

# Low Cost Microwave Plasma Generation System – A Power Analysis study

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## ABSTRACT

In the study of thin film preparation using a low cost microwave induced plasma method, we have carried out calorimetric power analysis in a microwave oven with different loads. The calorimetric calibration was done with various heating loads like coconut oil, engine oil, fruit juice and water. The power consumption of water was higher when compared to other loads. The results show the comparison of thermal properties and heating characteristics of coconut oil, engine oil, fruit juice and water when they are exposed to microwave radiation.

## Keywords

Microwave plasma, calorimetric method, power, Microwave oven.

## 1. INTRODUCTION

Microwave plasma deposition system has several advantages when compared to other deposition systems [1]. Nano structures of various materials like ZnO, SnO<sub>2</sub> etc can be deposited using a low cost microwave induced plasma deposition system developed from a domestic microwave oven. A quartz tube inside the chamber of the oven acts as the applicator which when exposed to microwaves generates a plasma within the tube. Plasma is formed by the interaction of microwaves with the gases at appropriate low pressure inside the quartz tube. Pressure inside the quartz tube can be adjusted using a vacuum system. Vacuum system consists of a Rotary vacuum pump, vacuum lines, valves and Pirani gauge. For microwave power calibration inside the chamber, we adopted calorimetric calibration method with various types of heating loads such as coconut oil, engine oil, fruit juice and water. We followed the International Standards set by IEC 705(1988) [2]. This standard gives a relation between microwave power applied and increase of temperature in loads, as

$$P = \frac{\Delta T \times V \times C \times \rho}{t}$$

where,

P: Microwave power consumption in watts.

V: Volume of load within the cavity in mL

C: Specific heat capacity in kJ/kg.K

$\rho$ : Density of the fluid in kg/m<sup>3</sup>

t: Time of heating in seconds.

$\Delta T$  : Mean temperature rise in Kelvin

## 2. EXPERIMENT DETAILS

The equipments and materials used are:

- Microwave oven: - Whirlpool Magic cook 20S, 2.45GHz microwave oven with supply voltage 230V/50Hz, and rated input 1100W. Output power consumption 700W, 20L cavity volume, Cavity dimensions, 196x292x295 mm.
- Dimmer stat: - Supply voltage variation can affect the magnetron output power. To prevent such fluctuation we need to use dimmer stat which fixes the supply voltage at rated level.
- Calorimetric calibrations were carried out using equipments such as thermometers, borosil glass beaker and stop watch.
- The containers used for the experiment are borosil glassware. Weight of the glass beakers used is as follows. Small beaker 67.834 g (140ml), Medium Size beaker 105.563g (200ml), Large sized beaker 163.444g (400ml). Plastic containers (polypropylene PP) round and angular shape.
- Engine oil (HP racer 2T), virgin coconut oil Rasna fruit juice concentrate and water.

Fig.1 shows the block schematic of the plasma deposition unit. The domestic microwave oven was set to act as a low cost plasma deposition unit by inserting a cylindrical quartz tube through the heating cavity of the microwave oven [9].

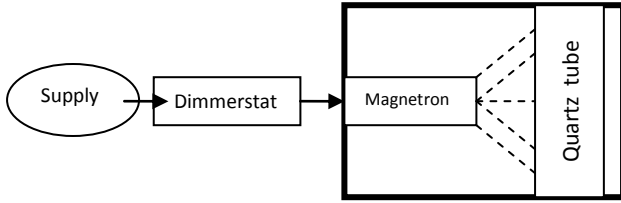


Fig.1 Block schematic of the plasma deposition unit.

### A. Procedures for calorimetric power analysis on heating loads.

- Take V ml of the heating load in a borosil glass beaker. Stir the beaker contents for 20 seconds and record the initial temperature ( $T_1$ ) using thermometer in degree Celsius scale [3].
- Dimmerstat is varied for obtaining the rated voltage of the oven.
- Place the container at the centre position of the oven.
- Switch on the oven, and heat the load for time 't' seconds.
- After 't' seconds oven is switched off and the beaker is taken out carefully.
- Stir the contents for 20 seconds. And find the final temperature ( $T_2$ ).

The output power is determined by the equation [3]

$$P = \frac{(M_f C_{p-f} + M_g C_{p-g}) \Delta T}{t}$$

where,  $M_f$  and  $M_g$  are the mass of the fluid and the beaker respectively.  $C_{p-f}$  and  $C_{p-g}$  are the specific heats of the fluid and beaker respectively.  $\Delta T$  is the rise in temperature and t is the time in seconds.

