODETECTOR AND — CORRESPONDING ON-OFF TIME ON VARIABLE POWER SWITCH. (S)	AVERAGE OUTPUT POWER (W/cm^3) ± 0.2
HIGH	22/22(100%)		12.0
MEDIUM HIGH	19.5/22(89%)		10.6
MEDIUM	17/22 (77%)		9.3
MEDIUM LOW	11.5/22(52%)		6.3
LOW	5/22 (23%)		3.3

Fig. 5: Relationship between the output power of microwave oven and the corresponding duty ratio

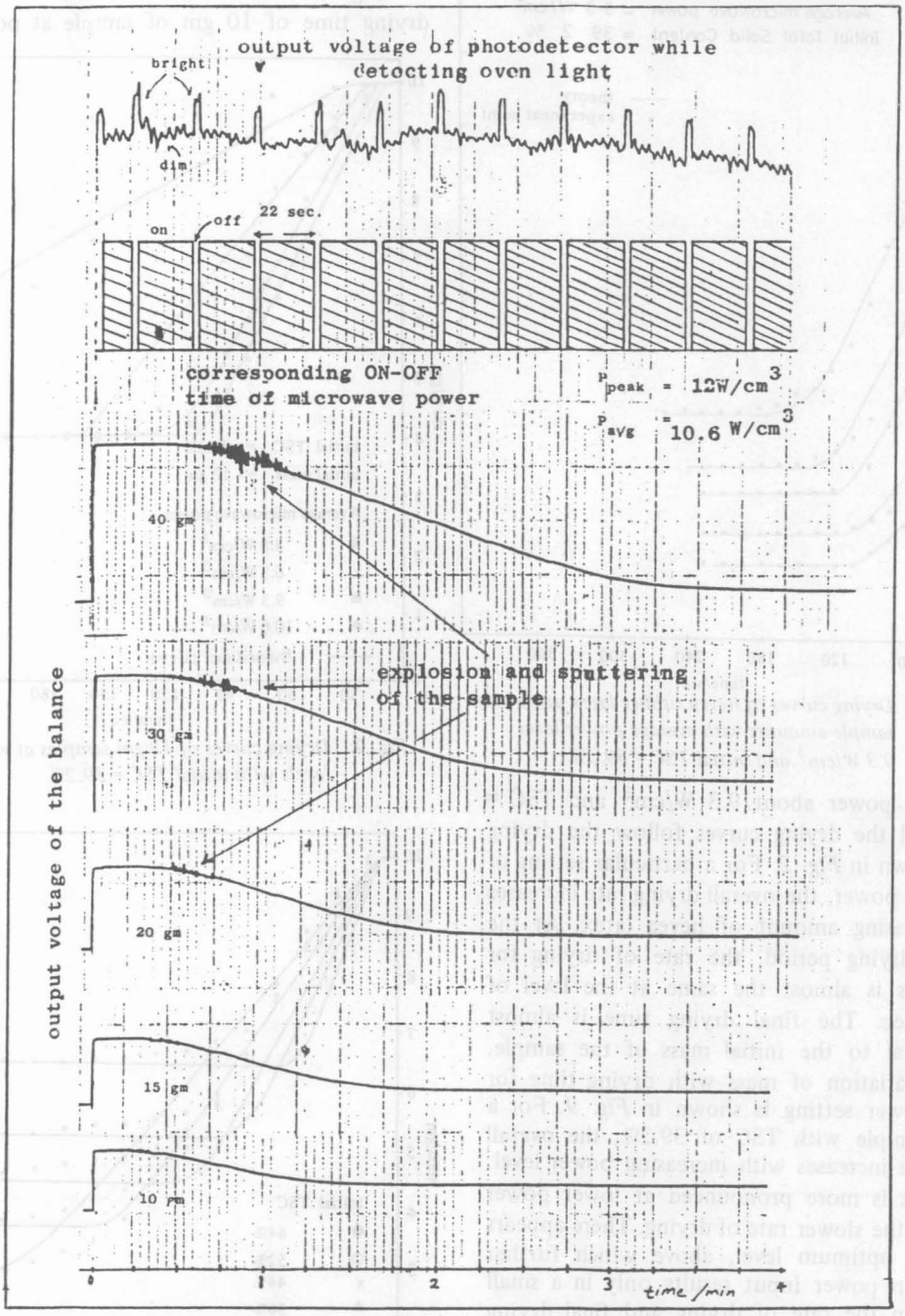


Fig. 7: Drying characteristics of hevea rubber latex at various sample amounts with average power level 10.6 W/cm^3 and initial TSC = 39.2%.

Rubber Research Institute Malaysia) and fresh hevea rubber latex (from the university farm).

RESULTS AND DISCUSSOIN

The experimental data and theoritical prediction of the microwave drying of the hevea rubber latex are summarized in *Figs. 8, 9 and 10.* The drying curves were generated by plotting mass versus drying time. All figures show a good agreement between theory and experiment.

