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# Numerical simulation of silica particle trajectory in flow field and silica particle spheroidizing in oxygen–acetylene flame spheroidization process

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ABSTRACT

A numerical simulation was developed for particle trajectory in flow field and spheroidizing of silica particle in oxygen–acetylene flame spheroidization process. Gas flow field and silica particle behavior in oxygen–acetylene flame spheroidization process was simulated using a Computational Fluid Dynamics (CFD) package FLUENT. A model was proposed for optimizing spheroidization process of silica particle. Oxygen gas and acetylene gas were used as the continuous phase. Silica particle was used as the dispersed phase. The three-dimensional, steady and isothermal flow field was showed for illustrating the continuous phase and the dispersed phase. Conservation equations of mass and momentum for each phase were solved using the finite volume numerical technique. Various gas conditions were discussed systematically. The injected silica particle trajectories were simulated by using dispersed particle surface trajectory. The trajectories and spheroidizations of different size particles were analyzed. The results of numerical simulation reveal that the flame length was reasonable and overall temperature was highest when acetylene gas flow rate was $10\ L \cdot min^{-1}$, oxygen gas flow rate was $20\ L \cdot min^{-1}$ and powder carrying gas flow rate was $5\ L \cdot min^{-1}$ and 40 μm silica particles were difficult to finish spheroidizing within $5 \times 10^{-4}$ s. The comparison shows that temperature distribution, velocity distribution, particle trajectories, and deformation which were predicted by simulation, were in good agreement with the corresponding experimental results.



## 1. Introduction

With the rapid development of aerospace and information industry, spherical silica particle has attracted more and more attention [1–5]. Because it has the advantages of good fluidity, low thermal expansion and low stress concentration. The spherical silica particle was indispensable, especially in the large-scale integration (LSI) circuits packaging field. The flame spheroidizing process also was widely found in many industrial applications such as spraying industry, metal industry and ceramic industry. Therefore, it was very worthy and necessary to study spheroidizing process of raw silica material to improve the spheroidization rate and flame furnace design.

In order to obtain perfect spherical silica particle, particle character and experimental operating condition were investigated [6–8]. In previous study, the researchers tried many experimental methods, which include the direct current arc plasma method, the ratio frequency plasma process, the high-temperature fused quartz jet route and so on [9–12]. The literatures demonstrated changes in the particle morphology, structure and crystallinity during the spheroidization process [13–15]. For economic cost and high spheroidization efficiency, a new oxygen–acetylene flame spheroidization process has been developed [2]. Although the experimental researches for oxygen–acetylene flame spheroidization process have been conducted excessively, the process fundamentals were not yet fully understood due to difficulty of observing in the limited furnace zones, because of its extremely high-temperature and high-speed gas in the furnace. According to literatures, researchers did a lot of investigations on spheroidizing process of silica particle [16–21]. Some investigations of different heat source and spheroidizing process have been performed. Moreover, some empirical formulas have been built in experimental study. However, the process cannot easily realize enlargement of the furnace and optimization of the parameters due to high cost. Previous studies indicate that flame flow field, temperature field characteristics and feed particle size were the major influencing factors of spheroidization rate. Therefore, the computational method was capable of predicting detailed evolution of gas dynamics and particle dynamics would be very useful.

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**Table 1**
Gas flow rate set in the simulation.

| Gas number | Acetylene gas flow rate/L · min$^{-1}$ | Oxygen gas flow rate/L · min$^{-1}$ | Powder carrying gas flow rate/L · min$^{-1}$ |
|---|---|---|---|
| 1# | 5 | 10 | 2.5 |
| 2# | 10 | 20 | 5 |
| 3# | 20 | 40 | 10 |

In recent years, FLUENT fluid software has been applied as a useful tool in more and more fields for offering a new method [22–28]. Weihong Yang et al. [29] simulate flame obtained by combustion of liquified propane gas with highly preheated air using a regenerative burner. The results of the numerical calculation showed that the flame spread is very well predicted. Mingheng Li et al. [30] obtained statistical distribution of particle velocity, temperature, impinging angle and position on the substrate as well as particle residence time in a high velocity oxygen–fuel thermal spray coating process by FLUENT. Lu Xin et al. [31] performed the numerical simulation of the argon flow field of inductively coupled plasma spheroidization system by using FLUENT fluid software. They predicted particle collection rate of TiAl alloy powders in spheroidization system. Rory F. D. Monaghan et al. [32] validated a steady-state 3D CFD simulation of the combustor using standard numerical techniques. They used SIMPLE coupling and second-order upwind discretization of the momentum equation. The solution was generally found to give better results. While many studies on the numerical simulation have been undertaken, literatures on the simulation about melt and spheroidization of silica particles in the furnace have not been reported. In a word, so far no references introduce the numerical simulation of oxygen–acetylene flame spheroidizing process for spherical silica particle in detail by FLUENT.

