CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Micro tubular coil heaters have been widely investigated because of their extensive applications in PET (PolyEthylene Terephthalate) preformed moulds, hot runner nozzles and bushings, thin walled container moulds and other microsystems. Micro tubular coil heaters are made as rectangular, square and circular sections, with or without built-in thermocouple. The features of these heaters are 360° heated area, readily confirms to surface, fast response and quick heat transfer, helical coil design for superior performance, good resistance to corrosion and it can easily be coupled with J or K type thermocouple. The helical wound heating wire is made of a high temperature resistant Ni/Cr alloy. The insulation consists of superior grade Magnesium Oxide (MgO).

As the heaters are swaged, they have excellent electrical insulation and high heat transfer even at high sheath temperatures. The experimental investigation of Nichrome micro tubular coil heater proved that it is suitable for low temperature applications and alternate materials for micro tubular coil heaters are to be identified for medium and high temperature applications.

An attempt was made to study the various aspects of micro tubular coil heating such as heater coil geometry, rupture temperature of the heater and other related process parameters.
1.2 ROLE OF NICHROME FOR MICRO TUBULAR COIL HEATER

Nichrome is a non-magnetic alloy of Nickel, Chromium, and often Iron, usually used as a resistance wire. A common alloy is 80% Nickel and 20% Chromium, by mass, but there are many other materials to accommodate various applications. It is silvery-grey in colour, corrosion-resistant, and has a melting point of about 1400 °C (2552 °F). Due to its relatively high electrical resistivity and resistance to oxidation at high temperatures, it is widely used in electric heating elements.

Typically, Nichrome is wound in coils to a certain electrical resistance, and current is passed through it to produce heat. Due to its ductility and strength at high temperature, Nichrome 80/20 is especially suitable for applications in the electrical appliance industry. In industrial furnace, use of Nichrome 80/20 has many advantages due to its excellent mechanical properties in the hot state. Nichrome 80/20 has superior life compared to competitive Ni-Cr alloys because of extremely good adhesion properties of the surface oxide.

Typical applications for Nichrome 80/20 are ironing machines, water heaters, soldering irons, metal sheathed tubular elements, cartridge elements and so on. Presently, the micro tubular coil heater wires are manufactured using Nickel-Chrome alloys, which are resistant to high temperatures. 80/20 Nickel-Chrome alloys containing long life additions, making it eminently suitable for applications such as resistance wire, which is subject to frequent switching and wide temperature fluctuations.

A relatively low temperature coefficient of resistance with a high resistivity makes it suitable for control resistors and heating element for tubular heaters. Nichrome wire is almost 100% efficient in converting
electrical energy into heat. Due to increase in resistivity with the reduction in cross sectional area, its operating temperature is limited to 900 °C, which is very low for most of the heating applications. In order to use micro tubular coil heaters more than 900°C, new materials are to be identified which are stable even at high temperatures.

1.3 RELATED PROCESS PARAMETERS

The limitation of micro tubular coil heater and all types of heaters is the change of resistance with the change in dimensions and temperature. The resistance increases as temperature increases. For a typical Nichrome wire element, the resistance increases 5.8 times for a temperature of 650° C when compared to resistance at room temperature.

The operating temperature of the heater materials is limited because of the increase in resistivity with the reduction in cross sectional area. The resistance increases with the increase in length and decrease in cross sectional area i.e., diameter. The rupture temperature of the Nichrome heating coil element linearly decreases with reduction in its diameter. When diameter is reduced to 50%, the change of resistance for the Nichrome wire was found to be 6.5%. This decrease in operating temperature limits the usage of Nichrome wire at high temperatures. Therefore, dimension is considered as one of the process parameters, as it influences the resistance of the heater. Since the process of micro tubular coil heater is Joule heating, the coil is heated by electrical means.

The joule heating test can be conducted for various electrical input parameters viz., current, voltage, wattage etc. Therefore the process parameters considered in the analysis are dimensions, current, voltage and wattage.
1.4 RAMAN SPECTROSCOPY IN THERMAL ANALYSIS

Spectroscopic techniques have been widely used to study vibrational, rotational, and other low-frequency modes in a system. It relies on inelastic scattering, or Raman scattering of monochromatic light, usually from a laser in the visible, near infrared, or near ultraviolet range. The laser light interacts with molecular vibrations, phonons or other excitations in the system, resulting in the energy of the laser photons being shifted up or down. The shift in energy gives information about the vibrational modes in the system.

