PART A: Application of MPC to SISO System

Task A1.1

The MPC controller demonstrates limited ability to track the set point, as the controlled output exhibits persintent oscillations and fails to converge to the desired set point value, instead behaving more like the open loop step response. Regarding the disturbance rejection ability, the controlled output does show some response to the step disturbance introduced at t = 20 s. In the open loop response, the disturbance causes a change in the oscillation period, while the closed loop response maintains a constant oscillation period, indicating the controller's effort to counteract the disturbance. However, the system still fails to converge to the set point. As for the trend of the manipulated variable, it exhibits abrupt adjustments and is frequently hitting the constraints. This aggressive control effort reflects the controller's attempts to regulate the output but shows the limitations caused by the nonoptimal settings for the cost function.

After modification on cost function weights, it was found that when u_weight = 1 and y_weight = 891.5, set point tracking improved greatly with reduced oscillations and faster settling compared with previous settings. While some oscillations are still present, the controlled output manage to converge and maintain the set point. The output weight (y_weight = 891.5) is chosen because further increase does not improve the ±2% settling time, which is at 7.8 s. The MPC controller is able to counteract the step disturbance at t = 20 s, adjusting the output back to the set point after initial deviation following the disturbance. As for the manipulated variables, abrupt changes are still observed, while hitting the constraints is less frequent.

Task A1.2

Increasing the prediction horizon length to N = 9 significantly improves the MPC controller's performance compared to Task A1.1. The controller demostrates better set point tracking, shown by the controlled output able to converge to the set point with minimum overshoot and oscillation. The controlled output is able to achieve ±2% settling time at 4.95 s. Further increase in the prediction horizon length does not improve the settling time as well as the overall closed loop performance. The controller is also able to handle step disturbance effectively by driving the output back to the set point with reduced oscillations compared to Task A1.1. As for the trend of the manipulated variable, it initially shows large adjustments as the system work to track the set point. These adjustments are more gradual compared to Task A1.1, indicating less aggressive control actions.

Task A1.3

The range of controlled output weighting factor and control input weighting factor such that the control input does not saturate is obtained when $1 \leq$ y_weight / u_weight ≤ 6.2.

Task A1.4

The values of controlled output weighting factor and control input weighting factor that achieve a ±2% settling time at 10 s is y_weight = 1 and u_weight = 3.5

Task A1.5

The values of controlled output weighting factor and control input weighting factor that minimise set-point tracking settling time is found to be y_weight = 474.8 and u_weight = 1. With these values of weighting factor, the ±2% settling time is at 2.95 s.

Task A2.1

Due to plant model mismatch, the controlled output now exhibits a 62% overshoot, significantly higher than 9% overshoot observed in Task A1.5. Oscillations are also present, increasing the settling time to 15.05 s compared to previous 2.95 s. Additionally, the controllled output struggles to reject the disturbance effectively, as oscillations persist after the step disturbance is applied. The manipulated input shows more frequent adjustments as the controller attempts to dampen the oscillations and bring the controlled output back to the set point.

Task A2.2

The values of controlled output weighting factor and control input weighting factor that improve the performance found to be y_weight = 141.3 and u_weight = 1. Further increase of y_weight does not improve the closed loop performance.

PART B: Application of MPC to CSTR

Task B1

The response plot for the product concentration resembles its open loop response in Task B0. A decline in product concentration is observed, following an initial decrease in reactant concentration. The product concentration then increases as the cooling water temperature rises. Similarly, the reactor temperature response matches its open loop behaviour. The volume response remains constant throughout, with no variation observed.

For the manipulated variables, both output flow rate and the jacket flow rate are constant. This lack of variation suggests that the controller is not taking any action to minimize the output error relative to the desired set point. Such a response occurs when the cost function weights for the controlled variables are set to 0.

Task B2

In Task B2.1, the cost function weights for all controlled variables are set to 10, while the weights for the manipulated variables are set to 1. Initially the reactor temperature decreases, and the controller adjusts to this by reducing the jacket flow rate. When the reactor temperature suddenly increases, the controller responds again by increasing the jacket flow rate. These adjustments successfully bring the reactor temperature back to the desired set point. However, the adjustment in the jacket flow rate does not correct the product concentration, which only shows a small increase before settling at a steady value far from the set point. The volume of reactor content remains constant as no change in the output flow rate is observed.

