Developing a numerical heat transfer model for a high-temperature concentrated solar thermal collector

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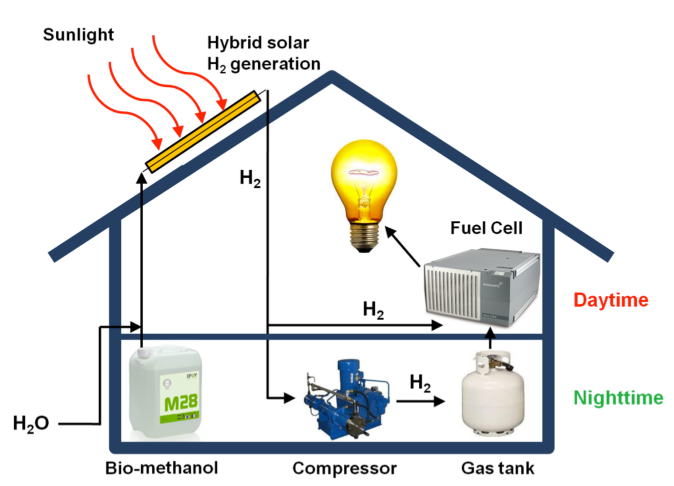
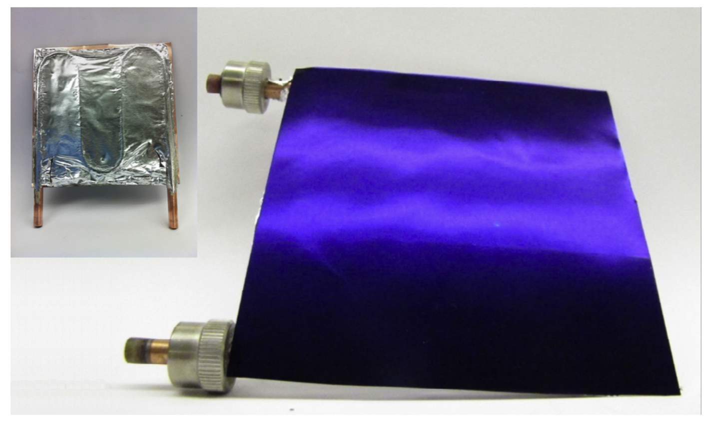
Introduction

- Tremendous research efforts in capturing thermal energy from the sun
- 2 main areas: non-concentrated vs. concentrated solar power (CSP)
- Non-concentrated solar power has limits to temperatures and therefore applications
- Current application: steam reforming of biofuels into hydrogen
- Denser biofuels require higher outlet temperatures, meaning CSP is necessary

