Process Control – Exercise 2

1 Distillation Case Study

Distillation is a method of separating liquid mixtures by means of partial evaporation. The volatility α of a compound determines how enriched the liquid or vapour phase will be in that compound. Components with high volatility will enrich the vapour phase and components with low volatility will enrich the liquid phase. A distillation column uses counter current flow of vapour an liquid and several distillation stages to achieve a high purity product.

1.1 Control Structure

Task 1: A typical distillation column with valves and measurements is given in Figure 1. Please do the following:

(a) Define the control objective.

(b) Classify the variables into: Control Variables, CVs (y), Manipulated Variables, MVs (u) and disturbance variables DVs (d).

(c) Fill in the process matrix. (Table with CVs along the rows and MVs along the columns, where the elements are filled 0, +, -, (+), (-) representing qualitative relation between them).

(d) Suggest a control structure for the column.

1.2 Modeling

In rest of this case study we are going to investigate a simple 4 stage (considering reboiler and total condenser) distillation column. See Figure 2 for a sketch of the process. Consider the following assumptions and parameters:

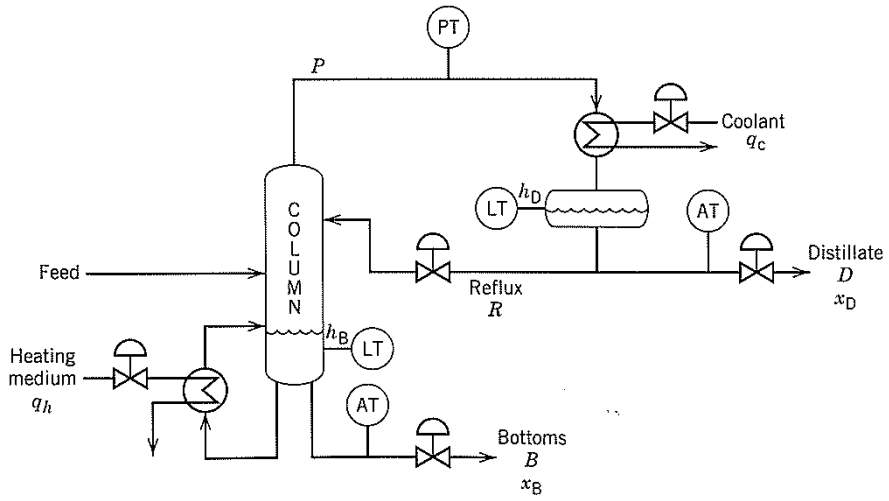


Figure 1: Distillation column setup. x_D and x_B, respectively, are the mole fraction of light component at the top and bottom of the column

- Constant relative volatility.
- Constant pressure and no pressure drop.
- Constant molar overflow.
- Top stage is a total condenser (i.e. all vapour is condensed and there is only liquid flow out)
- The feed is saturated liquid.

Parameters	
Number of stages	4
Number of components	2
Relative volatility, α	4.78

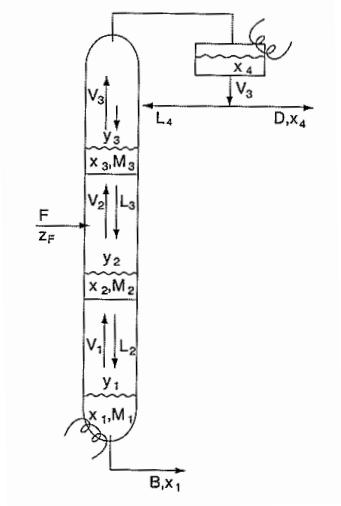


Figure 2: Sketch of distillation column model

Task 2: Using the nomenclature in Figure 2 and the assumptions and parameters given above, please write a dynamic model for the distillation column (Hint: write the dynamic component balances for all stages). Use the following liquid vapour equilibrium relation:

$$y = \frac{\alpha x}{1 + (\alpha - 1)x}$$

where y and x is the light component molar fraction on the vapour and liquid, respectively.

1.3 Simulation and Control

From here on we are going to use the finished model of the distillation column is given in the Simulink file `simdist.mdl`. (you must put `simdist.mdl`, `sfdist.m`, and `steadystate.mat` in the same folder). Write *»simdist* in the Matlab command window and the Simulink diagram will appear. You can see the actual model in the `sfdist.m` file.

