

Physics Simulator Coding Exercise

For PassiveLogic

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Background: Almost all equations and the process are taken from [Solar Engineering of Thermal Processes](#). Some concepts and ideas also came from other resources and AI. AI also provided with code implementation, although generally after initial attempts by me.

Assumptions: Most assumptions are mentioned next to the relevant variable or equation. Some key assumptions include: steady state conditions for the collector (i.e I'm not updating values with time or temperature in a given hour), no heat loss from pipes, no load on the tank.

Setup Parameters

```
# Packages needed for everything
using Pkg
Pkg.activate("PassiveLogic"; shared = true)
using DifferentialEquations, Plots
# Note: These are both big packages, and as I am importing the whole thing for both,
# compilation may initially take a while.
```

```
[32m [1m  Activating [22m [39m project at `C:\Users\child\.julia\environments\PassiveLog
```

```

# Environmental
Tsurr = 20.0 + 273.15 # K, Surrounding temperature (20C)
SunIrradiance = vcat(range(50, 1000, length = 12), range(1000,50, length = 12)) #
W/m^2, solar irradiance over the day. Assuming 1000 W/m^2 around noon and 10 at
midnight (zero causes issues). Note: this can be replaced by real hourly data

# Panel
TiltAngle = 45.0 # degrees, tilt angle of the solar panel
Ac = 2.0 # m^2, area of the solar collector
PanelAbsorptivity = 0.9 # Absorptivity of the solar panel (this can be taken from a
datasheet, but is assumed for now)

# System
mdot = 0.02 # kg/s, mass flow rate of the fluid. Note: I am assuming that the pump
would be actively controlled, ie run related to load needs and temperature conditions
in the tank and collector. For now I am assuming constant.
Cp = 4180 # J/kg K, specific heat capacity of water at about 20C. This could be made a
function of temperature for more accuracy without much difficulty.
rho = 1000 # kg/m^3, assumed density of water

# Note: I am assuming no heat losses from the pipes (ie adiabatic pipes). This is just
to simplify, and wouldn't be too difficult to add.

# Tank
TankVolume = 10 # m^3, This means about 0.72% is replaced per hour at 0.02 kg/s flow
rate.
UA_Tank = 3.0 # W/K, overall heat loss coefficient of the tank. This is an assumed
value for now. It would be taken from the datasheet, or wall material and thickness

# Initial Values
Tinit = 20.0 + 273.15 # K, initial temperature of the tank water
N = 4 # discretization for the tank, pg 382 of the book says this is a conservative
balance of mixing and stratification (more efficient)
TsTank = fill(Tinit, N) # K, temp of discretized tank elements
tspan = (0.0, 3600.0) #seconds in an hour, needed to solve the tank ODEs every hour

# Calculated/derived values from the above
S = SunIrradiance .* PanelAbsorptivity # W/m^2, solar radiation absorbed by the panel
m_node = (rho * TankVolume) / N # kg, mass of each tank node
UA = UA_Tank/N # W/K, UA per tank node or section

