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Microwave Drying of Palm Oil Mill Effluent

Kaida bin Khalid, Evelyn Soon Mee Lin and Chow Kok Fei
Department of Physics
Faculty of Science and Environmental Studies
Universiti Putra Malaysia
43400 UPM, Serdang, Selangor, Malaysia

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ABSTRAK

Kertas ini membicarakan tentang perawatan sisa pembuangan kilang kelapa sawit (POME) menggunakan kaedah pengeringan mikrogelombang. Kajian ini tertumpu kepada perubahan kadar pengeringan pada pelbagai jisim awal, paras kuasa dan kesan bahan Silikan Karbit (SiC) dalam meningkatkan kesan pengeringan.Jisim awal dan paras tenaga yang digunakan masing-masing adalah dalam julat 20 - 50 g dan 90 - 504 watt. Hasil eksperimen menunjukkan bahawa menerusi rawatan mikrogelombang masa pengeringan untuk menurunkan jisim sampel kepada 25% dari jisim awal pada 504 watt adalah diantara 3.5 - 6.4 minit. Sementara dengan memasukkan SiC kedalam sampel dan pada paras tenaga yang sama, masa pengeringan adalah dalam julat 1.8 - 3.6 minit. Masa ini merupakan sepertiga sahaja daripada masa yang diperlukan jika menggunakan kaedah pemanasan ketuhar biasa. Daripada hasil eksperimen diatas jelas menunjukkan bahawa pengeringan mikrogelombang sesuai untuk dipertimbangkan sebagai teknik alternatif dalam rawatan POME kerana ianya lebih efisen, cepat, ekonomi dan pencemaran sifar.

ABSTRACT

This paper describes the treatment of palm oil mill effluent (POME) by using microwave drying. The study concentrated on the variation of the drying rate with respect to different initial mass and microwave power and the effect of silicon carbide (SiC) to enhance the drying. The initial mass of sample and energy level ranges from 20 - 50 g and 91 - 504 watt respectively. The experimental results show that under the microwave treatment the drying time required to reduce the amount of sample to 25% of its initial mass at power level of 504 watt was within 3.5 - 6.4 min. While with SiC and at the same power level the drying time was only 1.8 - 3.6 min. This time is almost one-third of the time taken by conventional drying. The experimental results clearly showed that microwave drying can be considered as an alternative technique for the POME treatment since it is efficient, quick and does not pollute the environment.

Keywords: microwave drying, permittivity, palm oil mill effluent

INTRODUCTION

Palm oil mill effluent (POME) is a liquid waste from palm oil mills which consists of 95% water and 5% fibrous fruit residues and a small amount of palm oil. POME has a biochemical oxygen demand (BOD) of 25000 - 30000 mg/l which is highly polluting (Anon 1982). In 1993 alone, Malaysian oil palm mills

generated about 20 million tonnes POME which would have been a source of pollution if it was discharged directly into water sources (Yusof and Loke 1994). In solving this problem the palm oil industry uses the ponding system or direct disposal on land. POME can also provide material for fertilizer. The ponding system requires a reasonably large land area and close monitoring in order to comply with the environmental discharge standard prescribed by the Environmental Quality Act (1975) of less than 100 mg/l (Megat Johari *et al.* 1990).

Another way to dispose of POME is by evaporation. With this process 80% of the water can be recovered and the 20% of the solid concentrate produced as a co-product can be useds for fertilizer or animal feed production (Ma 1996).

The electrical power generated by a steam turbine operated using waste products is normally more than the needs of the mill. This energy can be converted to microwave energy for the drying of POME.

Evaporation enables the oil palm industry to achieve zero waste discharge. Microwave drying has the advantage of shorter time required for drying, conservable, controllability of the process, uniform drying and high heating efficiency.

The present study describes the theoretical and experimental aspects of microwave drying of POME. The study includes the variation of the heating time for samples with different initial mass and with different power levels.

Previous studies have shown (Breccia *et al.* 1995) that microwave heating of material is improved by addition of silicon carbide (SiC); this results in better heat transfer, thus improving the speed of vapour formation in substances containing water. This study also shows the ability of SiC to enhance microwave effects on the drying of POME.

