Modeling the Solar Thermal Receiver for the CSPonD Project

by

Jennifer A. Rees

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Author ....
Jennifer Rees
Department of Mechanical Engineering
May 10, 2011

Certified by ....
Alexander Slocum
Pappalardo Professor of Mechanical Engineering
Thesis Supervisor

Accepted by..
John H. Lienhard V
Samuel C. Collins Professor of Mechanical Engineering
Undergraduate Officer

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Abstract

The objective was to create an accurate steady state thermal model of a molten salt receiver prototype with a horizontal divider plate in the molten salt for Concentrated Solar Power on Demand (CSPonD). The purpose of the divider plate is to separate the heated salt on the top from the colder salt on the bottom while allowing some of the salt to pass around the plate. The thermal model used is a one dimensional resistance model which uses bulk temperatures for the top and bottom layers of salt. An assumption needed to be made to allow the model to be solvable, so it was modeled using two different assumptions, a given energy input and a given top salt bulk temperature. The system was solved for the maximum and minimum heights that the divider plate transverse, with the top of the plate being 2 centimeters and 5.5 centimeters from the bottom of the receiver. The given energy for the two heights was 1,598W for the 2 centimeter height and 1,512W for the 5.5 centimeter height. For the given top temperature for the two heights the temperatures were 367.2°C for 2 centimeter height and 360.0°C for 5.5 centimeter height. It was observed that both models showed correlation with the trends in the temperature gradients and heat losses as the tested experiment, varying at a maximum temperature difference of 55K to a minimum of less than 2K. The observations show that the assumed temperature models show a closer correlation with the experimental results than the assumed energy model. The experiment, however, was only run for 8000s, which suggests that it might not have reached steady state making the energy model the better model for steady state analysis.

Thesis Supervisor: Alexander Slocum
Title: Pappalardo Professor of Mechanical Engineering

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Table of Contents

List of Figures

List of Tables

Appendices

Introduction

The testing of solar thermal receivers with molten salt is needed for renewable energy research. The solar thermal receivers are used for Concentrated Solar Power on Demand (CSPonD) where sunlight is concentrate into the receiver by heliostats that follow the sun's path. There are already various types of solar thermal systems with molten salt. The beam up tower is an example of one. The beam up tower has heliostats concentrating the solar rays towards a certain area on the tower. The resulting high angles of reflection cause high cosine losses. The CSPonD concept is to have the heliostats concentrate the solar rays downward towards a receiver from a hillside or other higher elevation to reduce cosine losses. Also, for the molten salt system to work, enough salt must be heated so that it can be stored and extracted at night to produce electricity. This typically requires two tanks for the molten salt to be stored in, one for both the hot and cold salts. This requires extra pumping and other complications that a one tank system with a divider plate to separate the different temperatures of salt might simplify. Therein, testing prototypes and coming up with accurate models for the temperature gradients and heat losses for the receiver is needed to help understand how the system may operate at more industrial levels.

2 Background on Solar Thermal Receivers and Light Absorption

This section is a general introduction to the theory of light absorption and energy loss for solar receiver applications.

2.1 Light Absorption

The receiver absorbs the energy from the sun's rays that are reflected by the heliostats into the receiver. In the simulation model the light from metal halide lamps, commonly used for stadium lighting and industrial uses, are directed into the tank by the solar simulator. The amount of energy absorbed into the tank can be found by using the following equations. First, the intensity of the light through the salt is found by using the equation

$$I = I_0 \cdot e^{-\gamma x},$$

Equation 1

where I is the intensity of light through the layer, I_0 is the incident intensity, γ is the salt attenuation coefficient, and x is the depth of the salt [1]. The resulting intensity can then be used to find the absorbance of the light into the salt using the equation

$$A_b = -\log_{10}\left(\frac{I}{I_0}\right),$$

Equation 2

where A_b is the absorbance of light into the salt as defined for liquids [1].

The absorption coefficient of steel can be assumed to be the same as its emissivity rate due to Kirchhoff's Law [2]. What light is not absorbed by the steel is reflected back into the molten salt where some of the reflected light is absorbed. The light that is not absorbed is assumed to pass through the top of the salt perpendicular to the molten surface, causing no refractions back into the system. The total energy absorbed into the system is assumed to be in the top area of the salt.

2.2 Light Losses due to Reflection

The light reflection off the top of the salt is calculated using Snell's Law and Fresnel's Equations. First the angle of light in the salt is solved for using Snell's Law which is

$$\frac{\sin(\theta_a)}{\sin(\theta_s)} = \frac{n_a}{n_s}$$

Equation 3

where θ_a is the angle of light in the air, θ_s is the angle of light in the salt, and n_a and n_s are the respective refractive indexes of the air and salt[1]. Once θ_s is solved for the reflection coefficient for the light that is reflected off the salt from the solar simulator can be solved for. The total reflection coefficient for the salt is the average of the reflection coefficients of light for s and p polarizations, or

$$R = \frac{R_s + R_p}{2}$$

Equation 4

where R is the total reflection coefficient and R_s and R_p are the reflection coefficients of their respective polarized lights [1]. To find the reflection coefficients of the polarized lights the equations are

$$R_s = \left(\frac{n_a \cdot \cos(\theta_a) - n_s \cdot \cos(\theta_s)}{n_a \cdot \cos(\theta_a) + n_s \cdot \cos(\theta_s)} \right)^2$$

Equation 5

and

$$R_p = \left(\frac{n_a \cdot \cos(\theta_s) - n_s \cdot \cos(\theta_a)}{n_a \cdot \cos(\theta_a) + n_s \cdot \cos(\theta_s)} \right)^2$$

Equation 6

where R_s is the reflection coefficient of s polarized light and R_p is the reflection coefficient of p polarized light [1]. The total reflection coefficient can then be used to find what the total amount of light into the storage tank is.

