Distillation Controlled by Internal Model Controller

The Application

The distillation column is used to separate benzene from toluene.

A mixture of benzene and toluene is fed into the column.

Benzene is drawn from a side draw tray, and should contain no more than 250 ppm of toluene.

An on-line analyzer is used to perform composition analysis in the side draw flow every 9 minutes.

There are temperature sensors on each tray of the column.

A change in the temperature differential between the trays above and below the draw tray indicates toluene content increase or decrease in the side draw stream.

A modulating valve is used to control how much benzene to draw.

The more benzene we draw, the more toluene it will contain, thus putting the balance of the column in danger right above the 200ppm of toluene mark.

The less benzene we draw, the purer it is (can be as low as 5ppm), but the efficiency of such operation is lower since some benzene is lost in other less valuable streams (such as the bottoms).

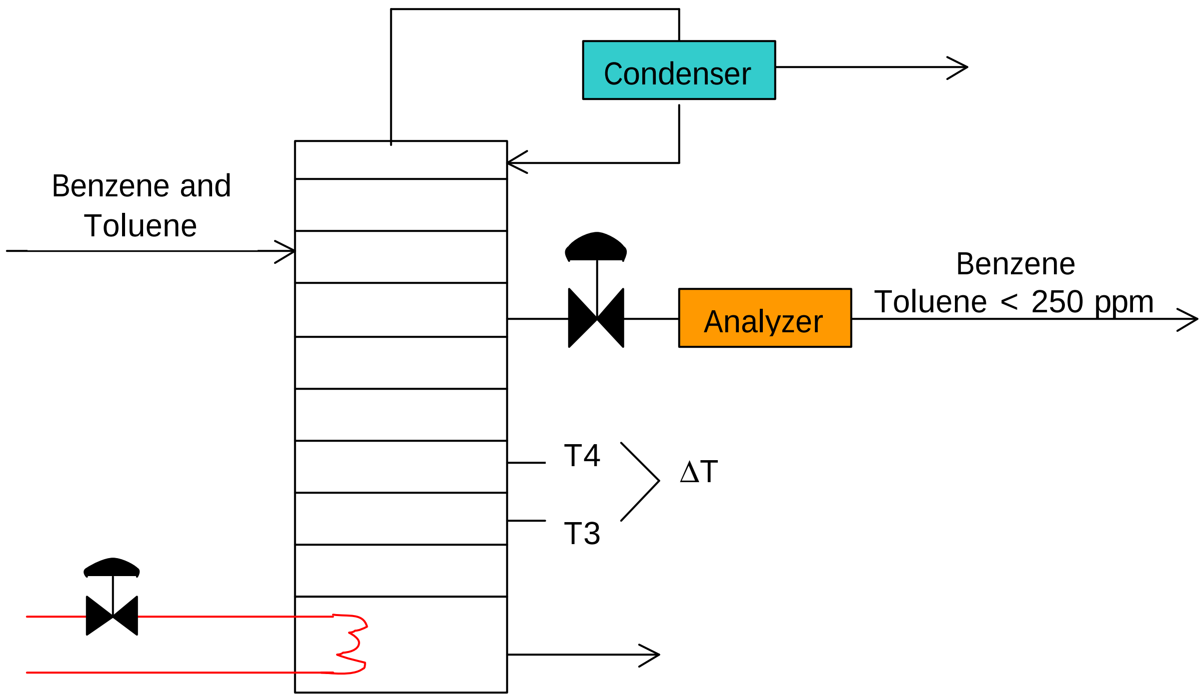

Figure 1: Schematic of the distillation column used to separate toluene from benzene.

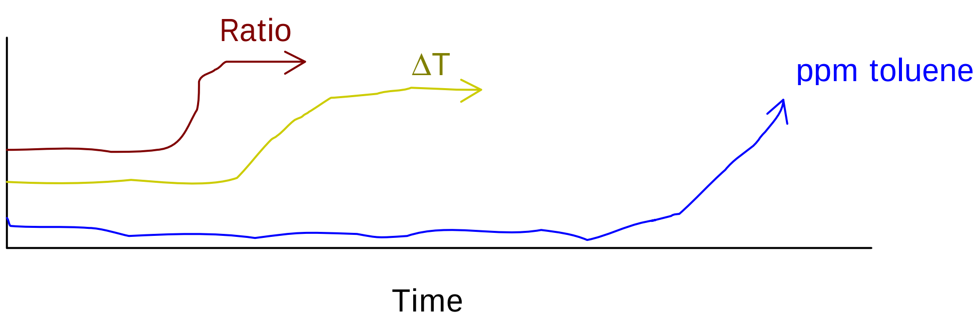

Figure 2: Plots showing the response to a change in setpoint over time. The ratio is the side draw flow rate over the column feed rate. ΔT is the temperature difference across the trays in a column. The ppm measurement is the toluene composition in the side stream.