To simplify your work we also provide Matlab scripts (`task3.m` and `task4_.m`) containing the initialization of the Simulink model and a suggestion of how to run and plot the simulation results. You might use the scripts as an starting point for your solution.

Condenser and reboiler levels are controlled with P-controllers by using the MVs; D and B, respectively. The top composition is controlled with a PI-controller by using the MV. The controller gain is *Kc* and the integral time is *taui*; LT (called L_4 in Figure 2, and R in Figure 1). The MV; VB, i.e. the vapour boilup is kept constant (called V_1 in Figure 2, we have neglected the heat transfer dynamics so setting VB is the same as setting q_h in Figure 1).

Task 3: Here we consider the loops are all open(no control). This means that *Kc=Kd=Kb=0*. In the script `task3.m` we apply a 1% step increase in the reflux Lt, 10% in the boilup Vb and distillate (D) and bottom (B) flows. Run the script and then compare the responses you will see with the process matrix you obtained in Task 1. Were your predictions correct? Together with this exercise we provide a sheet with some initial plots. Fill in by hand the remaining plots according to what you see from the simulations.

Task 4: In this task we must close the level control loops. For this task we are going to use the files `task4_steptest.m` and `task4_controleval.m`. Before starting, be sure $Kb = Kd = -10$ in the Matlab scripts. We want to control the top composition (x_D) using the reflux (u). Please design a

PI-controller to accomplish this task by following the SIMC procedure presented below.
Should the gain of the controller be negative or positive? Please explain.

Procedure for PI tuning:

1. Apply step change on u and check how the top composition changes in open-loop ($Kc = 0$). (Hint: this can be done by running the script `task4_steptest.m`)

2. Obtain a 1st order transfer function model $\left(G(s) = k\frac{e^{-\theta s}}{\tau s+1}\right)$ from u to y (where $y \equiv x_D$). (Hint, the static gain is $\frac{\Delta y}{\Delta u}$ at steady state. The time constant τ is approximately the time it takes, after the delay, for y to reach 63% of its total variation value). Make a plot with responses and mark the key information as seen in Figure 3.

3. Tune a PI controller using SIMC rule (must be memorized!). Try $\tau_c = 3$ min, $\tau_c = 1$ min and $\tau_c = 0.5$ min and simulate for disturbances and setpoint changes. Print the results and give the parameters obtained. *Notice that a measurement delay of 1 min has been included in the feedback loop, so* $\theta = 1$ *min.*.

The evaluation of the controller and the plotting of the results is done by running the script `task4_controleval.m`.

Open the file, write your proposed values for *Kc* and *taui* and run the script. The script simulates the closed-loop system with the following changes:

- Increase of 10% in feed rate (*feed_ dist*);
- Increase of 10% in feed composition (*comp_ dist*);
- Setpoint increase from 0.9 to 0.92 (*xd_sp*).

Please comment on the simulations. Which value of τ_c would you recommend? For which τ_c does it become oscillatory?

For τ_c= 1 min plot BY HAND the closed-loop response of x_D, x_B and L_t to a 20% step increase in feed rate. Can it be correct that the reflux L_t is reduced?