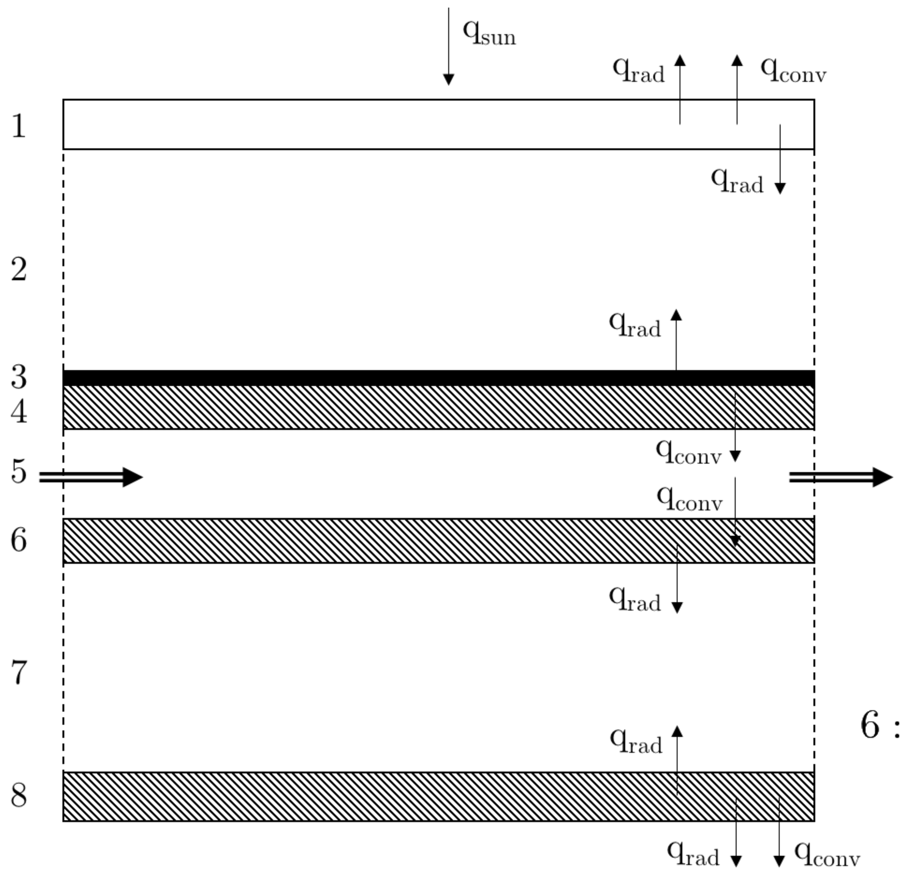


Objectives

- Goal: develop a numerical heat transfer model to predict collector temperatures as a function of concentration
- Model based on existing novel non-concentrating solar thermal collector
- Experimental setup consists of flat plat collector inside an insulting vacuum
- Predict temperatures of all collector components to determine efficiency



Methods



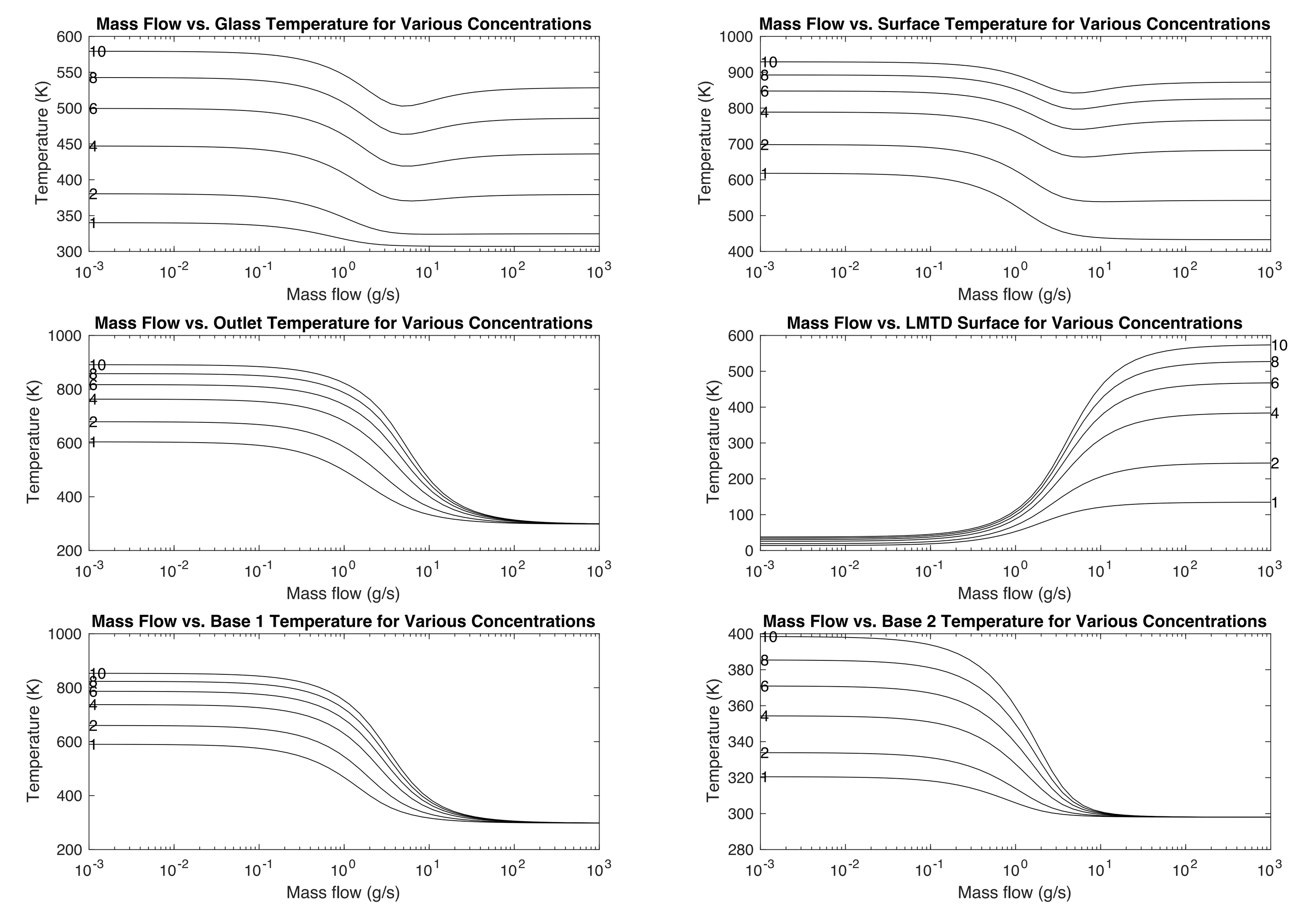
1. Glass cover
2. Vacuum
3. Absorption coating
4. Top metal surface
5. Fluid flow channel
6. Bottom metal surface
7. Vacuum
8. Reflective metal cover