2.3 First Law of Thermodynamics and Assumptions

The system is modeled as steady state. The total absorption of light into the system is the sum of the absorption into the salt on entry and the light that reflects off the steel plate back into the salt plus what the steel plate absorbs itself. The energy input into the system is then

$$\dot{Q}_{in} = A_{tot},$$

Equation 7

where Q_{in} dot is the energy into the system. The system's temperatures can then be found using the first law of thermodynamics, which is simplified to

$$\dot{Q} = \frac{1}{R} \cdot (T_{in} - T_{out})$$

Equation 8

where R is the thermal resistance [3]. R is either

$$R = \frac{L_c}{k_{salt} \cdot A}$$

Equation 9

or

$$R = \frac{1}{h_{salt} \cdot A}$$

Equation 10

depending on where the heat transfer is conductive, Equation 9, or convective, Equation 10. L_c is the characteristic length, k_{salt} is the thermal conductivity of the molten salt, h_{salt} is the coefficient of convective heat transfer of the salt, and A is the area of the affected area [3]. For radial conduction the thermal resistance is

$$R = \frac{\ln\left(\frac{R_O}{R_I}\right)}{2 \cdot \pi \cdot k_{in} \cdot L}$$

Equation 11

where R_O is the outer radius, R_I is the inner radius, k_{in} is the thermal conductivity of the insulation, and L is the length over the heat transfer occurs[3].

Since there is no mass transfer of salt through the control volume at steady state in the simulation the velocity cancels. The system is assumed to have reached steady state which allows for the conservation of energy to be used in the model so that energy into the system equals energy out of the system. The temperatures are modeled only to vary with height within the model, and that the radial temperatures are constant.

2.4 Radiation and Air Convection Losses

The two predicted main sources of heat losses in the system are radiation and convection of air losses off the top layer of salt. The equation for radiation losses is

$$\dot{Q}_{rad} = \varepsilon_{salt} \cdot \sigma \cdot A(T_{salt}^{\ 4} - T_{air}^{\ 4})$$

Equation 12

where ε_{salt} is the emissivity of the salt, σ is the Stephen Boltzmann constant, A is the area affected, T_{salt} is the temperature at the top of the salt, and T_{air} is assumed to be room temperature or approximately 25 degrees Celsius [3].

The convection losses use the equation

$$\dot{Q}_{conv} = h_{air} \cdot A \cdot (T_{salt} - T_{air})$$

Equation 13

where h_{air} is the coefficient of convective heat transfer of the air and A is the area of the top of the salt [3].

3 Setup and Calibration

3.1 Apparatus: Solar Simulator

The solar simulator used in testing and for the model numbers has seven 1500W metal halide stadium lights with a high reflective metal cone to concentrate the light towards a 38 centimeter diameter aperture. One stadium light is directed directly downward towards the aperture, while the other six stadium lights are at an angle of about 18.5° from vertical [4].

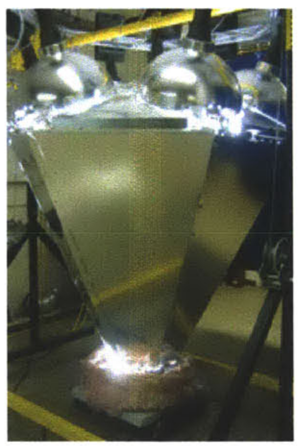


Figure 1: The experimental set up with the solar simulator turned on. The receiver is under the simulator, and is surrounded by the pink insulation at the bottom of the picture [4].

3.2 Solar Thermal Receiver: Divider Plate Tank System

The two dimensional models are based on a small molten salt thermal receiver used for testing. The receiver is constructed out of 316L steel with the dimensions of an inner diameter of 28 centimeter, a height of 10 centimeters, and a thickness of 0.125 inches. The separating plate is one eighth inch thick 316L steel with a diameter of approximately 26.5 centimeters to allow for the molten salt to pass around the edges. Connected to the steel plate is quarter inch RSLE-57 for temperature insulation between the top and bottom areas of molten salt. The insulation for the bottom of the system is 6 inch thick Zircal 18 and the insulation around the tank is normal housing insulation [5]. The salt used for testing and in the MathCAD models is Hitec Solar Salt with the chemical composition of 60% $NaNO_3$ and 40% KNO_3 [6].

The receiver is modeled and tested with the molten Hitec Solar Salt filling up to the height of 7 centimeters from the bottom with the insulating plate in the receiver. The temperature profiles are tested and modeled with the top of the plate at five and a half centimeters and at two centimeters from the bottom of the receiver. The model does not take into account the center steel rod used to guide the separating plate or the lever system that holds the plate at the correct height.

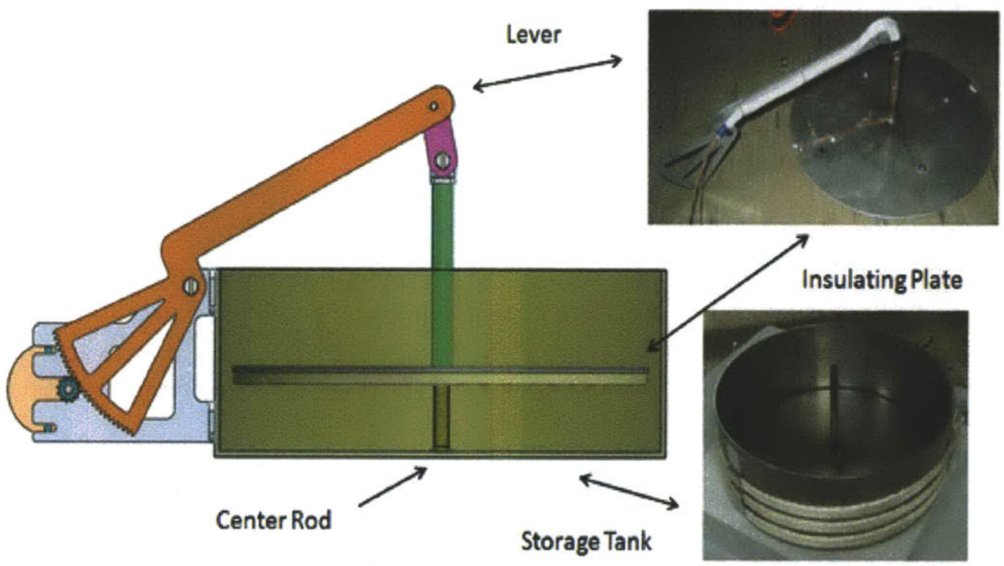


Figure 2: Left image is a Solidworks model of the thermal storage system. The upper right image is the lever and insulating plate wired up with thermocouples. The bottom right is of the tank on top of the brick insulation [5].

