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Summary, Conclusions and Future work

6.1. Summary

Fossil fuel-based electricity or gas-fired systems are commonly used as a heat source for industrial process heating, heat treatment of metals, etc. For example, heat treatment of aluminum requires about 400 kWh/Tonne in a standard heat treatment furnace at Aditya Birla Science and Technology Center (ABSTC) for heating of aluminum from 300 – 600 °C. This leads to emission of greenhouse gasses such as CO, CO_2. Freely available solar energy can be utilized for such heat treatment processes. Two of the major advantages associated with such a system are (a) the need for conversion of heat to electricity and reconversion of electricity to heat will be avoided, which leads to an enhancement of thermodynamic system efficiency, and (b) the emission of unwanted greenhouse gases will be mitigated substantially. A point focusing concentrated solar thermal (CST) systems offer one such possibility owing to its capability of generating high temperature, which can be easily transported with a heat transfer fluid, like air, to a furnace for heat treatment of metals.

Considering the above-mentioned aspects, a novel concept of open volumetric air receiver (OVAR)-based solar convective furnace (SCF) system is developed. The SCF system comprises an OVAR for generating hot air, pebble bed sensible thermal energy storage (TES) for storage and recovery of heat, a blower for operating the air flow at the desired mass flow rate, a retrofitted industrial aluminum soaking furnace, and a piping network for transport and utilization of hot air from OVAR to SCF through. Furthermore, the SCF system includes a mechanism for waste Experimental and computational investigations are performed for assessing the operation and feasibility of SCF systems. The following provides an outline of the same:

Experiments are performed for individual sub-systems like OVAR, TES, and the furnace and for the integrated SCF system. These investigate (a) the effect of air mass flow rate on the charging and discharging process, and the related thermodynamic parameters, for pebble bed TES, (b) the involved heat transfer process in the retrofitted heat treatment furnace with an externa heating unit as well as TES to maintain the desired heating rate, (c) experimental assessment of the integrated SCF. It is worth mentioning that an extensive experimental and numerical campaign was carried out by previous authors for the assessment of OVAR. Thus, the same is not undertaken in this work.

In line with the experiments, simulations are performed for OVAR, TES, and the furnace. This includes (a) the development of a unsteady, multi-zone, mathematical model for OVAR, including all the modes of heat transfer, for design scaleup in future, (b) the development of a mathematical model for unsteady heat transfer to and from a metal ingot, placed inside the retrofitted furnace, to investigate the heat treatment process, (c) the development of a unsteady heat transfer model for pebble bed TES, (d) an integrated unsteady heat transfer model for the entire SCF systems, and (e) finally, a system—level mode is developed for operating the integrated SCF system.

6.2. Conclusions

The major findings of the experimental and numerical investigations are as follows:

a) A low exposed surface area for the OVAR designs is recommended for the scale-up of straight pore absorber-based OVAR designs, which is also beneficial to mitigate the dust deposition-related critical challenges.

b) For volumetric and non-volumetric heating conditions, the recommended ratio of absorber diameter (d_{ab}) to length (L) is $1 \leq d_{ab}/L \leq 2$ for the scale-up OVAR design with three intermediate absorber layers.

c) For volumetric and non-volumetric heating conditions, the recommended ratio of absorber gap (G) to length (L) is $0.15 \leq G/L \leq 0.25$ for the scale-up OVAR designs with three intermediate absorber layers.

d) Based on the performed numerical investigations, the use of multiple intermediate absorber layers is recommended for the scale-up of the OVAR design. This is expected to mitigate the radial and axial thermal non-uniformity for absorbers and enhance the durability of an OVAR design.

e) Experiment-based time-averaged charging and discharging efficiencies for TES is found to be 65-70% and 72-75%, respectively. The exergy efficiency for charging and discharging is found to be 45-50% and 58-60%, respectively. The analyses also revealed that a greater emphasize to be placed for the charging process than that of the discharging process during the operation of SCF system.

f) Experimental results of SCF such as temperature profile, heating process demonstrate the feasibility of heat treatment of metal-ingot via forced convection.

g) Numerical model of sensible heat thermal energy storage (SHTES) is able to predict the temperature values within 15% of the experimental temperature values. Also, the mathematical model of SCF predicts within 15% of the experimental results and the mathematical model of insulated pipe predictions are within 10% deviation from the experimental results.

h) The integrated numerical model of the whole solar convective furnace system is capable of predicting the temperature values in system with a reasonable confidence and can be used up for the scaling up studies of the whole SCF system

i) Lastly, an operation strategy using solar energy as a heat source is developed for a 0.58 MW aluminum soaking furnace in which the ingots are heated from 300 °C to 600 °C for 6 hours and kept isolated for 4 hours (soaking phase). The strategy is developed to run the system

24X7 by dividing the whole day into three parts. The time-dependent mass flow rates for each subsystem for 10 hours are calculated by choosing Jodhpur's monthly average DNI for July. An integrated model is made and using experimental condition the temperature values are calculated. The calculated value compare well with the experimental values.

6.3. Future Work

Current work demonstrates the potential of SCF system for heat treatment of metal based on CST energy. Also, the developed numerical models are capable to predict the temperature values for given power input and geometrical parameters. Considering the implementation possibility of the developed technology the following aspects may be considered for the future :

1. Assessment of the developed multi-zone model for OVAR on the field. This will also enable isolating the direct effect of ambient conditions, such as heat loss, and its indirect effect on the concentrated solar irradiance.
2. The model for TES can be extended including the radial variation of temperature, which is expected for single or multiple storage systems in series or parallel arrangements. Also, numerical investigations can be performed to find an optimal capacity for TES, which will allow a high charging efficiency without enhancing the pumping power significantly.
3. The scaleup of the SCF, its optimization, and assessment on the field conditions. Also, in-situ assessment of the SCF system, including the underground placement of a TES, which is expected to enhance the efficiency of the overall system.