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V&V Exercise for a Solar Tower Power Plant

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Outline

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Motivation

• How can we generate electricity from the natural convection effect?
• Alternate sustainable energy pathway from solar radiation to electrical available for night operation?
• Are we able to combine our cycle?
Solar Tower Power Plant
Background

• Spanish colonel proposed this idea (1903).

• The most famous prototype built in Manzanares at Spain in 1982 and rebuilt in 1989.

• China recently started to invest on this industry.
Numerical Analysis-I

- Turbulent Flow
- Air
- Natural Convection
Numerical Analysis-I

Manzanares Simulation
Numerical Analysis-I
Numerical Analysis-I

Verification

- Mesh Independency
- Iterative Convergence
- Consistency: 0.001 mass flow rate
- Boundary Condition Sensitivity
- Density Sensitivity Analysis
- Second Order of Discretization
Numerical Analysis-I

- Calibration of pressure boundary condition
- Calibration of collector boundary condition
Numerical Analysis-I

Validation

• Updraft Vel. of experimental set up: 10-12 m/s
• Updraft Vel. of numerical analysis: 11.56 m/s
Experimental Setup
Experimental Setup
Experimental Setup
Experimental Setup
Numerical Analysis-II
CFD Analysis of Solar Chimney Power Plant Prototype

- Finite Volume Method to solve N.S. equations
- Reynolds Stress Model
- Density calculation by ideal gas equation
- Steady State two Dimensional Analysis
- First order spatial discretization
CFD Analysis of Solar Chimney Power Plant Prototype

- Detail of Boundary Conditions, 53k nodes.
CFD Analysis of Solar Chimney Power Plant Prototype

Case I

\[ \Delta T = 15 \text{ K} \]

No Wind

Case II

\[ \Delta T = 5 \]

5 m/s wind flow

Case III

\[ \Delta T \approx 0 \]

5 m/s wind flow
CFD Analysis of Solar Chimney Power Plant Prototype

- **Case I**

  Velocity contour plot, Unit is m/s, mass flow rate= 0.0521 kg/sec, Buoyancy effect is dominant.
CFD Analysis of Solar Chimney Power Plant Prototype

• Case II

Velocity contour plot, Unit is m/s, mass flow rate= 0.0559 kg/sec, Dynamic pressure is dominant.
CFD Analysis of Solar Chimney Power Plant Prototype

- Case III

Velocity contour plot, Unit is m/s, mass flow rate = 0.0557 kg/sec.
Validation

• 4-5 m/s wind, probe shows: 2.5 m/s
• 5 m/s wind, at the same position: 2.3 m/s
Schematic of Basic Solar Tower (chimney). They are only 1 to 5% efficient. With various modifications, they can be upgraded to about 35% efficiency.

Molten Salt Reactor with Advanced Solar Tower. The cooling tower is replaced with an advanced solar tower. The idea can be used in any nuclear reactor as well as coal plant.
Innovations

- What differentiates our approach (two patents).
  - Optimize solar chimney with new enhancements for higher energy efficiency:
    - Optimal design of sloping collectors and divergent towers.
    - Convergent-divergent shape to increase energy production by about 15%.
    - Performance gains from a flow-directing hub on the ground.
    - Higher harvestable kinetic energy at the turbine.
    - Double tray collector.
  - Adapt the advanced solar chimney onto a power plant for more efficient energy:
    - The above modifications can be incorporated into an optimized solar chimney, which is then interfaced onto a power plant, such as nuclear and coal.
    - Instead of releasing the waste heat through a cooling tower, the heat is transformed from buoyant to kinetic energy that drives the turbines, thereby significantly increasing the overall power plant efficiency.
Conclusion

• For BC, it is better to use temperature difference for the ground.
• Code calibration plays an important role for SCPP.
• It is better to validate the calibrated code with another experimental model too.
• Wind situation should be considered in CFD to be closer to the reality.
References

- “Use of waste heat to enhance solar chimney power plant (SCPP) performance (Combined Solar Cycles)”, N. Fathi, P. Vorobieff, A. Mammoli, Seyed Sobhan Aleyasin, Salvador Rodriguez, application filed with USPTO, Application No. 61982950, EFS ID. 18834289.


Special thanks and questions?