Fig. 8 show the variations for various initial masses ranging from 5 gm to 15 gm average

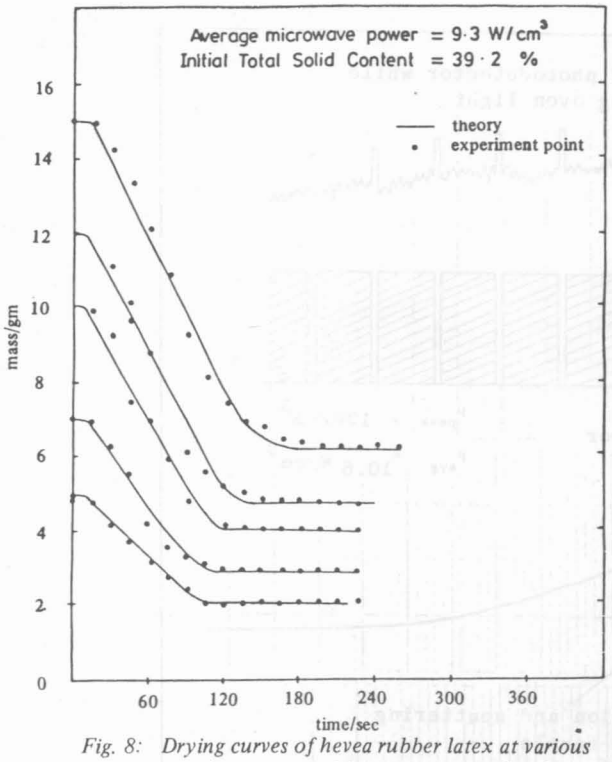


Fig. 8: Drying curves of hevea rubber latex at various sample amounts with average power level 9.3 W/cm³ and initial TSC = 39.2%.

microwave power about 9.3 W/cm³ and TSC = 39.2%. All the drying curves follow the drying curves shown in *Fig. 2.* For a particular setting of microwave power, the overall drying rate increases with increasing amount of hevea latex. At the constant drying period, the rate of drying for all samples is almost the same at the level of 0.08 gm/sec. The final drying time is almost proportional to the initial mass of the sample.

The variation of mass with drying time for various power setting is shown in *Fig. 9.* For a 10 gm sample with TSC of 39.2%, the overall drying rate increases with increasing power level. The effect is more pronounced at lower power level with the slower rate of drying. There appears to be an optimum level, above which further increases in power input results only in a small increases in the rate of drying and final drying time. For example at 6.3 W/cm³ the drying rate is 0.07 gm/sec. and is comparable to that at 9.3 W/cm³ but on the other hand, it was far superior to that at 3.3 W/cm³ with drying rate of only 0.03 gm/sec. It takes from only 2 to 4 minutes to dry 5 to 15 gm samples at 9.3 W/cm³ and 10.6 W/cm³, whereas approximately 8 minutes are required at 3.3 W/cm³.

Fig. 10 shows the variation of mass with drying time of 10 gm of sample at power level

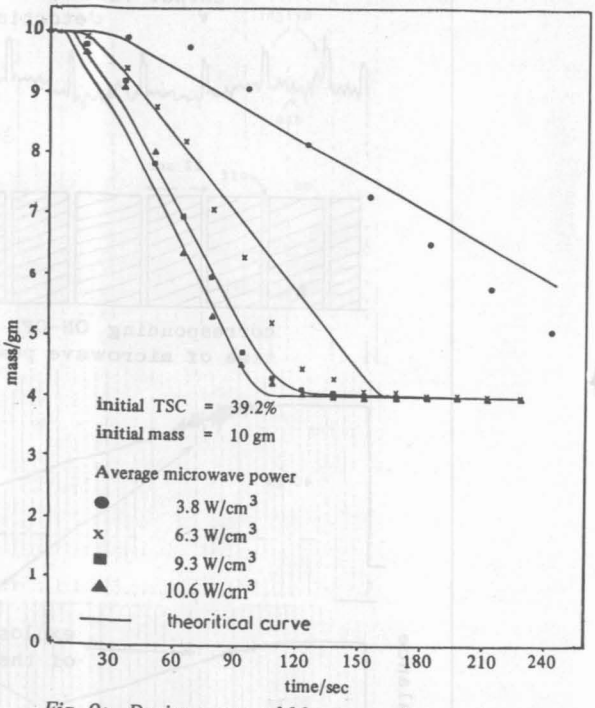


Fig. 9: Drying curves of 10 gm samples at various power levels with initial TSC = 39.2%.

