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Wind Flow Around a Parabolic Dish Solar Concentrator

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Abstract

Wind flow around parabolic dish solar concentrators can significantly affect the loss of heat from the receiver, and thus the performance of these systems. Numerous studies have examined the heat loss from various receiver geometries under natural and forced convection conditions; however there is a marked absence of studies that take into account the effect that the dish may have on the heat loss, particularly for forced convection conditions. Given that forced convection can greatly increase the heat loss from such systems, there is a need for an improved understanding of the effect of the wind velocity and flow structure around parabolic dish solar concentrators.

In this work, computational fluid dynamics is used to model the flow of air around a parabolic dish concentrator operating at varying angles of attack. The results show that the orientation of the dish has a significant effect on the flow structure near the receiver. For flows normal to the surface of the dish, fore or aft, the dish acts much like a bluff body, or pressure blockage, “shielding” the receiver from the flow, such that the air velocities near the receiver are relatively low. However, other operating conditions exhibit recirculation areas near the receiver that could lead to increased heat loss. Further work is required to determine the magnitude of this effect and subsequently the overall effect on the performance of parabolic dish solar concentrators.

1. Introduction

Concentrating Solar Power Systems (CSP) can be classified into two categories based on their optical configuration: point collector (parabolic dish, solar tower) and line focus collectors (parabolic trough, Fresnel reflector). Parabolic dish systems are considered to be the most efficient among all CSP Systems (Tyner et al., 2001). The key components of a parabolic dish system are the parabolic dish reflector and a cavity receiver positioned at the focal point of the dish. The reflected highly concentrated solar radiation is focused on the cavity receiver through a small opening, and as a result significant increase in temperature of receiver and receiver fluid is achieved. The high concentration ratio achieved by parabolic dishes (10,000 Suns) compared with parabolic troughs (100 Sun) and solar towers (1000 Sun), means that higher temperatures at the receiver are possible (Steinfeld, 2004). Due to the higher achievable temperatures, parabolic dish systems could be used in a wide range of applications (Wang and Siddiqui, 2009).

However, the performance of CSP systems is influenced by the heat losses to the environment from the thermal receiver, particularly at high operating temperatures. As such, the receiver has a decisive influence on the overall efficiency of the solar power plant (Price et al., 2002). In real situations, the CSPs are installed in open terrain, and the surrounding turbulent air can significantly affect the loss of heat from the receiver, and thus the performance of these systems (Lupfert et al., 2001). The thermal losses from the solar receiver occur by convection, conduction and radiation losses. Radiation and conduction heat losses from the receiver can be determined by analytical techniques (Holman, 1997); however, convection heat loss from the receiver is much more complicated.



Several experimental and analytical studies have been performed by a number of researchers in recent years, focusing the convective heat transfer heat loss characterization from solar concentrator receivers (Kumar and Reddy, 2010 and Wang and Siddiqui, 2009). However, many of these studies examine heat loss from receiver in isolation and almost none have studied the wind flow around parabolic dish system and its effect on heat loss from the receiver.

Paitoonsurikarn and Lovegrove (2006) investigated numerically the effect of paraboloidal dish structure on the wind near the cavity receiver. It was found that the local wind speed at the aperture was largest when the free stream wind was parallel to the aperture plane. Christo (2012) established a numerical model for a solar dish to investigate the transient flow behaviour and vortex shedding characteristics around the dish, but did not explore the effect on heat loss from the receiver.

Given the lack of work that has been undertaken on wind flow around parabolic dishes, and its impact on heat loss, there is a need to understand this in order to develop better models of parabolic dish based CSP systems

2. Problem Formulation

In order to examine the effect of wind flow on the heat loss from parabolic dish receivers it was decided to undertake a computational fluid dynamics (CFD) analysis of the flow around the dish at varying angles of attack. For this study it was decided to use the geometry of the Australian National University's 20 m² dish and frustum shaped receiver used in their solar thermochemical demonstration plant. The parabolic dish has a focal length of 1.84 m and an aperture diameter of 5m with a rim angle of approximately 70° and receiver dimensions as shown in Fig 1 (Paitoonsurikarn and Lovegrove, 2003). The domain around the dish-receiver system extends 75m upstream, 105m downstream and 30m in the lateral direction as shown in Fig 2.

