Numerical Analysis of Airblast Atomizer

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***Abstract*-In gas turbine application the combustion characteristics and emission generally depends on the atomization process. There are many types of atomizing devices namely Pressure, Air assist, Air Blast and Effervescent etc. the most commonly used atomizer in the gas turbines is the air blast, because free stream air which is freely available can be used as the atomizing medium, hence no external pressure device is not required for the atomization.**

The present study carried by using commercial numerical code to predict the atomization process which defines the physics behind the flow and its characteristics like SMD size and distribution along radial direction due to the effect of various factors like Pressure, Mass flow rate and axial location.

The Numerical study is carried-out by using SN-Type nozzle design; obtained results are validated against the known experimental results carried out by B.K. Park and J.S.Lee et al, [8].

1. INTRODUCTION

1.1 Atomization

Atomization [1] is the first and possibly the most important step involved in the combustion of liquid fuels in propulsion devices. The combustion of liquid fuel is vapour-phase process, and to accelerate vaporization by breaking up the liquid into droplets of the proper size is the fundamental function of atomization. An additional and equally important function of atomization is to distribute the fuel particles throughout the combustion space.

The distribution of droplets is the initial step in the mixing of the fuel with air. The three processes of atomization, vaporization and mixing are, therefore, closely related. All three processes greatly affect the functioning of the fuel and combustion systems

1.2 The Mechanism of Atomization

"The Mechanism of Atomization" - It is shown that atomization generally takes place in three steps:

a. The initial disturbance of the surface of the liquid jet

b. The formation of ligaments which then break up into fragments, and

c. The further breakup of the fragments into smaller droplets.

The most important factors that influence drop size in the atomization process are:

a. Nozzle design

b. Operating conditions, especially pressure

c. The properties of the liquid and of the air into which it is injected, and

d. The relative velocity between the liquid and the air.

2. LITERATURE REVIEW

C.T. Poovanna and S.N. Sridhar et al, [3] carried the Numerical Investigation of Droplet Distribution from Pre-filming Airblast Atomizer. The numerical investigations reveal a clear picture, how the SMD is going to vary along the axial and radial distances. And also they predicted the swirl number variation on the atomization and results shows when the swirl number increases the SMD also increases.

Jyotichandra and S.N. Sridhar et al, [4] carried the Numerical Investigation of Spray Characteristics of a Swirl

Airblast Atomizer for Varying Geometry and Flow Condition. The following changes have made.

- Increasing air flow by keeping Mass flow rate constant
- Swirl number effect of atomization
- Inner and outer air swirl in clockwise and counter clockwise direction
  And predicted the well SMD results.

K.D. Kihm and N. Chigier. [7] Effect of shock wave on liquid atomization of 2-dimensional airblast atomizer. Following changes have made to predict the SMD. They used convergent nozzle which gives mach 0.7 to 1 and studied the effect of shock wave on the atomisation process. And finally results shows there is no mush effect of shock wave on atomization and suggest to use supersonic configuration.

In this study Airblast atomizer configuration is used for primary atomization and TAB model for secondary atomization.

The SN-Type nozzle design and Fluent 14.5 are used, to study the atomization characteristics like SMD size and distribution due to the effect of various factors like Pressure, Mass flow rate and axial location. Obtained results are validated against the known experimental results carried out by *B.K. Park and J.S.Lee et. al,* [8].

3. PHYSICAL DOMAIN AND MESH

Figure 3.1 showing the schematic diagram of the plain co-axial airblast atomizer used for present study.

It consist of 2 co-axial tubes, inner is for liquid and outer for the gas. The inner tube having dia 4mm is plain tube and outer has convergent nozzle configuration with exit diameter of 0.3mm.

