ICSolar Model

Daniel W. Zaide

March 2, 2015

1 Steady Model

Consider the model of air and water interaction consisting of an initial inlet region (denoted by 0) and a pair of regions, an open region with pipe followed by a module, denoted by (1,2) satisfying

$$
\begin{aligned}
W_1: &\quad \dot{m}_w C_{p,w}(T_{w,1} - T_{w,0}) - h_{wa}(T_{a,1} - T_{w,1}) = 0 && (1)\\
A_1: &\quad \dot{m}_a C_{p,a}(T_{a,1} - T_{a,0}) - h_{wa}(T_{w,1} - T_{a,1}) - h_e(T_e - T_{a,1}) - h_i(T_i - T_{a,1}) = 0 && (2)\\
W_2: &\quad \dot{m}_w C_{p,w}(T_{w,2} - T_{w,1}) - Q_w = 0 && (3)\\
A_2: &\quad \dot{m}_a C_{p,a}(T_{a,2} - T_{a,1}) - Q_a = 0 && (4)
\end{aligned}
$$

Where i and e are interior and exterior contributions. Each pair of these forms a 'module'. In this work, we use

$$
\begin{aligned}
C_{p,w} &= 4.218 kJ/(kgK) && (5)\\
\dot{m}_w &= 0.0008483 kg/s && (6)\\
C_{p,a} &= 1.005 kJ/(kgK) && (7)\\
\dot{m}_a &= 0.384 kg/s && (8)\\
h_{wa} &= 4.823 \times 10^{-5} kW/(Km) && (9)\\
h_i &= 1.572 \times 10^{-4} kW/(Km) && (10)\\
h_e &= 4.837 \times 10^{-4} kW/(Km) && (11)\\
& && (12)
\end{aligned}
$$

With Initial and Boundary Conditions of $T_{a,0} = 20C, T_i = 25.0C, T_e = 22.5C$. At this point, we set $Q_a = 0$ as the surrounding air acts like a reservoir and its effect is currently minimal. Our inputs are $T_{w,0}$ and Q_w from experimental data. We take experimental data from the file `nov25_2.csv` located in the github repository.

1.1 Feb 11 data

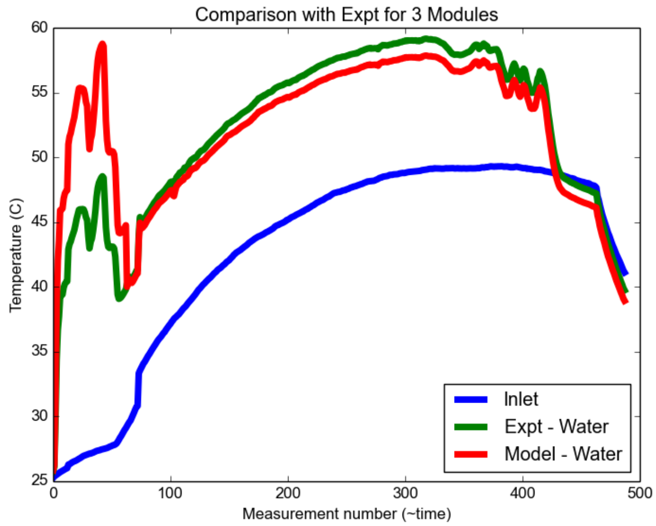

Figure 1: Comparison between experiment and model for 3 modules, water temperature in last module compared.

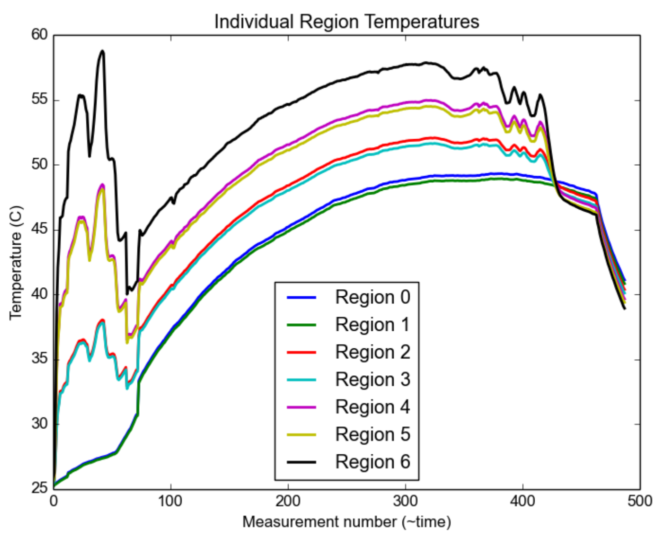

Figure 2: Model results for 3 module case, using experimental inputs. Regions 2,4,6 correspond to modules.

