Guidelines for Dynamic Modeling of Column Startup
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Agenda

- Background of case study
- Determining scope of model
- Simulation Guidelines
- Case Study
- Summary
Background of Case Study

• Customer – Calumet Montana Refining, LLC
• Had existing steady-state model of entire facility
• Shared P&IDs, PFDs, procedures, & process data from previous start-up
• New crude unit being built & would like accurate simulation of startup conditions
Original Steady State Simulation
Goals of Case Study

• Simulate crude unit only
• Model existing tower startup
• Compare to historical startup data
• Determine if dynamic simulation could be used as tool to predict startup performance of new crude unit
Determining Scope of Model

Use operating procedure to determine sequential steps & model targets:

1) Crude charge introduced to tower at increasing temp & flow rate
2) Target level reached in overhead accumulator
3) Reflux system placed in service
4) Stripping steam introduced to tower
5) Product streams reach specification
Simulation Guidelines

• Start with a simple model
• Get model to converge
• Validate results
• Add complexity as required to reach desired engineering solution
Start with a Simple Model

- Crude tower only
- Change to dynamic simulation mode
- Pumparounds/side strippers not in service
- Crude Heater modeled as temp & flow ramps
- Use actual data & equipment parameters
  - Feed temps & flows from actual data
  - Accumulator dimensions & condenser setpoints
  - # trays, feed stage, etc.
Simplified Flowsheet

Startup from Dry Column

- Atmos Offgas
- Heavy Naphtha
- Kerosene
- Diesel
- AGO
- TO VACUUM TOWER
Change to Dynamic Simulation Mode

- Convergence Parameters -

- Take a snapshot before running flowsheet
- Recycle Convergence Methods
  - Convergence method: Direct substitution, Wegstein, Dominant Eigenvalue (DEM)
  - Max. flowsheet iterations: 40
- Plot stream history
- Speed up frequency: 4

- Recycle Tolerances
  - Flow rate: 0.001
  - Temperature: 0.001
  - Pressure: 0.001
  - Vapor fraction: 0.001
  - Enthalpy: 0.001

- Flash Calculations
  - Flash algorithm: Normal
  - Flash damping factor: 1
  - Flash tolerance: 1e-005
  - Thermo Accel. tolerance: 0.001

- Calculation sequence
  - Steady state/dynamics: Dynamics
  - Flow/pressure conversion: Steady state

- Display trace window
- Generate run history
- Refresh data boxes after each run
- Refresh data boxes after each iteration
- Run Data Map at each dynamic time step

- Run one time step for dynamic simulation
- Allow dynamic editing any time

Help | Cancel | OK
Startup Conditions

Initial Column Conditions
- Steady state continuous process
- Startup the column
  - Dry tray startup
- Continue from previously saved state

Tray holdup calculation
- Ignore liquid holdup
- Constant liquid holdup
- Variable liquid holdup
- Ignore vapor holdup
- Calculate vapor holdup

Pressure Calculation
- Fixed Pressure

Display plot during simulation

Record frequency

Include column metal heat transfer

Use operator training algorithm

Help  Cancel  OK
Tower & Feed Configuration

- Tower Configuration -
  ID: 19
  Tower Plus Configuration:
  - Number of strippers
  - Number of pumps
  - Number of exchangers
  - Number of side products: 4

- RAMP for Equipment / Stream Parameters -
  Type: Stream
  ID: 1
  Variable: 1 Temperature
  Component: <None>
  Variable units: 2 Temperature

0 Use the table below

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>325</td>
</tr>
<tr>
<td>60</td>
<td>700</td>
</tr>
<tr>
<td>120</td>
<td>717</td>
</tr>
</tbody>
</table>

Additional time steps...