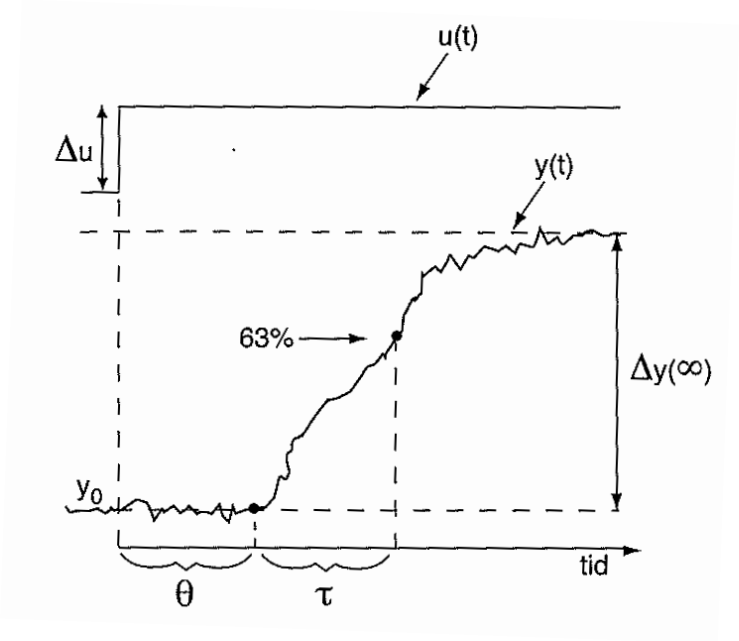
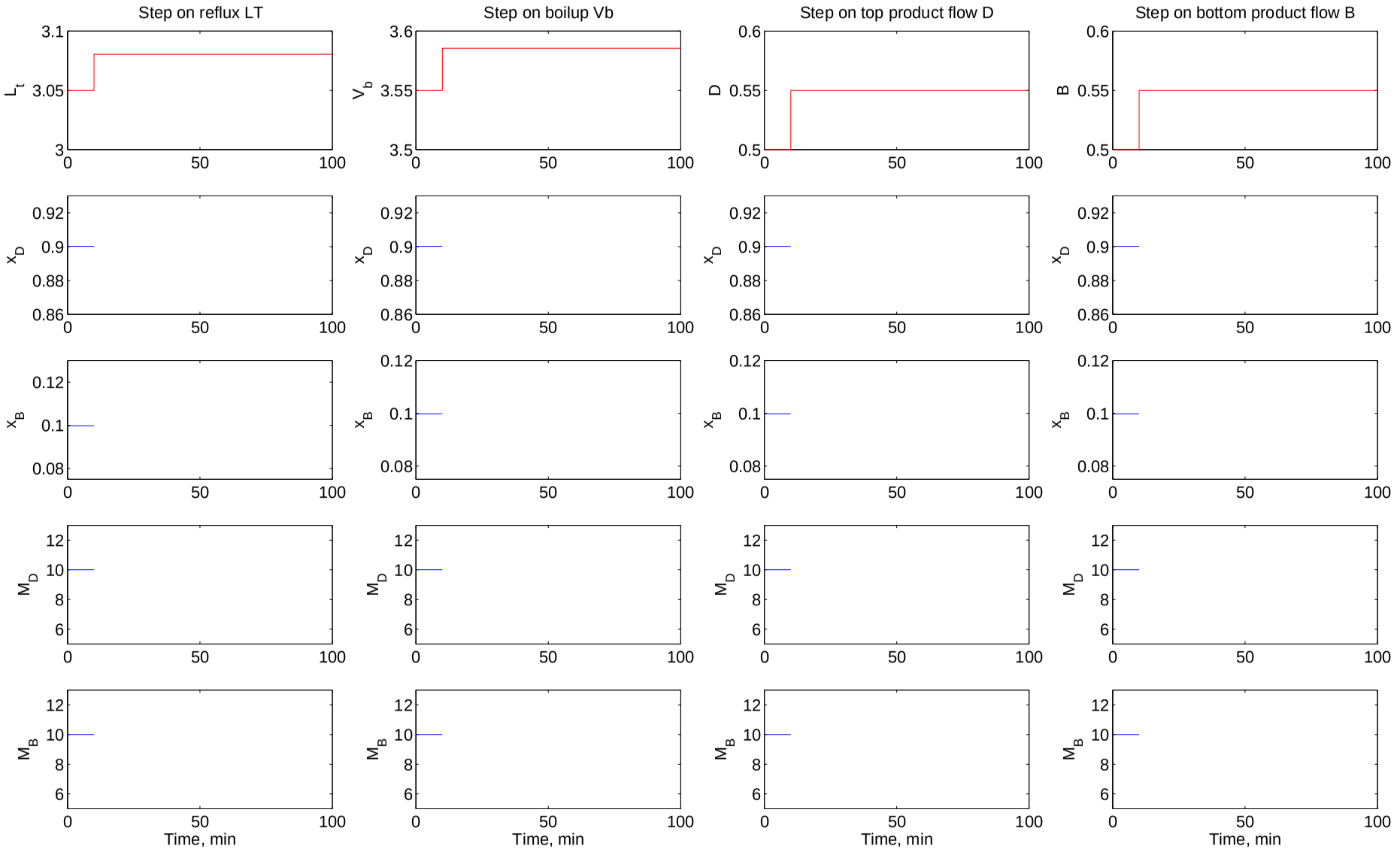


Figure 3: Step response plot with key informations marked


Step on reflux LT
Step on boilup Vb
Step on top product flow D
Step on bottom product flow B
L_t
V_b
D
B
x_D
x_B
M_D
M_B
Time, min