Physical Aspects

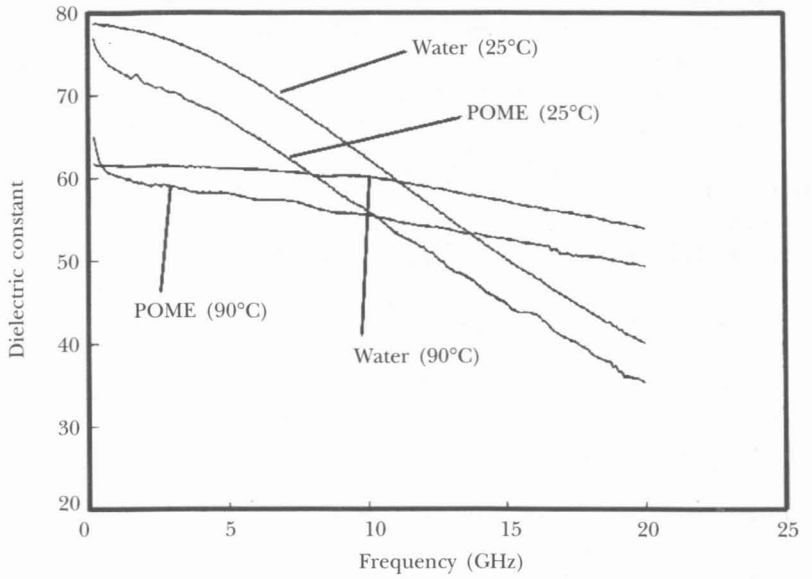
The interaction of electromagnetic waves with non-magnetic materials can be described by the complex permittivity of the dielectric material, $\varepsilon = \varepsilon' - j\varepsilon''$. The real part ε', which is known as the dielectric constant, expresses the ability of a material to store energy. The imaginary part, ε'' known as the dielectric loss factor, is a measure of the energy absorbed from the applied field.

The average power absorbed per volume is given by

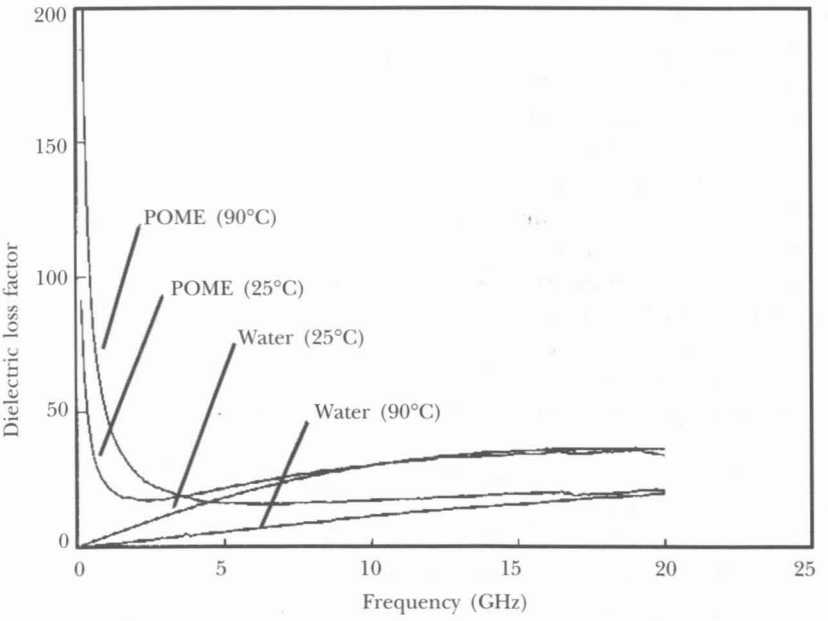
$$\frac{\overline{P}}{V} = \sigma_e \overline{E}_i^2 \qquad (1)$$

where $\overline{E}_i$ is the root mean square electric field strength inside the material and σ_e is the effective electrical conductivity of the material.

Referring to the spectrum of the dielectric properties of the POME as in *Fig. 1*, it is clearly shown that the heating mechanism in the POME is mainly due to the dipole orientation and ionic conductivity. In these figures the dielectric constant (*Fig. 1a*) and dielectric loss factor (*Fig. 1b*) of the POME and water at 25°C and 90°C are plotted against frequencies ranging from 0.2



(a) dielectric constant



(b) dielectric loss factor

Fig. 1. Variation of dielectric properties with frequency of POME and water at 25°C and 90°C

GHz to 20 GHz. It is clearly shown that at 2.45 GHz both ionic conduction and dipole orientation take place simultaneously. Therefore, the term σ_e in equ. 1 can be expressed by

$$\sigma_e = \sigma_D + \sigma_I \tag{2}$$

where σ_D is the conductivity due to the dipole orientation and σ_I is the ionic conductivity.
In terms of dielectric permittivity, equ. 1 can be written as

$$\frac{\overline{P}}{V} = E^2_i \, \varepsilon_0 \kappa \, 2\pi f (\tan\delta_I + \tan\delta_D) \tag{3}$$

where $\tan\delta = \frac{\varepsilon''}{\varepsilon'}$, $\kappa = \frac{\varepsilon'}{\varepsilon_0}$, f is the frequency of the applied field and ε_0 is the free space permittivity.

