CHAPTER I. Introduction

Heating of materials is required for many processes used in industry, such as curing, thawing, tempering, drying, and sintering. Microwave processing is a method that is relatively new in industrial applications and is being tested for these processes. The concept behind microwave heating is that the microwaves penetrate the material and vibrate the polar molecules at high frequencies, producing energy in the form of heat.

Microwave processing of ceramics, composites and polymers is being studied as an alternate to conventional heating. Microwave processing offers many advantages over conventional heating. In conventional heating, the surface of the material is heated, and the heating of the interior is induced by conduction. This may cause large temperature gradients which in turn may lead to inferior properties. Smaller temperature gradients often occur for microwave heating since the microwaves penetrate the surface to produce more uniform and volumetric heating. Rapid heat transfer and shorter processing times are other benefits of microwave processing. Also, no pollution is created locally since there are no combustion products. Another advantage is the quickness that microwave heating can be turned on or turned off by varying the applied electric field in contrast to the long lag times which occur when using thermal heating. These characteristics are promising, but further study and experimentation are required before microwave energy can be used as a major source of heating outside of home cooking.

The research reported in this thesis is a continuation of the research that Wilfried Duchez performed [1] as a graduate student with Dr. James R. Thomas Jr. at Virginia Tech in 1996. He developed a one-dimensional thermal model for heating of zirconia or alumina fibers or rods traveling through a microwave applicator. His objective was to determine conditions necessary to stabilize the fiber at high enough temperatures for a long enough time so that the heating process would allow the required physical transformation. This was to be done while avoiding thermal runaway.

The objective for this research is to develop a model which accurately reproduces experimental results and thus can be used to explore new applicator designs. Instead of a one-dimensional model, a two-dimensional model was created to accounts for temperature variation along the radius of the sample. This improvement is necessary for thicker rods where the one-dimensional analysis may be less accurate. Along with the alumina and zirconia studied by Duchez, an additional ceramic, mullite, was added to the model and a more accurate value for the convection heat transfer coefficient is used. The simulated results are compared to results of experiments performed at the Los Alamos National Laboratory (LANL) [11].

The difficulty in maintaining high temperatures without thermal runaway stems from the temperature dependence of the dielectric loss coefficient, ε'', that appears in the heat source term of the heat conduction equation given by

$$\dot{q} = 2\pi f \varepsilon_o \varepsilon''(T) |E|^2 . \quad (1)$$

The dielectric loss coefficient for ceramics generally increases with temperature. As a ceramic becomes hot, the dielectric loss increases which in turn increases the volumetric heating. Since the volumetric heating increases, the material becomes even hotter which increases the value for the dielectric loss even more. This process quickly leads to what is called thermal runaway, an effect which causes the material to quickly melt.

The heat source is also dependent on the electric field strength, E. This research will examine how the electric field must vary in order to hold the absorbed power constant. Holding the absorbed power constant proved to be a method to overcome thermal runaway problems. A model is used to produce this data as accurately as possible.

This thesis outlines the development of a model used to simulate an actual heating experiment performed at LANL [12]. Parameters and physical properties are described, and the results of microwave heating of 2mm and 4.67mm diameter mullite rods ($3Al_2O_3$-$2SiO_2$) are summarized and plotted. The results show that for both cases of mullite, temperatures above 1200°C can be obtained by controlling the absorbed power. Finally the simulated results are compared to the experimental data, and it is shown that the data match qualitatively.