（論文博士用）

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（別記様式－論７）

# 千葉大学審査学位論文（要約）（**Summary**）

審査専攻　　基幹工学　専攻

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## Particle Flow Measurement in Two-phase Flow in Pneumatic Conveyance by Electrical Capacitance Tomography Method

## 電気容量トモグラフィー法による空気輸送における二相流の粒子流測定

The aim of this thesis is to develop the particle flow measurement method in two-phase flow in the pneumatic conveyance by electrical capacitance tomography (ECT) method for the iron-making process in order to solve the technical issues of conventional measurement method and to support the improvement of the products' quality in the iron-making industry. The aim is accomplished in the following two main objectives: (1) particle volume flow rate measurement by the combination of dual electrical capacitance tomography (dECT) sensors with the plug flow shape model and (2) real-time controlling the particle distribution in pneumatic conveyance by electrical capacitance tomography with airflow injection system (ECT-AIS).

The whole thesis describes the two objectives by conducting some experiments with a lab-scale machine which attached with a circle shape of ECT sensor. The results of study were successfully addressed the two objectives as a development of ECT for measuring the particle-gas two-phase flow in the pneumatic conveyance. Moreover, the volume fraction of each phase in solid-liquid-gas three-phase flow which is the most important part in the iron-making process is highly necessary to conduct as future study in order to improve the efficiency of the combustion process in the blast furnace and to upgrade the iron quality.

In this thesis, the development of the particle flow measurement method in two-phase flow in the pneumatic conveyance by ECT method for the iron-making process was described by five chapters as follows:

## Chapter 1

Firstly, the background of research and current problem in multiphase two-phase flow in pneumatic conveyance and introduction of blast furnace operation for iron-making process are mentioned. Additionally, both particle flow measurement methods and real-time particle distribution controlling in particle-gas two-phase flow including some conventional methods, intrusive and invasive methods, non-intrusive and non-invasive methods are discussed. Finally, the aim and objectives of this research in blast furnace operation for iron-making process are described.

## Chapter 2

In this chapter, governing equations of electrical tomography (ET) are described. Moreover, the fundamental principle of electrical capacitance tomography method and the detailed design of ECT sensor are presented. Furthermore, accuracy detection of ECT sensor is discussed by conducting some experiments with details experimental set-up, method and results.

## Chapter 3

Volume flow rate measurement of particle plug flow in the pneumatic conveyance are expressed. To calculate the volume flow rate of particle plug flow, signal rising time difference, velocity, length and volume of each region of one plug flow are measured. After that, volume flow rate of one plug flow are measured and validated with the conventional Cross-correlation (CC) method and high-speed camera (HSC) method. According to the results, the velocity of the plug flow by dECT-PF method have good agreement with that of HSC method. Moreover, the absolute errors $E_{abs}$ of each volume flow rate between dECT-PF and HSC were less than that of between dECT-CC and HSC. The absolute errors $E_{abs}$ between the dECT-PF and HSC were acceptable and were under $0.8 \times 10^{-4}$ m$^3$/s. Therefore, this proposed method is used to measure the flow rate of the particle plug flow.

## Chapter 4

In this chapter, monitoring and controlling method of the particle distribution in pneumatic conveyance has been described by electrical capacitance tomography with an airflow injection system (ECT-AIS). ECT-AIS is developed by a combination of electrical capacitance tomography sensor and airflow injection system to monitor the upstream particle distribution $\boldsymbol{\varepsilon}_i^{up}(t)$ and to control the downstream particle distribution $\boldsymbol{\varepsilon}_i^{do}(t+\tau)$ in real-time. The spatial mean permittivity of the upstream ECT sensor $\langle \varepsilon^{up} \rangle(t)$ and the spatial standard deviation of permittivity distribution $\varepsilon_{SD}^{up}(t)$ are determined the homogeneous particle distribution based on the comparison of $\varepsilon_{SD}^{up}(t)$ and the threshold value $\delta$ in the upstream ECT sensor. The mean velocity of particles$\bar{u}_p$, 3D images, $\boldsymbol{\varepsilon}_i^{up}(t)$ and $\boldsymbol{\varepsilon}_i^{do}(t+\tau)$ are discussed under the homogeneous and inhomogeneous particle distribution in the case of the particle loading ratios ($\phi$ = 0.25, 0.50, and 0.75). Moreover, the spatial standard of permittivity distribution using Landweber $\varepsilon_{SD}^{up,LW}$ was calculated and validated with that using linear back projection algorithm. The tendency of $\varepsilon_{SD}^{up,LW}$ is similar to $\varepsilon_{SD}^{up,LBP}$. As a result, the homogeneous particle distribution is successfully controlled via ECT-AIS according to the relationship between the spatial mean permittivity $\langle \varepsilon \rangle(t)$ in ECT sensors and the normalized pressure $p_n(t)$ in the pressure sensors.

## Chapter 5

The conclusion of this study and recommendation for this study are discussed in this chapter. Although the lab-scale machine is used in this research, it can be used in the real blast furnace. However, in order to use it in the real blast furnace, the sensor should be demonstrate based on some issues such as number of measurement electrodes, length and width of electrodes, dimension of earth screens and ground screens according to the pipe diameter. Moreover, in order to validate for the accuracy and limit of the ECT sensor, it is necessary to do more experiments with the real blast furnace dimension.