Under steady state conditions, the heat transferred from the microwave power is exactly balanced by the latent heat of water in the POME and the rate of evaporation is given by

$$\frac{\Delta m}{\Delta t} = \frac{1}{L}\left(\frac{\overline{P}}{V}\right) V_s \tag{4}$$

where L is the latent heat, Δm is the mass of water evaporated during period Δt and V_s is the volume of the sample.

Microwave heating and drying phenomena involve very complex physical processes. The prediction of drying profile follows the same technique which has been discussed in detail by the author (Kaida *et al.* 1988). By substituting the physical parameters for POME the prediction of the drying process can be obtained.

The following parameters are needed for the calculation of the variation of mass of the sample with time:

(a) Initial mass of POME
(b) Moisture content of POME
(c) Temperature rise of water with the same mass as POME after 30 seconds of heating.
(d) Specific heat of POME (KJ/kg °C) ~ 4374.89 J/kg °C
(e) Room temperature
(f) Initial temperature of POME (duty cycle)
(g) ON and OFF time (seconds) of the microwave oven at particular power level (duty cycle)
(h) Time interval between every calculation
(i) Dielectric properties of dried POME at 2.45 GHz

$$\varepsilon_p = 1.25 - j0.03$$

Note: The contribution to the dielectric loss due to ionic conductivity must be added to the previous calculation.

MATERIALS AND METHODS

The set-up of the microwave drying system used is shown in *Fig. 2.* A domestic oven (National, NE-6760) operating at 2.45 GHz was attached to the electrical balance to record the variation of mass with time of heating. A metallic fan was incorporated in the oven to distribute the heat evenly inside the oven cavity.

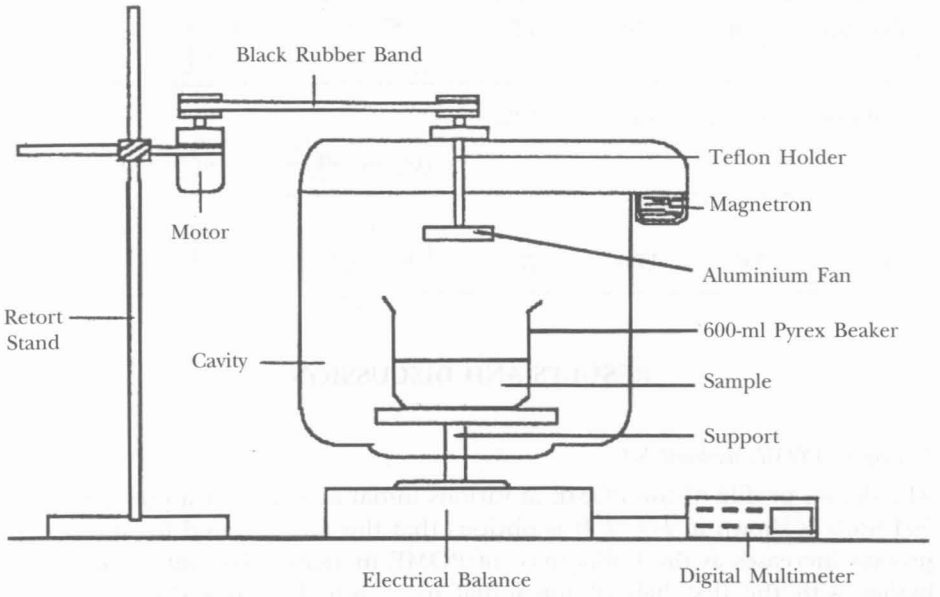


Fig. 2. Modified microwave oven for drying of POME

The oven features four different power settings and their equivalent on-off time is shown in Table 1. In a typical experiment, a sample of POME is held in a 600-ml Pyrex beaker. During the drying process, the changes in mass were recorded at half-minute intervals until about 20% of its initial mass was left.