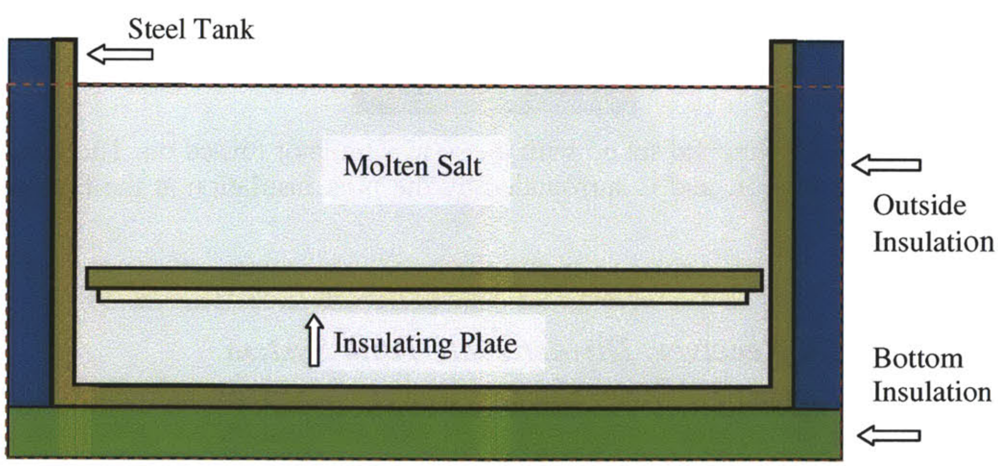


Figure 3: Diagram of the simplified storage tank which was used for the MathCAD models. The model is not to scale. The control volume is shown by the red dashed line.

3.3 Solar Absorption

Using the wavelength and absorption data from **Figure 4** and **Figure 5**, the amount absorbed into the salt for different wavelengths is calculated. The total absorption of the molten salt is then calculated as the sum of all the absorbed wavelengths. Using the total amount of light absorbed, the amount of light hitting the plate can be calculated, and the amount absorbed by the plate and the reflecting absorption into the salt is solved. The absorption calculation use Equation 1 and Equation 2.

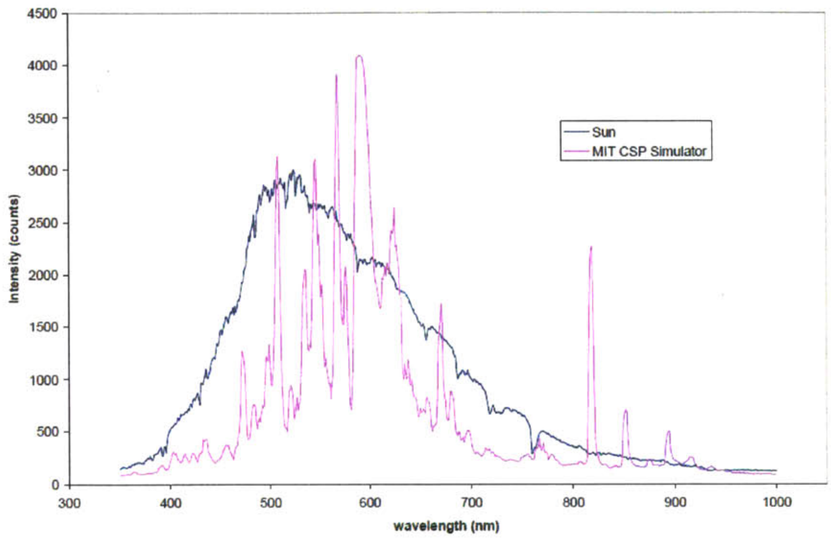


Figure 4: The graph shows the solar simulator wavelength intensities outputted versus the sun's wavelength intensities [5].

