Grid Independence Study for Convergent and Convergent-Divergent Nozzles used for Spray Atomization Process using CFD Techniques (Fluent)

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Abstract— Grid independence study is performed to eliminate/reduce the influence of the number of grids/grid size on the computational results. Any changes for geometry, meshing grids definitely will changed. When grids changed, we need to ensure the grid independence is applied. Another good test to do is numerical sensitivity test. The important boundary conditions and parameters can be tested to see the effect of certain conditions to the result[1]. Grid convergence is the term used to describe the improvement of results by using successively smaller cell sizes for the calculations. A calculation should approach the correct answer as the mesh becomes finer, hence the term grid convergence. The normal CFD technique is to start with a coarse mesh and gradually refine it until the changes observed in the results are smaller than a pre-defined acceptable error[2]. Gas atomization is a process to manufacture high quality metal powders. During the gas atomization process, the molten steel is atomized thanks to inert gas jets into fine metal droplets which cool down during their fall in the atomizing tower[3]. In the present investigation, an attempt was made to obtain the optimum grid size (mesh) that are required for Convergent-Divergent (CD) nozzle and Convergent (C) nozzle for conducting CFD trails using Fluent required for Gas Atomization process.

Key words: Grid Independence, Gas Atomization, CFD

I. INTRODUCTION

The solution of governing Navier-Stokes equation is said to be grid independent only when there is no significant change in it by increasing total number of grid points further. To estimate minimum number of grid points required to achieve the grid independence, following procedure is adopted. First analysis is carried out on a crude grid with successively finer grids being taken by increasing number of grid points in both axial and radial directions. The solution is said to be grid independent if all the values of the solution at common grid points in two successive grids does not change by more than 0.5% or alternatively, overall performance conditions like total pressure loss, area averaged Mach number at the nozzle exit do not change by more than 0.5% [4, 5].

Grid independence is done to ensure that the solution is independent on grid size. In this method, same problem is solved with fine grids and see variation in result. With finer grid resolution, percentage deviation from experimental observation decreases, but medium- and fine-grid solution produces an equivalent solution that is within acceptable range of deviation from the experimental data. Hence, medium-grid level was used for computational purposes to obtain computational economy without compromising accuracy [6, 7, 8, 9].

II. DETAILS OF THE PRESENT INVESTIGATION

The geometric configuration and process parameters used for CD nozzle and C nozzle for conducting Grid Independence Study & modelling to carry out Gas atomization trials using Fluent software is shown as described below.

A. *CD Nozzle Dimension obtained from Design Principles*

The dimensions for CD nozzle obtained from design are shown in figures 1 and 2, with and without presence of axial fitted Metal Delivery Tube (MDT). The parameters and boundary conditions considered for simulation of Mach number for conducting Gas Atomization trials are shown in table-1 and 2.

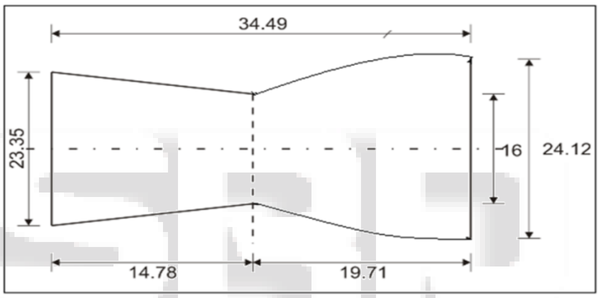

Fig. 1: CD Nozzle dimensions (without presence of MDT)

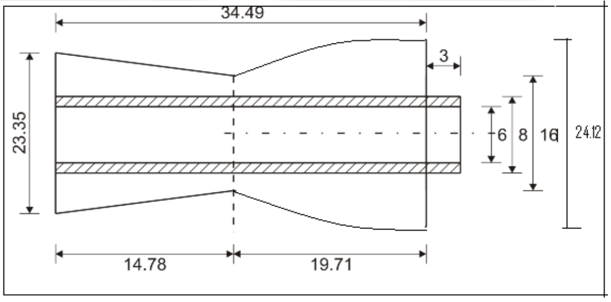

Fig. 2: CD Nozzle dimensions (with presence of MDT)

For C nozzle, convergent portion of CD nozzle dimensions (geometric configuration) was considered and dimensions & process parameters will remain same as that of CD nozzle.