## 3. RESULTS AND DISCUSSION

The average power absorbed for various values of load parameters were calculated. Magnetron input voltage was kept at the rated voltage of 230V 50Hz by the dimmer stat. Power absorbed was calculated using the IEC 705 formula.

### A. HEATING LOAD 1: Power absorbed with heating load as Coconut oil.

Weight of 100ml of coconut oil is 88.766g. Specific Heat of coconut oil is 1.67 KJ/kgK.

Table.1 Power analysis of 50ml Coconut oil as heating load with heating time of 60 seconds.

$m_f = 44.38g$ $c_f = 1.67KJ/KgK$ $m_g = 67.834g$ $c_g = 0.74J/KgK$ .				
Sl. No	Initial Temp(C)	Final Temp(C)	$\Delta T$	Power-W
1	29	125	96	198.899
2	29	123	94	194.755
3	29	124	95	196.827
Avg Power				196.827

Table.2 Power analysis of 100ml Coconut oil as heating load with heating time of 120 seconds.

$m_f = 88.766g$ $c_f = 1.67KJ/KgK$ $m_g = 67.834g$ $c_g = 0.74KJ/KgK$				
Sl. No	Initial Temp(C)	Final Temp(C)	$\Delta T$	Power-W
1	28	185	157	259.621
2	28	190	162	267.889
3	28	187	159	262.928
Avg Power				263.479

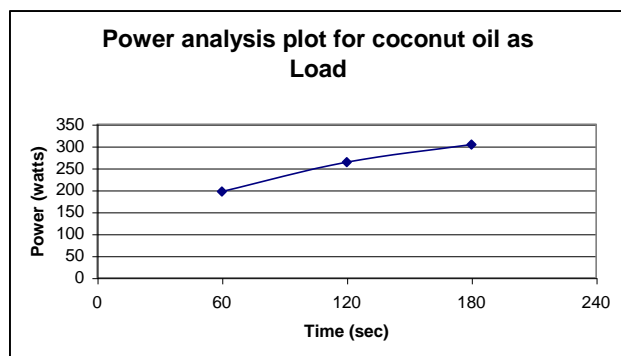
Table.3 Power analysis of 150ml Coconut oil as heating load with heating time of 180 seconds.

$m_f = 133.149g$ $c_f = 1.67KJ/KgK$ $m_g = 105.563g$ $c_g = 0.74KJ/KgK$				
Sl. No	Initial Temp(C)	Final Temp(C)	$\Delta T$	Power-W
1	27	210	183	305.483
2	28	208	180	300.475
3	27	210	183	305.483
Avg Power				303.814

**Table 4: Final average values of analysis of coconut oil.**

Time	Power In watts
60seconds	196.827
120 seconds	263.479
180 seconds	303.814

**Fig.2 shows the average power analysis graph for coconut oil as heating load with variable quantity and time.**



**Fig.2 Average power analysis for coconut oil.**

Vegetable oils are perceived to be alternatives to mineral oils as base oils for industrial lubricants due to growing environmental concerns. Vegetable oil based lubricants offer significant environmental benefits with respect to resource renewability, low toxicity, and provide satisfactory performance in a wide array of applications [4],[5]. Vegetable oils in general have excellent properties such as high viscosity index, high lubricity, high flash point, and low evaporative loss with regard to their use as base oils for lubricants. On the negative side, they are known to possess low thermal, oxidative and hydrolytic stabilities and poor low temperature characteristics. Vegetable oils are also found to be temperature sensitive in the case of tribological properties especially at high temperatures. Some of the important base oil properties of industrial lubricants are viscometric, physico-chemical, tribological, oxidative, thermal, hydrolytic, corrosion and low temperature properties.[4,5,6]. The poor cold flow properties of vegetable oils can be attributed to their unique molecular structure, namely, triacylglycerol structure [5]. Vegetable oils have a tendency to form macro crystalline structures at low temperature through uniform stacking of 'bend' triacylglycerol backbone. Such macro crystals restrict the easy flow of the system due to loss of kinetic energy of individual molecules during self stacking. The predominantly saturated fatty acid content of certain tropical oils like coconut oil compounds the problem further. This is attributed to close

packing of the saturated fatty acid chains in triacylglycerols. During heating process these chain distance increases, so the power absorbed increases.

