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Optimization of tungsten particles spheroidization with different size in thermal plasma reactor based on numerical simulation

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ABSTRACT

Micro-size tungsten particles have been prepared by radio-frequency (RF) thermal plasma reactor. SEM images show that spheroidization ratio of small particles is obviously lower than that of big particles. Numerical model has been founded to simulate the spheroidization system to explain this phenomenon based on FLEUNT software. The calculation results indicate that small particles are easy to diffuse and 'back-mix', which will urge small particles to escape from the high temperature area, while big particles are flowing straightly through the high temperature area, as a result that small particles cannot absorb enough heat and cannot be spheroidized well. The forces of diffusion and 'back-mixing' are each radial velocity and axial velocity. With some calculations based on the change of each gas flow, it can be found that appropriate combinations of gas flow can improve the spheroidization ratio of small particles.

1. Introduction

With the highest melting temperature (3410 °C) of all metals, good thermal conductivity, big specific gravity (19.3 g/cm^3), good corrosion properties, lowest vapor pressure, tungsten is widely applied in high temperature structure, national defense industry, nuclear fusion reactors, etc. [1–6]. Companied with the development of productive forces, the demand of tungsten particles with good shape keeps growing up in recent years. Especially, spherical tungsten particles, which obtain better fluidity, better isotropy, higher bulk density and lower friction coefficient, are attracting more and more attention on porosint preparation, thermal spraying, powder metallurgy, etc. [7–10]. Since the tungsten particles are difficult to melt because of its high melting point, traditional methods cannot be employed to prepare spherical tungsten particles, which illustrates that it is very important to utilize suitable process to produce spherical tungsten particles. Radio-frequency (RF) thermal plasma is just the appropriate method because of its good characteristics, including high enthalpy, high temperature, highly ionized, good conductivity of heat and electric [11,12], etc. and Wang, Jiang, Han et al. [13–16] have successfully applied this technology to prepare spherical tungsten powders.

Experiment is a good method to have a research on particles spheroidization with plasma reactor, which has been combined with numerical simulation by many researchers, obtaining many significant progresses. Numerical simulation is a research method that can largely reduce the consumption of experimental costs and cycle, which has been widely used in many fields such as fluid dynamics [17–19], heat transfer [20,21], machinery manufacturing [22], etc. Additionally, it can also provide lots of information that cannot be dynamically captured during the experiment process, such as velocity, viscosity, concentration, etc. Ye et al. [23] founded numerical model to analyze the synthesis of alumina nanoparticles for preparing the products with desired size and narrow size distribution in controlled conditions. Punjabi et al. [24] built 2D model to find out the effect of swirl velocity on plasma torch to analyze the torch's heat loss and stability. Xue et al. [25] modeled the effect of ferrite on thermal plasma torch based on FLUENT codes, in order to find out the influence of ferrite on electromagnetic fields and RF power efficiency. In general, it can be found that numerical simulation is a good research method, which can direct the research work well in RF thermal plasma field.

In the present work, experiments have been completed to study the process of tungsten particles spheroidization with different sizes. The spheroidization results can display the difference of spheroidization ratio between different size particles. Then, numerical model is built to simulate the spheroidization system, aiming at finding out the effect of particle size on spheroidization process. In addition, numerical model can also provide the impact factor of spheroidization ratio of tungsten

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particles, which can provide optimization methods to improve spheroidization ratio. It is hoped that this work can help to find out the effective methods to improve the production quality of tungsten particles, which will be applied in the future experimental work.

2. Plasma spheroidization experiment

2.1. Spheroidization system in laboratory

Fig. 1(a) is the present spheroidization system in laboratory, consisted by thermal plasma reactor in the top with RF power, cooling chamber in the bottom, collector and vacuum system. The RF power is 30.0 kW, and the cooling carrier is water in both powder injector and cooling chamber. Fig. 1(b) is the plasma reactor's geometric appearance, consisted by carrier gas injector, inner quartz tube, outer quartz tube and the quartz tube holder. The main specific geometry parameters of the reactor are mentioned in Table 1.

