Powder Technology 325 (2018) 161–166

Contents lists available at ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

Experimental analysis of the flow conditions in spiral jet mills via non-invasive optical methods

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ARTICLE INFO

Article history:
Received 11 March 2017
Received in revised form 19 September 2017
Accepted 29 October 2017
Available online xxxx

Keywords:
Milling
Grinding
Jet mill
Particle image velocimetry
Flow conditions

ABSTRACT

Although most of the parameters affecting spiral jet milling have already been studied, there are no investigations of several parameters and their effects on the flow conditions over the entire cross-section inside the spiral jet mill via non-invasive methods. In order to vary several geometrical and operative parameters and to determine the flow conditions inside the jet mill, a new type of experimental spiral jet mill apparatus was designed and constructed. It has an almost entire optical accessibility and its highly modular construction enables a very convenient variation of the geometric parameters. This paper describes the new type of mill apparatus and preliminary experimental results concerning the flow conditions inside the spiral jet mill as well as grinding effects under different conditions on particle size distributions of barium sulphate micro particles.

1. Introduction

Despite of their relatively high energy consumption, spiral jet mills are often used in the industry when particles with diameters below 10 μm are recommended, e.g. in the grinding of micronized iron oxide pigments, such as magnetite, goethite and hematite. The most important benefits are the possibility of accelerating fluids through nozzles up to 500–600 m/s, the absence of agitated built-in elements and therefore the absence of contamination through mechanical wear. Starting with first exploratory and explanatory investigations by Rumpf [1], a lot of further research concerning spiral jet milling was done. Some researchers made efforts to investigate the flow conditions inside the spiral jet mill. Rumpf [2] as well as Kürten and Rumpf [3] studied the flow conditions and more particularly the comminution inside the spiral jet mill via triboluminescence: As manganese-activated zinc sulphide emits light in the moment of fracture propagation, it is possible to localise the place of comminution, mostly at the back side of the jets. Kürten and Rumpf [4] also visualised the flow conditions with ink in a spiral jet mill filled with water and showed the possibility of determining the flow conditions at the inner walls of the mill with the carbon black method by Euteneuer. Muschelknautz et al. [5] also used triboluminescence, whereas Müller et al. [6] recorded the comminution process optically through a glass plate at the bottom cover. In 1999, Bauer [7] combined most of the methods mentioned above, making investigations with triboluminescence, ink drops at the bottom cover of the spiral jet mill and recording the comminution process with a video camera, all through a glass plate in the bottom cover. Later Katz and Kalman [8] visualised the feeding and exit zones through a transparent top cover. Stajescu and Fulga studied the flow conditions at the nozzle outlets of the cylindrical core using a suspension of micronized powder from activated coal in oil [9] as well as pitot tubes [10]. Other researchers like Hagendorf [11] also used pitot tubes as an invasive method trying to determine entire velocity fields inside the spiral jet mill. Besides, numerous CFD-DEM studies on particle velocity within the spiral jet mill were done as the works of Brosh et al. [12] or Teng et al. [13].

In this study, in order to acquire entire velocity fields over the cross-section inside the mill via non-invasive optical methods, a new type of spiral jet mill apparatus with an almost entire optical accessibility was designed and constructed. In addition, the apparatus was designed in a highly modular way so that the geometrical and operative parameters can be varied conveniently and their effects on the flow conditions can be investigated. One focus was on investigations via Particle Image Velocimetry (PIV). The working group Schultz already gained great experience with this optical method and in several studies [14,15,16] PIV had been used for investigations of flow and mixing processes in various other systems.

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https://doi.org/10.1016/j.powtec.2017.10.048
0032-5910/

2. Experimental setup

The aim of the first stage of the research project was to develop a new type of experimental spiral jet mill apparatus that offers the possibility to determine velocity fields over the entire cross-section inside the spiral jet mill with non-invasive methods. Fig. 1 shows the sectional view of the experimental spiral jet mill apparatus. As the flow conditions inside the spiral jet mill should not only be recorded via high speed camera but also studied via particle image velocimetry (PIV) at several heights of the mill, at least a double optical accessibility of the apparatus was necessary (for LASER light cut and observation horizon). Therefore not only the bottom and top cover but also the cylindrical core of the mill apparatus have to be transparent [14] and are made of polymethyl methacrylate (PMMA). Furthermore the commonly used milling gas manifold of the spiral jet mill would have restricted the optical accessibility and had to be decoupled from the interior of the mill. A modular loop with a mechanical coupling system was installed, so that it is possible to connect as many milling nozzles as needed. By this way, only the small inclining arranged nozzles restrict the optical accessibility of the cylindrical core and e.g. the LASER light cut can be placed at this plane. The whole experimental spiral jet mill apparatus is tightened by using a convenient bolted-seal technique: The bottom and top covers (20 mm thick) are equipped with an exact notch to mount the cylindrical core (milling chamber) with an O-ring seal between the contact surfaces. The top cover is pressed against a massive base plate via socket screws and therefore the mill apparatus (bottom cover, top cover, cylindrical core) is gas tight. The diameter of the cylindrical core of the spiral jet mill apparatus was chosen in the same range as in appropriate literature [6,8,17], i.e. with an inner diameter of 190 mm. The base plate has a round hole with a diameter of 200 mm in the center of the socket screws in order to have optical accessibility inside the spiral jet mill from the bottom side of the base plate. The feed material drops through the feed funnel and is accelerated by the injector nozzle gas stream and enters the milling chamber with high velocity. The inclining arranged nozzles create a spiral vortex inside the milling chamber. Particle-on-particle impact causes autogenous grinding with coarser particles remaining in the outer area of the milling chamber. Fine product particles are carried out through the product outlet tube of the milling chamber with a diameter of 24 mm which is relevant for the output particle size in particular as described by MacDonald et al. [18]. The process inside the spiral jet mill apparatus can be illuminated and recorded via camera. The light cut is generated by a Nd:Yag LASER with a wavelength of 532 nm, DualPower 135-15 provided by Dantec Dynamics. The observation horizon through the bottom cover of the spiral jet mill and the round hole in the base plate is recorded by a FlowSenseEO 4M camera of Dantec Dynamics with 4 million pixels. The LASER pulses and camera frames are triggered by a 80N77 timer box.