A three dimensional simulation of the wind flow over the system was employed using the commercial CFD program ANSYS CFX 15.0.7 and the Shear Stress Transport (SST) turbulence model. The SST model has been shown to be one of the most accurate two-equation models for separation prediction and has been successfully used for studies of wind flow over parabolic troughs (Paetzold et al., 2014). Buoyancy effects were also included in the calculation as the combined effect of natural and forced convection could be significant. High-quality meshes were constructed, after performing a mesh independence test for the virtual wind tunnel. Finally steady state simulations were performed by changing the angle of attack of dish relative to the wind, from 90° to -90°, under a free stream wind velocity of 5 m/s and 25°C temperature. While doing this all the internal cavity walls were considered to be isothermal at a temperature of 600°C.

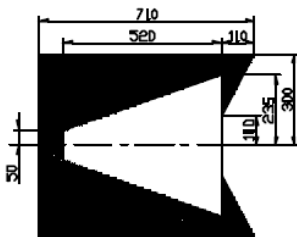


Fig 1: Dimensions of cavity

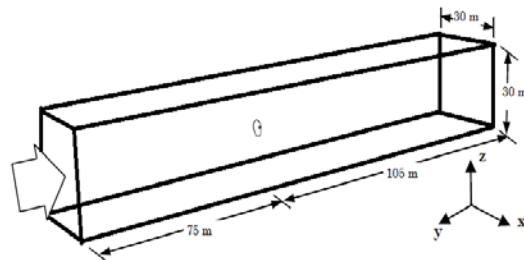


Fig 2: Virtual Wind Tunnel



3. Results:

Detailed simulations of flow around the cavity receiver were carried out with and without the of dish structure being present. Velocity contours along the centre plane of virtual tunnel are shown in the figures for different dish angles of attack with flow moving from left to right. In a qualitative sense, the streamlines obtained are in good agreement with numerical studies by Christo (2012) and Paitoonsurikarn and Lovegrove (2006).

In the case of 90° flow towards the aperture plane (Fig 3), a low-velocity zone around the receiver aperture can be seen (a white cross-section of dish and receiver is shown in all the velocity contour figures). The formation of this zone, results in vortices inducing a low-velocity flow toward the cavity. As, in the presence of dish structure, the local velocity is predominately parallel to the aperture plane (Paitoonsurikarn, Lovegrove, 2006), the low-velocity parallel flow yields greater convective heat transfer in the presence of the dish structure. Similarly, in the case of -90° (Fig 4), there is a low velocity air flow toward the aperture plane due to the large scale vortices formation behind the dish structure. This flow eventually increases the convective heat transfer inside the cavity receiver as seen in the temperature variation shown in Fig 5 and 6.