$$h_x = 3.66k\frac{a+b}{2ab}$$

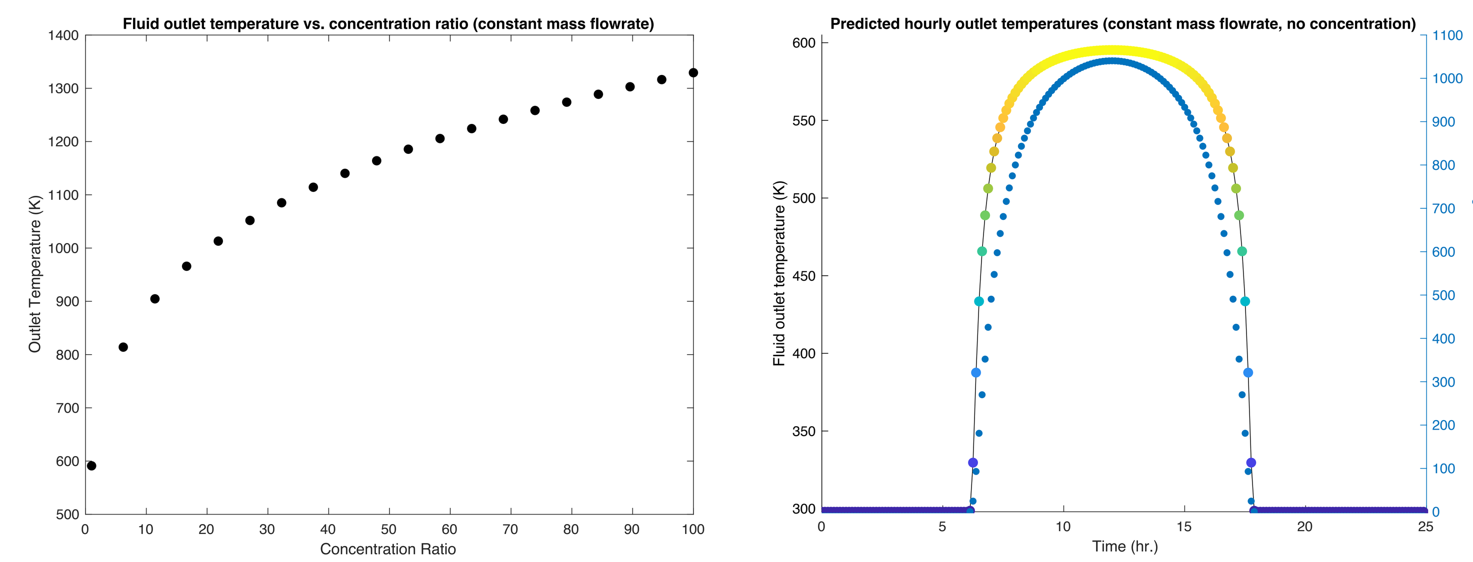
$$6: -h_x(\Delta T_{LM_6}) + \frac{\sigma}{\left(\frac{2}{\epsilon_6}-1\right)}(T_6^4 - T_8^4)$$