The experimental data were compared with those calculated from the theoretical prediction. The whole procedure was repeated by adding SiC to the sample. The mass of a piece of SiC is about 20 g. The final part of the experiment involved the measurement of the rate of distillation and the mass of distillate collected at various amounts of SiC and comparison was made with conventional heating with a 500-watt heater. Some modification to the domestic microwave oven was made to attach the conical flask to the condensation tube outside the oven.

TABLE 1
Duty cycle of microwave oven for five different power settings

Power indication	On time t_{on} (sec)	Off time t_{off} (sec)	Duty cycle x 100%	On and Off time in diagram	Average power level (watt)
High	22.0	0.0	100%	on on on on	504
Medium high	19.5	2.5	89%	off off on on on on	448
Medium	17.0	5.0	77%	off off on on on on	357
Medium low	11.5	10.5	52%	off on off on off on off on	245
Low	5.0	17.0	23%	on on on on off off off off	91

RESULTS AND DISCUSSION

Drying of POME without SiC

The drying profile of the POME at various initial mass and at a power level of 504 watts is shown in *Fig. 3*. It is obvious that the time needed for the drying process increases as the initial mass of POME increases. The rate of drying is higher with the first half of the initial mass and decreases slowly with the following half. For example, for the POME with initial mass of 50 g, the rate of drying for the first 25 g is about 6.25 g/min and for the second 25 g is about 3.3 g/min. This is due to the drop in the microwave absorption or rate of evaporation as water content decreases. At the same initial mass, the rate of drying in POME is slightly higher than that of fresh rubber latex with drying rate of 5 g/min. This effect is due to the contribution of the microwave absorption from the ionic conductivity and higher moisture content in the POME.

Fig. 4 shows the drying process for various power settings with initial mass of 50 g. The drying rate at a lower power level (91 watts) is slower then medium, medium high and high. This is mainly due to the duty cycle of the magnetron with longer on-time for medium, medium high and high power settings. The longer on-time of the duty cycle provides a faster drying rate. Both *Fig. 3, 4* show good agreement between theory and experiment.

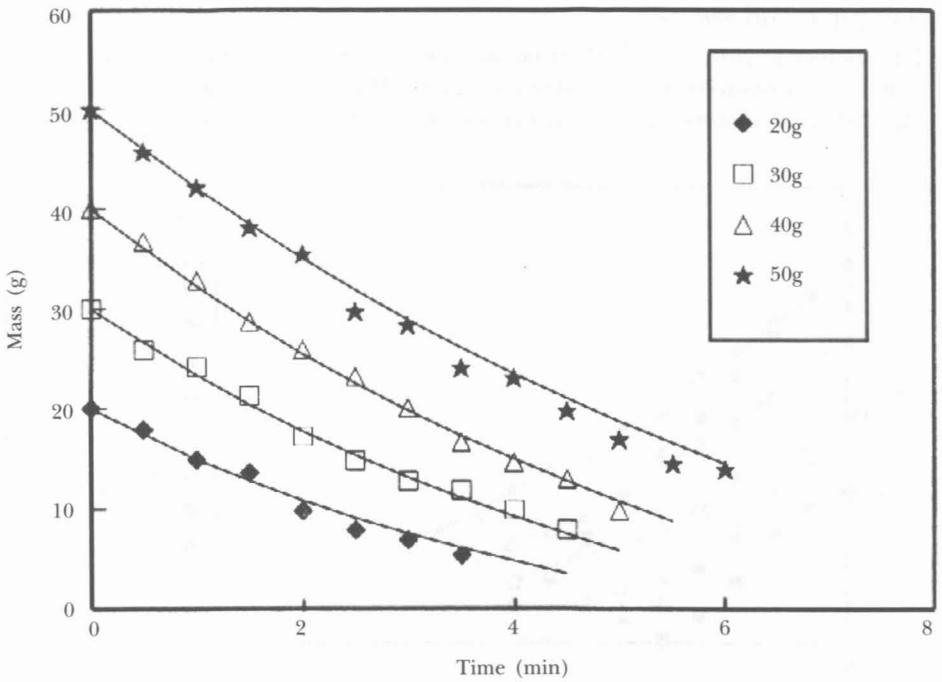


Fig. 3. Relationship between mass and drying time of POME at high power level with different initial masses. Solid lines show the theoretical value.