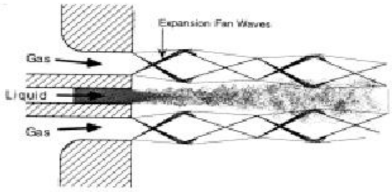

Figure 3.1 Schematic diagram of atomizer

The Figure 3.2 shows the geometry of the atomizer having coaxial passages one for the nitrogen gas and another for water as a atomizing liquid. The water passes through the inner tube and nitrogen gas through the SN-Type nozzle. The outer domain is of 100 X 210 mm, surface sweep is used to create the 30^0 domain.

Figure 3.2 Geometry used for numerical study

The Figure 3.3 shows the 3D-Structured mesh having 107778 elements and 95280 nodes. Boundary conditions used are the mass flow for liquid and pressure inlet for the nitrogen gas, the outflow imposed to atmospheric condition, other all wall. The computational domain considers here only 30^0 section, by imposing the periodic condition for the side surfaces and x-axis is considered as rotational axis and flow direction.

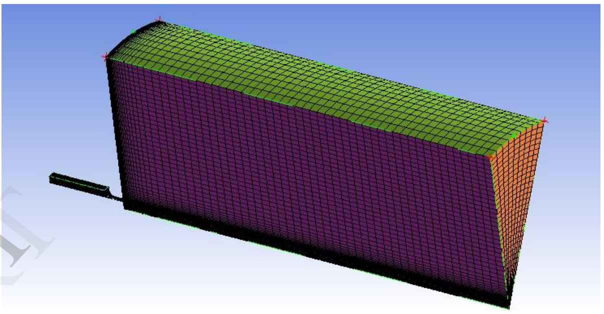

Figure 3.3 3D structured mesh

4. NUMERICAL IMPLEMENTATION

Three dimensional steady state simulations are carried out by using commercial finite volume based software package solver ANSYS FLUENT 14.5.

The governing equations used for the simulation are: the continuity, the momentum and the energy equations along with the equations for turbulence, species transport and discrete phase model. RNG K-epsilon turbulence two equation model is used to predict the droplet distribution with the scalable wall function as near wall treatment, the RNG k-epsilon is predict very good results then standard and Realizable.

The Airblast atomizer injection configuration is used for the primary atomization and TAB with dynamic drag for secondary atomization. The number of particle streams considered as 60, start time and end time as 0 and 100 respectively by assuming spray is continuous, flow rate is 0.0002778 kg/s (for 30^0 section), injector inner and outer diameter as 0 and 0.004m with azimuthal angle 30.

The coupled with Pseudo transient is enabled with the standard interpolation scheme for pressure, second order scheme for the density and momentum and first order upwind scheme for the turbulent kinetic energy and turbulence dissipation rate.

The solution is considered to be converged when the residual value falls below the order of 10e-3 and surface, volume monitors flatten with mass balance.

5. VALIDATION

5.1 First Set of Validation

The Figures 5.1.a, 5.1.b and 5.1.c shows Pressure, Velocity and Mach contours respectively, the results obtained for inlet pressure 0.4 MPa are better agreement with the known experimental results as follows.

Parameter	**Experimental**	**Numerical**
Exit Pressure	101325 Pa	8.09e+4 to 1.13e+5 Pa
Exit Velocity	322 m/s	311 to 388 m/s
Exit Mach	0.95	0.96 to 1.29

