Dynamic Models and Operating Training Simulators: Teaching students about how process plants operate

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Topics to be covered

- Design Course – what is covered
  - What we did 40 years ago
  - What we did 20 years ago
  - What do we do now
  - What we will do in the future
- Transition from design problem to performance/rating problem
  - Complex example (motivation)
  - Simpler example
  - Explanation of what happens in the plant
  - Flow driven vs. pressure driven simulations
  - Process upsets/subtle changes in plant performance
- Operator Training Systems
- Immersive Training Systems
- Conclusions

What is covered in the process control course

Design Course – what is covered

- What we did 40 years ago (1979)?
  - Designed a process at a single condition
  - Used simplified design heuristics and mostly hand calculations
  - Some detailed equipment design for a single piece of equipment (exchanger, column, etc.)
  - Process software introduced – write your own programs - batch submission/long processing times

- What we did 20 years ago (1999)?
  - Designed a base case process
  - Optimized process/sub-set of process
  - Basic equipment design and maybe some detailed equipment studies
  - Ran case studies did limited parametric/topological optimization
  - Used process simulator software (Aspen, HYSYS, Chemcad, Pro II, etc.) – icon driven
  - Considered some basic process safety

Design Course – what is covered

- What do we do now (2019)?
  - Design a base case process
  - Optimize the whole process wrt profitability criterion (e.g., NPV)
  - Use multivariable optimization (MINLP using particle swarm, genetic algorithms, etc.)
  - Consider process safety (HAZOPs, DOW EI, etc.), Relief valve sizing?,
  - Detailed design of most equipment – towers, exchangers, reactors, rotating equipment
  - Product Design? Batch Operation? etc.

<u>What will we do in the future?</u>

What will we do in the future?

Before I answer this question - I would ask what important skills do our students lack that we do not teach them and how can the tools of today and tomorrow be used to bridge that knowledge gap?

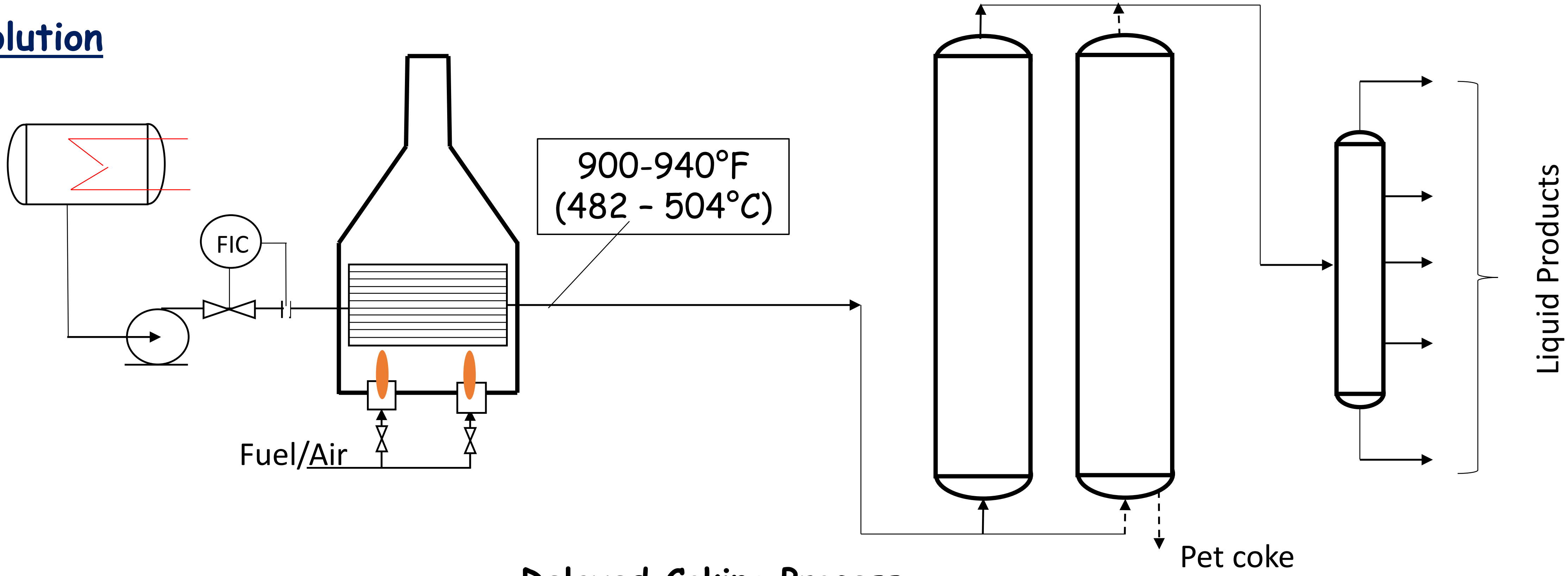
Example 1

A recently graduated process engineer starts work at a new refinery during the start-up phase. The operations superintendent asks the young engineer what is the minimum throughput at which the delayed coking unit can operate. The answer is?