- The above diagram was used to derive the governing heat transfer equations
- Most surfaces had simple radiative/convective energy balances
  - Example of energy balance for surface 6 shown above
  - Convection from fluid to surface 6, radiation from surface 6 to surface 8
  - Required derivation of ΔT_{LM} for top and bottom surfaces
- Imported coupled equations into Matlab to numerically solve for temperatures as a function of flowrate, vary q_{sun} to determine effects of concentration

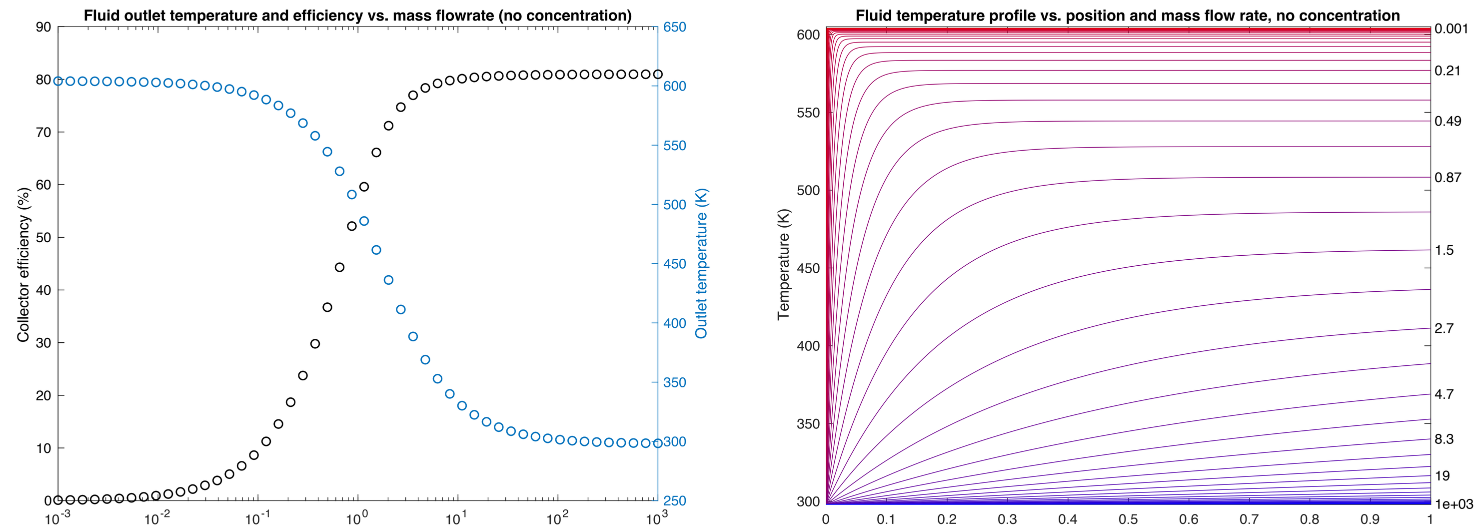
Results



- Predicted temperatures for surfaces 1, 3, 6, 8, and fluid outlet temperature
- Logarithmically scaled mass flow rates, concentrations ranging from 1 – 10
- Can see stagnation temperature and how temperature changes with flow



