Use of Computational Modelling For Investigation the Effect of Melt Delivery Nozzle Tip Length on Gas Flow Separation in Supersonic Gas Atomization

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Abstract

In this paper, the effect of different melt delivery nozzle tip length on gas flow separation for annular-slit gas atomization, in gas-only flow, was numerically simulated by solving the compressible Navier-Stokes equations. Gas flow separation in the vicinity of the melt delivery nozzle during operation of the supersonic gas atomizer causes a back-flow of melt from the melt delivery nozzle tip along its outer surface, leading to very poor atomization performance and finally will result in aborting of the run. The melt delivery nozzle tip length plays a crucial role in preventing this problem during operation. Four different melt delivery nozzles with the tip length of, 10, 8, 7 and 3mm were numerically modeled in the confined-feed annular slit geometry with gas pressures of 0.5, 1, 1.5, 2, 2.5,3 and 4MPa. The results indicate that the nozzles with 8 and 10mm melt tip length are very sensitive to flow separation even in at a low gas pressure of 1MPa. With increasing atomization gas pressure the flow separation moved forward to the melt nozzle tip and at the gas pressures of 3MPa and above, flow separation was completely suppressed. In addition, no flow separation was seen on the two other melt nozzles at any gas pressure. These results specify that the flow separation occurrence is a function of melt delivery nozzle tip length and atomization gas pressure.

Introduction

Gas atomization is one method for producing ultra fine metallic powders. In this method, high velocity gas jet such as argon, nitrogen, helium or air disrupts a molten metal stream into fine droplets just below the melt delivery nozzle. These droplets subsequently solidify to form metallic powders. Due to the very high cooling rate experienced by the powders, excellent mechanical and chemical properties can be achieved. Such powders are also highly spherical which is important when good flow characteristics and dense packing are required [1], [2]. In the close-coupled gas system, molten metal is delivered from a tundish, which acts as a reservoir, to the ceramic nozzle melt delivery nozzle. It is at the tip of this nozzle the interaction with the high pressure gas jet occurs. It has previously found that boundary layers separation of the gas jet from the outer wall surface of the melt nozzle was as a major cause of negative pressure gradients in this region. This negative pressure gradient sucks the molten metal in to this area where it solidifies as a result of being exposed to very cold expanding gas which leads to alteration the melt delivery nozzle geometry. This phenomenon is a function of melt delivery nozzle tip length and atomization gas pressure. As a consequence of this the stream of molten metal may freeze-off and production will be aborted. Gas flow separation is therefore undesirable in the gas atomization process and as a result of, it's important to determining the optimum melt delivery nozzle length by computational modelling [2], [3].

Due to the rapid development of computer simulation software, the application of Computational Fluid Dynamic (CFD) simulation has been widely reported in the literature for designing efficient melt nozzles geometries for close-coupled gas atomization. A previous numerical study of single phase compressible gas flow on a melt nozzle with an annular slit gas die by Aydin et.al [2] has been shown that the flow separation alongside a fixed melt nozzle length is strongly influenced by a high atomization gas pressure with greater boundary layers separation occurring at the high gas pressures. In this paper, the effect on gas flow separation of melt nozzle tip length at different gas atomization pressure was studied numerically.

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Numerical Methods

Figure 1 shows the schematic view of four melt delivery nozzles under consideration in this study, each with differing melt tip length, but the same internal profile. In this study, high-speed gas flow through each of the three nozzles has been generated by commercial CFD code, ANSYS Fluent 13. The gas-only flow for each nozzle was considered as steady state flow and base on finite volume approach, the sets of mass conservation, momentum or Reynolds Navier-Stokes equations and energy conservation equation were numerically solved.

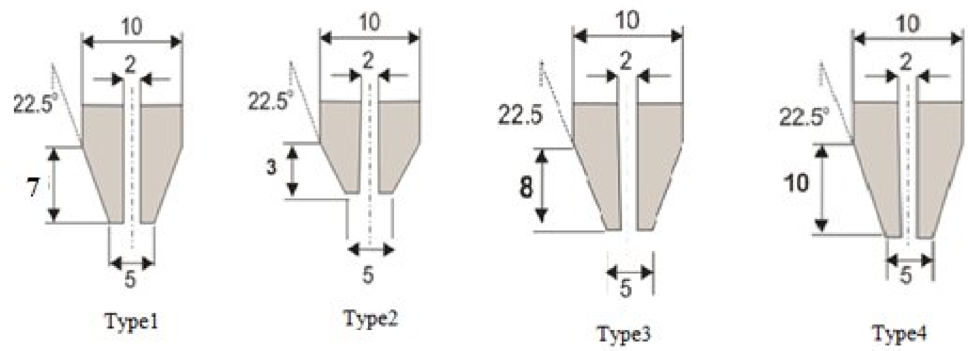

Figure 1 Different melt delivery nozzle profile Dimensions (mm).