2.2. Operation conditions

The plasma reactor is operated at −500 ~ −1000 Pa gauge. Carrier gas, carrying tungsten particles, is feed into the reactor through powder injector, while central gas and sheath gas are each split to two streams into two branch tubes. The component of carrier gas is hydrogen, and the component of central gas and sheath gas is argon.

2.3. Particles spheroidization result

After half an hour's continuous work, the tungsten particles are collected. The SEM images of tungsten particles are shown in Fig. 2.

By comparing the SEM images, it can be found that most of the big particles (>3.0 μm) have been spheroidized. Contrary to big particles, small particles (<3.0 μm) of agglomerated or dispersed are not spheroidized well. After long time's work, this phenomenon always keeps repeating, although some parameters have been changed. The possible reasons are various, including gas flow, particles flow, the pretreatment of particles, etc. To find out the specific reason, numerical model is built in the next part to analyze the flow field and the motion of particles in the system.

Table 1
RF thermal plasma reactor main specific geometry parameters.

Parameters	Value	Parameters	Value
n	4	d_0	3 mm
D_i	50 mm	D	100 mm
D_o	65 mm	L	80 mm
L_i	110 mm	L_o	220 mm

3. Numerical simulation based on FLUENT

3.1. Geometry model

The geometry model, which applies three-dimensional physical model to make the calculation results more intuitive, has been built to simulate spheroidization system in laboratory based on FLUENT software, as shown in Fig. 3. In this model, the branch tubes are set long enough, which can provide central gas and sheath gas long way to reach stable flow patterns, as a result that the influence of the position of inlet boundary surface on quartz inner area can be ignored. Additionally, the feed of central gas and sheath gas are tangential, similar to the actual plasma reactor, which can fully consider the influence of circumfluence in the reactor. Since the main research subjects are quartz inner region and reaction region, what need to be noted is that this model do not consider the cooling chamber and account the bottom cross-section of reaction region as one of the calculation zone boundaries.

3.2. Boundary conditions

The main inlet nozzles of plasma reactor include one carrier gas inlet nozzle, two central gas inlet nozzles and two sheath gas inlet nozzles. In the present work, each nozzle has been defined as the inlet boundary, while the outlet boundary is the bottom cross-section of reaction region. The inlet boundaries are all set as mass flow rate, which has been listed in Table 2, coupled with volume flow rate. Since the operation pressure is close to atmospheric pressure, the outlet boundary is defined as default value, 101,325 Pa.

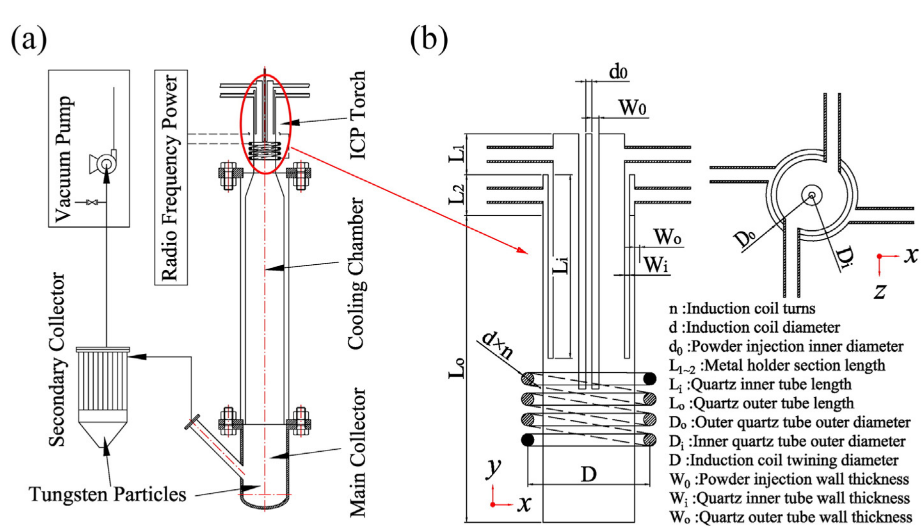

Fig. 1. (a). RF thermal plasma reactor equipment in laboratory, (b). RF thermal plasma reactor geometric appearance.