Old Controllers

The column was originally designed to run off inferred composition from temperature differential and other values.

Controller #1: Standard cascade PID

The inner loop (slave) manipulates the side draw valve position to match the ratio of the desired side draw versus the column feed. Desired ratio is the setpoint; the actual ratio comes from simple actual side draw over actual feed rate calculation. The feed rate can change, based on level controller upstream that manipulates the flow of benzene and toluene mixture from a drum upstream. The inner loop assures mass balance of the column.

The outer loop (master) manipulates the setpoint of the inner loop (the desired ratio) to maintain a temperature differential at a setpoint.

When ratio increases, three other factors also increase: the side draw flow, the temperature differential, and the content of toluene (impurity).

This outer loop provides for good control of the temperature differential, but the setpoint must be adjusted manually to maintain desired content of toluene. The setpoint value depends on current quality of feed (benzene-rich or toluene-rich).

This is where the original design stopped.

Controller #2: Triple cascade PID

The second PID controller was configured to manipulate the setpoint of the temperature differential based on desired toluene content compared with the actual value from the on-line analyzer.

Due to the nature of the process (quick changes of load and composition, integrating nature with about 20 minutes of deadtime) the operators were unable to tune the composition PID controller. The controller had to be detuned well beyond any capability to control a variable to its setpoint. More than that, a special PID was programmed to handle this type of the process, but was used unsuccessfully.

IMC Controller

When ControlSoft was asked to solve this composition control problem, we thought that we would have to scrap the original control scheme and start over implementing a model predictive controller. However, the thought process led us to the fact that the Controller #1 works well: mass balance is maintained and the temperature differential controller responds well to composition changes. The only remaining challenge was to control the toluene content to its setpoint.

We used the Internal Model Controller (IMC) instead of the special PID in the Controller #2 scheme. We ran a series of step tests to obtain a first order lag with deadtime model between the temperature differential setpoint and the toluene content.

We came up with the Gain, Time Constant and Deadtime and execution rate every 30 seconds. We compiled the IMC controller CL language code, and ran it on Honeywell TDC3000 Application Module. The controller takes less than 1% of capacity of the module.

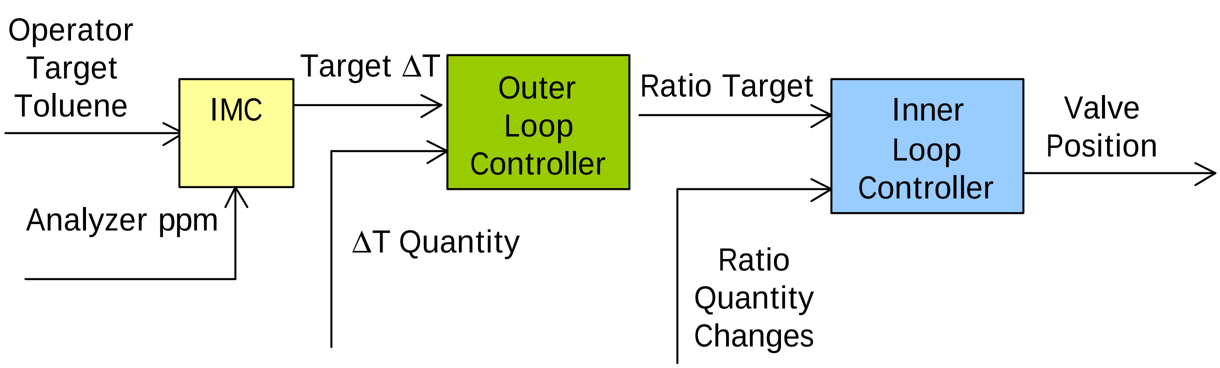

Figure 3: Controller Setup.

Result

Using Controller #1 the normal operation was between 20-50ppm of toluene, safe enough to meet product specification, less economical. The attempt with Controller #2 did not make any difference since only setpoints of 50ppm or less were achievable. The controller was not able to maintain higher setpoints of 100-150ppm since the stability margin is very narrow in this region and conservatively tuned PID failed to act rapidly under certain disturbances thus forcing the operators to switch it to manual and regain the control of the column.

The IMC controller operates the column at 100ppm setpoint with standard deviation of less than 5ppm, 24 hours a day, through operation changes and crude oil changes.

O.K./K.S.