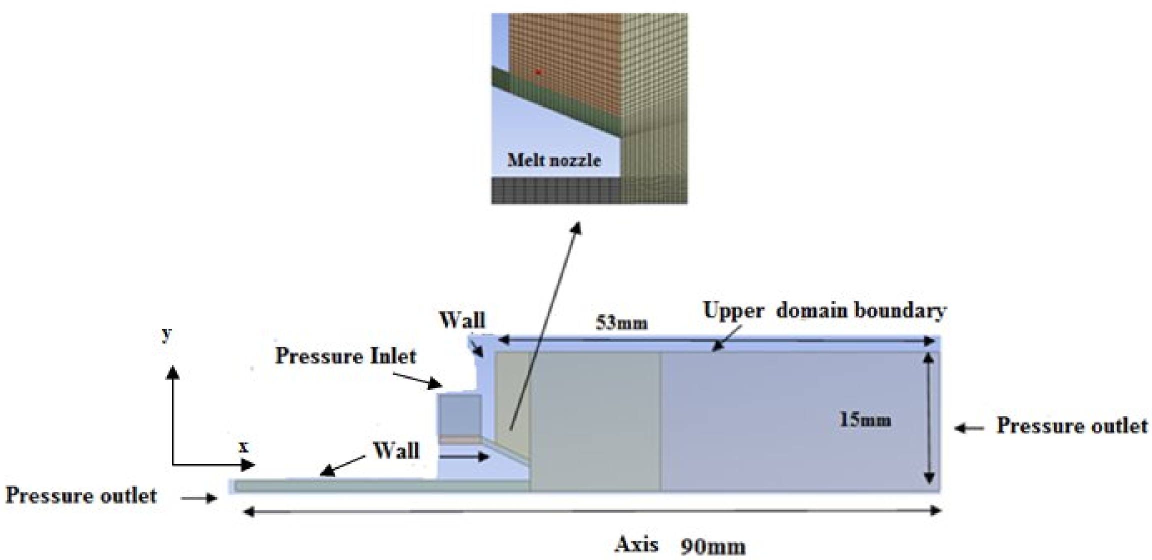

Figure 2 Computational domain and example of the mesh close to the melt nozzle tip for nozzle type1 and an annular slit gas die.

A range of different turbulence models were applied during the investigation, with the results being relatively insensitive to the choice made, which provide confidences in the numerical calculations presented. The k- ω model has been applied in the results presented here to close the Reynolds stress terms in the turbulent model. The conservation equations were solved numerically using the finite volume solver ANSYS Fluent 13 [4].

The SIMPLE algorithm was applied with an implicit 2nd order upwind scheme to solve the governing equations. A single phase compressible gas-only flow was resolved for computational domain. Steady state conservation equations have been implemented to simulate the compressible single phase gas flow for each of the nozzles. The molten metal was omitted at the model as the aim of this study is to understand the simplified situation of the high-velocity gas jet flow separation around melt delivery nozzle tip [5],[6]. Due to use of an annular slit gas die, the governing equations were solved for the r-z components of a cylindrical system which is independent of φ (a 2D axis-symmetric domain is considered which reflect the 3D situation of an annular slit well in this case).

The computation domain and the nozzle outlined are shown in figure 2. The flow direction is from left to right and the nozzles outlined in figure 1 are rotated by 90 degrees and the z-axis being the axis of rotation.

Model assumptions

In order to simplify the numerical calculations and establish the numerical model of gas flow pattern, the following assumptions have been made as below,

1- Flow is considered to be steady-state.

2- The effects of gravity are neglected.

3- Flow is 2D axis-symmetric.

4- Flow is considered as air and modelled as a compressible ideal gas.

5- The impact of the molten metal is not considered.