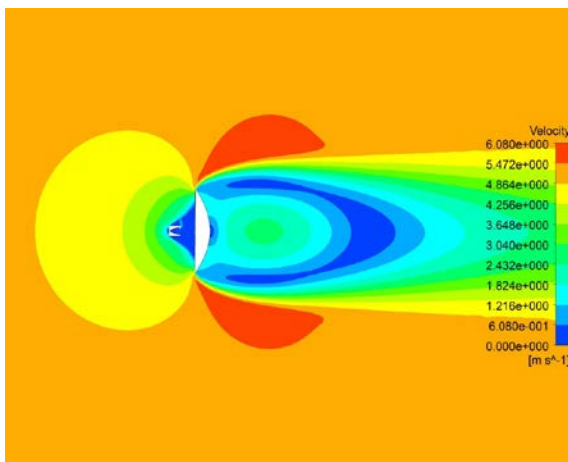


Fig 3: Velocity contours at 90°

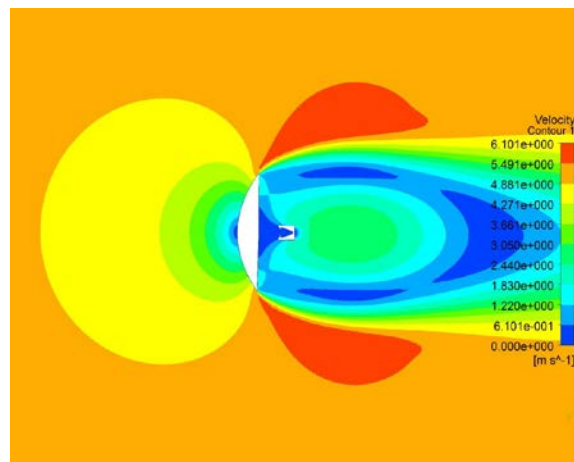


Fig 4: Velocity contours at -90°

Fig 5 and Fig 6 plot the temperature as a function of position along the centreline of the receiver cavity for the situation with and without the dish present. Fig 5 and Fig 6 show a noticeable variation in the temperature values of the air inside the cavity receiver for both cases (with and without a dish structure present). As shown in Fig 7, in the presence of dish structure, the streamlines show generation of strong recirculation vortices behind the dish for both cases i.e. 90° and -90° flow due to the negative pressure field behind the dish.

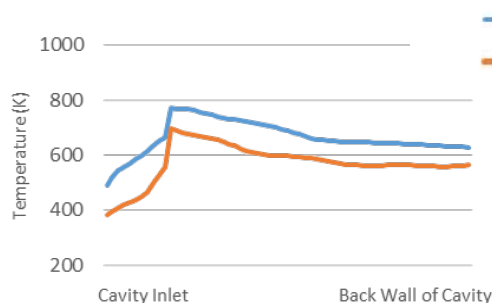


Fig 5: Air temperature inside cavity at 90°

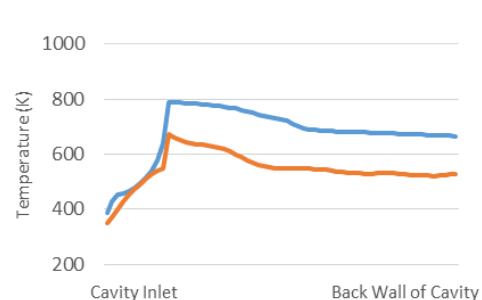


Fig 6: Air temperature inside cavity at -90°

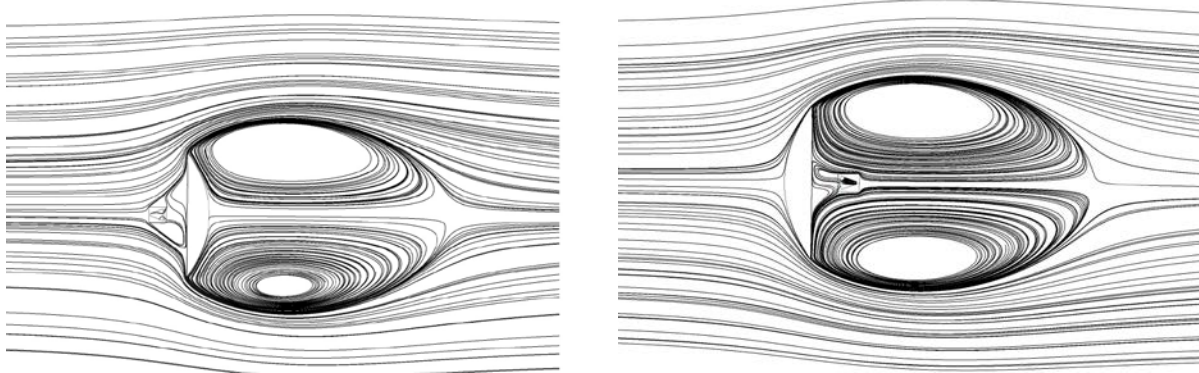


Fig 7: Streamlines for 90° and -90° flow

In the case of 60° flow, the velocity contours (Fig 8) show the low velocity near the cavity zone while the streamlines (Fig 9) show flow separation from the upper and lower portion of the dish structure. This flow separation generates two large recirculation vortices behind the dish, and negative pressure values are obtained in this flow separation region. Opposite to 60°, there is a very low velocity around the cavity receiver for -60° flow (Fig 10) and again the streamlines (Fig 11) show the formation of strong vortices around the cavity with a negative pressure. The effect this has on the air temperature values inside the cavity at 60 is shown in Fig 12.

