CHAPTER 1

INTRODUCTION

General.

The porous refractory is used in refining molten steel by injecting gases into it through the refractory of a ladle and a tundish to homogenize the temperature and composition of the molten steel. The refractory has to be prepared to satisfy almost contradictory requirements, such as larger flowability of gases versus higher resistivities against thermal and mechanical stresses and chemical attacks. The former requires a coarse structure, but the latter requires a dense structure. Hence, it is important to find a suitable pore structure by some means.

Image of the cross section of the refractory obtained with a microscope is one of the measurement of the internal pore structure. However, it gives only two-dimensional information of the surface being looked at, so that to obtain the structural information of the whole body, many images at different cross sections of it have to be observed. Porosity of the body can be determined easily to give some three-dimensional information but only some mean value. Hence, it is desirable to find another index, or method, which can express the pore structure more precisely.

According to the theory of fractal geometry, if a certain geometric phenomenon has fractal nature, its fractal property can be expressed as a function of a certain power or index of some measured scale, and the index, i.e., fractal dimension shows the geometric complexity of the phenomenon.

Although flow characteristics of gas through a porous medium depend largely on its pore structure, most expressions for the pressure drop across a medium is related only to its average properties such as specific surface area and porosity. At low gas pressures, the mean free path of gas molecules as well as the ratio of the mean free path of gas molecules to the pore radius, or Knudsen number, Kn, becomes larger and consequently the pressure drop across the medium increases even if mass flow rate remains the same. Under this situation, the frequency of the penetration of gas molecules into the pores decreases and below certain pore sizes the channels become harder to penetrate as the mean free path increases. In other words, most of the gas molecules tend to flow through pores larger than some certain pore sizes and thus the effective flow area decreases as the absolute gas pressure decreases. This suggests that the complexity of a porous medium can be evaluated by combining the pressure drop measurement at different Kn numbers and the concept of fractal geometry. In this paper, a novel method to evaluate the structural complexity of the porous medium has been proposed based on the pressure drop measurement and fractal geometry. Then its applicability was demonstrated by the measurement of pressure drop and the determination of the fractal dimension of a porous refractory. Its plausibility was shown by comparing the fractal dimension thus obtained with that obtained by two-dimensional image of the medium using fractal counting analysis.

Physical and chemical properties of the porous refractory such as permeability of gas, resistivity against mechanical and thermal shock, shape and size of pores, pore size distribution, chemical bonding, and so on are shown to depend largely upon the combination of types and relative amounts of its aggregates and matrix materials.

When MgO particles were used as aggregates, and TiO_2 and Al_2O_3 powders mixed at equi-molar ratio were used as the matrix, pore shapes of the resulting porous refractory were found to have a fractal nature, and the degree of their structural complexity, as given by the fractal dimension, increased with the matrix contents (Tsuchinari, A. et.al. 1991). In one experiment (Tsuchinari, A. et.al. 1992), the fractal dimension of a refractory fired above 1,500 K increased with the aggregate size, and the temperature, at which the fractal dimension abruptly changed, coincided with the incipient generation temperature of the solid solution $MgO{\cdot}Al_2O_3$ - $2MgO{\cdot}TiO_2$, whereas the fractal dimension did not change for same type of the refractory fired below 1,500 K.

One purpose of this study is to investigate whether a similar change in the pore shape and size will take place, when the aggregate material was changed from MgO to spinel $MgO{\cdot}Al_2O_3$.

Purposes of Research Study.

An experimental apparatus has been designed and constructed here in order to determine the characteristics of porous ceramic refractories. The purposes are as follows:

1. To carry out the experimental study on the characteristics of air flow through porous ceramic materials, e.g., pressure drop across the sample versus the mean free path of air flowing through it.

2. To analyze the fractal characteristics of porous ceramic materials, e.g., the fractal dimension of the media, using an image analyzer.

3. To determine the relationship between air flow through and fractal characteristics of the porous media.

4. To study the effect of TiO_2 - Al_2O_3 contents on the physical properties and pore structure of porous spinel refractories.

5. To investigate whether a similar change in pore shape and size will take place when the aggregate material is changed from MgO to spinel $MgO \cdot Al_2O_3$.

Materials Studied.

To study the relationship between air flow through and fractal characteristics of porous ceramic materials, these materials are prepared with the following characteristics:

1. Chemical composition of the ceramic materials consists of alumina bead (0.1-1.41 mm) 18-57 % by weight, clay 3.5%, $ZrO_2 \cdot SiO_2$ 3.0 %, alumina powder (5 μm) 5-12 % and calcium lignosulfonate 2-5 %. These materials are used to study the pore structure through pressure drop measurements.

2. Ceramic materials containing TiO_2 and Al_2O_3 ranging from 5 to 30 wt. % as matrices with the balance being $MgO \cdot Al_2O_3$ as aggregates are used to study the effect on physical properties of porous spinel refractories.

3. The pore size (diameter) of the porous ceramic materials range between 0.12-1,000 μm.

4. The shape of the porous ceramic samples is of circular slab, with a diameter of 0.05 m and thickness between 0.003 to 0.009 m.