Domain and Meshing

A detailed study of both the domain size and boundary locations were undertaken to identify the effect of inlet /outlet moving boundaries and the size of computational domain. The final geometry was constructed and domain independence was demonstrated. A series of high-quality meshes were developed with increasing spatial resolution to evaluate the effect of that on the CFD results. These contained 15000, 22500 and 30762 elements, respectively. It was established that the results where the mesh containing 30762 elements were acceptably mesh independent and these were subsequently used for the simulations reported here. The domain size and a sample of mesh independent can be seen in Figure 2.

Boundary Conditions

Atomization gas pressures of 0.5, 1, 1.5, 2, 2.5,3, and 4MPa were considered for the pressure inlet boundary condition to the nozzle gas chamber, these pressures being based on commercial operating practise for gas atomisation. The outlet of the domain (down stream of the melt nozzle) was taken as a pressure condition at atmospheric pressure. The outer boundaries for the gas chamber, melt delivery nozzle and the gas die were considered as a wall with no-slip velocity condition. For the boundary labelled 'Upper domain boundary' in figure 2, two boundary models were considered, a wall with no-slip condition and an atmospheric pressure outlet. Calculations have been undertaken for both above a part of the domain independence test. It was noted that the results were comparable for both boundary conditions and, as such, the wall boundary was used since this provided more consistent model convergence. In addition, for the thermal boundary conditions, for upper boundary flow inlet and outlet, the gas temperature was set at 300K.

Results and Discussion

Figure 3 illustrates the total pressure contour of four melt delivery nozzles at the gas atomization pressure of 0.5MPa. As can be seen in this figure, the gas flow boundary layers are attached to the outer surface wall of all the four melt delivery nozzles.

With increasing the atomization gas pressure to 1MPa, the gas flow layers were detached from melt nozzle wall for the nozzles types3 and 4, indicating flow separation has occurred. This situation is shown in figure 4. This flow separation for nozzle types3 and 4, occurred at around 2 and 5mm from the melt nozzle tip, respectively and a point is known as the separation point. At the separation point of nozzle types3 and 4, there was a large adverse gradient pressure which is shown with dark blue colour in the total pressure contour of figure 4.

This adverse pressure will cause the liquid metal to be sucked from the end face of the melt delivery nozzle in to its outer surface of melt nozzle in the dark blue area. The melt is then exposed to a very cold gas jet from gas die and solidifies rapidly, accumulating around the outer surface of the melt delivery nozzle.

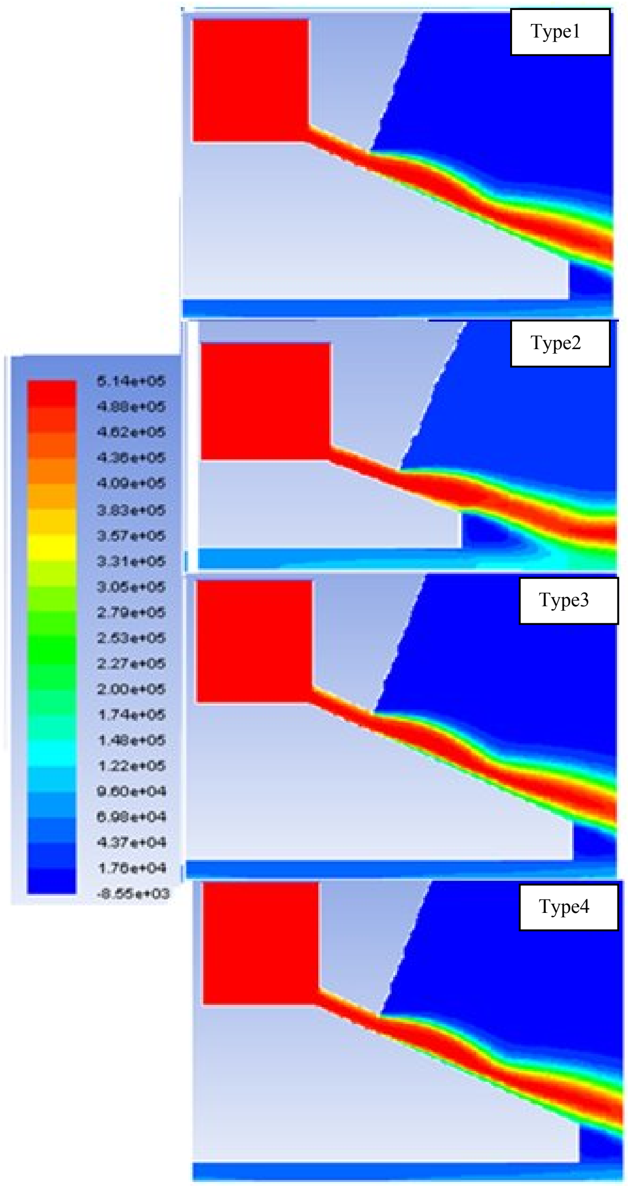

Figure 3 Total pressure contour of four melt delivery nozzles at 0.5MPa.

