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CFD MODELLING OF AERODYNAMICS IN A SOLAR – ENHANCED VORTEX GASIFIER (SVG): PART II. A PRELIMINARY STUDY OF THE LOCATIONS OF SEAL GAS INLETS

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ABSTRACT

This paper reports a computational fluid dynamics (CFD) study of isothermal gas flows and particle trajectories in a Solar-enhanced Vortex Gasifier (SVG). The aim of this study is to develop a novel aerodynamic method to replace the critical quartz window in the current SVG design. A CFD model of the SVG has been developed based on the commercial CFD package ANSYS/CFX. Seal gas curtains injected from six different inlets, namely three different radial inlets, two different horizontal inlets and one tangential inlet at the aperture in the SVG, are simulated and compared using the CFD model. From this preliminary analysis, it is found that the radial gas inlet located on the middle of the conical surface of the reactor has better performance in keeping particles inside the SVG than the other two radial inlets. However, it is insufficient to keep all particles in the SVG. The two horizontal inlets are not ideal for particle sealing purpose either. The case with six tangential inlets at the aperture is found to be the most promising configuration identified to date for retaining particles in the SVG.

INTRODUCTION

Solar driven gasification is a new technology that uses solar energy to transform solid fuels into syngas, comprising H_2, CO and inerts (Piatkowski et al., 2011). Compared with conventional gasification systems, the products of solar enhanced gasification system are cleaner, with higher utilization ratio, and wider applications (Piatkowski et al., 2011).

The Solar-enhanced Vortex Gasifier (SVG) is one type of solar enhanced gasification system. Figure 1 shows one type of SVG developed by Professor Steinfeld at ETH, Zurich and co-workers. In this SVG, the concentrated solar radiation passes through the quartz window at the left end of the Figure, then through the aperture and finally enters into the reactor cavity. Particles with inert gas (e.g. argon) are injected into the cylinder through the particle feeding inlet. Steam is injected through eight tangential primary steam inlets. The steam and particles form a strong swirling flow in the reactor. Particles absorb the concentrated solar radiation and react within the cylinder.

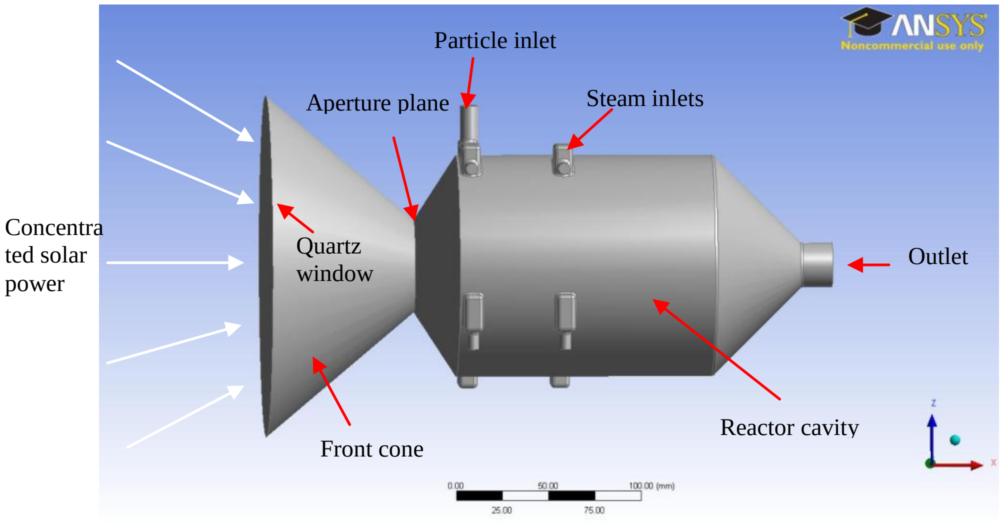

Figure 1: Geometric configuration of the Solar-enhanced Vortex Gasifier (SVG).

One important part of the reactor is the quartz window that is used to control the atmosphere in the gasifier and prevent the egress of particles from it. Current design of the SVG system includes several purging nozzles installed in the front cone region, aiming to prevent particle collisions with, and deposit on, the window. However, previous designs of purging flows have not been totally effective so that particles still can deposit on the window. Due to the decreased transmissivity of the quartz window covered by the particles, reduction of the solar power absorption will lead to a drop of the reactor's efficiency. Furthermore, the deposited particles reach very high temperatures by absorbing the concentrated solar radiation, leading to a high probability of failure of the window. Therefore, an aerodynamic method is sought to replace the quartz window, i.e. using seal gas curtains to retain the particles within the reactor.

