

Measurement of Systemic Power Efficiency of Microwave Heating Application

Yi He, Nutdechatorn Puangngernmak, Suramate Chalermwisutkul

Abstract—Microwave heating process has been developed about sixty years while measurement system has also progressed. Because of irradiation of high frequency of microwave, researchers have been utilized many costly technical instrument measuring parameters to evaluate the performance of microwave heating system. Therefore, this paper is intended to present an easier and feasible efficiency measurement method. It can help inspecting efficiency of microwave heating system with good accuracy, while the method can also give reference to optimizing procedure for microwave heating system for various load material.

Keywords—Measurement, Microwave heating, Systemic power efficiency

I. INTRODUCTION

MICROWAVE heating system is not only applied as household appliance, also widely used in industrial areas in these days, such as food industry, environment treatment, medical treatment and chemical process.

Microwave heating uses microwave energy to process material. Microwave is a very short wave of electromagnetic energy, which frequency is 300MHz to 300GHz. In order to get microwave energy, household AC power is converted to a pretty higher DC voltage and high current. Magnetron, the generator of microwave energy, will generate the required 2450MHz of microwave energy by using such higher voltage, which is widely used for microwave heating in most countries; 915Hz is another option in some countries. The rapid change of electromagnetic field goes through water molecules or moisture of material to affect water molecule, which is polar molecule, oscillating along with changes of the external electric field with high speed, since different polarity molecules would orientate with proper polarity in the electromagnetic field. Such motion causes molecule friction, which takes place millions of times each second. Hence, the microwave energy can be converted to heat energy in medium to raise the temperature of materials. Accomplishing heating, puffing and a series of physical and chemical processes, and so, microwave heating is achieved. Throughout the entire microwave heating processing, energy must go through two times of energy transformation, which includes electric energy transformation to microwave energy and microwave energy transforms to heat energy.

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In these days, all industries aim to decrease product cost. Energy saving is a major issue in the production chain. However, microwave energy is a special energy source that could cause unexpected disaster to human health. Thus, it is critical to measure performance of microwave heating system while it is working.

To give an explicit measuring systemic power efficiency of the microwave heating system, this paper presents a feasible systemic power efficiency measurement method for microwave heating system, which allows use the results of measurement as a reference to optimize the procedure of processing material.

II. MEASUREMENT OF MECHANISM

Because of irradiation during microwave heating system operation, delicate measurement instruments are required to secure safety of operators from radiation harm. And security protection is demanded, too. These requirements are not affordable for all users. In order to carry out measurement, we separate the whole system to three parts, as shown in Fig.1, so that we can use common instruments to complete a measurement and protect operator from harm. The procedure also meets the demand of accuracy.

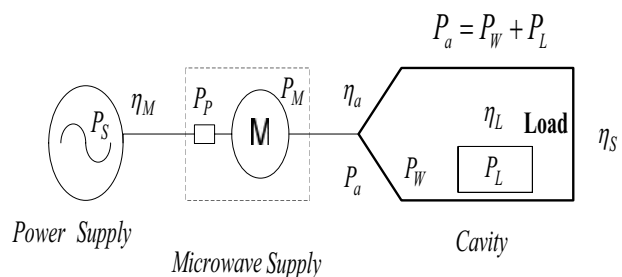


Fig. 1 Diagram of measuring parameters of different sections of microwave heating system

A. Power Supply

Electric energy is from the utility power system. P_s , here as incident power, is delivered into the microwave heating system, is given by

$$P_s = \frac{1}{T} \int_0^T v(t)i(t)dt \quad (1)$$

B. Microwave Energy

Microwave energy P_M is generated by magnetron, which is supported by peripheral circuit and transformers. During this operation, part of transmitted energy is absorbed by peripheral circuits and transformers, which is first energy loss in the

heating system. The more peripheral circuit and heavy transformers, the more energy was absorbed. So that appropriate circuit design is an important concern.

$$P_s = P_M + P_p \quad (2)$$

Since the transformer is made of lossy ferrite material, so that it is a major energy absorption object in this part, an energy loss is considerable high along with microwave heating operation. Electronic circuit consumption is smaller by comparison with transformer. P_p indicates the sum of these losses. Measuring the condition of a magnetron is difficult when it is working. It is a flaw of this measurement. It cannot be overcome without advanced instrument. So we use rated power of specification of magnetron to indicate magnetron's output power. η_M is to indicate power efficiency in this part. It means how much power is transformed to microwave energy in this part. It is described by

$$\eta_M = \frac{P_M}{P_s} \quad (3)$$

C. Heat Energy

Delivered microwave energy is transmitted to cavity through waveguide. Here, VNA (Vector Network Analyzer) is used to measure S11 to know how much power was reflected back to the magnetron, indicated by P_r . In common cases, small proportion of energy is reflected back to microwave generator via energy transmission path. It could be negligible with good matching design. To evaluate energy loss during the heating operation, the experiment also considers this loss. This step could be done before performing the measurement. Inside the cavity, microwave energy is absorbed by two parts of object and transformed to heat energy, which includes metallic wall of cavity, other protection metallic objects and the material that we want to process. Absorbed power would be indicated by P_w , P_L , P_a , which are wall absorption, material absorption and cavity absorption, respectively. Their relations are shown by

$$|S_{11}|^2 = \frac{P_r}{P_M} \quad (4)$$

$$P_a = P_M - P_r \quad (5)$$

$$P_a = P_L + P_w \quad (6)$$

$$P_L = \frac{CM\Delta T}{\Delta t} \quad (7)$$

$$\eta_L = \frac{P_L}{P_a} \quad (8)$$

From equations above, user can know how much energy losses on the metallic objects during the energy transformation of microwave energy to heat energy. Thus, properly choosing material for cavity and other metallic objects could incite designers to take this energy loss into account.