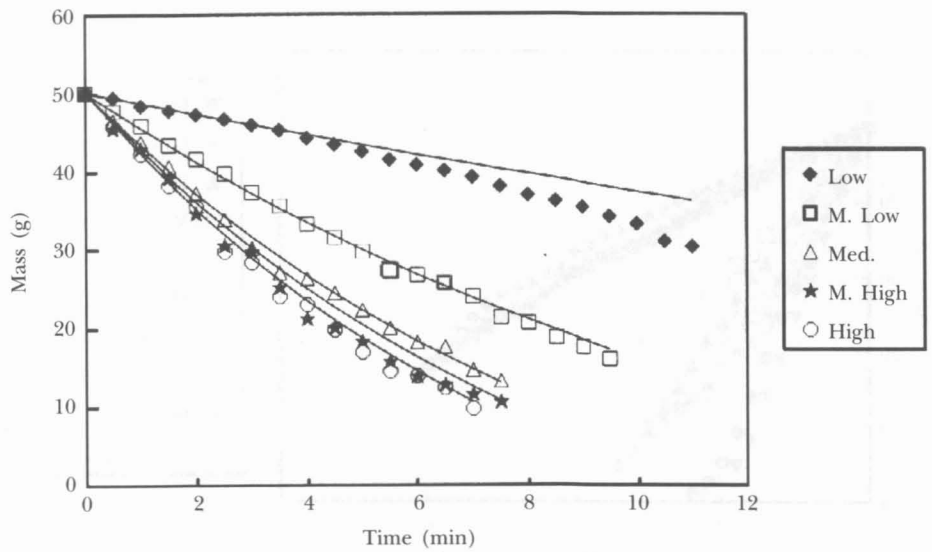


Fig. 4. Relationship between mass and dryig time of POME with 50 gm as initial mass at different power levels. Solid lines show the theoretical value

Drying of POME with SiC

The dielectric propert of SiC used in this experiment is about $\varepsilon = 4.4 - j\ 0.2$ which was measured at 2.45 GHz and 27°C. The graphs of Fig. 5 and 6 show experimental results of drying process with SiC and those without SiC at

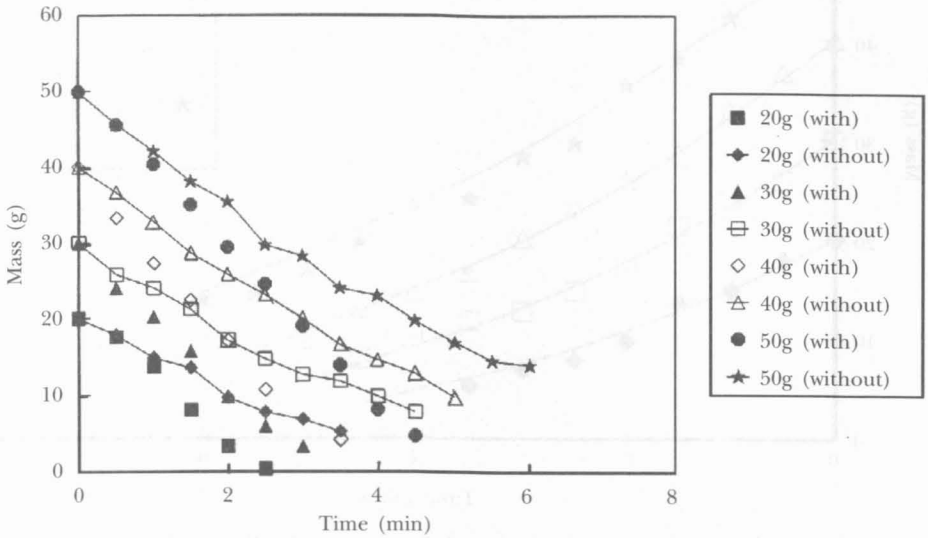


Fig. 5. Relationship between mass and drying time of POME with different initial mass at high power level, with and without SiC