A computational fluid dynamics (CFD) study of isothermal gas flow in the SVG is currently being undertaken in the School of Mechanical Engineering, University of Adelaide. The CFD model is based on the SVG furnace of Z'Graggen et al. (2006).

There are no measurements of gas velocity fields in the SVG available in the literature for model development and validation. Therefore, a level of confidence of the modelling results has been established by validating the CFD model in an isothermal flow in another solar chemical reactor (Meier et al., 1996) developed by the same group. This solar chemical reactor has similar swirling flow patterns to those in the SVG and properties of isothermal flows in the reactor are available from the literature. In this validation case, it is found the Baseline Reynolds Stress (BSL) model, and Speziale, Sarkar and Gatski (SSG) Reynolds Stress model perform better than the Shear-Stress-Transport (SST) model. The SSG Reynolds Stress model is chosen, however, since it has better convergence. The validation results were reported in part I of this work (Cao et al., 2012), presented at the same conference.

The aim of the present investigation is to use this validated CFD model to investigate effectiveness of various configurations of seal-gas inlet at preventing particle egress through an open aperture, with a view to eventually replacing the quartz window with seal-gas curtains. The current paper reports some preliminary results of influence of six configurations of seal-gas curtains on particle trajectories through the aperture of the SVG.

Case number	1	2	3	4	5	6
Curtain inlet configuration	Radial inlet 1 See Figure 2	Radial inlet 2 See Figure 2	Radial inlet 3 See Figure 2	Axial inlet 1 See Figure 3a	Axial inlet 2 See Figure 3b	Tangential inlet See Figure 4
Seal gas velocities	1 m/s	1 m/s	1 m/s	2.5 m/s	2.5 m/s	2.5 m/s
Particle inlet mass flow-rate	6e-4kg/s	6e-4kg/s	6e-4kg/s	6e-4kg/s	6e-4kg/s	6e-4kg/s
Total No. of mesh nodes	497,333	491,088	492,586	492,948	494,773	492,556
No. of Elements	2,029,869	1,968,855	1,985,654	1,839,737	2,002,172	1,859,746

Table 1: Details of the different cases investigated.

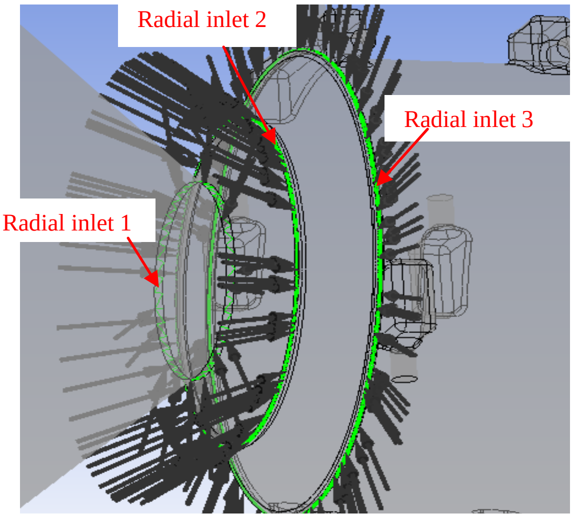

Figure 2: Radial gas inlets of Case 1 (Radial inlet 1), Case 2 (Radial inlet 2) and Case 3 (Radial inlet 3).

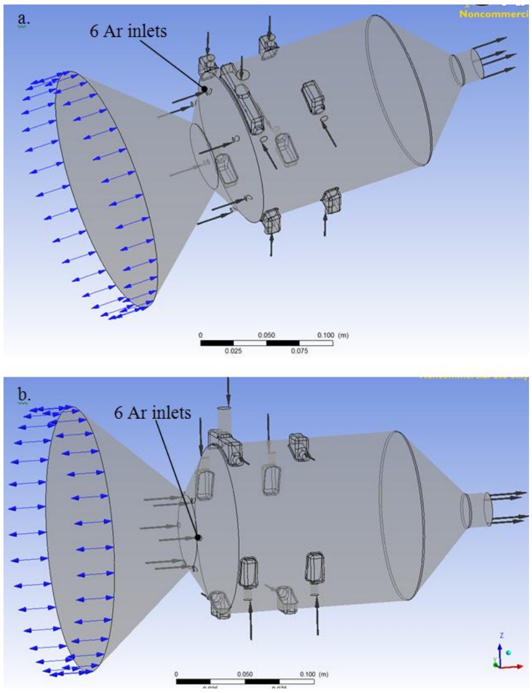

Figure 3: Axial inlets at the same location as for part (a), termed Case 4, (b) Case 5.