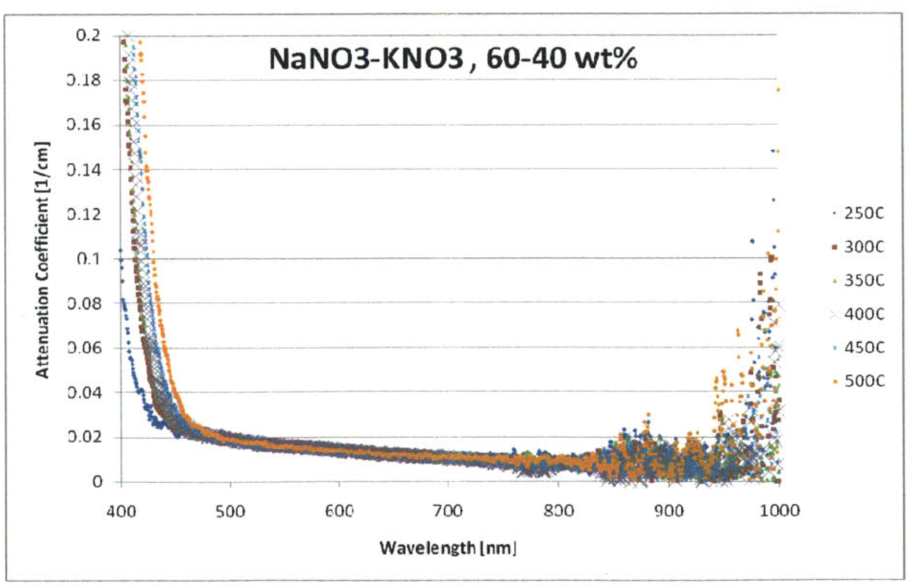
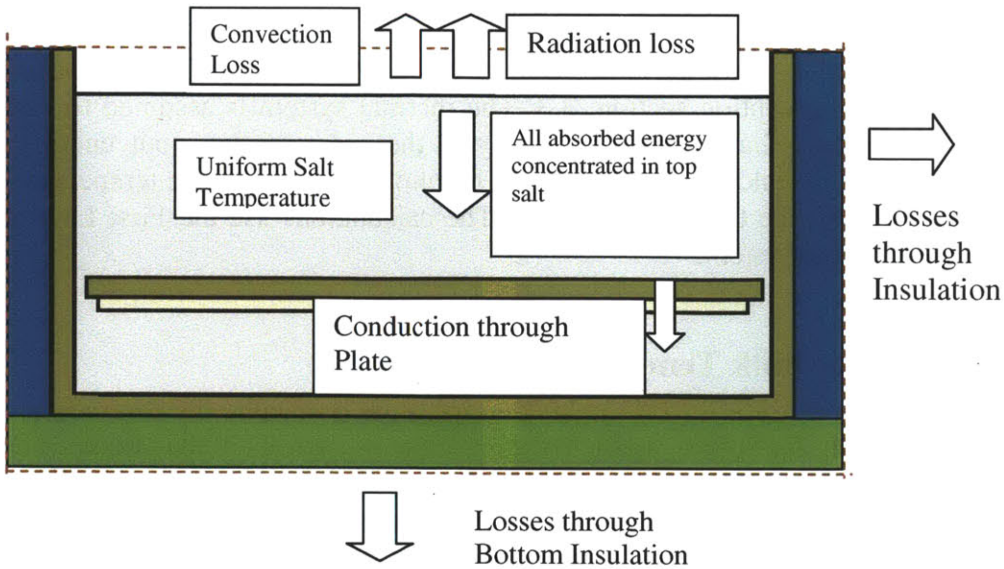


Figure 5: The attenuation of the Hitec Solar Salt versus wavelength over various temperatures [5].

3.4 Solar Receiver Thermal Model

The solar receiver is modeled as steady state with the divider plate at the two maximum and minimum height positions which are with the top of the plate at 5.5 centimeters and 2 centimeters from the bottom of the receiver. There are two models that are used for the calculations of the receiver's temperatures and heat losses. One is calculated using the found input flux from the solar simulator and the other assumes a top bulk salt temperature. Given the air temperature and then one other variable, the rest of the receiver's temperatures and heat losses can be calculated for both models. The ambient air temperature is assumed to be 25C or 293K. This is a good approximation due to other tests showing the areas around the simulator with less insulation as being 28C.

Both models use a resistance model to solve for the respective temperatures and heat losses. The resistance model is shown in **Figure 6**. Both thermal models assume that all of the incoming energy is absorbed by the top layer of salt and that the salt temperatures are bulk temperatures. The assumption that the salt temperatures are bulk temperatures is justified by the results from the experiments where the salt temperature gradients are between 10K and 1K.



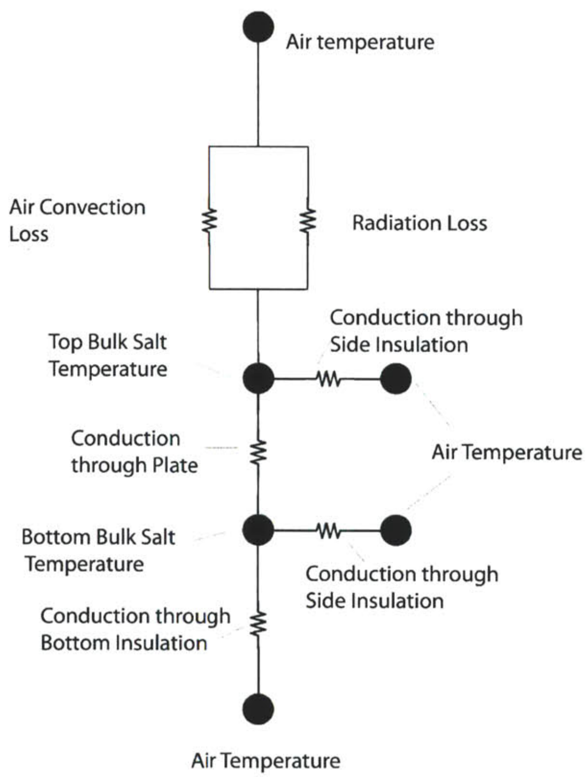


Figure 6: Thermal model used in both cases for calculating the rest of the temperatures and heat losses. The image on top is a general picture for the energy flows in the system. The one on the bottom is the resistive model used in the calculations.

3.4.1 Assumed Input Energy

One of the models uses the input energy calculated from the solar simulator data as described in the solar absorption section, 3.3. The thermal system is assumed to have reached stated state which means that the output energy is the same as the input energy. The bulk temperatures can then be calculated through the iteration of the top bulk temperature until the total energy losses equal the total input energy. The calculations use the First Law of Thermal Dynamics to solve for the system.

3.4.2 Assumed Top Bulk Temperature

The second model assumes top salt bulk temperature is equal to the one measured in the experiment after running for 8000s. Again, the sum of the heat losses in the system is equal to the total energy into the thermal tank since the receiver is modeled as steady state. With these assumptions, the total energy input is iterated until the input energy is equal to the heat losses. The model also used the First Law of Thermal Dynamics to solve for the various temperatures and heat losses.