- this is a scale-down problem (reverse debottlenecking).
- not easy to solve with steady state tools
- all equipment is designed, built, and in place – the design has already been completed and implemented.
- Solution depends on the controls in place in the plant
- As flow decreases, the pressure balance through the plant changes, equipment no longer operates as designed what is the limiting piece of equipment as flow ↓

very interesting, very rich, very complex problem but it is also **untaught**

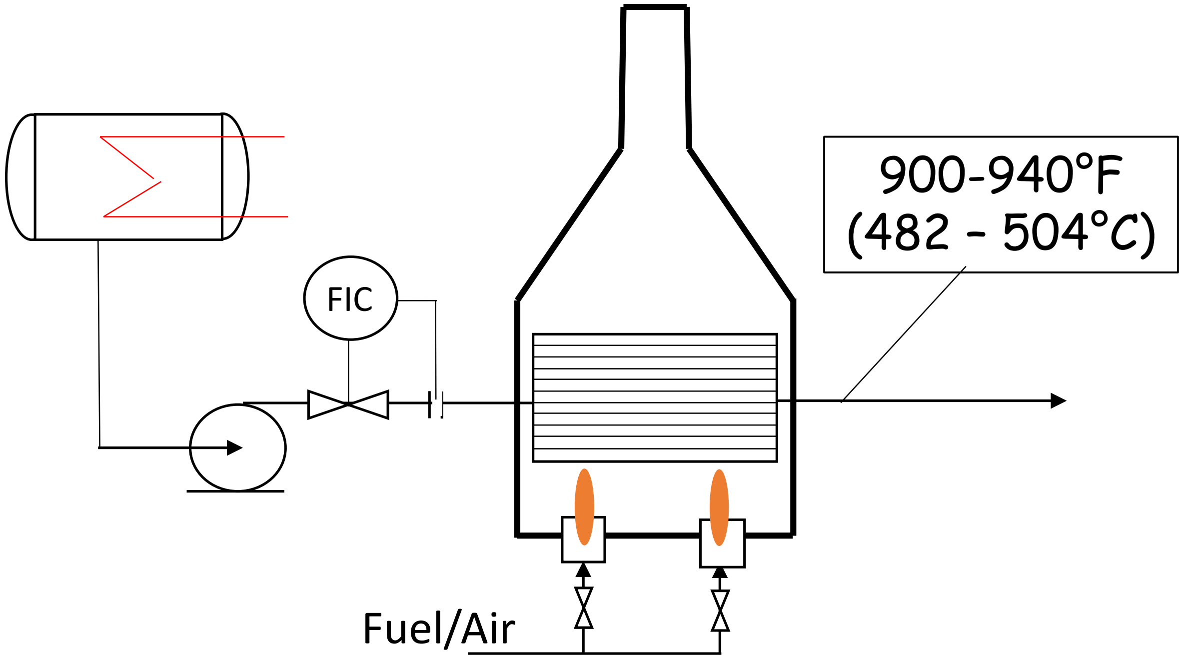
Solution



Delayed Coking Process

- The idea is to take a heavy oil stream (vacuum residuum) and heat it up in a furnace
- By controlling the velocity (6-8 ft/s) in the tubes, coking on tubes is minimized
- Heated oil stream then goes to a set of massive coking drums where majority of coking takes place and volatiles produced that are sent to a column to separate the various products.