D. Systemic Power Efficiency

Systemic power efficiency is easy to get via the material absorption energy divided by the supply power, as shown below:

$$\eta_s = \frac{P_L}{P_s} \quad (9)$$

Thus from above equations we get a simple relation:

$$\eta_s = \frac{CM\Delta T}{\Delta t} \cdot \frac{1}{T} \int_0^t v(t)i(t)dt \quad (10)$$

We can reduce more complex measurement for the heating system to make this method practicable, while we assure to get better accuracy. Thus, we need to consider some technical problems that could cause accuracy compromise.

III. MEASUREMENT PROCEDURE OF MICROWAVE HEATING

To ensure data from different part of heating system would be collected in real-time. The measurement design has a software interface to complete this task. A simplified diagram is shown below.

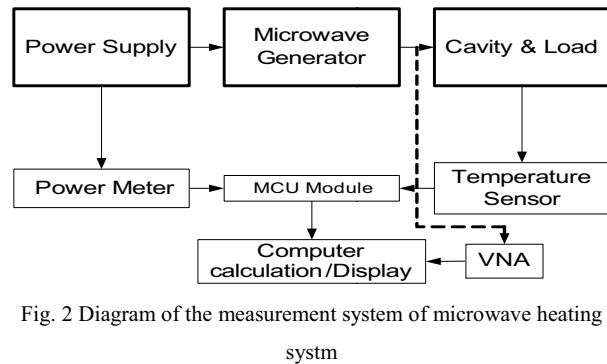


Fig. 2 Diagram of the measurement system of microwave heating system

The measurement process uses Microcontroller module to collect data of supply power in real time from power meter and temperature of heated material before and after heating operation. This could keep user far away from the heating system in order to prevent potential microwave radiation damage. Using VNA measures S11 of tested cavity before the measurement starting corresponding to different volumes of load. Then, values of S11 are saved into computer memory for calculation. Computer collects data and calculation to produce measurement record. Due to different evaluation standard, experiments could choose benchmark of fixed heating time, or approximate end temperature of the heated object, or

temperature rising rate of the heated material in the fixed time interval. Measurement results can be presented as a table with all results, or be displayed as a graph of average temperature of the heated object, supply power and other forms of displaying method by using computer programming.

Due to communication delay between MCU and computer and computing delay in the computer program, we need to calibrate this to prevent measurement error.

IV. EXPERIMENT EXAMPLES

The experiment of measurement system of microwave heating system uses water as load to demonstrate measurement procedure and calibration operation of a commercial microwave heating system, which uses Samsung magnetron OM75S that rated power is 800W. The heating system is multiple mode cavity, which dimension is $30.5 \times 28 \times 18.8$ centimeter. To demonstrate different application, experiment was carried on a lab-made heating system. It has two magnetrons of rated power 800W from LG 2M214. The cavity's dimension is $61.5 \times 31.5 \times 50$ centimeter. Experiment sets room temperature between 20~25 Celsius degree and the start temperature of water load between 20~25 Celsius degree as environment of heating operation.

For commercial heating system, water load of 500ml placed in beaker was heated in different time. For lab-made heating system, water load of 5 liter placed in the cavity. And experiment repeats all same procedures for commercial one on it.

Water is a good absorption object. Usually, it is used as load to evaluate performance of microwave heating system. Its specific heat could be considered, which would change with temperature rise. But the change is smaller, which would not affect accuracy much.

Measurement results are shown in Figure 3 to Figure 8. They are calculated by equations (9) and (10). All parameters needed are from equation (1) ~ (8). It displays that power efficiency of same volume of load is decreasing while the heating time is increasing. Meanwhile, temperature of load is increasing. The lower volumes of water load, the lower the power efficiency. The increasing temperature per minute keeps approximate stable corresponding to specific material. Power efficiency decrease. It notes that convection of the heat energy from microwave energy to cavity metallic walls is increased.

The measurement system can also give some advices to user, except technical support about the microwave heating system. Measurement system could give some sense about how much power energy would be consumed on certain load and how much energy loses in each part of microwave heating system. User can design an optimum processing method to process material depends on results of the measurement.