4 Results and Discussion

4.1 Divider Plate at 2cm Height

The receiver was modeled with the top of the divider plate at two centimeters from the bottom with both an assumed energy input and an assumed top bulk temperature.

4.1.1 Assumed Energy Input

With the plate at 2cm height from the bottom of the tank, the input flux into the system from the solar simulator was calculated to be 1598W, or 25,774W/m^2, with reflective losses. Using the input flux, the top temperature was solved for assuming losses through the top from radiation and air convection, conduction through the side insulation, and bottom plate. The bulk top temperature was found to be 418°C or 691K. The actual top temperature varies between 369°C at the top of the salt to 371°C at the top of the divider plate. This is averaged to a 48 K temperature difference between the study state calculation and the measurements found at 8000s or approximately 2 hours and 15 minutes. The loss through the side insulation around the top layer of salt was calculated and found to be 381W. The radiation loss through the top salt was found to be 694W or 11,208W/m^2 and the air convection loss was found to be 363Wor 5,864 W/m^2.

The energy going through the divider plate was calculated to be 157W. With energy into the bottom salt, the temperature could be calculated along with the losses through the side and bottom insulation. The bulk temperature of the bottom layer of salt was found to be 392°C or 665K. The measure temperature at 8000s was measured as being 358.7°C or 631.7K. The difference between the calculated and measured temperatures is 34.1K. The remaining side losses were calculated and were found to be 142.5W and the losses through the bottom layer of insulation was found to be 14.8W. The losses are shown in **Figure 7** in such a way so that the heat losses may be compared to one another. The respective flux numbers for the heat losses can be seen in Table 1**Error! Reference source not found.** in comparison to the assumed top bulk temperature and the actual measured system.

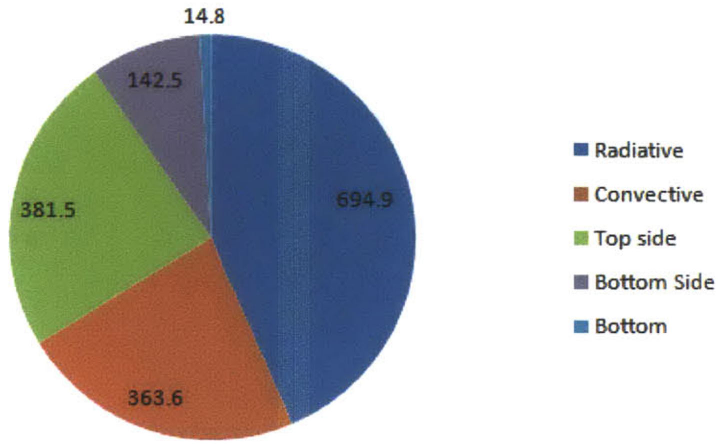


Figure 7: The pie graph shows the energy losses in Watts and where the energy losses occur with the plate at 2cm height and with the calculated energy input from the solar simulator.

4.1.2 Assumed Top Salt Temperature

The model assumes that the top salt temperature is the same as the measured top bulk temperature. The other temperatures were then solved for. The assumed top bulk temperature was 367.2 °C or 640.2K. The bottom salt bulk temperature was then found to be 344.7°C or 617.7K. The top and bottom bulk temperatures differ from the actual temperatures by 7.1K and 21.7K respectively.

The total energy input was found to be 1288W. The energy losses were also calculated. The radioactive losses were 503.4W and the convective losses were 316.0W. The energy losses through the side insulation for the top salt are 331.6W. The energy going through the insulating plate is 136.7W. Then the side insulation losses for the bottom bulk of salt are 123.9W and the losses through the bottom insulation are 12.9W. **Figure 8** shows the heat losses in comparison. The respective flux calculations for the energy losses can be seen in Table 1.

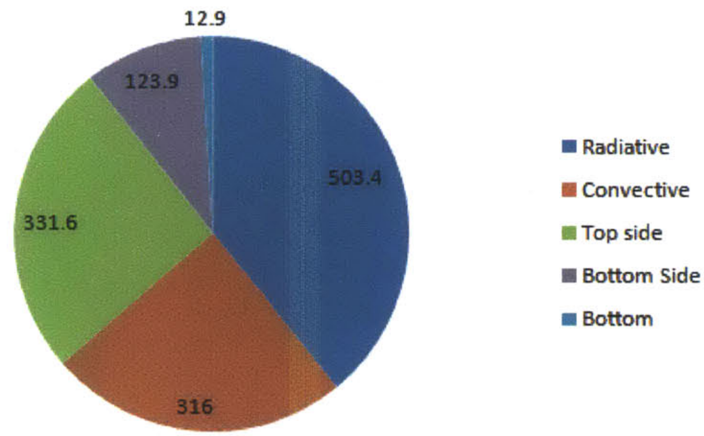


Figure 8: The pie graph shows the heat losses in Watts and where they happen for the plate at 2cm height and for the assumed top bulk temperature model.

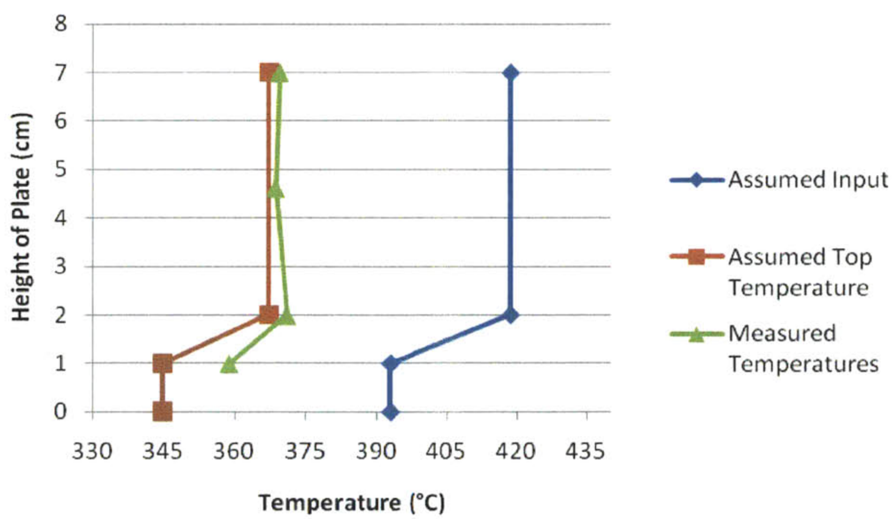


Figure 9: The chart shows 2cm modeled and measured temperature distributions in the salt.