**B. HEATING LOAD 2: Power absorbed with heating load as Engine oil.**

Weight of 100ml of Engine oil is 91.3gm. Specific heat capacity of Engine oil is 2.09 KJ/kgK.

**Table.5 Power analysis of 50ml Engine oil as heating load with heating time of 60 seconds.**

m <sub>f</sub> = 45.65 g      c <sub>f</sub> = 2.09K J/KgK				
m <sub>g</sub> = 67.834g      c <sub>g</sub> = 0.74 KJ/KgK				
Sl. No	Initial Temp(C)	Final Temp(C)	ΔT	Power-W
1	29	38	9	21.841
2	29	39	10	24.268
3	28	38	10	24.268
Avg Power				23.459

**Table.6 Power analysis of 100ml Engine oil as heating load with heating time of 120 seconds.**

m <sub>f</sub> = 91.3 g      c <sub>f</sub> = 2.09 KJ/KgK				
m <sub>g</sub> = 67.834 g      c <sub>g</sub> = 0.74 KJ/KgK				
Sl. No	Initial Temp(C)	Final Temp(C)	ΔT	Power-W
1	29	48	20	40.169
2	28	49	21	42.177
3	28	49	23	46.194
Avg Power				42.847

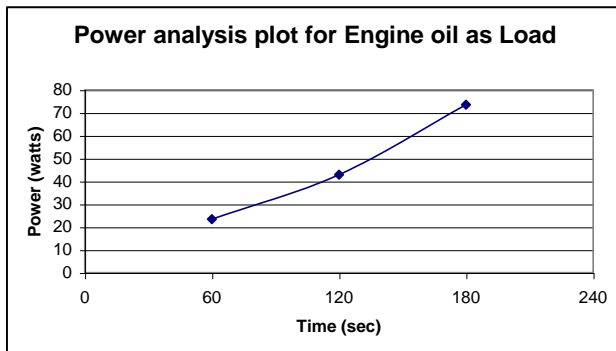
**Table.7 Power analysis of 150ml Engine oil as heating load with heating time of 180 seconds.**

$m_f = 136.95 \text{ g}$ $c_f = 2.09 \text{ KJ/KgK}$ $m_g = 105.563 \text{ g}$ $c_g = 0.74 \text{ KJ/KgK}$				
Sl. No	Initial Temp(C)	Final Temp(C)	$\Delta T$	Power-W
1	29	69	40	80.965
2	28	68	40	80.965
3	29	67	38	76.917
Avg Power			79.616	

**Table.8 Final average values of analysis of Engine oil.**

Time	Power in watts
60 seconds	23.459
120seconds	48.847
180 seconds	79.616

**Fig.3 shows the average power analysis graph for Engine oil as heating load with variable quantity and time.**



**Fig.3 Average power analysis for Engine oil.**

Most motor oils are made from a heavier, thicker petroleum hydrocarbon base stock derived from crude oil, with additives to improve certain properties. One of the most important properties of motor oil in maintaining a lubricating film between moving parts is its viscosity [7]. The viscosity of a liquid can be thought of as its "thickness" or a measure of its resistance to flow. The viscosity must be high enough to maintain a lubricating film, but low enough that the oil can flow around the engine parts under all conditions. The viscosity index is a measure of how much the oil's viscosity changes as temperature changes. A higher viscosity index indicates the viscosity changes less with temperature than a lower viscosity

index. Depending on the performance of the oil, engine oil is classified into two-single grade oil and multi grade oil. Single grade engine oil is used in low capacity engine. Single step engine oil doesn't have viscosity modifiers. As a result of the polymeric additives in the multi grade engine oil, the heat absorption changes. The rise in power absorption of the engine oil as heating load is lower when compared to other heating loads on account of the additives which are added (Viscosity Modifiers).

### C. Heating Load 3: Power absorbed with heating load as fruit juice.

Weight of 100ml of fruit juice is 100g. Specific heat capacity of fruit juice 3.93 KJ/KgK.