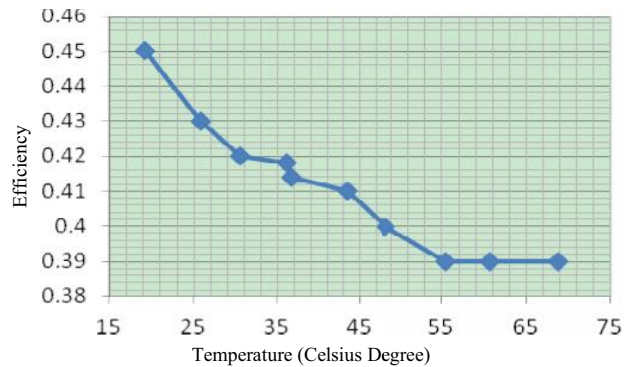


Fig. 3 Systemic Power Efficiency of the Microwave heating system as a function of the rising temperature measured as 0.5 liter of the water was heated

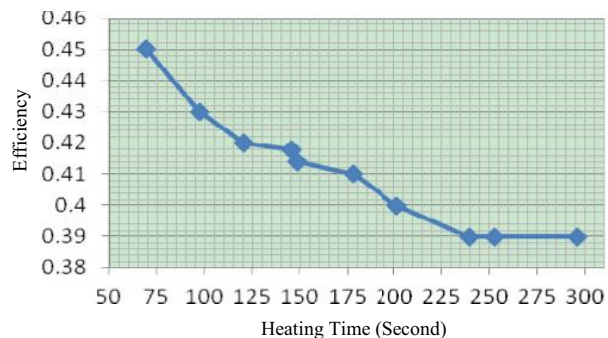


Fig. 4 Systemic Power Efficiency of microwave heating system as a function of the heating time after 0.5 liter of the water was heated

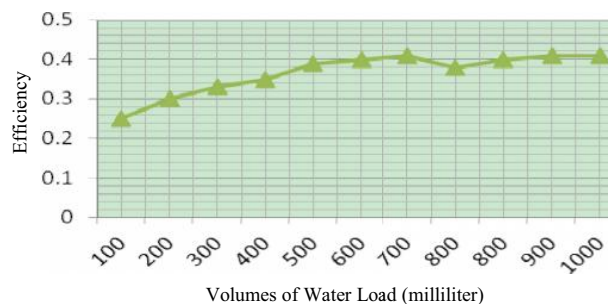


Fig. 5 Systemic Power Efficiency of the Microwave heating system as a function of different volumes of the water was heated.

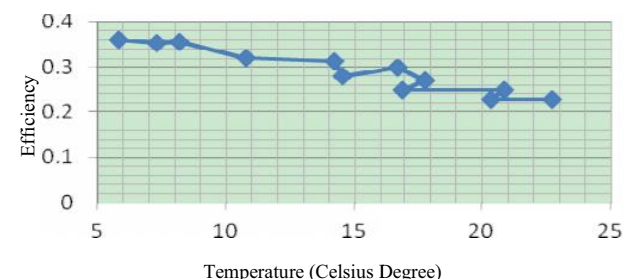


Fig. 6 Systemic Power Efficiency of the Microwave heating system as a function of the rising temperature measured as 5 liter of the water was heated in lab-made system

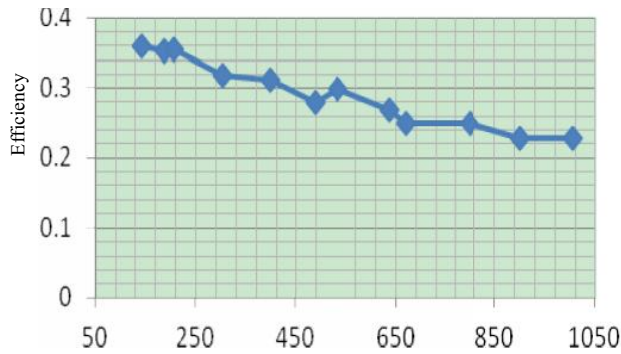


Fig. 7 Systemic Power Efficiency of microwave heating system as function of the heating time after 5 liter of the water was heated in lab-made system

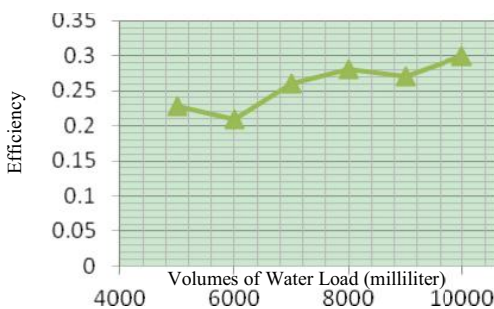


Fig. 8 Systemic Power Efficiency of microwave heating system as function of different volumes of the water load was heated in lab-made system

V. CONCLUSION

Systemic power efficiency of the microwave heating system is not a constant value and depends on many factors, such as the temperature and mass of material, position of material in the cavity and characteristic of material. Therefore, we need repeat measurement many times with water load to calibrate the system. This paper is presenting a method that is feasible and practicable in the field. It can help users rapid and relatively accurate to know power consumption of the microwave heating system without more microwave knowledge. Meanwhile, the method would help user to make an optimum method to process material.

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