In Task B2.2, the cost function weight for product concentration is increased to 1000, while the other weights remain unchanged. This change produces similar response trends for the product concentration and reactor temperature plots. However, the steady state value for the product concentration increases by 0.025 g/L, though it still does not reach the set point. Similarly, the reactor temperature shows a higher steady state value, deviating by 0.5 K and failing to achieve the set point. These differences are affected by variations in the steady state values of the jacket flow rate. The volume of the reactor content remains constant as no changes in the output flow rate occur.

In Task B2.3, the cost function weight for the volume of reactor content is reduced to 0.001, while the other weights remain the same as in Task B2.2. This reduction results in a response where the product concentration and reactor temperature plots remain like those in Task B2.2, but with significant improvements. The product concentration’s steady state value increases by 0.075 g/L, making it closer to the set point, while the reactor temperature’s steady state value decreases by 0.5 K, also moving closer to its set point. However, the volume of reactor content no longer remains constant, deviating by 80 L before stabilizing at a higher steady state value. This deviation is caused by changes in the output flow rate.

The observations from Task B2.1, B2.2, and B2.3 show that adjusting cost function weights have impacts on the system’s performance. In Task B2.1, balanced weights allow for desired reactor temperature control but fail to improve product concentration. In Task B2.2, increasing the weight for product concentration slightly improves its response but compromising in the reactor temperature control. In Task B2.3, a decreased weight for reactor content volume allows for flexibility in the output flow rate, increasing the reactor's residence time. This longer residence time provides more opportunity for the reactants to convert into products, thus improving the product concentration. However, none of the manipulated variables directly control the product concentration. Instead, the controller tries to adjust the jacket flow rate and output flow rate, which indirectly affect product concentration through changes in reactor temperature and residence time.

Task B3

In Task B3, the reactor volume is no longer controlled to its desired set point but instead allowed to stay within specified constraints. This is achieved by modifying the cost function weights from Task B2, specifically by setting the cost function weight for reactor volume to 0. This adjustment means that maintaining the reactor volume at a set point is no longer a priority in the overall cost function. As a result, the product concentration increases by approximately 0.0125 g/L in its steady state value, bringing it closer to the set point. A change in the reactor temperature's steady state value is also observed where it decreases by 0.01 K, moving closer to the set point. Since reactor volume is no longer prioritized, its response is not maintaned at the set point and instead increases by 100 L before reaching a steady value after hitting the constraint. This behaviour aligns with the output flow rate plot. The output flow rate shows a drastic change, briefly hitting the constraint resulting in no output flow. After this, it eventually returns to a constant value, thus keeping the reactor volume at a steady value. Additionally, the jacket flow rate exhibits a more aggressive response in comparison with Task B2. It briefly hits the constraint before settling at a higher steady value than of what is observed in Task B2.

Task B4

In Task B4, the primary control objective is to tightly control the product concentration to its set point, while the other variables, such as reactor temperature and reactor volume, only need to lie within their constraints. To achieve this, the reactor temperature is no longer controlled to its set point and is allowed to fluctuate freely within its natural dynamics. This is achieved by setting the cost function weight for reactor temperature to 0. As observed in the reactor temperature plot, the temperature deviates significantly from the set point and settles at a steady state value 4 K higher than its set point. The corrective action done shown by the jacket flow rate is also minimal and primarily intended to keep the reactor temperature within its constrains. At certain points, the jacket flow rate hits its lower constraint and drops to 0, stopping the cooling system and allowing the reactor temperature to fluctuate freely. This behaviour aligns with the primary objective, which prioritizes product concentration over reactor temperature. Reactor temperature indirectly affects product concentration by influencing the reaction rate. Maintaining temperature at a fixed set point may conflict with achieving the desired product concentration since the optimal temperature for maximizing product concentration can vary with the system's dynamics.

The reactor volume is not uncontrolled. Its response plot show deviations from the set point, briefly hitting its constraints before settling at a steady state value close to its set point. This indicates a non-zero cost function weight for reactor volume. Additionally, the volume adjusts to a steady value that aligns with the natural fluctuations in temperature, ensuring that the residence time is sufficient to maintain product concentration at its set point. Correspondingly, the output flow rate shows significant changes, before returning to a constant value to maintain a steady volume. Finally, the product concentration plot confirms that it achieves tight control and closely tracks its set point, thus reflecting the high priority placed on its cost function weights.