B. *CD Nozzle Dimensions and Parameters*

Sl. No	CD Nozzle Dimensions and Parameters	Values
1	Inlet diameter	23.35 mm
2	Outlet diameter	24.12 mm
3	Throat diameter	16.00 mm
4	Distance between inlet and nozzle throat	14.78 mm
5	Distance between nozzle throat and outlet	19.71 mm
6	Inlet pressure	0.3 MPa

7	Gauge pressure	0.1 MPa
8	Exit Mach	2.1 Mach
9	Temperature of gas at inlet	300 K
10	MDT dimensions	ID = 6mm, OD = 8mm, t =1 mm
11	MDT length	L = (35+3) m
12	Nozzle protrusion length to obtain maximum aspiration pressure	3 mm

Table 1: CD nozzle dimensions and process parameters

- Geometrical mesh (grid) of both nozzle and atomizing zone were generated using Gambit software. The boundary conditions applied were pressure inlet, pressure outlet, wall and symmetry. Turbulence model was defined as Spalart-Allmaras for fluid flow solver in Fluent 5/6 and mesh type as QUAD.

C. *Boundary Conditions Applied*

The boundary conditions applied for CD nozzle are as mentioned in table – 2.

Sl. No	**Boundary Condition Details**	**Values**
1	Boundary condition applied at inlet	PRESSURE_INLET
2	Boundary condition applied at outlet	PRESSURE_OUTLET
3	Boundary condition applied for atomization zone	PRESSURE_OUTLET
4	Boundary condition applied at the axis	Symmetry
5	Boundary condition applied at nozzle wall	Wall
6	Boundary condition applied for MDT	Wall

Table 2: Boundary conditions for CD nozzle

III. CFD TRAILS CONDUCTED USING FLUENT

Boundary conditions were applied for CD nozzle as mentioned in table-2. A pressure of 0.3 MPa and temperature of 300K was given as input for inert gas at inlet. Converged CFD results were plotted for exit velocity/Mach Number as shown in figure -3.

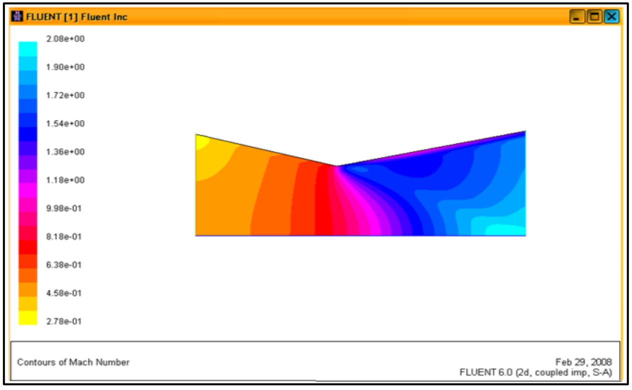

Fig. 3: Mach number plot for CD nozzle of 2.1 Mach

A. *Grid Independence Study for CD Nozzle*

The grid independence study was carried out for all cases for CD-nozzle and C-nozzle in the present investigation. This is explained with different cases as mentioned below:

- CD nozzle: Without extension of axial domain
  1) Case 1- without presence of axial MDT
  2) Case 2 - with MDT
- CD nozzle: With extension of axial domain
  1) Case 3 - without MDT
  2) Case 4 - with MDT

Similar cases were considered for C – Nozzle for Grid Independence study (Case 5 to 8)

1) CD Nozzle: Without Extension of Axial Domain

a) Case 1

Figure CD-1 show grids generated from Gambit software for CD nozzle without presence of axially fitted MDT with 70*60 grid points (results i,e Mach number will become grid independent from this grid size) in axial and radial directions. Table CD-1 shows grid independent study for the case -1 considering Mach number as an example.