**Table.9 Power analysis of fruit juice concentration of 0.2g/ml with heating time of 45 seconds.**

$m_f = 0.06 \text{ Kg}$ $c_f = 3.93 \text{ KJ/KgK}$ $m_g = 0.067 \text{ Kg}$ $c_g = 0.74 \text{ KJ/KgK}$				
Sl. No	Initial Temp(C)	Final Temp(C)	$\Delta T$	Power-W
1	32	94	55	288.261
2	33	95	54	283.02
3	28	94	54	283.02
Avg Power			284.767	

**Table.10 Power analysis of fruit juice concentration of 0.4g/ml with heating time of 45 seconds.**

$m_f = 0.07 \text{ Kg}$ $c_f = 3.930 \text{ KJ/KgK}$ $m_g = 0.067 \text{ Kg}$ $c_g = 0.74 \text{ KJ/KgK}$				
Sl. No	Initial Temp(C)	Final Temp(C)	$\Delta T$	Power-W
1	33	88	66	403.554
2	32	90	67	409.668
3	33	91	66	403.554
Avg Power			405.592	

**Table.11 Power analysis of fruit juice concentration of 0.6g/ml with heating time of 45 seconds.**

$m_f = 0.08 \text{ Kg}$ $c_f = 3.930 \text{ KJ/KgK}$ $m_g = 0.067 \text{ Kg}$ $c_g = 0.74 \text{ KJ/KgK}$				
Sl. No	Initial Temp(C)	Final Temp(C)	$\Delta T$	Power-W
1	29	95	69	482.157
2	28	96	70	489.145
3	29	96	70	489.145
Avg Power				486.816

Table.12 Final average values of analysis of Fruit Juice.

Concentration	Power In watts
0.2g/ml	284.767
0.4g/ml	405.592
0.6g/ml	486.816

Fig.4 shows the average power absorption characteristics of fruit juice with varying concentration.

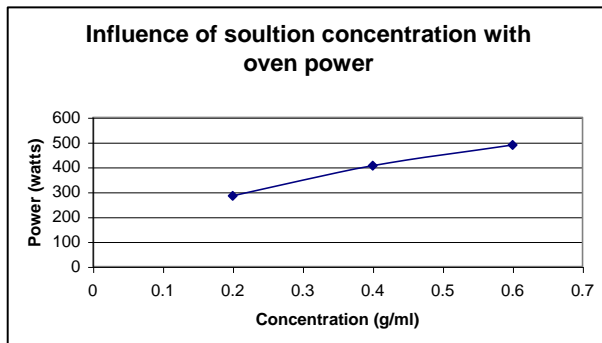


Fig.4 Average power analysis for fruit juice

The susceptibility of a load to heating in a microwave oven depends on many factors probably connected with both the load parameter and the oven characteristics. The value of the microwave power absorbed in the unit volume of heated load ( $P_v$ ) is described theoretically according to BUFFLER by equation below [2].

$$P_v = 2 \times \pi \times f \times \epsilon_0 \epsilon'' |E|^2$$

$P_v$  – power absorbed in the unit volume of load ( $\text{W/m}^3$ )

f- Microwave frequency

$\epsilon_0$  – permittivity of free space.

$\epsilon''$  - dielectric loss factor of the load.

E- Strength of the electric field inside of the load ( $\text{V/m}$ ).

Since the microwave frequency (2450MHz) and permittivity of free space ( $10^{-9}/36\pi \text{ F/m}$ ), the remaining parameters in the equation are related both to the load and to the oven(E).

The variation of the solution power absorption is in line with the expectation of the BUFFLER's equation. The change in concentration changes the dielectric properties of the solution. The change in dielectric influences the heating characteristics [8].

#### D. Heating Load 4: Power absorbed with heating load as water.

Different quantity of water was tested for heating time of 120 seconds. The specific heat capacity of water is  $4.2 \text{ kJ/kg.K}$ .

Table.13 Power analysis of 2L water heating time of 120 seconds.

Sl No	Initial Temp	Final Temp	Power-W
1	27.5	35.5	558.266
2	27.5	35	523.375
3	27.5	36	593.1583
Avg power			558.27

Table.14 Power analysis of 1.5L water heating time of 120 seconds.

Sl No	Initial Temp	Final Temp	Power-W
1	27.5	37.5	523.375
2	27.5	38	549.543
3	27.5	37	497.2065
Avg power			523.375

Table.15 Power analysis of 1L water heating time of 120 seconds.