Help  Cancel  OK
Actual Data Determined Ramp Settings
1) Crude charge introduced to tower at increasing temp & flow rate
2) Target level reached in overhead accumulator
3) Reflux system placed in service
4) Stripping steam introduced to tower
5) Product streams reach specification
Accumulator Dimensions & Reflux

Set reflux to zero initially.
Accumulator Level Target Specification

For column startup only:

- Duration time: 3 h
- Reboiler heat duty: 0 MMBtu/h

Accumulator holdup unit: Volume
- Max. accumulator holdup: 185 ft³
- Initial holdup: 74 ft³

Pressure Calculation: Fixed Pressure
Get Dynamic Model to Converge

• Set initial run time based on actual data if available
• Modify step size:
  – If needed to assist with convergence
  – Depending on target parameter’s rate of change
• Run one time step manually & view results
• Other convergence adjustments:
  – # of iterations
  – tolerances
Run Time Parameters

[Image of a software interface showing run time parameters with options for Time, Stream, and Equipment. Parameters include run time, step size, ID number, variable, component, stop mode, stop value, and tolerance.]
Accumulator Level Plot
Accumulator Level Target Reached

Accumulator liq. level(ft)
Scope of Model

1) Crude charge introduced to tower at increasing temp & flow rate

2) Target level reached in overhead accumulator

3) Reflux system placed in service

4) Stripping steam introduced to tower

5) Product streams reach specification
Switch to maintain level & adjust reflux rate
Scope of Model

1) Crude charge introduced to tower at increasing temp & flow rate

2) Target level reached in overhead accumulator

3) Reflux system placed in service

4) Stripping steam introduced to tower

5) Product streams reach specification
Start Stripping Steam to Tower

- **Column Number of stages**: 17
- **Pressure of colm top**: 21 psia
- **Column pressure drop**: 7.5 psi

**Steam**

- **Bottom steam rate**: 59.111 lbmol/h
- **Steam temperature**: 760 F
- **Steam pressure**: 163.1 psia

**Stage efficiency**

- **Top stage**
- **Bottom stage**

**Feed Stages**

- 1st feed stage #: 15
- 2nd feed stage #: 
- 3rd feed stage #: 
- 4th feed stage #: 
- 5th feed stage #: 
- 6th feed stage #: 
- 7th feed stage #: 
- 8th feed stage #: 
- 9th feed stage #: 
- 10th feed stage #:
Scope of Model

1) Crude charge introduced to tower at increasing temp & flow rate
2) Target level reached in overhead accumulator
3) Reflux system placed in service
4) Stripping steam introduced to tower
5) Product streams reach specification
Product Stream Reaching Specification

30 min after reflux begins
Scope of Model

1) Crude charge introduced to tower at increasing temp & flow rate
2) Target level reached in overhead accumulator
3) Reflux system placed in service
4) Stripping steam introduced to tower
5) Product streams reach specification
Validating Results

• Time to reach accumulator level:
  – Model ➔ 30 min
  – Actual ➔ 20 min

• Time to side product specs after reflux begins:
  – Model ➔ 30 min
  – Actual ➔ 40 min
Further Validation of Results

• Compare to additional sets of startup data
  – Is the delta between the model & actual consistent?

• Add complexity as required to get desired results
  – How close is close enough?
Add Complexity As Required

- Fired heater
- Reflux/distillate control valves
- Pumparounds/side strippers
- Relief valve studies
- Additional upstream / downstream units
Switch Back to Steady State Model
Review Simulation Guidelines*

- Start with a simple model
  - Fix what you can, i.e. pressures, etc.
  - Ignore what you can, i.e. utilities, etc.
- Get model to converge
- Validate results
- Add complexity as required to reach desired engineering solution
  - more detail may not be better!
  - i.e. don’t add utilities controls systems to flowsheet just because they’re on the P&ID

* True for steady state & dynamic simulations!
Special Thanks

Ron Colwell, PE – Engineering Manager
David Fleming – Senior Process Engineer

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Calumet Montana Refining processes Canadian heavy crude oil to produce gasoline, middle distillates and asphalt which they market primarily into local markets in Washington, Montana, Idaho and Alberta, Canada.