```

0.75

Solar Collector Functions

```
### Solar Panel Functions ###
```

```
"""
```

```
Q_Solar(Sf, Tif; Taf = Tsurr, Acf = Ac)
```

```
Sf: Absorbed solar radiation
```

```
Tif: Fluid inlet temperature
```

```
Taf: Ambient temperature
```

```
Acf: Area of the solar collector
```

```
Note: Follows processes shown in Chp 6 of the book, mainly sections 6.4 and 6.9
```

```
"""
```

```
function Q_Solar(Sf, Tif; Taf = Tsurr, Acf = Ac)
```

```
    Tpm = Tif + 10 # Initial guess for mean plate temperature
```

```
    Ulf = UL_Solar(Tpm; Taf = Tsurr) # Overall heat loss coefficient
```

```
    Frf = FR_Solar(Ulf) # Heat removal factor
```

```
    Qu = Acf * (Sf - Ulf * (Tpm - Taf)) # Useful gain of the collector, eqn 6.9.3
```

```
    New_Tpm = Tif + (Qu / Acf) / (Frf * Ulf) * (1 - Frf) # New mean plate temperature
```

```
eqn 6.9.4
```

```
    #Iterate
```

```
    k = 0
```

```
    while k < 100
```

```
        Tpm = New_Tpm
```

```
        Ulf = UL_Solar(Tpm; Taf = Tsurr) # eqn 6.4.9
```

```
        Frf = FR_Solar(Ulf)
```

```
        Qu = Acf * (Sf - Ulf * (Tpm - Taf))
```

```
        Old_Tpm = New_Tpm
```

```
        New_Tpm = Tif + (Qu / Acf) / (Frf * Ulf) * (1 - Frf)
```

```
        if abs((New_Tpm - Old_Tpm)/Old_Tpm) < 0.01
```

```
            break
```

```
        end
```

```
        k += 1
```

```
        if k == 100
```

```
            println("Warning: Max iterations reached in Q_Solar calculation")
```

```
        end
```

```
    end
```

```
    # Final calculations
```

```
    Ulf = UL_Solar(New_Tpm; Taf = Tsurr)
```

```
    Frf = FR_Solar(Ulf)
```

```
    # Total Q to the fluid
```

```
    Qf = Acf * Frf * (Sf - Ulf*(Tif - Taf))
```

```
    return Qf
```

```
end
```

```
"""
```

```
FR_Solar(Ulf; Acf = Ac, mdotf = mdot, cpf = Cp)
```

```
Ulf: Overall heat loss coefficient
```

```
Acf: Area of the solar collector
```

```
mdotf: Mass flow rate of the fluid
```

```
cpf: Specific heat capacity of the fluid
```

```
"""
```

```

function FR_Solar(Ulf; Acf = Ac, mdotf = mdot, cpf = Cp)
    # Fprime = Uof / Ulf # eqn 6.5.19 in the book, ranges from 0.75 to 1.0, to
    # simplify, I am going to arbitrarily set it to 0.875. This avoids calculating Uof,
    # which would also require calculating h for the fluid which is doable, but involved.
    Fprime = 0.875 # see above for explanation, and Fig 6.5.4 in the book, this is
    # called the collector efficiency factor

    cap_rate = mdotf * cpf / (Acf * Ulf * Fprime) # Dimensionless collector
    # capacitance rate, sec 6.7

    # Heat removal factor (Eq. 6.7.4)
    FRf = cap_rate * Fprime * (1 - exp(-1 / cap_rate)) # from eqn 6.7.4
    return FRf
end

"""
UL_Solar(Tpm; B=TiltAngle, Nf = 2, Taf = Tsurr)
Tpm: Mean plate temperature
B: Tilt angle of the solar panel
Nf: Number of glass covers
Taf: Ambient temperature
"""
function UL_Solar(Tpm; B=TiltAngle, Nf = 2, Taf = Tsurr)

    # Solve for Utop first. All below is from eqn 6.4.9
    hw = 10 # W/m^2 K, assuming minimal wind
    eg = 0.93 # emissivity of glass, https://www.engineeringtoolbox.com/emissivity-coefficients-d\_447.html
    ep = 0.95 # emissivity of plate (assumed), this would be from the collector
    # datasheet
    f = (1+0.089*hw - 0.1166*hw*ep)*(1+ 0.07866*Nf)
    if B > 70
        B = 70
    end
    C = 520 * (1 - 0.000051*B^2)
    ef = 0.43 * (1 - 100 / Tpm) # Tpm is the mean plate temp
    term1 = (Nf / (C/Tpm * ((Tpm - Taf)/(Nf+f))^ef) + 1/hw)^-1
    sigma = 5.67e-8 # Stefan-Boltzmann constant
    term2 = sigma*(Tpm + Taf)*(Tpm^2 + Taf^2)
    term3 = 1 / (ep + 0.00591*Nf*hw)
    term4 = (2*Nf + f - 1 + 0.133 * ep) / eg
    Utop = term1 + term2 / (term3 + term4 - Nf)
    Ubot = 0.9 #arbitrary, from book example. It should be calculated as k/L for back
    # wall insulation material, taken from collector datasheet.

    return Utop + Ubot
end