Solution

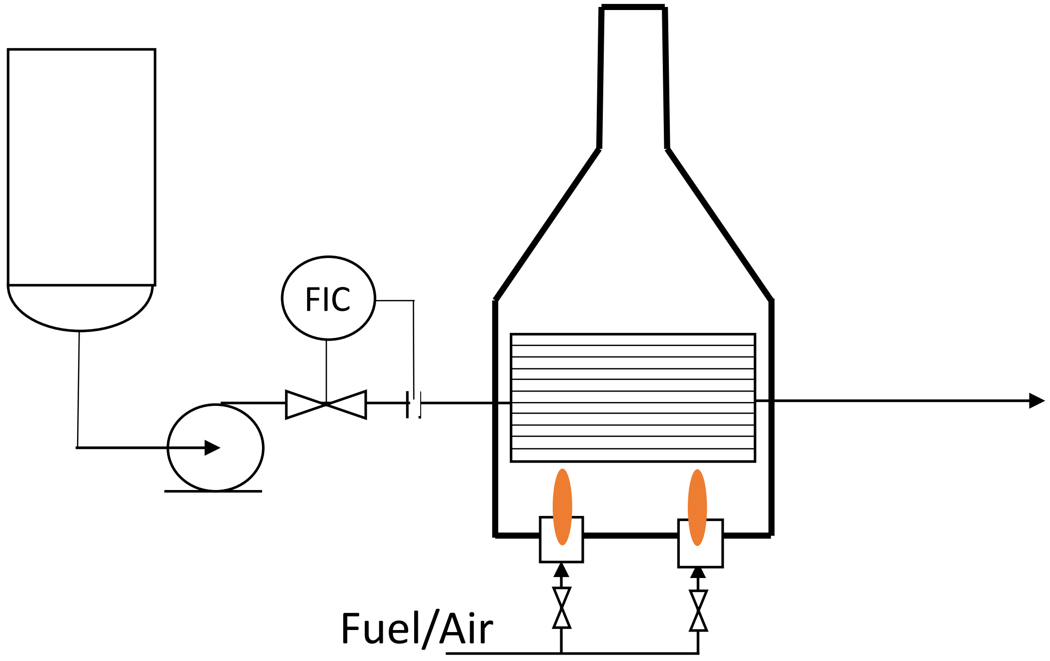


What happens during Scale-down?

Look at Coking Furnace

- As feed flow reduces, exit temp of process stream increases and residence time increases.
- Control of coking in the furnace tubes is critical – too much coke and tubes plug and process shuts down with a messy and costly clean-up.
- Some control possible by regulating fuel to burners and possibly shutting down one set of burners.
- Analysis difficult but as flow ↓ so the coking in tubes increases and becomes the limiting condition in process.

Solution



Teaching

- Looking at the whole pfd for the plant - it is not obvious that the coking furnace is the critical equipment – this takes some specific process knowledge and a lot of calculations and analysis
- Using a steady state design simulation is not very helpful for this type of problem
  - No controls
  - Flow-pressure relationship not modeled
  - Dynamics not modelled
  - Case study approach? – need a lot of additional process info that is not often included in the design case

Despite the importance of the question and richness of the problem this is not a good problem for an undergraduate to tackle or solve in a reasonable time