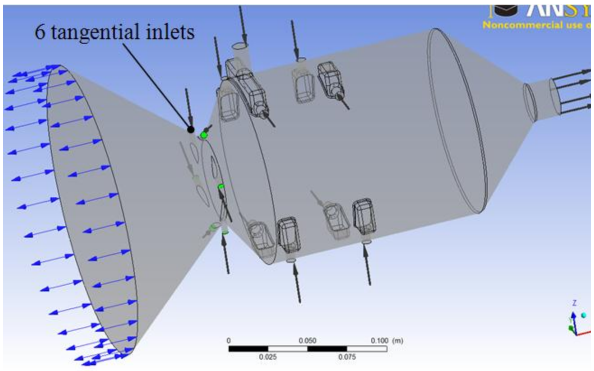

Figure 4: Six tangential inlets at the throat: Case 6.

MODEL DESCRIPTION

Figure 1 shows the geometry of the SVG device that was modelled with the commercial package ANSYS/Designmodeler 14.0. The dimensions are based on available data from the literature (Z'Graggen, 2008). The length of the cavity of the reactor from the aperture plane to the outlet is 0.210 m. The diameter of the reactor cavity is 0.12 m. The diameter of aperture is 0.05 m. Particles and Argon are injected through the particle inlet at 0.03 m downstream from the aperture plane. Steam is injected into the reactor from eight tangential inlets.
To find the best location(s) for the seal gas inlets, the CFD model is used to simulate the internal flows and particle trajectories for six cases, namely, three different radial gas curtain inlets (shown in Figure 2), two six-axial-inlet cases (Figure 3) and one six-tangential-inlet case (Figure 4). In all reported cases, there is no quartz window and it is opening at the left hand end of the SVG. For the radial inlet cases, gas curtain inlets are all 2 mm in width. Radial gas curtain inlet 1 is located on the aperture plane (Figure 2). Radial gas curtain inlet 2 is located at the middle of the conical surface of the reactor and perpendicular to the surface. Radial gas curtain inlet 3 is located at the cylinder surface next to the particle inlet. More details of these cases are given in Table 1.
ANSYS/Meshing 14.0 was used to generate unstructured meshes. Mesh quality was checked in terms of skewness, aspect ratio, orthogonality, and expansion factor. The mesh numbers of all cases reported in the paper are given in Table 1. Figure 5 shows the unstructured mesh of Case 2.
The commercial CFD software ANSYS/CFX 14.0 was employed to simulate the steady state flows in the reactor. Focusing on the aerodynamics characteristics of the flows in the SVG, isothermal gas flows and inert particle flows in the reactor are simulated in the preliminary analysis. The Lagrangian model is used to calculate the particle trajectories. Three thousand mono-sized carbon particles with the density of 2000 kg/m^3 are injected though the particle inlet. The mass flow rate of the particles is 6e-4 kg/s. The convergence criterion for the gas phase properties was 10^{-4} RMS.
The Stochastic model was used to take into consideration of turbulence of particles in this study. It is found that the effect of turbulence dispersion on the particle trajectories and final results is small.

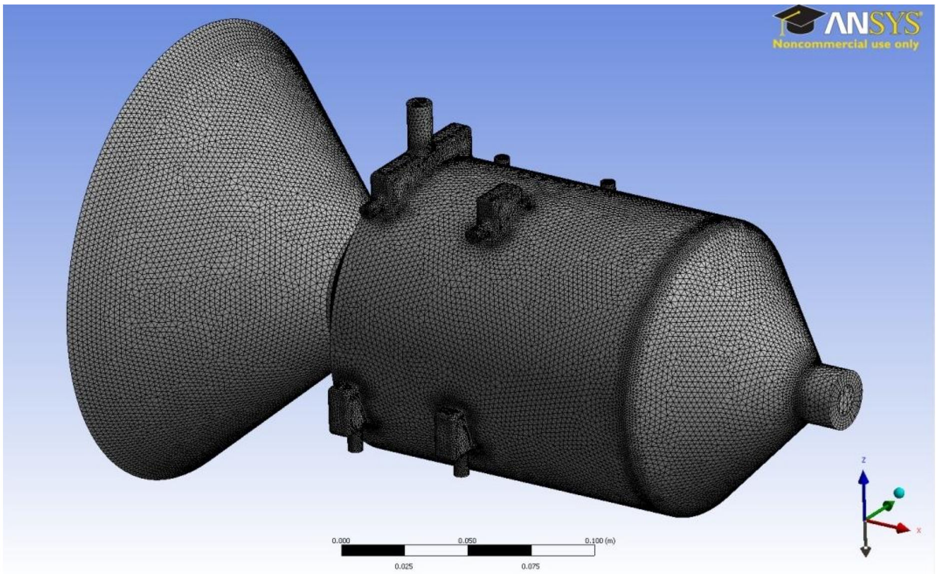

Figure 5: The unstructured mesh of Case 2.

