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Summary, Conclusions and Future Scope

7.1 SUMMARY

The arid desert regions like Rajasthan and Gujarat are blessed with a high level of direct normal solar irradiance. Therefore, such regions are increasingly favored for establishing the concentrating solar thermal systems to harness the solar energy. In these technologies the direct solar radiation is focused, after reflection from mirrors/collectors, onto a receiver. The recovered heat from this receiver using a heat transfer fluid may be utilized for the applications including, process heat, cooling and power generation. Worldwide, the dust in arid deserts offers a major constraint for the implementation and sustainable operation of such a system. One such challenge is the dust deposition in the receiver internals as a result of frequent dust-storms. Considering these aspects, the present thesis aims at investigating the operation and performance of an open volumetric air receiver. Such a receiver under a high flux concentration of ~ 600 - 1000 kW/m^2 is capable of producing an air temperature of up to 1000 K. This sub-system is the heart of the newly developed concept of solar convective furnace at IIT Jodhpur for the heat treatment of metals. This technology will (a) promote the direct utilization of the recovered heat from the receiver lends to saving the fossil fuel, (b) simplify the system layout without a power block and save water as a consequence, and (c) provide a higher system efficiency compared to a conventional heat treatment furnace. A solar air tower simulator (SATS) facility is installed at IIT Jodhpur for investigating the open volumetric air receiver based solar convective furnace system that requires an air temperature of ~ 750 K. Because the open volumetric air receiver is exposed to ambient air the deposition of dust is inevitable in the arid deserts. The receiver comprises straight pore based absorbers, which is likely to mitigate the dust deposition in comparison to a foam-type porous structure. The suction of ambient air through these porous bodies allows heat transfer by forced convection, and thus a blockage of pore is detrimental. Interestingly, the flow in these straight absorber pores is laminar in nature. A stable flow condition at a high temperature is desired for operating such a furnace system on the field condition, which is non-trivial.

In view of the above, the thesis is aimed at (a) investigating the detrimental effect of dust deposition on the heat transfer in the absorber pores, (b) mitigating the effect of dust deposition in the receiver, (b) flow stability analysis in receiver and (c) the development of a zonal model for identifying the important design parameter and for the scale-up in future. The detrimental effect of deposition of dust in absorber pores is analyzed using the two-dimensional numerical simulations. For the removal and subsequent collection of dust from the absorber pores, the cyclone separator is preferred based on a comparative assessment between the available options. A suitable cyclone separator is designed using the experiments and three-dimensional simulations in view of the collection efficiency and pressure-drop. The acceptable operating condition for the receiver equipped with a cyclone separator is deduced using the pressure-drop in each of the receiver component and the cyclone separator. An analysis for predicting the onset of thermally induced flow instability is also performed using the two-dimensional and analytic approaches. Finally, a one-dimensional zonal model is developed that includes the heat transfer by return air. In developing this model the absorbers in a receiver are categorized into the central and the peripheral based on their geometric location. The central absorbers are generally exposed to a higher heat flux compare to their peripheral counterpart. The model is validated with the available in-house experiments. The investigations show the predictive capability of this model is well within the experiment uncertainty. This is used for analyzing the current receiver design at IIT Jodhpur and for recommending various design parameters for improving thermal efficiency. In this chapter, the scope of extension of the research work is suggested. The concluding remarks are briefly discussed in the next subsection followed by the future scope.

7.2 CONCLUSIONS

Several important conclusions and results pertinent to the analysis of the open volumetric air receiver have emerged from these investigations, which are as follows:

1. The laboratory scale experiments have revealed that porous absorbers are prone to dust deposition. The two and three-dimensional heat transfer analyses in a pore with a dust layer reveal a substantial rise in absorber temperature in comparison to a clean pore. Thus, the deposition of dust is detrimental for the operation of an open volumetric air receiver. Therefore, the need of an in-situ cleaning device is realized.

2. A cyclone separator is selected as an in-situ cleaning device for the desiged open volumetric air receiver. The operation of this system will depend on the required power to overcome the parasitic loss viz. pressure-drop across this cleaning device. Therefore, a correlation to estimate the pressure-drop coefficient is deduced using experiments and computational fluid dynamics. This is necessary to estimate the total parasitic loss offered by a receiver – cyclone separator integrated system.

3. Inclusion of a cyclone separator will add up to the parasitic loss and thus, selecting a suitable operating condition is required. To address this issue, a new parameter called the *overall efficiency* is proposed including the total parasitic loss. Based on the detailed analysis it is recommended that the minimum (a) power to air mass flow rate ratio ($\dot{q}_s/\dot{m}_a$) should be 200 kJ/kg and (b) absorber porosity should be 50%. This is favourable, as the receiver usually operates at a much higher $\dot{q}_s/\dot{m}_a$ and thus, inclusion and operation of an in-situ cleaning device is plausible.

4. The receiver should operate at the minimum power to air mass flow rate of 200 kJ/kg. However, at a high heat flux, the variation in fluid properties may lead to the undesirable thermally induced flow instability. The same is analysing using the derived pressure drop correlation for the porous absorber based on experiment and three-dimensional simulations. This clearly reveals, under certain assumptions, a stable operation is envisaged for the designed open volumetric air receiver at a low Reynolds number. Such a condition is otherwise prone to the flow instability as a consequence of the enhanced viscous effects. Thus, the findings will promote the implantation of a straight pore based absorbers in the arid deserts including a cleaning device. Furthermore, two-dimensional analysis and the analytical model have confirmed that the flow instability is not expected even at a $\dot{q}_s/\dot{m}_a$ of 1000 kJ/kg.

5. Analysis using the zonal model revealed that the increase in absorber porosity is beneficial in terms of performance of the receiver. However, it must be restricted to an optimum value keeping the durability of the receiver in mind. For a straight pore absorber, the porosity in the range of 70-80% is recommended.

6. The selection of the absorber diameter d_{ab} and their spacing should be based on the thermal entry length, convective heat losses to return air and the packing fraction. An absorber diameter to length ratio (d_{ab}/L) in the range of 0.8 - 1 may be preferred for a high thermal efficiency and a low parasitic loss. The smallest gap between two absorbers may be limited to 20% of the absorber length. Additionally, a receiver should be designed for a high air return ratio that acts as an in-situ waste heat recovery mechanism

and allows achieving a high air temperature under a given power to air mass flow rate ratio.

7.3 FUTURE SCOPE

The objectives of the undertaken research activities provided (a) valuable insight to the discussed problems and (b) their outcome allows formulating future scope aiming at the optimization of designed receiver at IITJ. Some of the recommendations are as follows:

1. The improved absorber designs with a variable porosity along the radial and the axial directions may be considered. The placement of absorbers with the different porosities at the central and the peripheral regions based on the heat flux distributions may be helpful in improving the thermal uniformity at the receiver outlet.

2. An improved receiver design with transparent glass shield equipped with the fabric filters at the non-irradiated sides may be useful in mitigation of dust particles entering the absorber pores.

3. For the scale-up of the receiver, additional layers of porous absorbers may be introduced between central and peripheral absorbers. The zonal model may be extended including the notion of an intermediate absorber and solving an additional partial differential equation for the same.

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