So look at simpler problem

Examples

2. Depropanizer – a simple process system

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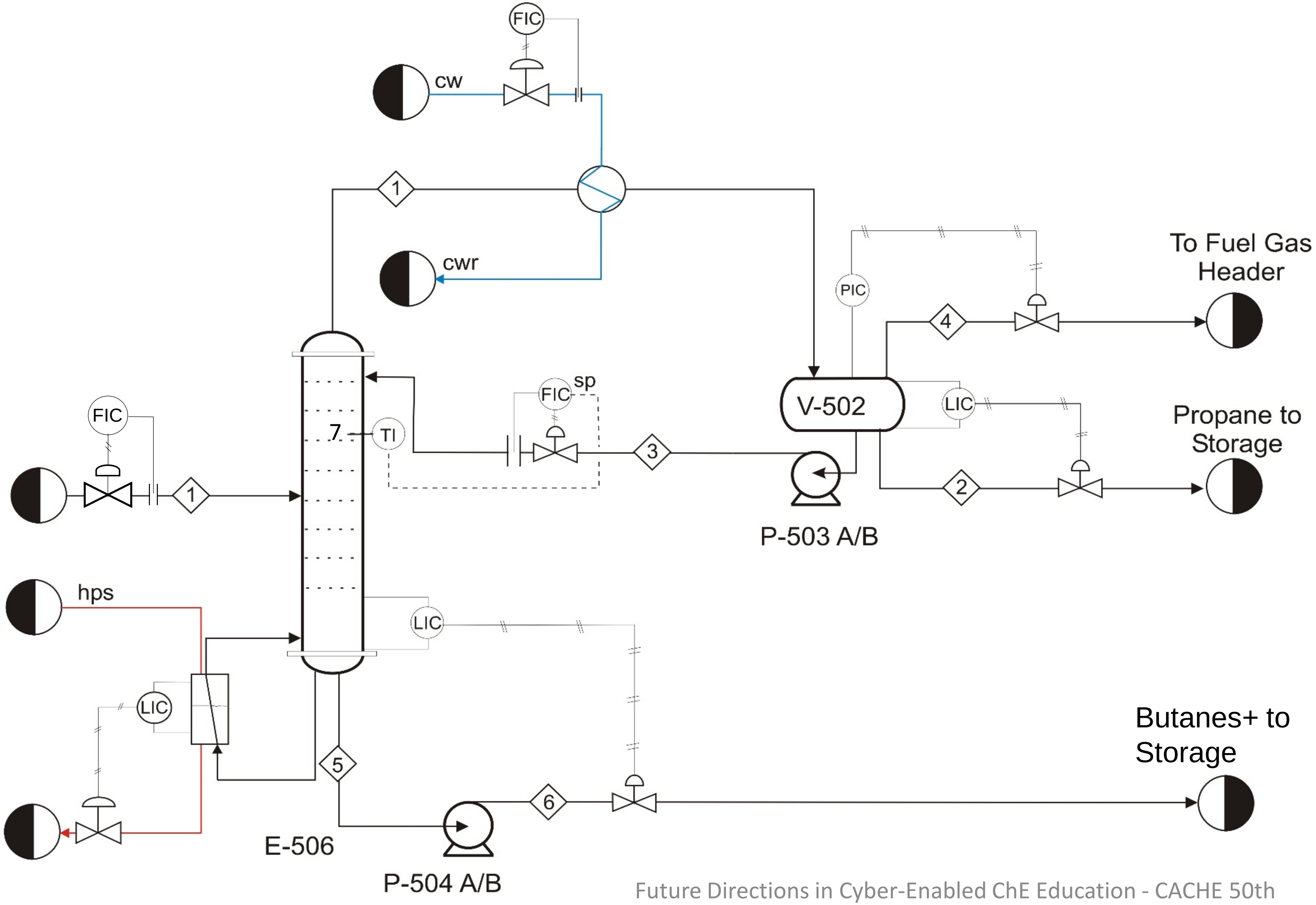
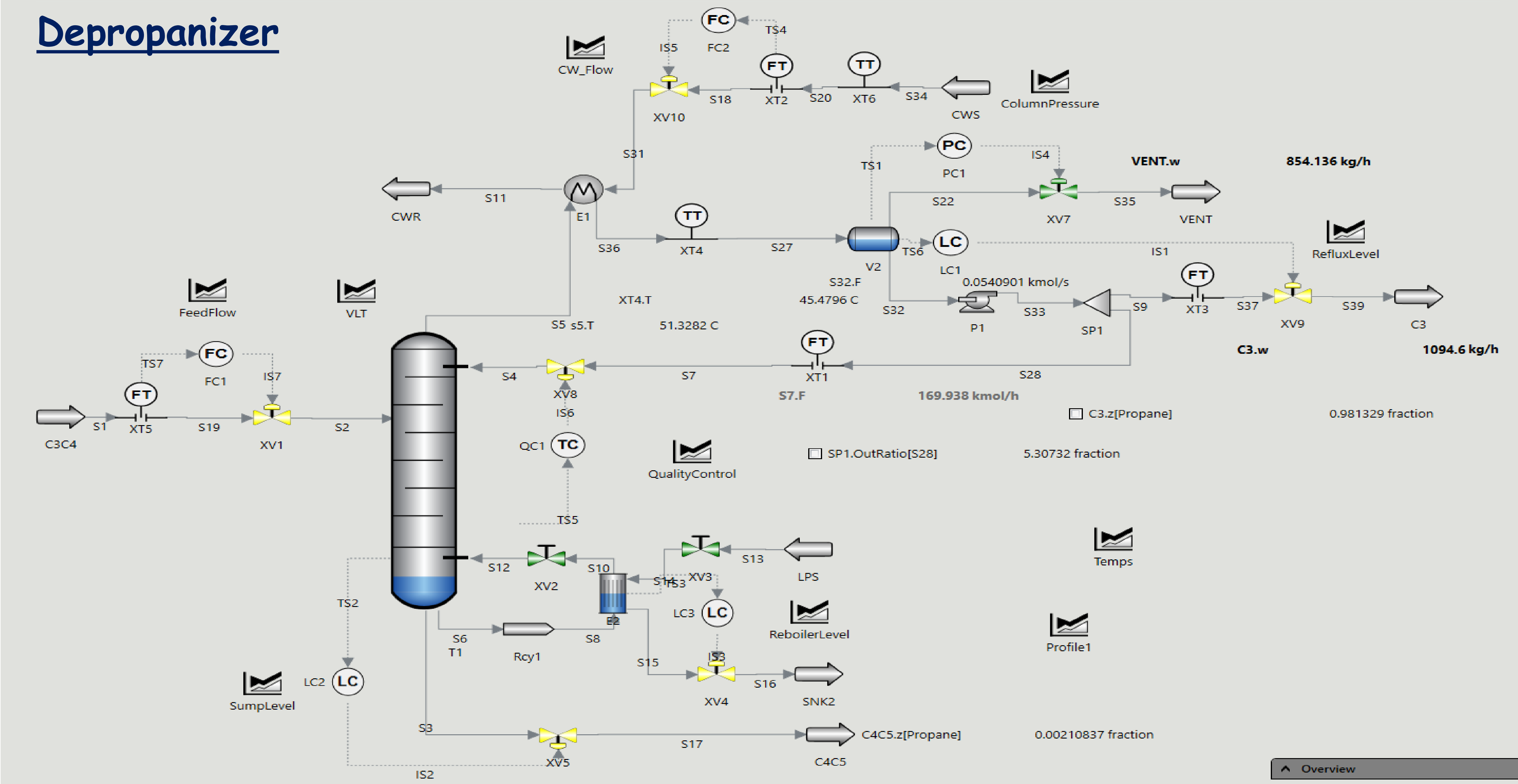