This will alter the shape of melt delivery nozzle and clog the gas jets on the die, halting the atomization process. The position of the separation point on melt delivery tip edge can play a crucial role in determining whether this occurs. If, the separation point happens far from melt tip the effect of melt back-flow will be more intense. Conversely, no flow separation occurred for nozzle types1 and 2 at this pressure [1], [7], [8].

At atomization gas pressure of 1.5MPa, for nozzle types1 and 2, similar to the previous gas pressure of 1MPa, the boundary layers were still attached to the outer surface of the melt delivery nozzle wall, but for nozzle types 3 and 4, the separation point was moved further towards the melt tip edge. At this pressure, the separation point for nozzle type3 was occurred at around 0.94mm and for nozzle type4 was 2.27mm from melt nozzle tip.

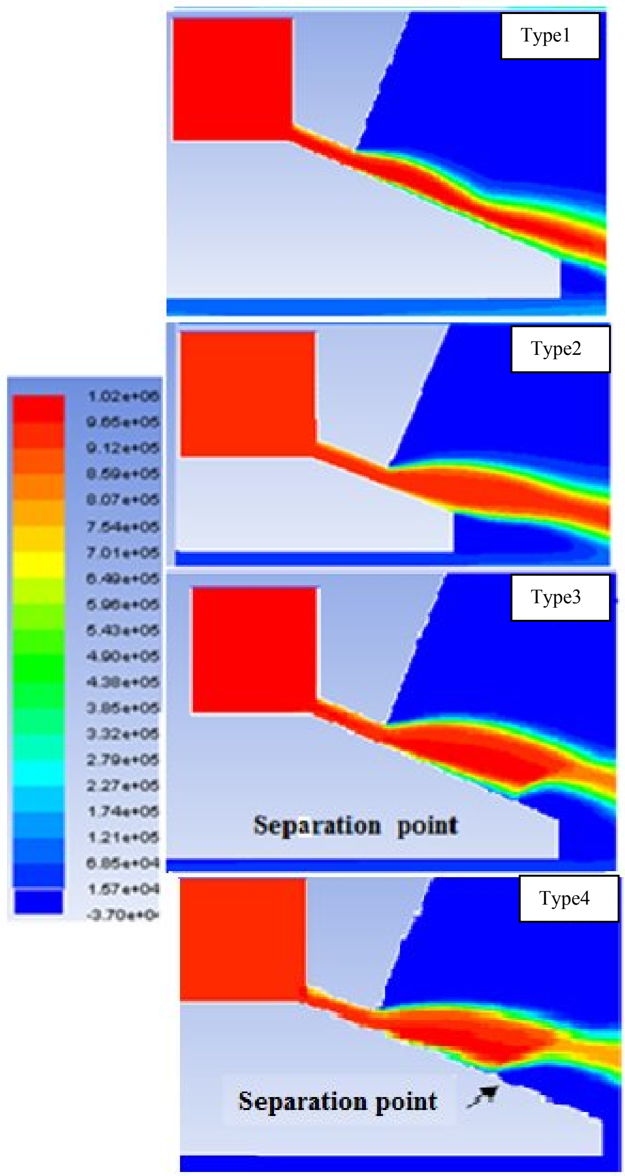

Figure 4 Total pressure contour of four melt delivery nozzles at 1MPa.

This situation was happened for nozzle type 4 at higher atomization pressures of 2 and 2.5MPa. The separation point has been occurred at 1.36mm at atomization gas pressure of 2MPa and 0.9mm from melt delivery nozzle tip for gas pressure of 2.5MPa. For nozzle type3, no flow separation happened at gas pressures of 2 and 2.5MPa. According to these results, the separation event is more likely to occur for nozzle melt tip length of 8mm and above at this experiment. It is seen clearly that the increase of atomization gas pressure had no effect on the flow separation for the nozzle types1 and 2. For the nozzle types3 and 4, flow separation did occur, but the separation point was moved closer to the melt delivery tip. Figure 5 illustrates this situation and explains the position of separation point for nozzle types3 and 4 against different atomization gas pressure. The flow separation for nozzle type4 is depicted at the atomization pressure of 2.5MPa in figure 6.