In case that some of the used materials cause too much abrasion on the bottom cover and therefore restrict the optical accessibility, a very thin float glass plate (1 mm) was precisely cut with the same diameter as the cylindrical core (190 mm). It can be placed directly on the bottom cover inside the milling chamber as an abrasion protection. If the height of the milling chamber should not be reduced by the added float glass plate, the depth of the groove in the bottom cover has to be reduced about the thickness of the glass plate, which can easily be realised by a CNC lathe. The combination of the decoupled modular loop with the coupling system, the bolted-seal technique, several cylindrical cores with different heights, nozzle numbers, nozzle designs, nozzle angles or similar, and several covers in stock, enables a convenient variation of the geometrical parameters of the spiral jet mill. Furthermore the injector nozzle can be changed in design and position very conveniently. With commonly used pressure-reducing devices, the injector and milling pressures and mass flow rates can also be varied very efficiently. The compressed air is supplied by a screw compressor with an integrated refrigeration dryer (RSDK-B 5,5, Renner GmbH) and can easily be augmented by a compressed air gas cylinder. The feed of the materials can be adjusted via vibratory (DR100/75, Retsch GmbH) or screw feeders (GLD75, Gericke Holding Ltd.). Side views of the spiral jet mill apparatus are shown in Fig. 2 (bottom and top cover with cylindrical core) and Fig. 3 (whole spiral jet mill apparatus with periphery). The feeding material was barium sulphate (supplier: Krockow GmbH) with a median particle diameter $x_{50,3}$ of 10.9 μm and a Mohs hardness of about 3.3 [19].

3. Results and discussion

After designing and constructing the new type of experimental spiral jet mill apparatus, first feasibility studies have been realised. It is possible to place the horizontal LASER light cut at any vertical position of the cylindrical core; under, above or at the height of the milling nozzles. First PIV measurements were undertaken in the spiral jet mill

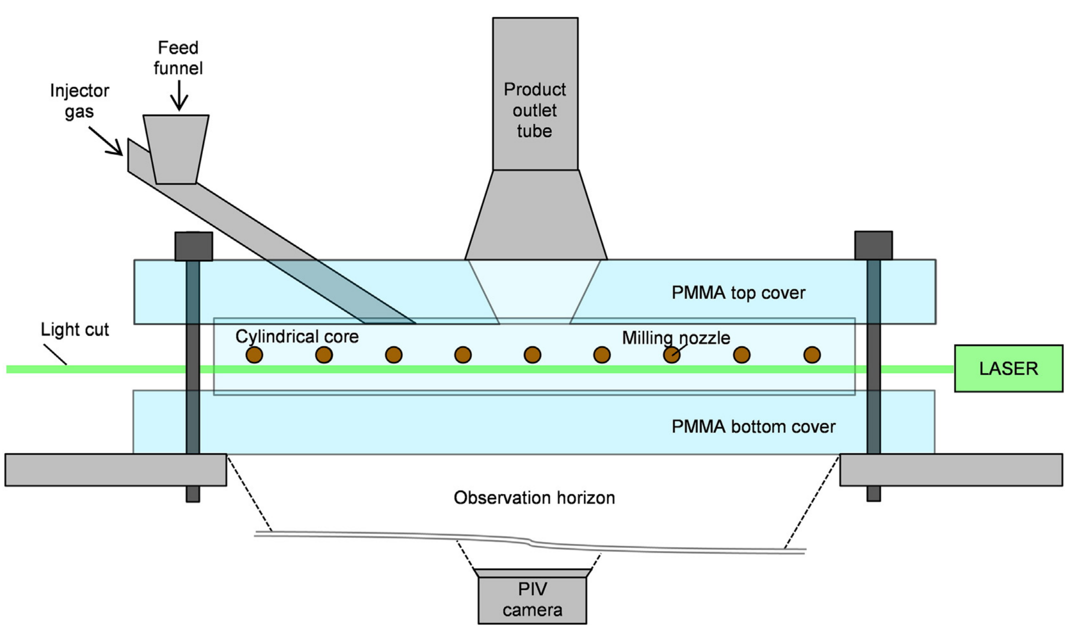

Fig. 1. Sectional view of the experimental spiral jet mill apparatus.