Energy Flux (W/m^2)	Assumed Energy (2cm Plate Height)	Assumed Temperature	Test Results
Total	25,774	20,774	22,017
Radiative	11,208	8,119	8,227
Convective	5,864	5,096	5,087
Top Side	8,670	7,536	7,531
Bottom Side	7,916	6,883	7,122
Bottom	238	208	215
Through Plate	2,882	2,503	1,220

Table 1: The chart states the energy flux due to heat losses for the two different models and the tested results for the divider plate at 2cm from the bottom. The test results were found by using the measured salt and air temperatures and then using the corresponding resistances to get the energy and flux.

The heat losses in both systems were predominantly radiation and air convection losses which account for almost two thirds of the losses in both models.

Both models represent the data well in terms of temperature trends, as seen in the temperature model in **Figure 9**. The assumed top salt bulk temperature shows a closer correlation to the measured data in both temperatures and fluxes than the calculated input energy model. This may be due to a couple of factors. The first is the measured experiment is only run for 8000s, which might not have allowed the solar receiver to reach steady state. **Figure 10** shows the measured temperatures of the receiver over time. The data shows that the increase in temperature over time is decelerating, but it not appear to have reached steady state at 8000s. Therein the calculated input energy model might be a more accurate model for the system at steady than the assumed top salt bulk temperature model.

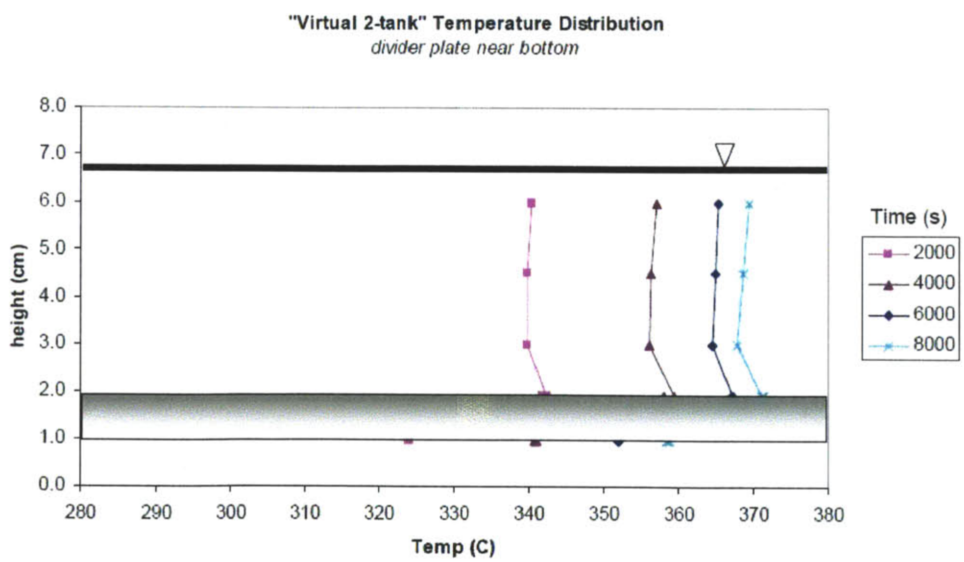


Figure 10: The experimental data with the plate at 2 centimeters high. The grey rectangle is where the separating plate is placed [5].

4.2 Divider Plate at 5.5cm Height

The receiver was modeled with the top of the divider plate at five and a half centimeters from the bottom with both an assumed energy input and an assumed top bulk temperature.

4.2.1 Assumed Energy Input

The model with the top of the plate at 5.5cm from the bottom of the tank was modeled with a calculated input energy into the system. The resulting total input was 1512W. The air temperature was assumed to be 25°C or 298K. The resulting top salt bulk temperature was 407.6C or 680.6K. The measured temperatures for the test model varied between 352.9°C and 367.0°C at 8000s after the solar simulator was started. The measured bottom temperatures varied between 343.7°C and 326.9°C. The mean differences between the modeled and measured temperatures for the top and bottom salts were 47.6K and 48.8K respectively. The losses through the top of the salt for radiation were 650.1W and through air conduction were 353.4W. The losses through the side insulation around the top salt were 111.2W. The resulting energy going through the plate was then 397.3W and the bottom salt bulk temperature was 384.1°C or 657.1K. The resulting losses through the side and bottom insulation were 382.8W and 14.5W respectively. The heat losses may be seen in comparison to one another in **Figure 11** and the respective heat fluxes due to heat losses can be seen in Table 2.

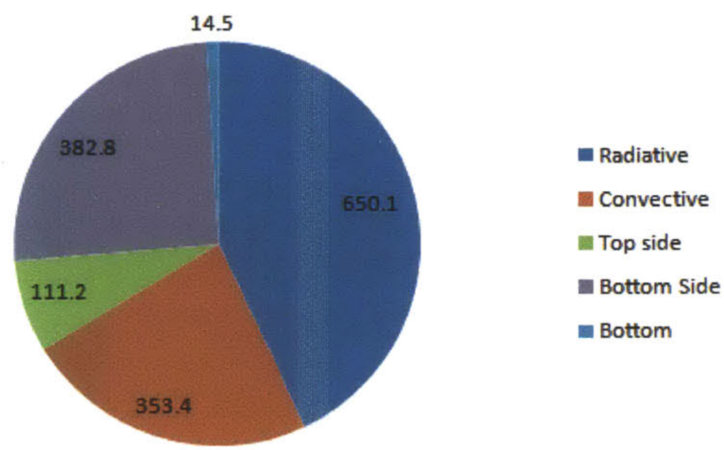


Figure 11: The heat losses are shown in Watts for model with the 5.5cm plate height and the calculated energy input from the solar simulator and where they are lost in the system.