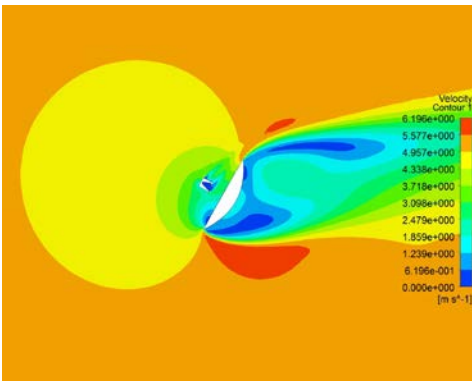


Fig 8: Velocity contours at 60°

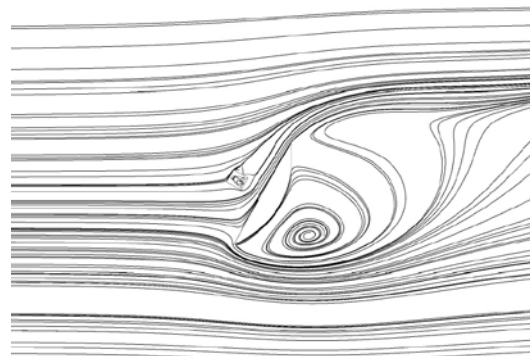


Fig 9: Streamlines at 60°

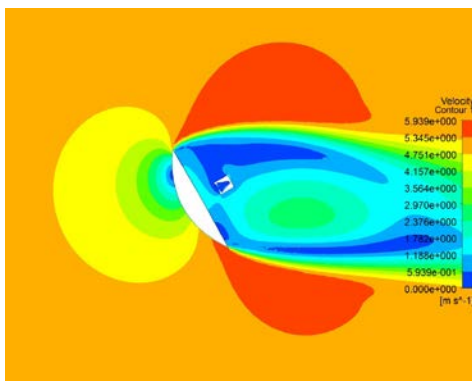


Fig 10: Velocity contours at -60°

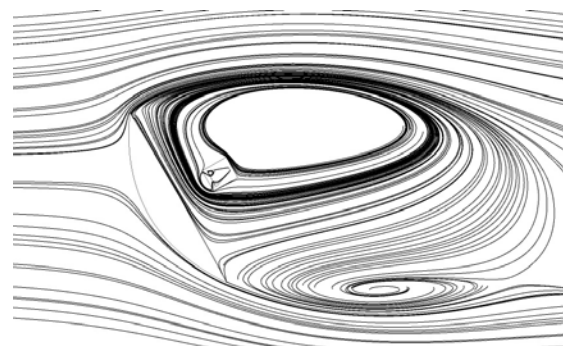


Fig 11: Streamlines at -60°



On the other hand, there is a marked reduction in the air temperature values inside the cavity in the case of -60° flow (Fig 13). The change in the temperature is due to the relevant direction of local velocity at the aperture plane. In the case of 60° , the air velocity direction at cavity inlet is opposite to the free stream wind, which changes the temperature inside the cavity. On the opposite side, in the case of -60° , the local velocity is in the same direction as the free stream wind and effectively decreases the air temperature inside the cavity.