RESULTS AND DISCUSSIONS

Figure 6 shows the particle trajectories when gas curtain inlet 1 is employed, i.e. the seal-gas is injected through the radial inlet at the aperture wall. It is apparent that some particles pass through the gas curtains and leave the SVG through the aperture. Perhaps surprisingly, when the seal gas is injected from radial inlet 2 (Figure 7), less particles are calculated to leave the SVG through the opening, which indicates the higher seal effectiveness of the gas curtain inlet 2 than that of radial gas inlet 1. When the seal-gas inlet is moved to the inlet 3 (Case 3), it is found from Figure 8 that more particles emerge through the front cone. One possible reason for this is that the mass flow rate of the gas curtain inlet 3 is higher than the other two cases, since the inlet velocity is 1 m/s for all cases, while the perimeter of inlet 3 is much larger than that of inlet 1 and inlet 2, leading to a larger inlet area and a higher inlet mass flow rate. A fraction of seal gas from the inlet 3 flows through the aperture and out of the SVG from the opening. Meanwhile, the seal gas curtain is close to the particle inlet.

Cases 1-3 provide confidence that seal-gas curtains offer the potential to limit particle egress from the chamber to an acceptably low limit, although further work is required to achieve this. The gas curtain injected at the middle of the conical surface of the reactor has better performance than the other two cases.

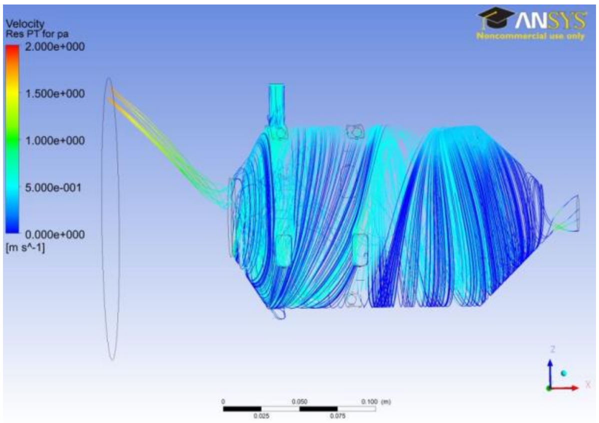

Figure 6: Trajectories of the injected particles in gas curtain inlet 1.

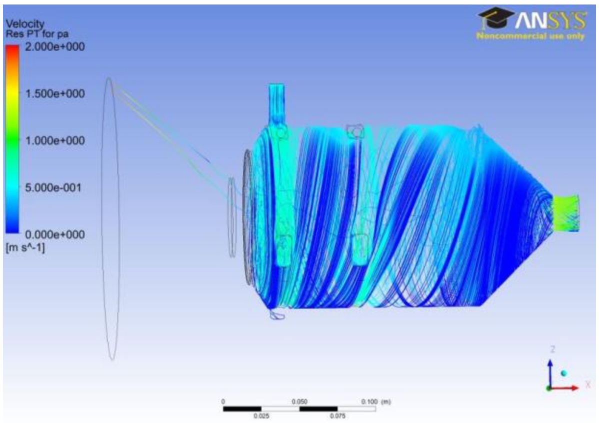

Figure 7: Trajectories of the injected particles in gas curtain inlet 2.

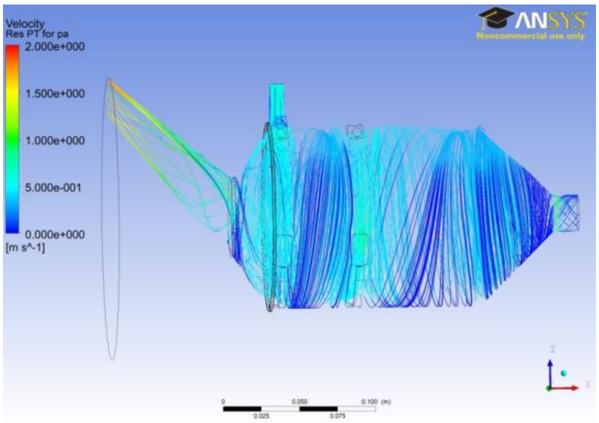

Figure 8: Trajectories of the injected particles for gas curtain inlet 3.