```

UL_Solar

Tank Functions

```
### Tank Functions ###
```

```
"""
```

```
function Fc(i, Tfi, Ts) # eqn 8.4.1 in the book
```

```
i: Index of the current tank node
```

```
Tfi: Inlet fluid temperature
```

```
Ts: Array of tank temperatures
```

```
"""
```

```
function Fc(i, Tfi, Ts)
```

```
    N = length(Ts)
```

```
    if i == 1 && Tfi > Ts[1]
```

```
        return 1.0
```

```
    elseif i >= 2 && Ts[i-1] >= Tfi > Ts[i]
```

```
        return 1.0
```

```
    elseif i == 0 || i == N + 1
```

```
        return 0.0
```

```
    else
```

```
        return 0.0
```

```
    end
```

```
end
```

```
# For now I am going to assume no load on the tank, so I will ignore the load terms
```

```
"""
```

```
function mixed_flow_mdots(Fcs, mdot) #eqn 8.4.3
```

```
Fcs: Array of flow control factors
```

```
mdot: Mass flow rate of the fluid
```

```
"""
```

```
function mixed_flow_mdots(Fcs, mdot) #eqn 8.4.3
```

```
    N = length(Fcs)
```

```
    mdot_m = zeros(N+1)
```

```
    for i in 2:N # indexing seems different, but [1] = 0 and [N+1] = 0 as they should
```

```
        mdot_m[i] = mdot * sum(Fcs[1:i-1])
```

```
    end
```

```
    return mdot_m
```

```
end
```

```
"""
```

```
ode form:
```

```
function f!(dT, T, p, t)
```

```
    where dT is the derivative of T with respect to time and p are parameters
```

```
    the function updates dT in place ie dT[i] = ...
```

```
end
```

```
Note: AI significantly helped with this function and putting it in the proper format  
to update all nodes of the tank at once and in place etc
```

```
"""
```

```
function TankODE!(dT, Ts, p, t)
```

```
    mdot, Tif, UA, Cp, m, Ta = p
```

```
    N = length(Ts)
```

```

Fcs = [Fc(i, Tif, Ts) for i in 1:N] # Flow control function

mdot_ms = mixed_flow_mdots(Fcs, mdot) # Mixed flow mdots

for i in 1:N
    Losses = (UA / Cp) * (Ta - Ts[i])
    InletTerm = Fcs[i] * mdot * (Tif - Ts[i])
    #mixing
    MixingTerm = 0.0
    if mdot_ms[i] > 0 && i > 1
        MixingTerm = mdot_ms[i] * (Ts[i-1] - Ts[i])
    elseif mdot_ms[i+1] < 0 && i < N
        MixingTerm = mdot_ms[i+1] * (Ts[i] - Ts[i+1])
    end
    dT[i] = (Losses + InletTerm + MixingTerm) / m # this assumes every section is
the same mass
end
end

```

TankODE!