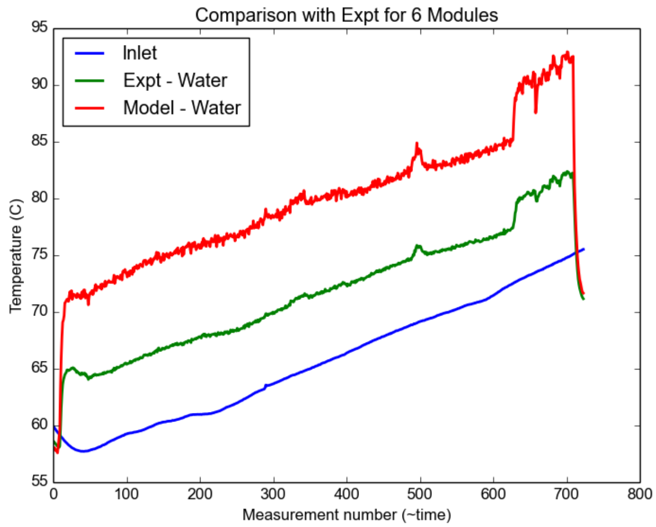

Figure 3: Comparison between experiment and model for 6 modules, water temperature in last module compared for Feb 11th data. Each module has its own Q_w from the data.

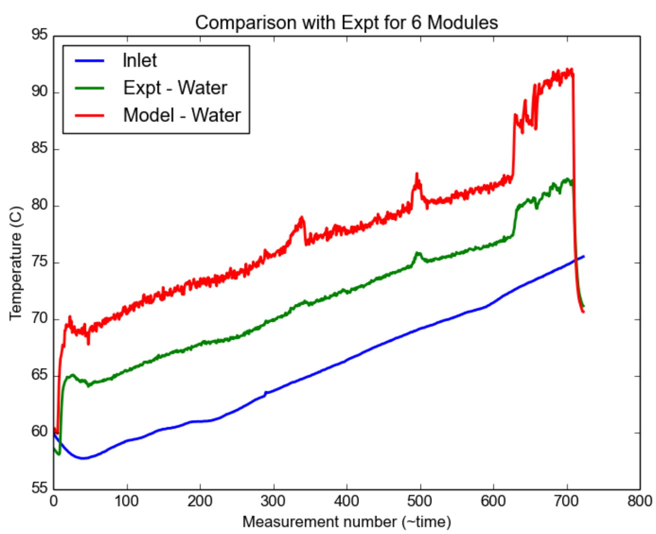

Figure 4: Same Comparison, in this case, regions 1-2, 3-4, etc are merged into one, as if the module is part of the general volume.

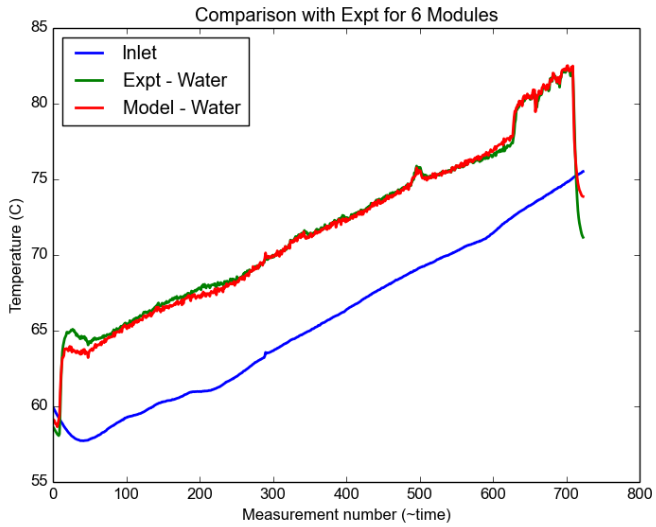

Figure 5: Same Comparison. In the model, the water flow rate is 2.4 times the number initially used. This gets closer to the experimental data.