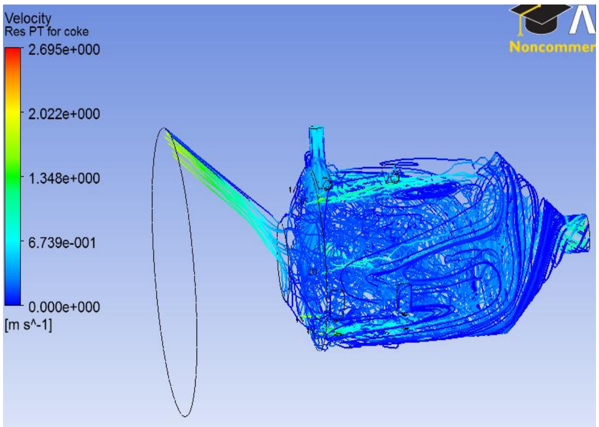

Figure 9: Trajectories of the injected particles in Case 4.

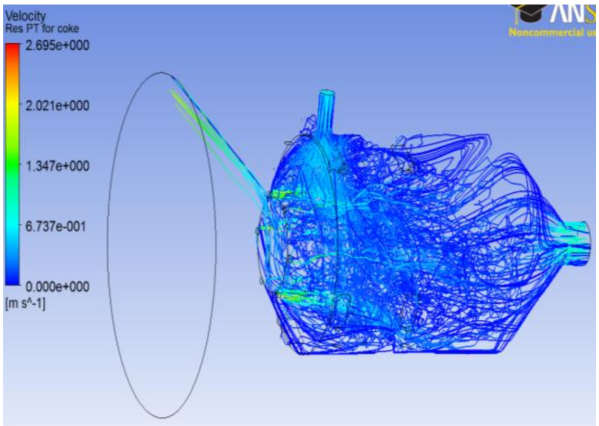

Figure 10: Trajectories of the injected particles in Case 5.

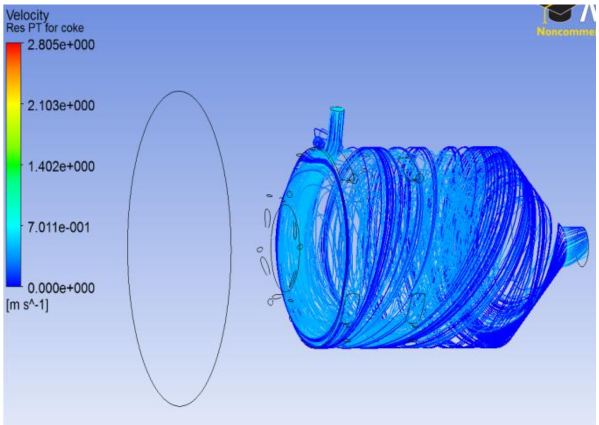

Figure 11: Trajectories of the injected particles in Case 6.

Figure 9 shows the particle trajectories for Case 4, with the seal-gas injected through six axial inlets through the middle part of the conical surface. The results show that some particles exit through the aperture for this case. Moving the position of the axial inlets closer to the aperture (Case 5) slightly improves the performance of the seal curtain, so that fewer particles emerge through the aperture, as shown in Figure 10. Hence, this configuration is less effective at preventing particle egress through the aperture.

The most promising configuration is found to be Case 6, with six tangential inlets at the aperture. As shown in Figure 11, all particles are predicted to be retained within the SVG. However, the sensitivity of this configuration to changes in operating conditions or time-varying flow patterns, such as a precessing vortex core, is yet to be investigated.

CONCLUSION AND FUTHER WORK

A CFD model of the vortex flow solar reactor was developed to analysis the flow pattern inside the reactor with different gas curtain configurations. The preliminary results reported here show that gas curtain injected at a proper location can reduce the particle loss to the ambient air through the opening at the left end of the SVG. From this preliminary analysis, it is found that the seal gas inject from six tangential inlets at the aperture is the most promising location to provide the highest seal efficiency.

Future work will firstly assess the amount of air ingress into the chamber. A systematic investigation will then be undertaken to seek to further improve the design, both by qualitative insight into the flow patterns and by quantitative assessment of sealing efficiency. Parameters to assess will include the seal gas inlet configuration and different operating conditions such as the seal-gas inlet velocity, particle size, and outlet conditions.

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