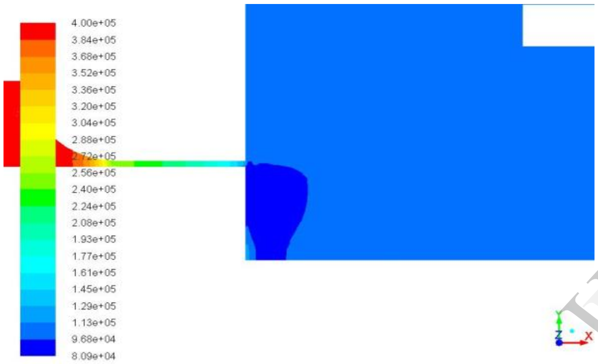

Figure 5.1.a Pressure contours

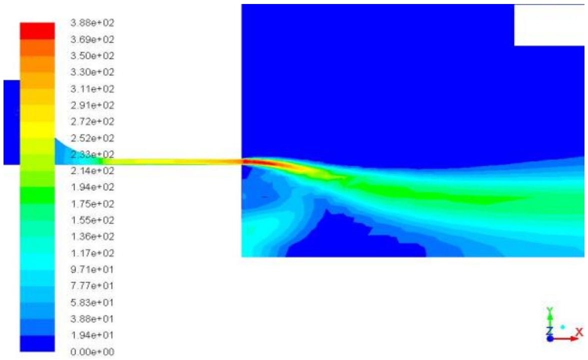

Figure 5.1.b Velocity contours

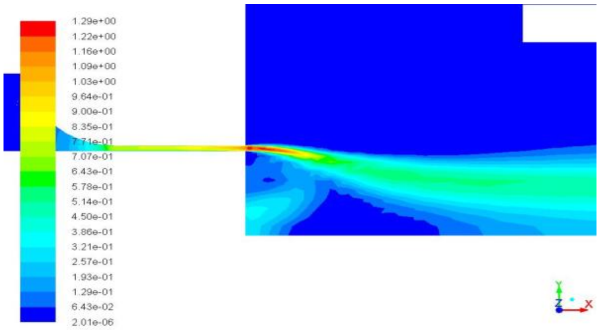

Figure 5.1.c Mach contours

5.2 Second Set of Validation

The numerical results obtained from the analysis for variation of SMD along radial direction due to effect of pressure (0.2MPa, 0.3Mpa and 0.5Mpa) is compared with the experimental results as shown in the figure 5.2.a. The comparison shows numerical results are very good agreement with the experimental results.

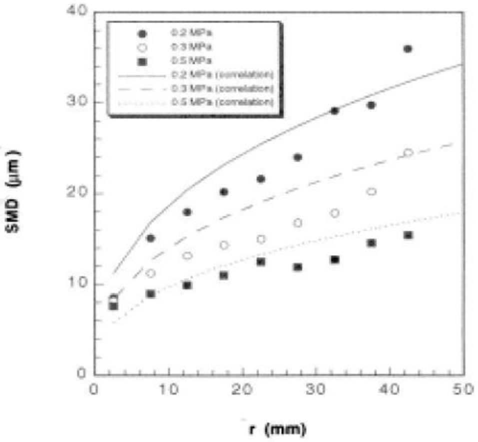

Figure 5.2.a Experimental Radial SMD Distribution at X=160mm under various gas injection pressure and Q=200ml/min

The following figure 5.2.b. shows the comparison between the Calculated and measured SMD values at X=160mm under various gas injection pressure for 200 ml/min flow rate.

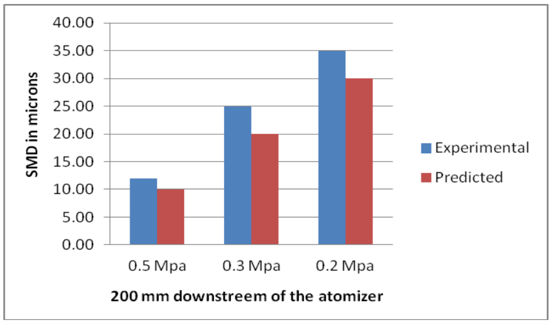

Figure 5.2.b. Calculated and measured SMD

Figure 5.2.c shows the 3D view of the spray the pattern, which is similar to the experimental view of spray as shown in figure 5.2.d