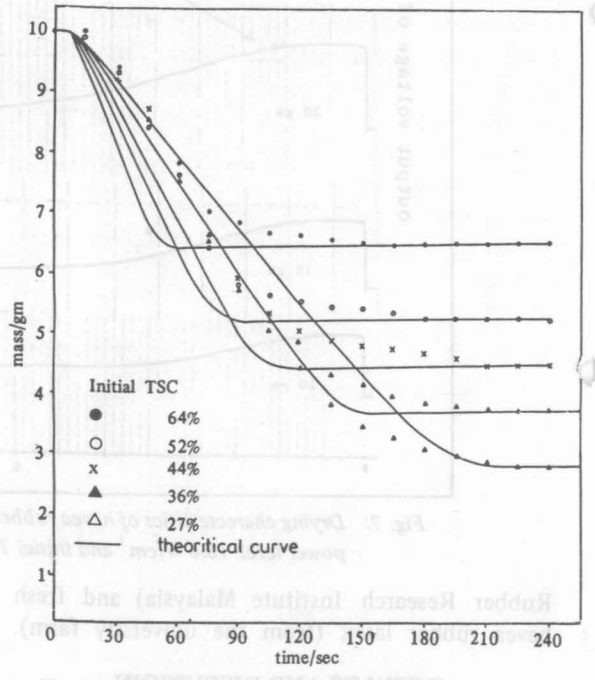


Fig. 10: Drying curves of 10-gm samples of hevea rubber latex at various TSC and with average power level 9.3 W/cm³.

9.3 W/cm^3 for various initial TSC. At the beginning, all curves started with the same drying rate and as time increased, the curves spread accordingly, to their TSC. The final drying time is almost inversely proportional to the initial TSC of the latex.

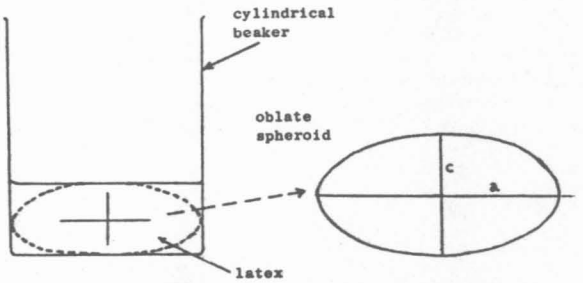


Fig. 11: Approximate shape of the hevea latex in the cylindrical beaker.

CONCLUSION

The performance of microwave drying for the determination of TSC of hevea rubber latex has been demonstrated and general conclusions can be drawn.

An optimal set of initial mass and power level which maximizes the drying rate and minimizes the final drying time can be determined theoretically and experimentally. A large amount of samples are avoided, to prevent any explosion and sputtering of the sample during the process. It is suggested that optimal mass and power level are 10 gm and 9.3 W/cm^3 respectively.

Finally the experimental results clearly showed that microwave drying has overcome the limitation of the conventional method by reducing measuring time from 1 hour to 2 minutes.

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REFERENCES

CHIN, H.C. (1979): Method of Measuring the Dry Rubber Content of Field Latex–RRIM Training Manual on Analytical Chemistry Latex and Rubber Analysis Rubber Research Institute Malaysia, K. Lumpur:63.

COOK, A.S. and B.C. SEKHAR (1953): Fraction brown Hevea Brasiliensis latex centrifuged at 59,000 g. *J. of Rubber Institute Malaya,* 14: 63

KHALID, K.B. (1982): Determination of dry rubber content of hevea latex by microwave technique, *Pertanika,* 5(2): 192-195.

KHALID, K.B. and ABD. WAHAB M.B. (1983): Microwave attenuation of fresh hevea latex, *J. Rubber Research Inst. of Malaysia,* 31-3: 145-150.

KHALID, K.B. (1987): The application of microstrip sensors for determination of moisture content in hevea rubber latex (to be published).

KRASZEWSKI, A, S. KULLINSKI, M. MATUSZEWSKI (1976): Dielectric properties and a model of diphase water suspension at 9.4 GHz. *J. Applied Physics.* 47(4): 1275-1277.

METAXAS A.C. and R.J. MEREDITH (1973): Industrial Microwave Heating, Peter Peregrinus and IEE, London. 60.

MACLATCHY, C.C. and R.M. CLEMENTS (1980): A simple technique for measuring high microwave electric field strengths, *J. of Microwave Power,* 15(1): 7-14.

SHUTE, R.A. (1971): Industrial microwave systems for the rubber industry, *J. of Microwave Power* 6(3): 193-205.

STUCHLY, S.S. and M.A.K. HAMID (1972): Phycisal parameters in microwave heating process, *J. of Microwave Power* 7(2): 177-137.

VAN HIPPEL, A.R. (1954): Dielectric and Waves, John Wiley, New York, 254-255.

VASILAKOS, N.P. and F. Magalheas, : Microwave Drying of Polymers, *J. of Microwave Power* 19(2): 135-144.

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APPENDIX

The geometrical shape of the latex in the cylindrical beaker can be considered as having the shape of an oblate spheroid as seen in *Fig. 11.*

The thickness of the sample is approximately equal to 2c and the radius of the cylinder is equal to a. a and c are the major and minor axis of the spheroid respectively.

By assuming and electric field E parallel to c, the shape correction w is (Von Hippel 1954)

$$w = \frac{1}{\varepsilon^2} - \sqrt{\frac{1-\varepsilon^2}{\varepsilon^3}} \arcsin \varepsilon$$

$$\text{where} \quad \varepsilon = \sqrt{1 - c^2/a^2}$$