Calculations

```

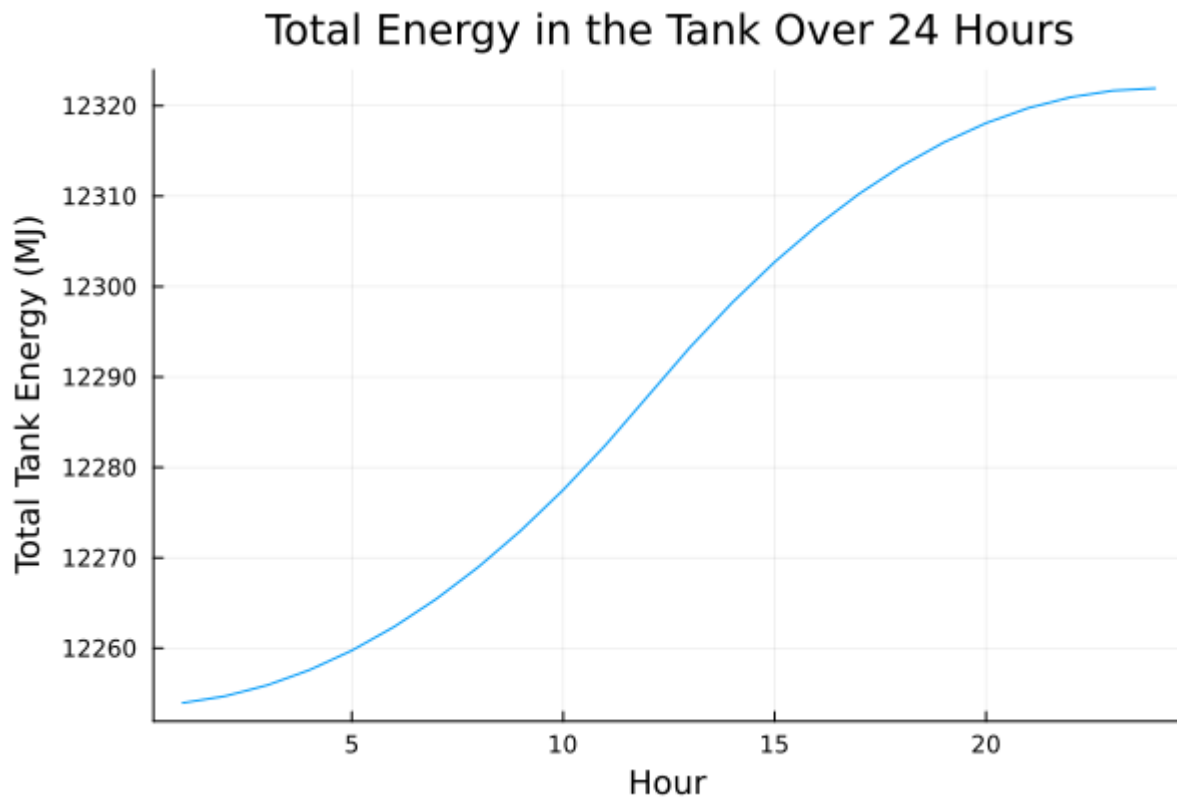
# Initialize
Tin_collector = Tinit
TsTank_new = TsTank
TotalTankEnergy = zeros(length(S)) # To track total energy in the tank over time

for (i, Sf) in enumerate(S)
    # Collector calculations
    Q = Q_Solar(Sf, Tin_collector; Taf = Tsurr, Acf = Ac) # W
    Tout_collector = Tin_collector + Q / (mdot * Cp) # K

    # Tank ODEs
    p = (mdot = mdot, Tif = Tout_collector, UA = UA, Cp = Cp, m = m_node, Ta = Tsurr)
    prob = ODEProblem(TankODE!, TsTank_new, tspan, p)
    sol = solve(prob, Rodas5(), reltol=1e-6, abstol=1e-8) #AI recommended solver and
tolerances, they seem to work.
    TsTank_new = sol.u[end] # Update tank temperatures for the next hour
    Tin_collector = TsTank_new[end] # Assume outlet temp (bottom of the tank) is inlet
temp of collector for next hour
    TotalTankEnergy[i] = sum(TsTank_new) * m_node * Cp # J, total energy in the tank
at this time step
end

```

```
TotalTankEnergy = TotalTankEnergy./ 1000000 #MJ  
hours = collect(1:length(S)) # hours for plotting  
plot(hours, TotalTankEnergy, xlabel = "Hour", ylabel = "Total Tank Energy (MJ)", title  
= "Total Energy in the Tank Over 24 Hours", legend = false)
```



Future Work: I think the most important future work is to put a load on the tank to make it more realistic. That shouldn't be too difficult. Then I should verify all of the assumed physical parameters (tank loss coefficient, collector absorption efficiency, etc). Also get accurate solar data. Combined, these will give the most realistic results. The last thing I would update is the simplifications I made, actually updating values with time and temperature, and calculating h and Nu and Pr on the fly etc. Bugs in the code I need to work out include why it doesn't work if $S = 0$ or less than about 40-50ish I think.