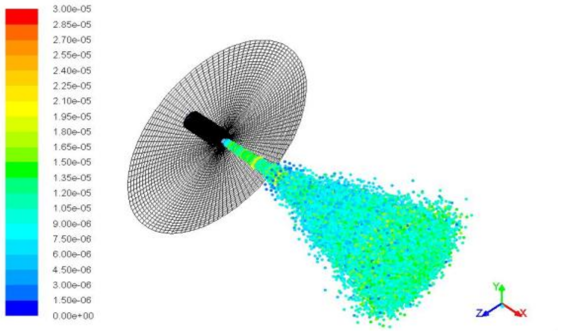

Figure 5.2.c CFD Particle distribution

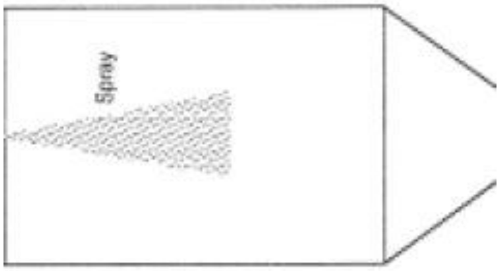

Figure 5.2.d Experimental Particle distribution

6. RESULTS AND DISCUSSIONS

The results are obtained from the CFD by applying the experimental condition to the computational model with radial distribution distance 55mm, were measured for three different liquid flow rates, pressure and at axial locations. The examination of individual parametric effects on the atomization as follows

6.1 Effect of Injection Pressure

Figure 6.1 shows radial distribution for the SN-type nozzle depending on different injection pressures ranging from 0.2 MPa to 0.5 MPa measure at X=160mm with Q = 200 ml/min.

As the injection pressure increases, the spray SMD decreases noticeably. As radial distance increases the gas velocity decreases by mixing it with the entrained air and the pressure reduces to the ambient level. And hence the SMD gradually increases in the radial direction.

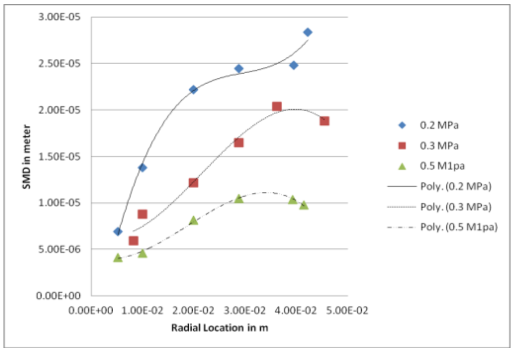

Figure 6.1 Radial SMD distribution at x=160 mm under various gas injection pressure with Q=200ml/min

6.1 Effect of Liquid Flow Rate

Figure 6.2 shows radial SMD distributions measured at x=160 mm for different liquid flow rates under 0.2 MPa gas injection from the SN-Type nozzle. Since the injection pressure is constant for all cases, gas flow rate remains unchanged.

For same gas injection pressure if liquid flow rate increased which reduces the gas-to-liquid mass ratio (GLR), and this decreasing GLR increases the drop SMD because of the reduction in shear energy per unit amount of the atomized liquid. The three liquid flow rates used are 100, 200 and 300 ml/min.

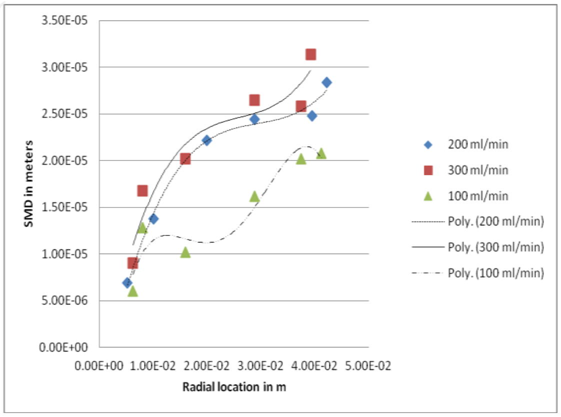

Figure 6.2 Radial SMD distribution at x=160 mm for different liquid flow rates under 0.2 MPa

6.1 Effect of Axial Location

Figure 6.3 shows the atomization characteristics measured at different axial locations downstream of the nozzle exit. The liquid flow rate remained at 200 ml/min and the nozzle pressure was a constant 0.4 MPa.

