

Dr. Fitzpatrick asked for me to clarify a few aspects of my model, this is an outline of what I felt needed clarification.

- The final time in my problem is free, meaning it is treated like a variable to be optimized.
 - More specifically, the problem from my presentation is a minimum time problem. The optimal time is the minimum time needed to maximize ethanol production.
- The optimality condition for the final time is that the value of the Hamiltonian at the final time is zero, $H(t_f) = 0$, this is the optimal end time (T^*) for the fermentation process.
 - At this optimal final time, the other state variables are also optimized.
- To solve my optimal control problem, I used direct collocation, a nonlinear optimization technique where state and control variables are approximated using piecewise continuous polynomials. The properties of these polynomials are used to simplify the numerical integration between each collocation point. The optimal solution is only required to satisfy optimality conditions at each of these points.
 - The main idea is that integrating over many of these collocation points results in a convergence towards the solution.
 - The actual direct collocation algorithm requires advanced knowledge of system dynamics, something I do not have, so I used Matlab to find the solutions.
- The program I used to solve my problem uses the tomlab add-on.
- To solve the problem in matlab, you first need to make initial guesses for the optimal solutions for each of the state variables, including the time variable, and the control variable.
 - One of the weaknesses of collocation method is that reasonable initial guesses are needed for any accurate solution.
 - I looked to previous research to find reasonable values for my guesses.
- I then created a forloop that first runs a direct collocation with all values equal to my initial guesses.
- The second part of the loop runs a direct collocation with constraints on the time variable and control variable, but not the other state variables.
- The ODE's and objective function are then inputted and the objective function is solved for.
- This loop is run numerous times with different numbers of collocation points.
- I chose not to use a fixed time version because there are numerous problems that could arise with it. In short, fixed time problems can lead to suboptimal solutions when the variables are not properly constrained.