論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	Study on Joule-heating Flow and Diffusion Flow in Glass Melter Models
著者(和文)	ZhouJiaju
Author(English)	Jiaju Zhou
出典(和文)	学位:博士(工学), 学位授与機関:東京工業大学, 報告番号:甲第10969号, 授与年月日:2018年9月20日, 学位の種別:課程博士, 審査員:木倉 宏成,竹下 健二,赤塚 洋,筒井 広明,相樂 洋
Citation(English)	Degree:Doctor (Engineering), Conferring organization: Tokyo Institute of Technology, Report number:甲第10969号, Conferred date:2018/9/20, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	要約
Type(English)	Outline

OUTLINE

Study on Joule-heating Flow and Diffusion Flow in Glass Melter Models

This thesis describes studies of Joule-heating flow and diffusion flow in LFCM process melter shape models used experimental model and numerical model. Chapter 2 observes Joule-heating flow behavior in a 2-D glass melter shape model cavity named slopping bottom cavity to understand characteristics of Joule-heating flow in the glass melter. Chapter 3 is devoted to develop GSMAC-FEM code applying on Joule-heating calculation in the slopping bottom cavity and the code was verified by experimental result written in the chapter 2. Chapter 4 describes diffusion flow of high viscosity fluid in a cylinder tank which is the validate results for HLLW diffusion simulation in the glass melter. Simulation of high viscosity fluid diffusion is reported in Chapter 5, followed by the overall conclusion in Chapter 6.

In the Chapter 1 “Introduction”, background of research about the vitrification technology of High Level Radioactive Wastes (HLLWs) using Glass melter is presented.

In the Chapter 2 “Experimental investigation of Joule-heating flow in a glass melter model”, the flow behavior of Joule-heating flow in a 2-D glass melter shape model cavity named sloping bottom cavity is observed. This chapter presents the characteristics observation of Joule-heating flow occurs in the sloping bottom cavity using glycerol-water solution as working fluid. For flow measurement, the instantaneous velocity profile is needed to understand the flow characteristic. In the chapter, the flow profile on the center vertical line is observed by the UVP method, and the PIV method is applied to observe the flow behavior two-dimensionally. The temperature profile is obtained by thermocouple measurements. In the sloping bottom cavity without the electrode cooling, chaotic flow occurred just in the upper part, only a small flow was in the sloping bottom part. Another result revealed that UVP technique could be applicable to the observation of the chaotic Joule-heating induced flow. The applicability of the UVP measurement was verified by means of the PIV method. In the condition with the electrode cooling, the chaotic flow also occurred in the upper part of the cavity. The Joule-heating area was similar to that without the electrode cooling. Therefore, heating area decided the chaotic flow area in a cavity. With the electrode cooling condition, a stable upflow occurred under the chaotic flow area and limited the flow area. However, the effect with electrode cooling also depended on the heating area.

In the Chapter 3 “Numerical investigation of Joule-heating flow in a glass melter model”, the simulation analysis of Joule-heating flow by computational codes is presented. The flow behavior in glass melter is too complicated by interfering of flow field, thermal field and magnetic Field. Hence, finite element analysis code, GSMAC-FEM, which applies coupled solution of temperature field, flow field and magnetic field, is utilized to simulate the molten glass. To validate the GSMAC code, experimental results reported in the Chapter 2 is used to compare the numerical result. As a results, a comparison of history of temperature measured at center of cavity shows good agreement between experimental data and numerical results. Moreover, Fast Fourier Transform (FFT) was used to investigate quantitatively the Joule-heating flow from the time-series velocity data. The same slop of FFT analyses of numerical data and experimental data could be observed. After the validation, the molten glass was applied as a working fluid in the real scale sloping bottom cavity model in the GSMAC method to predict the flow in the glass melter. The flow was stable at the beginning of heated. Stable

downflows could be observed at the center and close to the electrodes and other zone were upflow in the upper part. few flow in the bottom part. The flow became unstable with the fluid temperature increased. However, a stable downflow still could be observed close to the electrodes and under the electrodes which flows to the center. A low temperature layer close to electrodes and in the bottom part could be observed.

In the Chapter 4 “Experimental investigation of feeding flow diffusion led by concentration and density difference”, the flow behavior of diffusion flow by flow feeding in a cylinder tank modeled HLLW feeding is observed. To understand the flow diffusion, the injected fluid concentration was measured using an Electric Resistance Tomography (ERT) technique at the top, middle and bottom levels in the cavity. A vertical velocity component was also measured using an Ultrasound Velocity Profiler (UVP) technique. The concentration profiles of the injected fluid at different levels in the cavity were found to change with the viscosity of the injected fluid, and the velocity was found to depend on the density of the injected fluid. As a result, after injection into the cavity, the injected fluid formed a ball at first, and the liquid ball flowed down by gravity with the diameter increasing slowly. However, the liquid ball did not fall downward in a straight path due to the shape deformation and the drag force from the surrounding liquid changing its direction. As the liquid ball falls, a thin long stream of liquid was left behind by the ball. After the liquid ball reached the bottom of the cavity, some residual flow could still be measured in the surrounding fluid. When the fluid viscosity was low, the liquid ball fell to the bottom of the cavity without leaving a large amount of liquid behind. Therefore, to promote greater mixing of the injected fluid with the surrounding liquid, the viscosity of the injected liquid should be high.

In the Chapter 5 “Numerical investigation of feeding flow diffusion led by concentration and density difference”, the simulation analysis of diffusion flow by computational codes is presented. A commercial CFD code fluent using Volume of Fluid (VOF) model was applied to calculate the flow diffusion after injected into a cylinder tank. To validate the model, experimental results reported in the Chapter 4 was used to compare the numerical result. After injection into the cavity, the injected fluid formed a near spherical ball at first, and the liquid ball flowed down slowly by gravity. As the liquid ball fell, it left behind a thin long stream of the liquid. Qualitative agreement was obtained between the simulation results and experimental data. When comparing the width of liquid ball formed by the injected fluid, the experimental result was larger than the simulation result. It could be considered the difference from the viscosity setting. In the experiment, the viscosity was measured by the viscosity cup, the viscosities of the injected fluid applied in the experiment and simulation were different because the measurement error, and the width of the liquid ball was depended on the viscosity.

In the Chapter 6 “Conclusion”, insights the chapter 2 to chapter 5 are summarized in this chapter. Summarizing the results of the study, the flow behavior in the glass melter could be more cleary, the Joule-heating flow occurred in the upper part of the cavity and molten fluid leaded several upflows around itself. The Joule-heating flow is stable at the beginning, which stable downflows occurred close to electrodes and center of the glass melter. However, with the molten glass was heated by Joule-heating, the flow became unstable, while a stable downflow occurred close to the electrodes. In the future, the duffision flow and the Joule-heaitng flow should be coupling by the same code to calculate the flow behavior chainging by the feeding position changing.