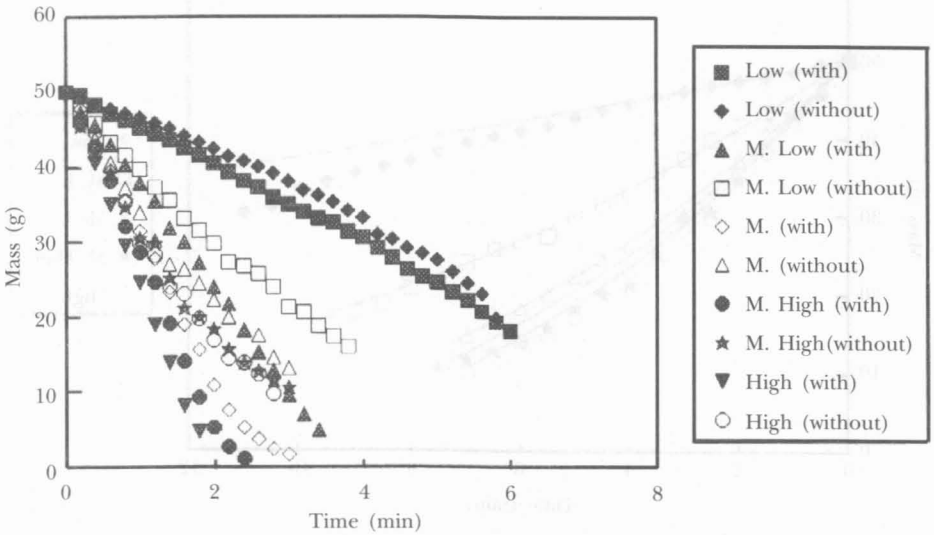


Fig. 6. Relationship between mass and drying time of POME with 50 gm initial mass at different power levels, with and without SiC

different initial mass and at different power levels respectively. From all these graphs it is clear that the time taken by a POME sample with SiC to dry is less than that without SiC. As mentioned earlier, SiC acts as a dielectric material which absorbs microwave radiation and transfers heat to POME with which it is in contact and thus accelerates the drying process.

Referring to *Fig. 6*, at high-power and with initial mass of 50 gms, it takes about 4 min for a sample with SiC to reduce its amount to 10 g. Without SiC, it takes about 7.5 min, which is almost double the drying process.

Fig 7. shows the variation of mass of distillate with time of heating at various amounts of added SiC, with high power level and 30 g of initial mass. It is clear that when the quantity of SiC increases the rate of distillation as well as the mass of distillation increases because the amount of SiC increases the absorption of microwave radiation and consequently increases the thermal effect.

The rate of distillation by microwave heating is higher than the conventional heating method. The time needed to achieve the same amount of distillate using the microwave method is about three times less then the conventional heating method.

CONCLUSION

The performance of microwave treatment of POME clearly shows that this drying technique has great opportunities towards the zero discharge vision for palm oil industries.

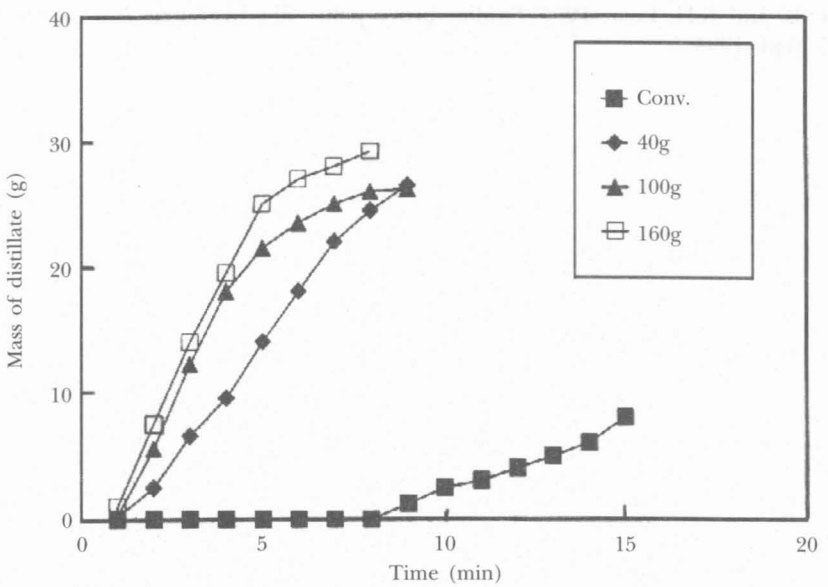


Fig. 7. Comparison between microwave incineration technique with different SiC content and high power level with conventional heating

By adding SiC as a dielectric material to enhance the drying process of POME, the rate of drying is three times that of conventional drying. Obviously, it requires further studies for a large-scale microwave incineration system to cater for the treatment at the industrial mills.

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