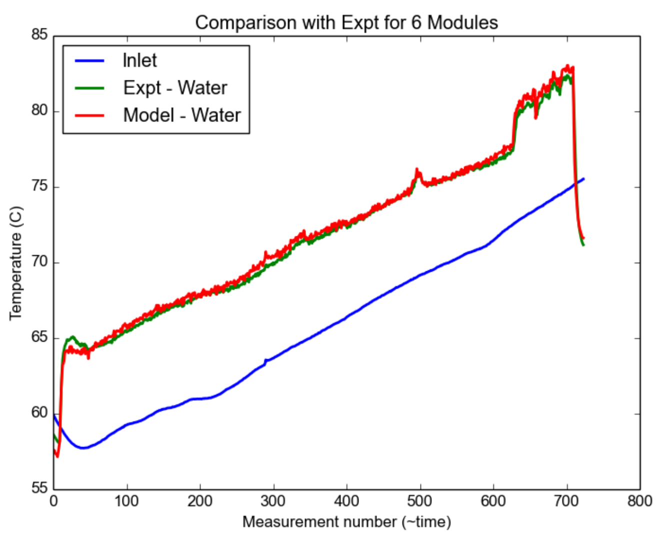

Figure 6: Same Comparison. In the model, the heat generated, Q_w in each module is 55% of the experimental number, suggesting better agreement if there is a loss of energy.

2 Unsteady Model

Consider the steady model in 4 and introduce the time derivative, $mC_p\frac{\partial T}{\partial t}$ and rearrange to get

$$W_1: \quad m_{w,1}C_{p,w}\frac{\partial T}{\partial t} + \dot{m}_w C_{p,w}(T_{w,1} - T_{w,0}) - h_{wa}(T_{a,1} - T_{w,1}) = 0 \tag{13}$$

$$W_2: \quad m_{w,2}C_{p,w}\frac{\partial T}{\partial t} + \dot{m}_w C_{p,w}(T_{w,2} - T_{w,1}) - Q_w(t) = 0 \tag{14}$$

$$A_1: \quad m_{a,1}C_{p,a}\frac{\partial T}{\partial t} + \dot{m}_a C_{p,a}(T_{a,1} - T_{a,0}) - h_{wa}(T_{w,1} - T_{a,1}) - h_e(T_e - T_{a,1}) - h_i(T_i - T_{a,1}) = 0 \tag{15}$$

$$A_2: \quad m_{a,2}C_{p,a}\frac{\partial T}{\partial t} + \dot{m}_a C_{p,a}(T_{a,2} - T_{a,1}) - Q_a = 0 \tag{16}$$

To handle the mass term, we need the volume. We have a length of the first tube as $L_1 = 0.15m$ and $L_{3,5,...} = 0.3m$. The cross sectional area of the tube is based on inner diameter, $d = 0.003m$ and outer diameter of $d = 0.0142m$. The volume of the surrounding air we are interested in has a cross section of $0.4m \times 0.4m$. Using the density and the specific heat, we get that $m_a = 0.0576kg$, $m_w = 2.12 \times 10^{-3}kg$.

For regions with modules, we can create a small volume, $m_{a,2,4,6,...} \approx Cm_a$ and $m_{w,2,4,6,...}Cm_w$. In these results, $C = 1/6$.

2.1 Feb 11 data

Using the Feb 11 data, given discrete data, we can determine $Q_w(t)$ for all times by quadratic interpolation. For the initial solution, we can set every

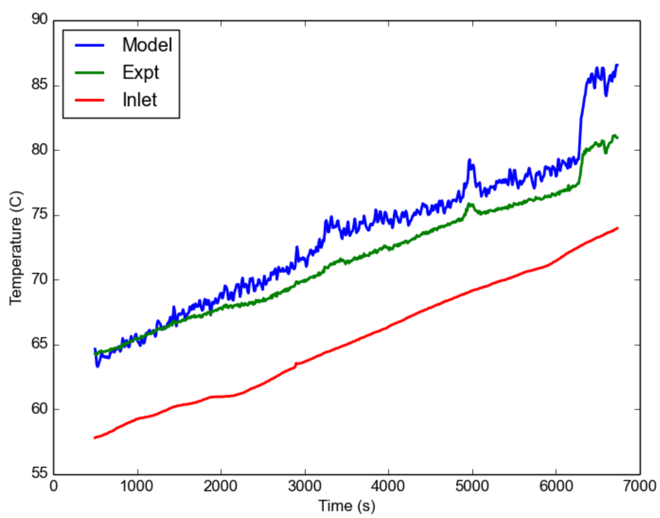

Figure 7: Same Comparison. In the model, the heat generated, Q_w in each module is 65% of the experimental number. Initially they start out in agreement, and then diverge as time goes on. Quadratic interpolation of the data (inlet temp, heat generated).