Sl No	Initial Temp	Final temp	Power W
1	27.5	42	505.921
2	27.5	42	505.921
3	27.5	42.5	523.375
Avg Power			511.744

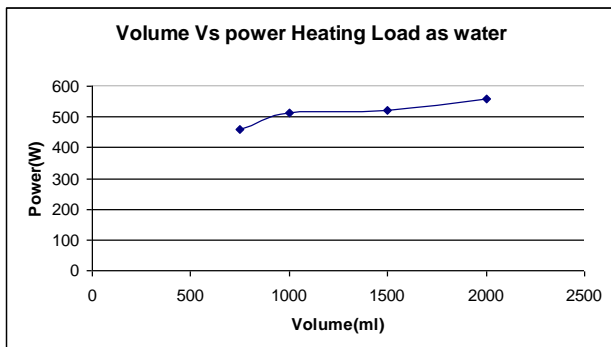
**Table.16 Power analysis of 0.75L water heating time of 120 seconds.**

Sl no	Initial Temp	Final Temp	Power W
1	27.5	45	457.953
2	27.5	45	457.953
3	27.5	45	457.953
Avg power			457.953

**Table 17. Final average chart for power analysis with water as the heating load.**

Sl no	Volume ml	Power –w
1	750	457.953
2	1000	511.744
3	1500	523.375
4	2000	558.266

**Fig.5 shows the Power Vs Volume plot characteristics with water as heating load.**



**Fig.5 Power Vs Volume plot characteristics with water as heating load.**

As the volume increases the power absorption capability of the medium also increase. The plot of the power vs volume is having a positive slope.

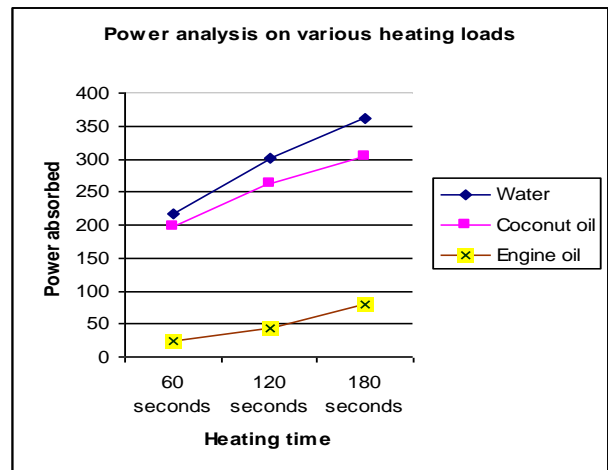
**E. Comparison of various heating loads.**

Table 18 shows the comparison of average values of power absorbed by various heating loads in different time.

**Table 18. Final average chart for power analysis with various load and time.**

Time In seconds	Power in watts for water	Power in watts for coconut oil	Power in watts for engine oil
60	216.205	196.827	23.459
120	301.36	263.479	48.847
180	360.322	303.814	79.616

**Fig.6 shows the power analysis graph for time Vs average absorbed Power for various heating loads such as water, coconut oil, and engine oil.**



**Fig.6 Time Vs average absorbed power for various heating loads**

**4. CONCLUSION**

Various heating loads like water, coconut oil, engine oil and, fruit juice were analyzed for power consumption. It was found that absorbed power varies with type of heating load.

Among the two oils, Coconut oil exhibited 50% increase and engine oil 300% increase in absorbed power as time of exposure to microwave was increased from 60 to 180 seconds. Power absorption of coconut oil goes to a steady value as time elapses, whereas engine oil does not exhibit this saturation tendency within the time frame of the experiment. Engine oil maintains a linear power - temperature relationship. On the other hand the overall power absorption by engine oil is very much less compared to an equal mass of coconut oil. These points are particularly interesting especially in the scenario of recent efforts to develop eco friendly engine oils using vegetable oils. In this experiment it was observed that water load exhibits largest absorption. This is due to the fact that microwave energy corresponding to the frequency 2.45GHz is absorbed very well by polar water molecules which results in efficient dielectric heating than many other molecules. Power absorption by water more or less saturates above a volume of 1L. This implies that minimum 1L volume of water load is required for efficient energy transfer between the microwave source and load. An important observation made in the case of fruit juice is that as the concentration increases the power absorption increases. This is due to the reason that when the solution concentration changes, the dielectric property changes which in turn changes the power absorption. Another reason for this can be that as the solute concentration increases the quantity of heat transferred between water molecules and solute molecules increases which in turn increases the power absorption.

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