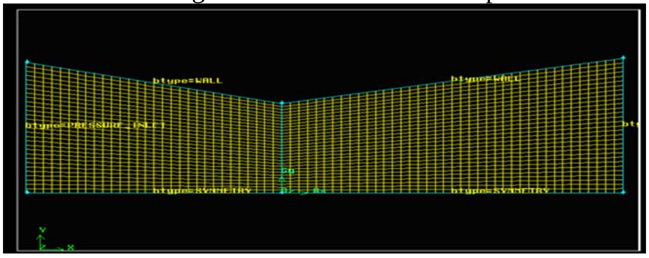

Fig. 3: CD-1, CD Nozzle without MDT, with grid points 70-60

Axial – Radial Nodes	40-50	50-50	60-55	70-60	70-65
Average Exit Mach	2.075	2.085	2.091	2.100	2.102

Table 3: Grid independence for case-1 (Mach number)

b) Case - 2

Figure CD - 2 shows grids generated from Gambit for CD nozzle with the presence of MDT with 40*50 grid points (results i, e. Mach Number will become grid independent from this grid size) in axial and radial directions. Table CD-2 show grid independent study for case -2.

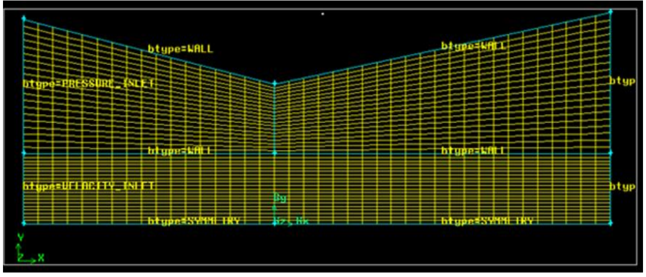

Fig. 4: CD-2, CD Nozzle with presence MDT, with grid points 40X50

Axial – Radial Nodes	30-40	35-40	40-45	40-50	50-50
Average Exit Mach	2.151	2.202	2.253	2.30	2.301

Table 4: CD-2, Grid independence for case - 2 (Mach number)

2) CD Nozzle: With extension of Axial Domain

a) Case -3

Figure CD-3 show grids generated from Gambit for CD nozzle without presence of MDT with 120*90 grid points (results become grid independent from this grid size) in axial and radial directions. In this case, axial domain was extended to simulate imposed atmospheric condition. Table CD-3 shows the grid independent study for Case -3.

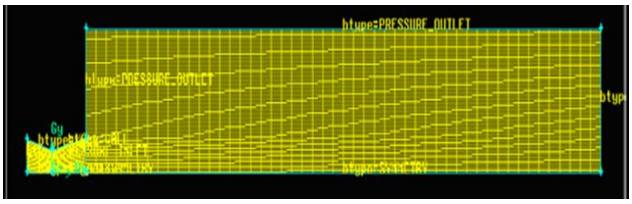

Fig. 5: CD-3, CD Nozzle without MDT, with grid points 120X90

Axial – Radial Nodes	90-60	100-65	110-70	120-90	125-95
Average Exit Mach	1.054	1.110	1.115	1.120	1.121

Table 5: CD-3, Grid independence for case -3 (Mach number)

b) Case 4

Figure CD-4 shows grids generated from Gambit for CD nozzle with presence of MDT of 100*90 grid points (results become grid independent from this grid size) in axial and radial directions. Table CD-4 show the grid independent study for case - 4.

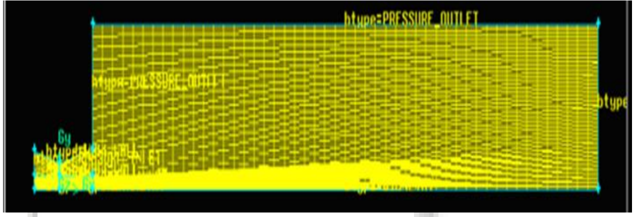

Fig. 6: CD-4, CD Nozzle with presence MDT, with grid points 100X90

Axial – Radial Nodes	70-70	80-70	90-80	100-90	110-95
Average Exit Mach	1.224	1.322	1.355	1.400	1.401

Table 6: CD-4, Grid independence for case-4 (Mach number)

B. Grid Independent Study for C- Nozzle

In this case similar conditions of process parameters and boundary conditions were considered for C-nozzle as used in CD nozzle.

1) C-nozzle - Without extension of axial domain

a) Case -5

Figure C-5 show grids generated from Gambit for C- nozzle without the presence of MDT, with 60*30 grid points (results become grid independent from this grid size) in radial and axial directions. Table C-5 shows the grid independent study for case-5.