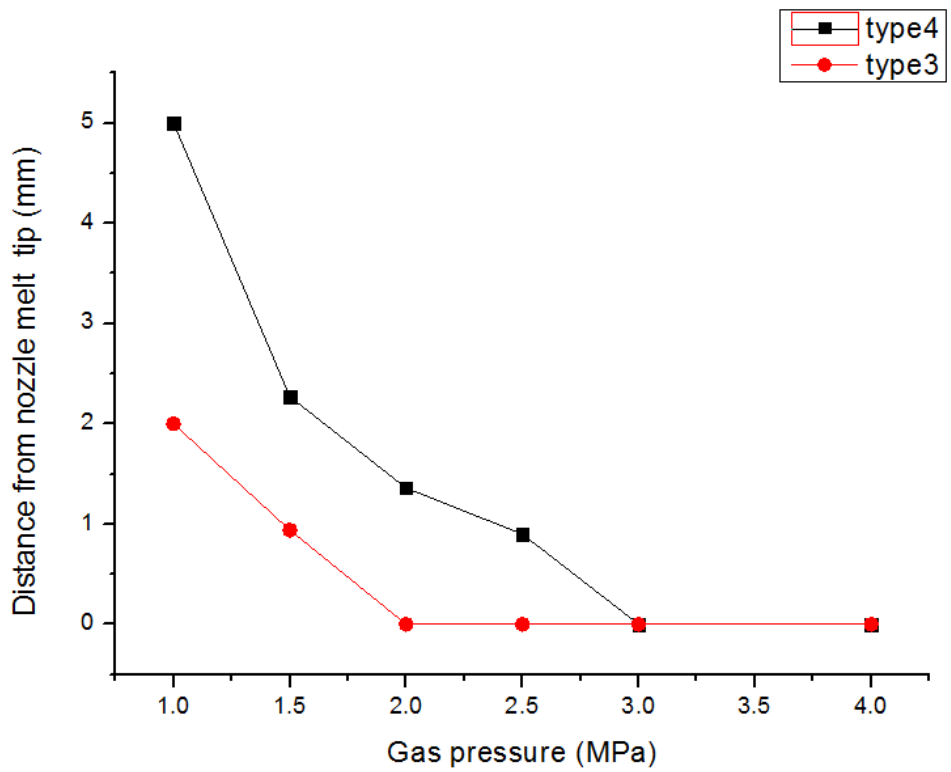

Figure 5 Separation point distance from melt delivery tip for nozzle types3 and 4.

Increasing the atomization gas pressure at the higher gas pressures of 3, and 4MPa had no further effect on the flow separation for any of four nozzles. The separation phenomenon is more severe at a low atomization gas pressure of 2MPa for the nozzle type3 and 2.5MPa for nozzle type4. This event can be explained due to the flow separation occurrence when the high speed gas jet boundary layers travel far enough against an adverse pressure gradient that the velocity of these boundary layers relative to the melt nozzle outer surface wall fall almost to zero and the gas flow boundary layers become detached from the surface of the melt nozzle wall. With increasing the length of the melt nozzle, more flow boundary layers can detached from surface. This explains that the flow separation is more related to melt nozzle length at a specific atomization gas pressure [9].