The purpose of this study was to develop two models that can predict silica particle spheroidization inside the gas flame furnace at various operating conditions and particle sizes. In this work, the use of numerical simulation method was discussed also as a predictive tool, and 3D modeling of oxygen–acetylene flame spheroidization system was performed by using FLUENT fluid software. First, temperature field and flow field of the furnace were simulated under different gas condition. Then, the different size silica particle trajectories were simulated in the furnace. Finally, the heat transfer, melt and spheroidization of silica particles were simulated. The flow behavior in oxygen–acetylene flame spheroidization furnace under varying gas conditions was investigated in detail by using the finite volume method on basis of the ANSYS FLUENT software. The effect of spheroidizing of silica powder in oxygen–acetylene flame spheroidization system was predicted.

## 2. Experimental and numerical modeling

### 2.1. Experimental setup

The silica raw material was natural vein quartz crystal dealt with chemo-mechanical disposal. The purity was 99.9% and the content of the radioactive microelement U was $2.5 \times 10^{-9}$ g/g. The size distribution of particles was 1–40 μm. The as-mechanical–chemical treated of

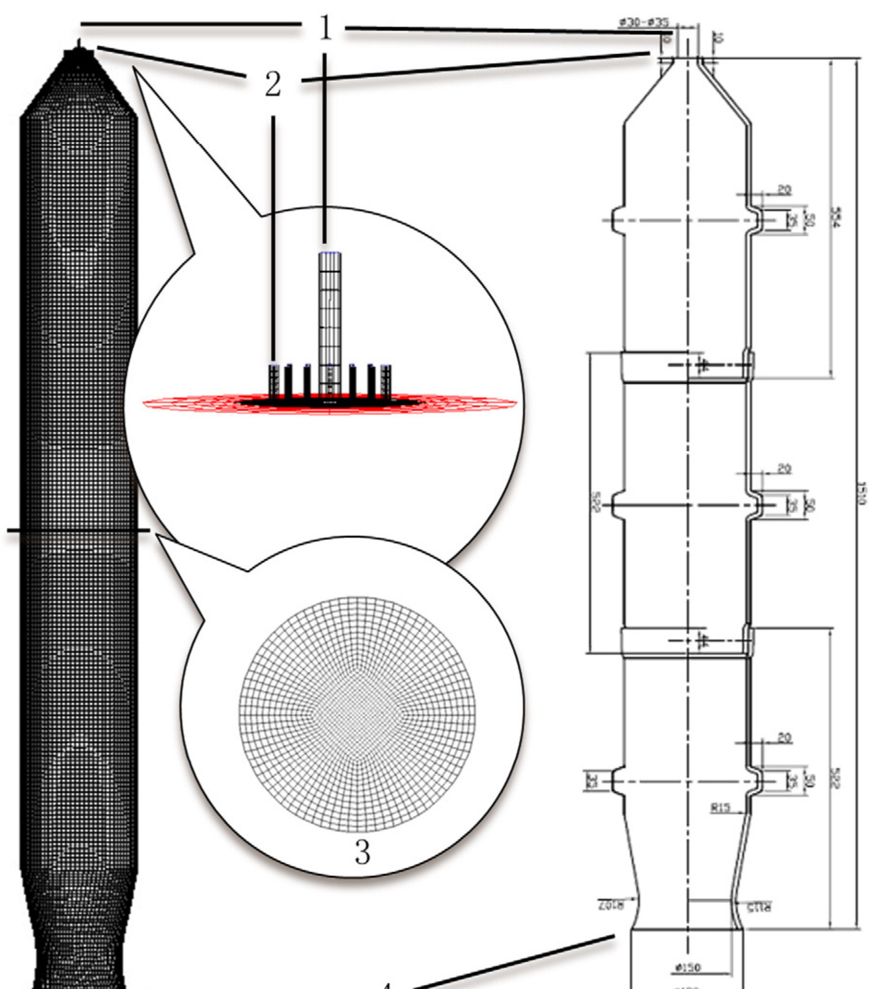


**Fig. 1.** Schematic diagram and mesh model of spheroidization furnace. 1: silica inlet; 2: gas inlet; 3: transverse section mesh; 4: bottom.