Larger droplets tend to move away from the centreline along with the spray because of their larger inertia-to-drag ratios. This depletion of larger drops can contribute to the gradual SMD decrease in the spray centre, whereas the same depletion will contribute to the SMD increase at the spray edge along increasing axial location.

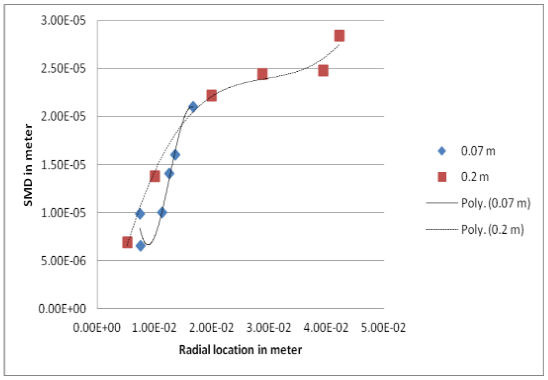

Figure 6.3 Radial SMD distribution at two different axial locations under 0.2 MPa and Q = 200 ml/min

7. CONCLUSION

Atomization characteristics of a single combination of twin fluid, water as fuel and nitrogen as a atomizing gas, were studied for SN-Type nozzle.

The airblast atomizer configuration for primary atomization and TAB model for secondary atomization are considered with the injection pressure ranges from 0.2 MPa to 0.5 MPa and mass flow from 100 ml/min to 300 ml/min.

From the simulation, following conclusions are made which are good agreement with the experimental data.

- If the injection pressure increases, the SMD decreases noticeably but the atomization characteristic will be better.
- By increasing the liquid flow rate, SMD increases but atomization characteristic decreases.
- As the axial distance increases the range of SMD also increases.

8. SCOPE FOR FUTURE WORK

The case studies in this work have a lot of scope for improvement of changes

- SMD can be predicted by using different nozzle design.
- Effect of direction of swirl (clockwise and counter clockwise) on SMD can be predicted.
- Shock wave effect on atomization can be predicted.
- Different liquid can be used to predict the viscosity effect on atomization.

REFERENCES

[1] Arthur H Lefebvre and Dilip R. Ballal., “Gas Turbine Combustion-Alternative Fuels and Emissions”, CRC Press Taylor & Francis Group, Third Edition-2010 pp.221-285.

[2] Caio Nunes Pereira., “Atomization and Combustion of Liquids”, MS Thesis., Nov 2012, pp.13.

[3] C.T. Poovanna S.N. Sridhara., “Numerical Investigation of Droplet Distribution from Pre-filming Airblast Atomizer”, SAS TECH, Vol. V, No.2, Nov 2006.

[4] Jyothichandra Jingade, S.N.Sridhara., “Numerical Investigation of Spray Characteristics of a Swirl Airblast Atomizer for Varying Geometry and Flow Conditions”, SAS TECH, Volume 7, No.1, April 2008.

[5] Hai-Feng Liu, Wei-Feng Li, Xin Gong, Xian-Kui Cao, Jian-Liang Xu, Xue-Li Chen, Yi-Fei Wang, Guang-Suo Yu, Fu-Chen Wang, Zun-Hong Yu, “Effect of liquid jet diameter on performance of coaxial two-fluid airblast atomizers”, ELSEVIER, Chemical engineering processing 45, 2006.

[6] Viriato Semibo, Pedro Andrade and Maria da GraCa Carvalho, “Spray characterization: numerical prediction of Sauter mean diameter and droplet size distribution”, ELSEVIER, Fuel Vol. 75, No.15. pp.1707-1714.

[7] K.D. Kihm, N. Chigier, “ Effect of Shock Wave on Liquid Atomization of a Two-Dimensional Airblast Atomizer”, Atomization and Sprays, Vol. 1, pp.113-136, 1991.

[8] B.K. Park and J.S.Lee and K.D. Kihm, “Comparative Study of Twin-Fluid Atomization Using Sonic or Supersonic Gas Jet”, Atomization and Sprays, Vol. 6.