Raman spectroscopy can be used for testing the materials at different temperatures in order to find its usability at these temperatures. As the temperature increases, the molecular structure also changes which limits the usage of the materials at high temperatures. From the Raman peaks taken at different temperatures, the level of molecular structure can be identified. The molecular structure gets changed at a point, where there is an abrupt change in the ratio of the intensity of the Raman peaks.

In order to find the stability of the materials at different temperatures, Raman spectroscopy is used. The existing material for micro tubular coil heater, Nichrome, and the selected materials Titanium Nitride and Aluminium Nitride were tested using Raman spectroscopy at different temperatures to determine the structural stability.

1.5 NEED AND OBJECTIVES OF THE RESEARCH WORK

The need of the present thesis is to contribute to the understanding of finite element simulation of rupture temperature of micro tubular coil heaters and to analyze the structural stability of the materials using Raman spectroscopy. Though many research studies have been carried out with regard to finite element simulation of micro heaters in general, only a few researchers have done a research on simulation of micro tubular coil heaters.
But, the present research work is different in respect of optimization of micro tubular coil heater process parameters and identification of new materials which are used for high temperature applications.

The objective of the present work is to study the Raman effect and characterization of different materials using Raman spectroscopy. Also a finite element model of micro tubular coil heater is to be developed for the prediction of rupture temperature, and to perform finite element analysis by varying current, voltage and wattage. An electro-thermal test is to be conducted to validate the finite element simulation results.

1.6 PLAN OF THE RESEARCH WORK

It is essential to study the finite element prediction of joule heating histories in the heaters from the existing literature and to develop a finite element model for the prediction of operating temperature in micro tubular coil heaters since the primary objective of this research is to develop a thermo-electrical finite element model for simulation of rupture temperature in a circular micro tubular coil heater. In order to validate the results of finite element predictions of rupture temperature, it is required to fabricate the circular micro tubular coil heaters with different materials and with different sizes.
The plan of the present research work is presented in Figure 1.1.

![Figure 1.1 Plan of the research work](image)

1.7 SEQUENCE OF THE RESEARCH WORK

Figure 1.2 shows the detailed sequence of the present research work leading to the estimation of rupture temperature and identification of suitable materials for medium and high temperature micro tubular coil heaters. The research work was initiated from the literature review on various coil heaters in the journals, followed by interactions with experts.
With the idea of identifying suitable materials for high temperature micro tubular coil heaters, different materials were selected and analyzed. The selected materials have been characterized using Raman spectroscopy, which is a versatile tool for characterizing materials. Then, the results of Raman spectra of the materials were compared with the results, published in journals. The finite element model of micro tubular coil heater was developed using Pro-E for simulation. The finite element simulation of micro tubular coil
heaters has been performed using COMSOL Multiphysics, commercial finite element analysis software to determine the rupture temperature of different micro tubular coil heaters. Then, the experimental tests have been carried out on existing and new micro tubular coil heaters. The finite element simulation results have been validated with the experimental results.

1.8 STRUCTURE OF THE THESIS

The scope of the research work is confined to the development of finite element model for the prediction of rupture temperature of micro tubular coil heaters and identification of suitable materials for micro tubular coil heater for medium and high temperature applications.

Chapter 2 highlights the survey of literature in finite element simulation of micro heaters and other heaters, and the characterization of materials using Raman spectroscopy. It first deals with the literature in respect of Raman characterization of materials at different temperatures which is useful in determining structural stability of the materials at different temperatures. Secondly, it covers some of the research works in the development of Joule heating simulation of finite element model.

Chapter 3 deals with the applications and limitations of the existing commercial micro tubular coil heaters. It also deals with the various factors of material selection for micro tubular coil heaters and different materials available for manufacturing the micro tubular coil heaters. It also describes some of the limitations of the micro tubular coil heaters and the need to identify materials for the heater for high temperature applications. The electro thermal behavior of the micro tubular coil heater with respect to input process parameters is also dealt with.
Chapter 4 describes the Raman effect and the need of using Raman spectroscopy for characterization of materials to find the structural stability at higher temperatures. It also covers the Raman spectra analysis of existing and newly selected materials.

Chapter 5 covers the development of finite element model using Pro-E and the need for using COMSOL multiphysics software for finite element simulation. It also deals with the finite element simulation of micro tubular coil heaters with different materials and different dimensions, to find out the rupture temperature of micro tubular coil heaters.

Chapter 6 describes the development of micro tubular coil heaters with the existing and identified materials, with different dimensions. It also deals with the testing of these heaters with various electrical inputs to obtain the rupture temperature and it covers the validation of the finite element results with the experimental results.

Chapter 7 which serves as the conclusion of the research.