4.2.2 Assumed Top Salt Temperature

The model assumes that the top salt temperature is the same as the measured top bulk temperature. The other temperatures were then solved for. The assumed top bulk temperature was 360.0°C or 633.0K. The bottom salt bulk temperature was then found to be 308.4°C or 581.4K. The actual top salt temperature was measured as varying between 352.9°C at the top and 367.0°C at the top of the plate. The actual bottom salt temperatures varied between 343.7°C at the bottom of the plate to 326.9°C one inch from the bottom of the tank. The averaged difference for the calculated and measured bottom salt was 26.9K.

The total energy input was found to be 1200.6W. The energy losses were also calculated. The radioactive losses were 480.1W and the convective losses were 309.4W. The energy losses through the side insulation for the top salt are 97.4W. The energy going through the insulating plate is 313.7W. Then the side insulation losses for the bottom bulk of salt are 302.2W and the losses through the bottom insulation are 11.4W. The heat losses can be seen in **Figure 12** and the respective heat fluxes due to heat losses can be seen in Table 2.

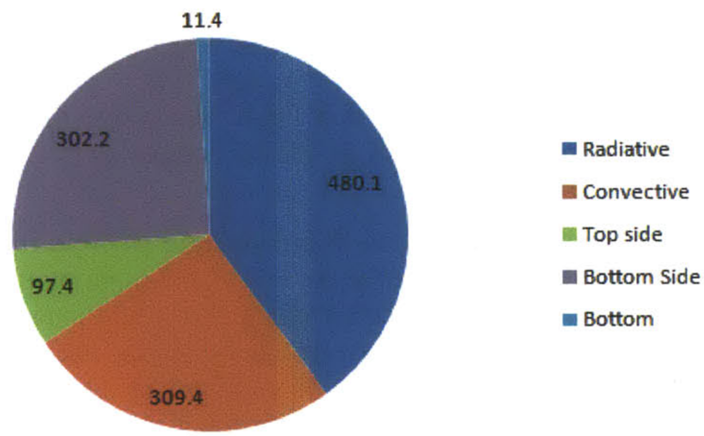


Figure 12: The chart shows the heat losses in comparison to one another in Watts for the model with the plate at 5.5cm from the bottom and with the assumed top bulk temperature.

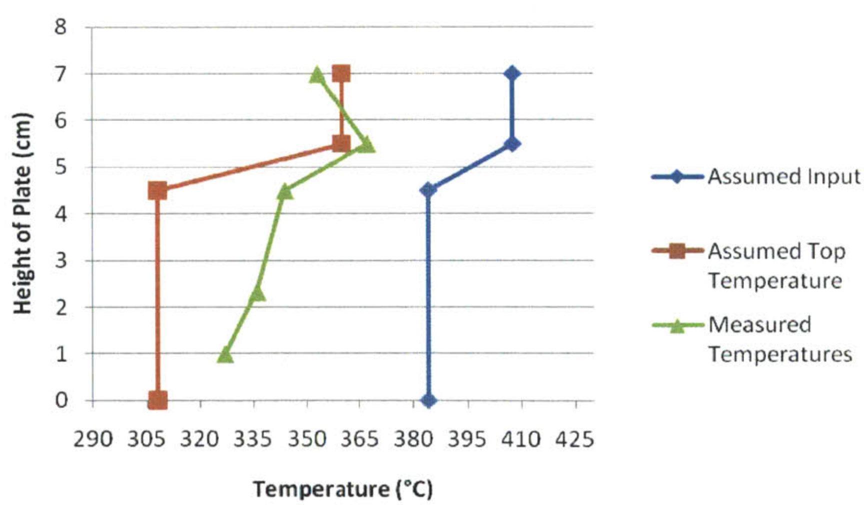


Figure 13: The chart shows the temperature distributions for the modeled and measured systems for the plate at 5.5cm from the bottom of the receiver.

Energy Flux (W/m^2)	Assumed Energy 5.5cm Plate Height	Assumed Temperature	Test Results
Radiative	10,485	7,743	7,367
Convective	5,700	4,990	4,838
Top Side	8,553	7,492	7,423
Bottom Side	7,975	6,295	6,829
Bottom	233	183	193
Through Plate	7,276	2,503	2,619
Total	24,387	19,354	21,550

Table 2: The table shows the heat flux losses and where they occur for the two calculated models and for the tested results for comparison.

Both models show the same trends in temperature changes through the system, though the temperature change through the plate for the calculated input model appears to more closely resemble the data than the assumed temperture model. Over all though, the assumed temperature model shows closer correlations to the measured data than the calculated input energy model in both the temperatures and energy fluxes. The assumed temperature model is a better representation of the experiment than the calculated input model. Once again, the assumped top temperature model uses the temperature from the 8000s experiment. This suggests that while the temperature model is a better representation of the experiment, the input energy model is the better model for the steady state of the receiver. The experiment shows that while the temperature is increasing with time, the amount it temperature increases for each interval decreases. This can be seen in Figure 14.