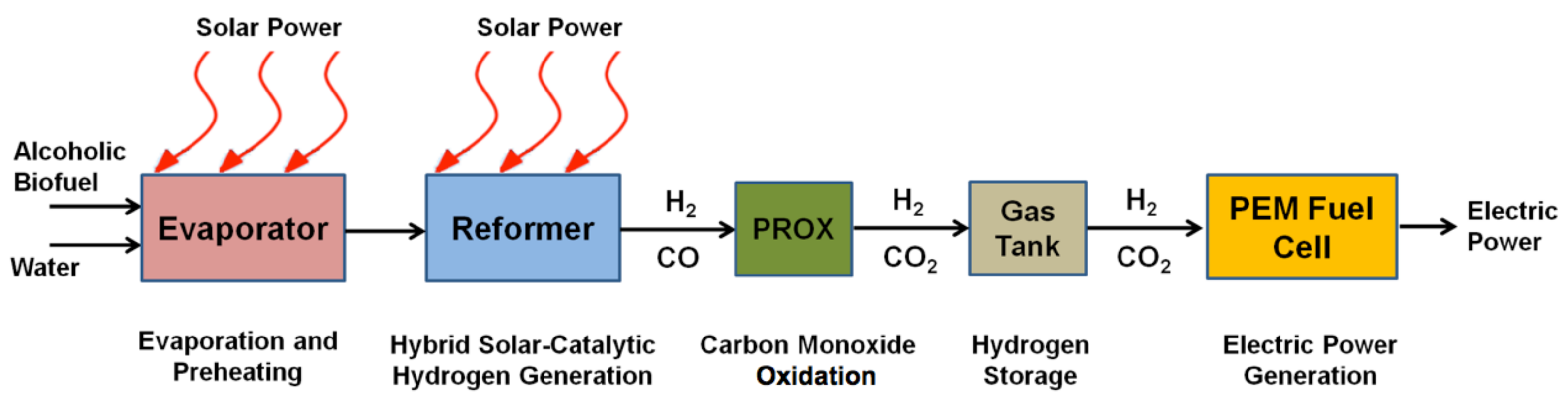
- Left graph shows fluid outlet temperature as a function of concentration ratio
  - Temperature increase starts to diminish as concentration ratio increases
- Right graph shows typical outlet temperatures expected over one day
  - Useful to determine when to operate collector; assumes ideal conditions



- Left graph shows efficiency as a function of mass flow rate
  - Middle region ideal: preserves efficiency while reaching high temperatures
- Right graph shows temperature profile as a function of position
  - Useful to determine size of collector required to achieve temperatures

Conclusions

- Concentrated solar power has the potential to increase fluid temperatures to values necessary to reform heavier biofuels into hydrogen
- Accuracy of model confirmed within ~10% when compared with historical experimental data on modeled non-concentrated system
  - Current model over-predicts outlet temperature at stagnation
  - Due to heat losses not accounted for in model (conductive losses, etc.)
- Steam reforming of heavier biofuels requires temperatures on the order of 1000 K, implying concentration ratio of 20 is required



Next Steps

- Refine the model:
  - Incorporate chemical reaction of steam reforming
  - Endothermic reaction with catalyst acts as heat sink, so model currently over-predicts temperatures of all parts of the collector
  - Model water as the working fluid and determine temperature increase
- Manufacture new absorption coating:
  - Current absorption coating degrades in high temperature applications
  - Testing of collector requires fabrication of new solar absorption coating
  - Must be able to both withstand high temperatures and perform efficiently
- Experimentally verify numerical predictions:
  - Determine best method of concentrating solar irradiance on collector
  - Use previously developed experimental methods to measure temperatures inside collector and at outlet versus mass flowrates and concentration

References

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