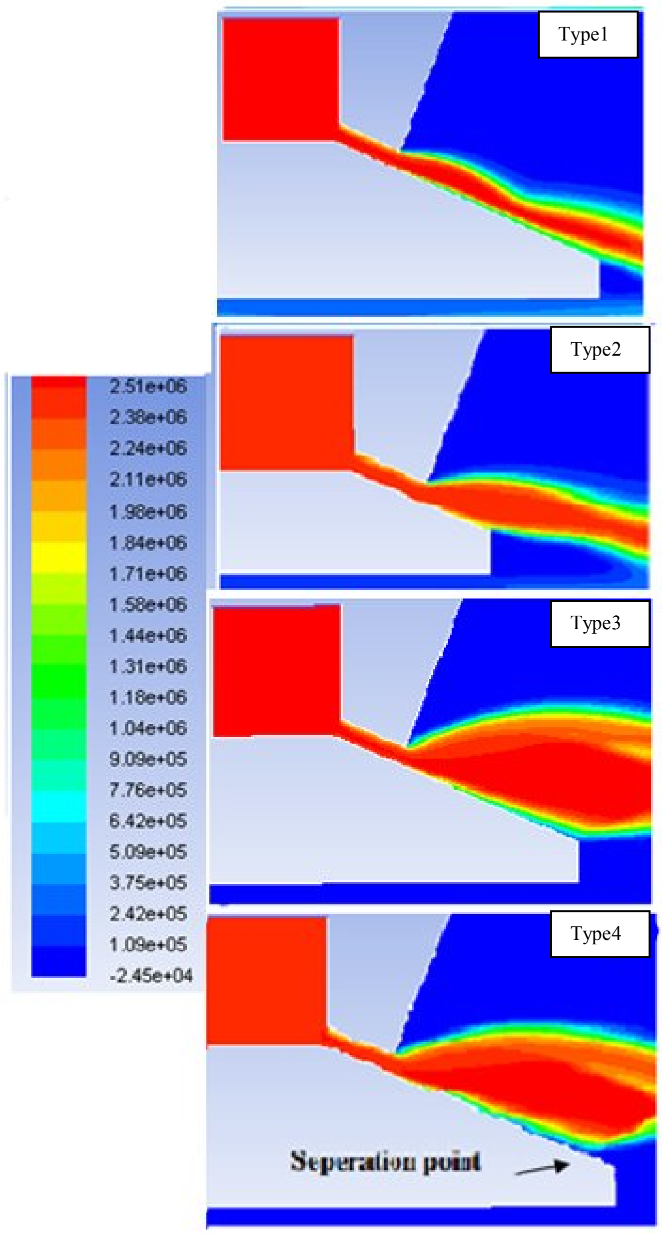

Figure 6 Total pressure contour of four melt delivery nozzles at 2.5MPa.

Summery and Conclusions

The effect of melt delivery tip length on flow separation of an annular slit gas atomization die has been examined numerically. The calculations indicate that the nozzle types3 and 4 are more sensitive to the flow separation phenomenon at even low atomization gas pressure of 1MPa. In addition, for nozzle type3, with increasing the atomization gas pressure from 1MPa to 1.5MPa, the separation point is moved further towards the melt nozzle tip and for nozzle type4, this situation was occurred between the gas pressures of 1 to 2.5MPa and further increasing the gas pressure has no effect on the flow separation for these particular melt nozzles design. In addition, the critical melt tip length which is sensitive to flow separation phenomenon at this experiment is 8mm. Therefore, this result explains the extension length of melt nozzle need to be chosen carefully to prevent of flow separation problem.

References

[1] P.S.Grant, Solidification in spray forming, Metallurgical and Materials Transactions A, 38: 1520-1529, (2005).

[2] Ozer Aydin and Rahmi Unal, Experimental and numerical modelling of the gas atomization nozzle for gas flow behaviour**,** Computers and Fluids: 37–43 (2011).

[3] J Otaigbe and J Mcavoy, Gas atomization of polymers, Advances in polymer Technology, 20: 145-160 (1998).

[4] J.Mi,RS Figliola and I.E. Anderson, A numerical investigation of gas flow effects on high pressure gas atomization due to melt tip geometry variation, Metallurgical and Materials Transactions B,28B :935-941, (1997).

[5] N. Zeoli, S. Gu, Computational validation of an isentropic plug nozzle design for gas atomization Computational ,Materials Science, 42: 245–258 (2008).

[6] N. Zeoli, S. Gu, Numerical modelling of droplet break-up for gas atomisation, Computational Materials Science,38: 282–292 (2006).

[7] CAI Wenxiang, Applying Numerical Simulation to Analyse the Performance of Nozzles, International Conference on Energy and Environment Technology, 207-210 (2009).

[8] J.Ting, I.E. Anderson, A Computational Fluid Dynamics investigation of the wake closure phenomenon Materials Science and Engineering, A 379: 264-276 (2004).

[9] R.Unal, Investigation of the metal powder production efficiency of a new convergent-divergent nozzle in close-coupled gas atomization, Powder Metal: 302-306 (2007).