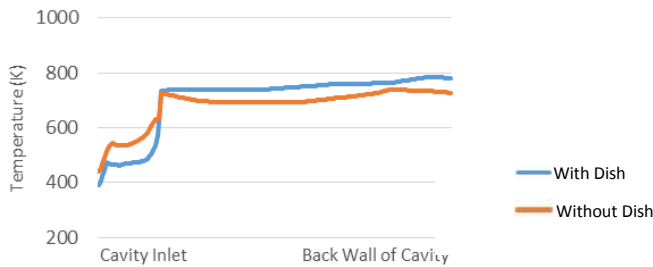


Fig 12: Air temperature inside cavity at 60°

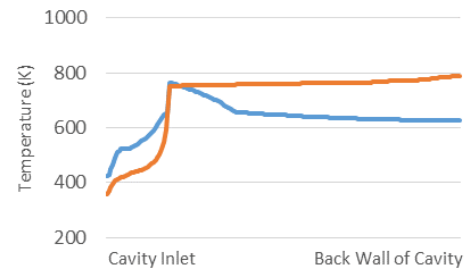


Fig 13: Air temperature inside cavity at -60°

Similar to 60° , the same phenomena occurs in the case of a 45° angle of attack (Fig 14). When the flow is from front side at 45° , there is no significant increase in the air temperature values inside the cavity, while a significant decrease in the temperature values can be seen in the case of flow from back side i.e. -45° (Fig 15). This decrease in the air temperature values is due to relevant local wind motion at aperture with the free stream wind. While in both cases, a large circulation surrounds the receiver, which creates the stronger tangential flow at aperture plane (Fig 16).

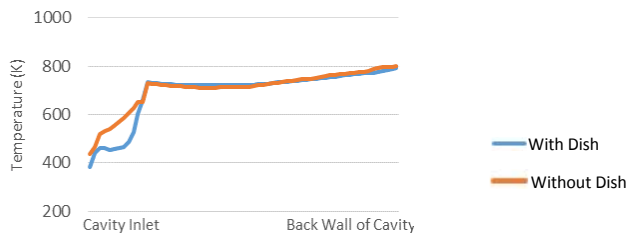


Fig 14: Air temperature inside cavity at 45°

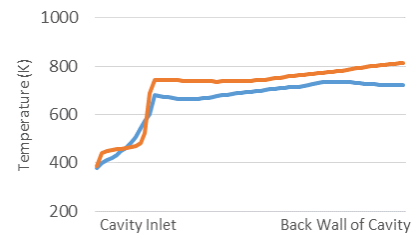


Fig 15: Air temperature inside cavity at -45°

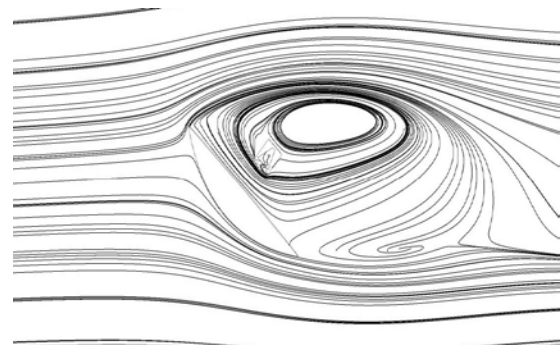
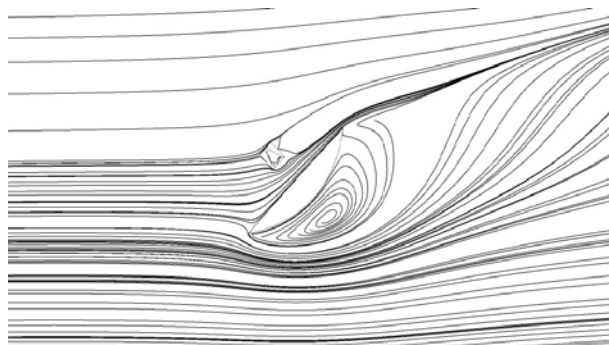


Fig 16: Streamlines for 45° and -45° flow



Fig 17 shows a streamlined wind flow with no larger flow separation other than a flow recirculation region behind the lower portion of dish for the case of 30° angle of attack. While in the opposite case i.e. angle of attack of -30° , there is a stronger flow separation at the upper portion of dish structure that creates a large eddy in that area (Fig 18). Opposite to 60° , the pressure values are positive in the flow separation case for 30° . The resultant variation in temperature values inside cavity is shown in Fig 19 and Fig 20.