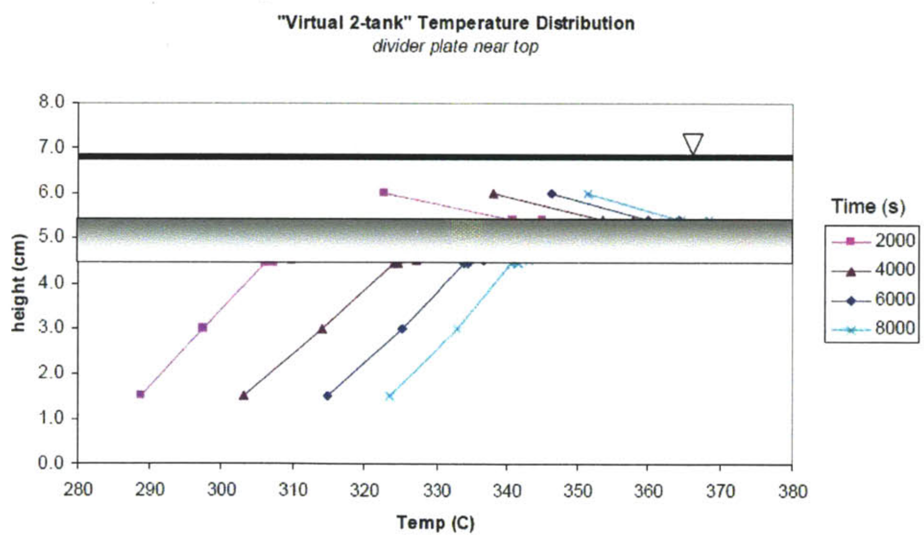


Figure 14: The charted experimental data for the thermal storage system with the plate at 5.5 cm height [5].

4.3 Discussion

The model that appears to best demonstrate the 2cm test results is the assumed temperature model since it has the closest temperatures to the results. On the other hand, some of the calculated temperatures are lower than the experiment ones. Since the models assume steady state, the calculated temperatures should be slightly higher than the test results since the results were only for 8000s. The graph of the experimental results over time shows an increasing trend in the temperatures of the system. The rate at which it is increasing appears to be decreasing, but the salt temperatures would probably raise another five to ten degrees before reaching steady state. The assumed temperature also uses the temperature from the experiment which was only 8000s into the experiment and had not reached steady state yet. So while the calculated temperature from the assumed energy input has a higher temperature difference than the assumed top temperature model, it is still a good representation of the data for steady state analysis.

4.4 Possible Errors in Energy Loss Calculations

There are assumptions made in the thermal models that differed from the experimental set up that may cause the model results to differ from the actual results. This section describes some sources that could lead to errors.

4.4.1 Hitec Solar Salt Purity

The Hitec Solar Salt was modeled with no impurities. The actual Hitec Solar Salt creates white foam like substance that floats on the surface when it is first melted due to impurities. During experimentation, the white substance is removed from the surface of the salt. While most of the impurities are removed before the testing is started, some impurities will remain. The impurities could reflect or absorb some of the incoming light, causing less of the light to be absorbed by the salt. The impurities would also mix in with the molten salt, which would cause changes in the way the salt absorbs energy and conducts heat. The impurities in the salt mixture would cause changes in some of the data, but to what degree is unknown. The impurities are not taken into account in the MathCAD model, which could increase the differences between the model and the experimental data.

4.4.2 Solar Simulator

The solar simulator used in experimentation has one of its seven lights pointing perpendicularly into the salt's surface and the other six metal halide stadium lights are at approximately 18.5° from horizontal. If the light angles are different than the approximation the total light reflected or absorbed would be affected. Since the light losses affect only 3% of the total energy losses to the system, the errors due to angle approximation would be minimal.

4.4.3 Solar Receiver Differences

In the test setup there is a lever that is attached to the insulating plate that holds the plate at the proper height in the thermal tank for the experiment. The lever, while 3.175mm thick, prevents some of the light from reaching the molten salt by absorbing or reflecting it, further causing the total amount of energy into the system to decrease. While the perpendicular light loss to the salt might be small, the width and length of the lever are 1.9cm and 20.3cm, which would absorb more of the angled light directed towards the thermal tank, once again decreasing the amount of energy going into the system. The other effect it may have is reflecting some of the light into the tank and may also redirect some of the reflected light from the salt back into the surface. For this matter, the lever has been left out of the calculations since its effects would be hard to predict.

4.4.4 Experimental Test Apparatus Difference

The thermal storage system has a steel cylinder in the center of experimental tank used to keep the insulating plate centered in the storage tank and horizontal with the ground which are neglected in the MathCAD models. The steel cylinder may act as a fin along with the steel sides of the tank to cool the top layer of salt and heat the bottom layer, making the height dependent salt temperature gradients more gradual. The cylinder in the center of the tank, in addition to the side wall, goes all the way through from the top of the system to the bottom, which causes the temperature difference between the top layer of salt and the bottom layer of salt to decrease. The fin effects of the cylinder in the center and the walls are neglected in the MathCAD model, which would cause the discrepancies between the model and the experimental temperatures.

5 Conclusion

In conclusion, both assumed the assumed energy input model and the assumed top bulk temperature model are good indicators of the receiver's temperature gradients and energy fluxes when compared to measured data. The assumed top salt bulk temperature is a more accurate representation of the experimental results than the calculated input energy model for both plate heights. This is probably due to the use of the top salt temperature from the measurements and should be used more as a model for that time period on what the energy losses are. As for the input energy model, it gives a better idea for a steady state system since the experiment was not run until it reached steady state. The models are also complimentary since they use the same thermal resistance model. The assumed temperature model verifies that the resistance model is fairly accurate at representing the receiver's temperatures and heat losses. This supports the idea that the input energy model would closely resemble steady state conditions of the receiver.

6 References

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7 Appendices

Salt Properties

Type:	NaNO3-KNO3 (60-40 wt%)
Freezing Temp:	222°C
Thermal Conductivity:	0.537 W/mK
Density	1,794 kg/m^3

Properties and Assumptions for the Models

Air Temp:	25°C
Air Convection Coefficient	15 W/m^2 K
Worst Case Emissivity	0.9
Divider Plate Insulation	0.64 W/mK
Bottom Insulation	0.1 W/mK
Side Insulation (Housing)	0.04 W/mK
Steel	16.3W/mK