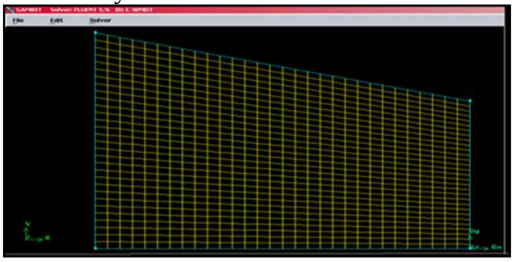

Fig. 7: C-5, C-nozzle without MDT, with grid points 60X30

Radial-Axial Nodes	40-25	50-30	50-25	60-30	65-35
Average Exit Mach	0.960	0.975	0.985	1.01	1.01

Table 7: C-5, Grid independence for case-5

b) Case - 6

Figure C-6 show grids generated from Gambit for C- nozzle with the presence of MDT with 56*30 grid points (results become grid independent from this grid size) in radial and axial directions. Table C-6 shows the grid independent study for case-6.

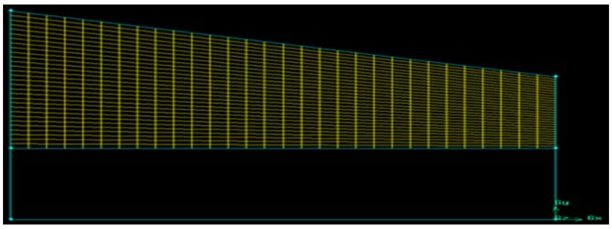

Fig. 8: C-6, C-Nozzle with MDT, with grid points 56X30

Axial – Radial Nodes	40-20	45-25	50-25	56-30	60-35
Average Exit Mach	0.965	0.978	0.985	1.02	1.02

Table 8: C-6, Grid independence for case -6

2) C-nozzle - With extension of axial domain

a) Case 7

Figure C-7 show grids generated from Gambit for C- nozzle with the presence of MDT with 140*90 grid points (results become grid independent from this grid size) in axial and radial directions. Table C-7 shows the grid independent study for case C-7.

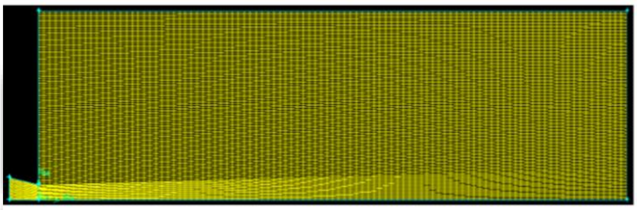

Fig. 9: C-7, C-Nozzle with MDT, with grid points 140X90

Axial – Radial Nodes	100-50	120-60	130-80	140-90	150-95
Average Exit Mach	0.665	0.670	0.680	0.70	0.71

Table 9: C-7, Grid independence for case -7

b) Case-8

Figure C-8 show grids generated from Gambit for the C-nozzle with the presence of MDT with 130*85 grid points (results become grid independent from this grid size) in axial and radial directions. Table C-7 shows the grid independent study for case-8.

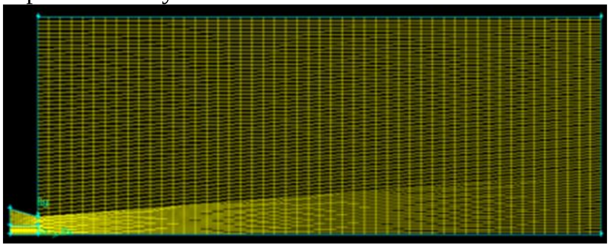

Fig. 10: C-8, C-Nozzle with MDT, with grid points 130X85

Axial – Radial Nodes	100-50	120-60	130-80	130-85	140-95
Average Exit Mach	0.675	0.69	0.712	0.72	0.721

Table 10: C-8, Grid independence for case-8

IV. CONCLUSIONS

In the present investigation, the Grid independence study was conducted for CD nozzle and C-nozzle. This was done to ensure that solution obtained for Mach number is independent on grid size. After certain point, even if the grid size is increased, the Mach number obtained (2 in case of CD nozzle and 1 in case of C nozzle) remains almost same. In this method, same problem (grid size to get optimum Mach number) is solved with fine grids and sees variation in result. With finer grid resolution, percentage deviation from experimental observation decreases, but medium- and fine-grid solution produces an equivalent solution that is within acceptable range of deviation from the experimental data. Hence, medium-grid level was used for computational purposes to obtain computational economy without compromising accuracy.

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