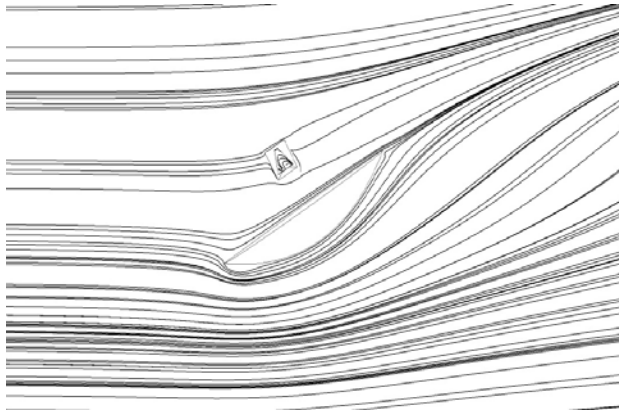


Fig 17: Streamlines at 30°

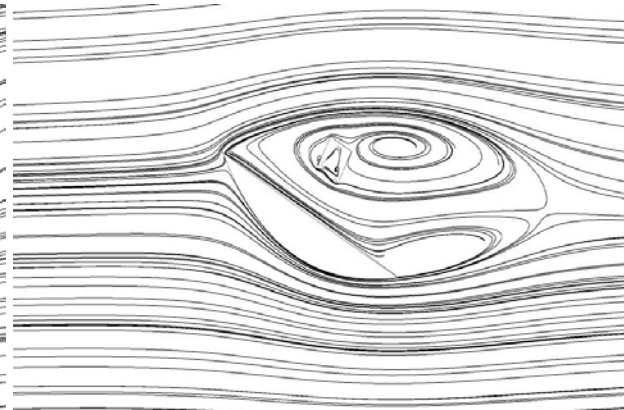


Fig 18: Streamlines at -30°

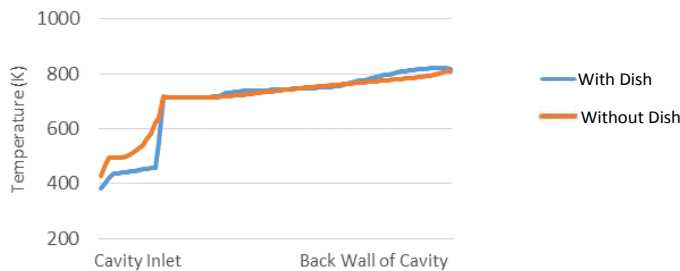


Fig 19: Air temperature inside cavity at 30°

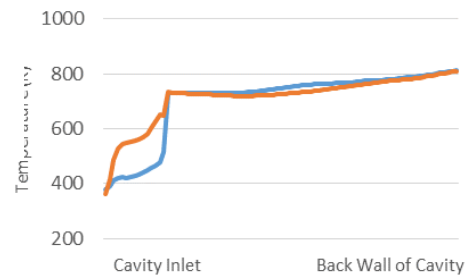


Fig 20: Air temperature inside cavity at -30°

Finally, in the case of a 0° angle of attack, there is no significant change in air temperature values inside the cavity receiver with and without the dish. The velocity contours (Fig 21) show a uniform velocity between the dish structure and cavity, while an area of low velocity can be seen in the wake of the cavity wall. The dominant tangential velocity streamlines can be seen near the aperture plane as expected in Fig 22, while in Fig 23 shows the air temperature values inside the cavity receiver. From this it can be seen that the dish does not impact the heat loss, when operating in this condition.

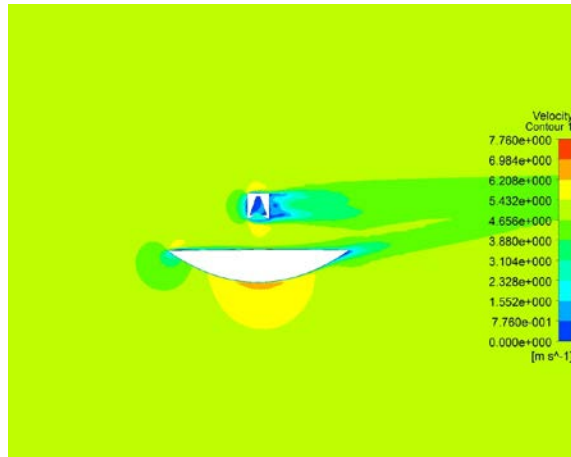


Fig 21: Flow at 0°

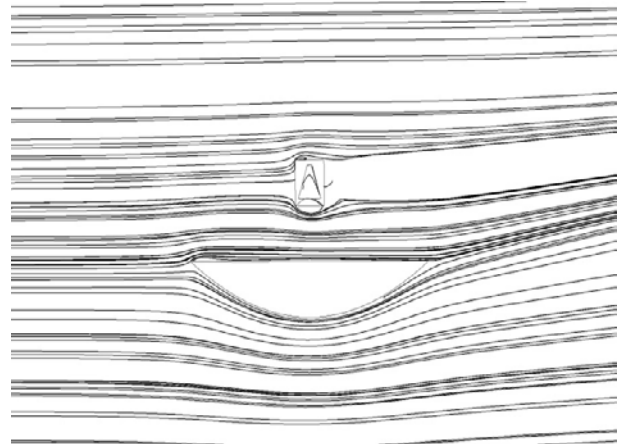


Fig 22: Streamlines for 0° flow

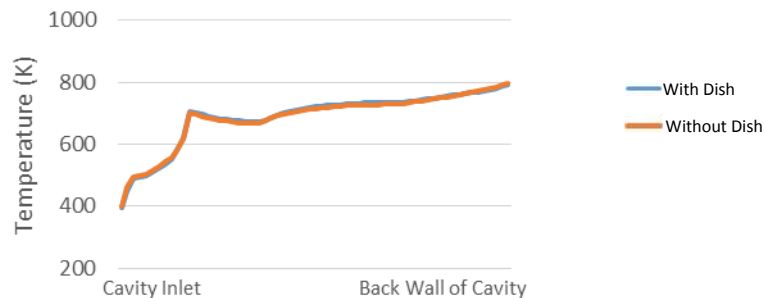


Fig 23: Air temperature inside cavity at 0°

Conclusion:

This study has shown that the presence of the dish structure of a parabolic dish CSP has a significant effect on the wind behavior near the receiver. A significant reduction in the local air speed is evident at all angles of attack except in the parallel flow i.e. 0°. The tangential component of the local air speed was found to be dominant in most cases, and dish structure stops the flow of air into the receiver. Despite this, this work has shown that there is a significant effect on convective heat losses due to the position and orientation of the dish relative to the receiver. However, further work is required to fully determine the magnitude of this effect at other wind speeds and subsequently the overall effect on the performance of parabolic dish solar concentrator system.

References

Ansys Inc. CFX User guide

Christo F., 2012, 'Numerical modelling of wind and dust pattern around a full-scale paraboloidal solar dish', *Renewable Energy*, 32, p356-366

Kumar S. and Reddy K., 2010, 'Investigation of Convection and Radiation Heat Losses From Modified Cavity Receiver of Solar Parabolic Dish using Asymptotic Computational Fluid Dynamics', *Heat Transfer Engineering*, 31, p597-607



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Lupfert E, Geyer M, Schiel W, Esteban A, Osuna R, Zarza E, 2001, 'EUROTHROUGH design issues and prototype testing at PSA', Proceeding of ASME international solar energy conference-forum, Washington DC., p289-394

Paetzold J., Cochard C., Fletcher D., Vassallo A., 2014, 'Wind flow around parabolic trough solar collectors- A parametric study for optimisation of wind forces and heat losses', Proceedings of Solar 2014, Melbourne, Australia

Price H, Lupfert E, Kearney D., 2002, 'Advances in Parabolic Trough Solar Power'. *Journal of Solar Energy Engineering*, 124(2), pg109–126

Paitoonsurikarn S., Lovegrove K., 2003, 'On the study of convection loss from open cavity receiver in solar paraboloidal dish applications', Proceeding of Solar 2003, ANZSES Annual Conference, Australia

Paitoonsurikarn S., Lovegrove K., 2006, 'Effect of paraboloidal dish structure on the wind near a cavity receiver', ANZSES Annual Conference, Australia

Steinfeld A., 2005, 'Solar thermochemical production of hydrogen-a review', *Solar Energy*, 78, p603-615

Tyner CE, Kolb GJ, Geyer M, Romero M., 2001, 'Concentrating solar power in 2001- an IEA/Solar PACES summary of present status and future prospectus', Solar PACES, www.solarpaces.org (Last cited 05/09/201)

Wang M., Siddiqui K., 2010, 'The impact of geothermal parameters on the thermal performance of a solar receiver of dish-type concentrated solar energy system', *Renewable Energy*, 35, p2501-2513