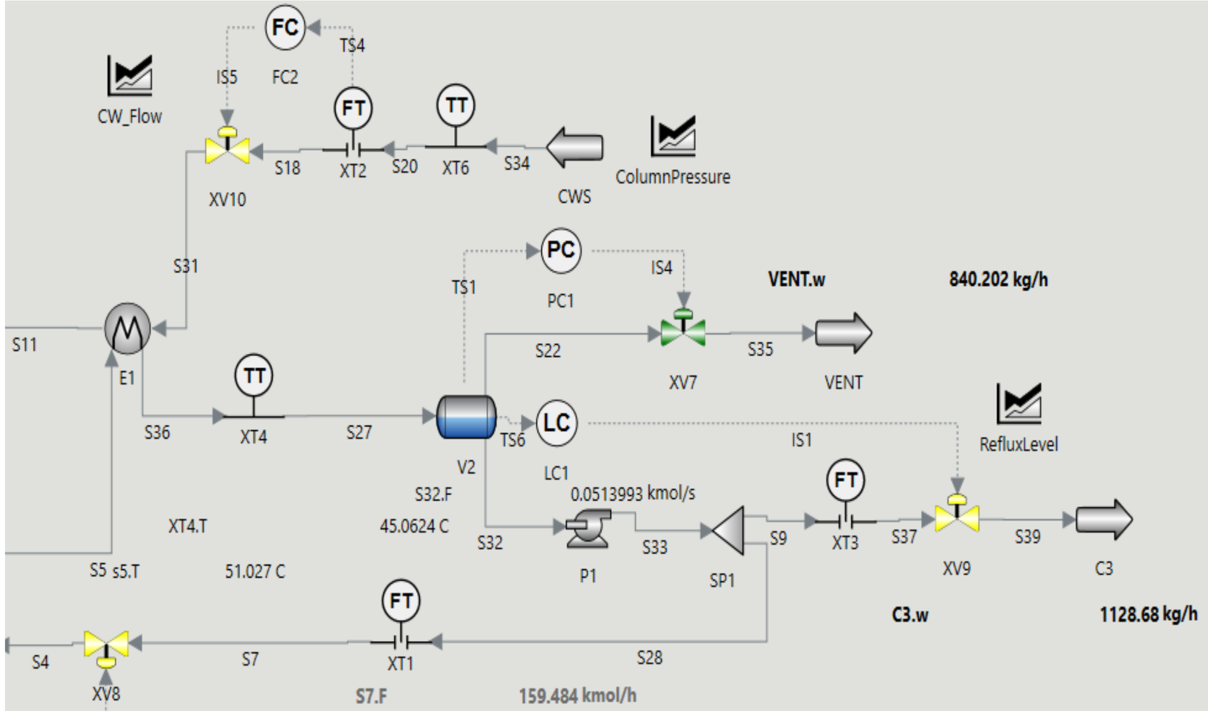
PFD – preliminary P&ID

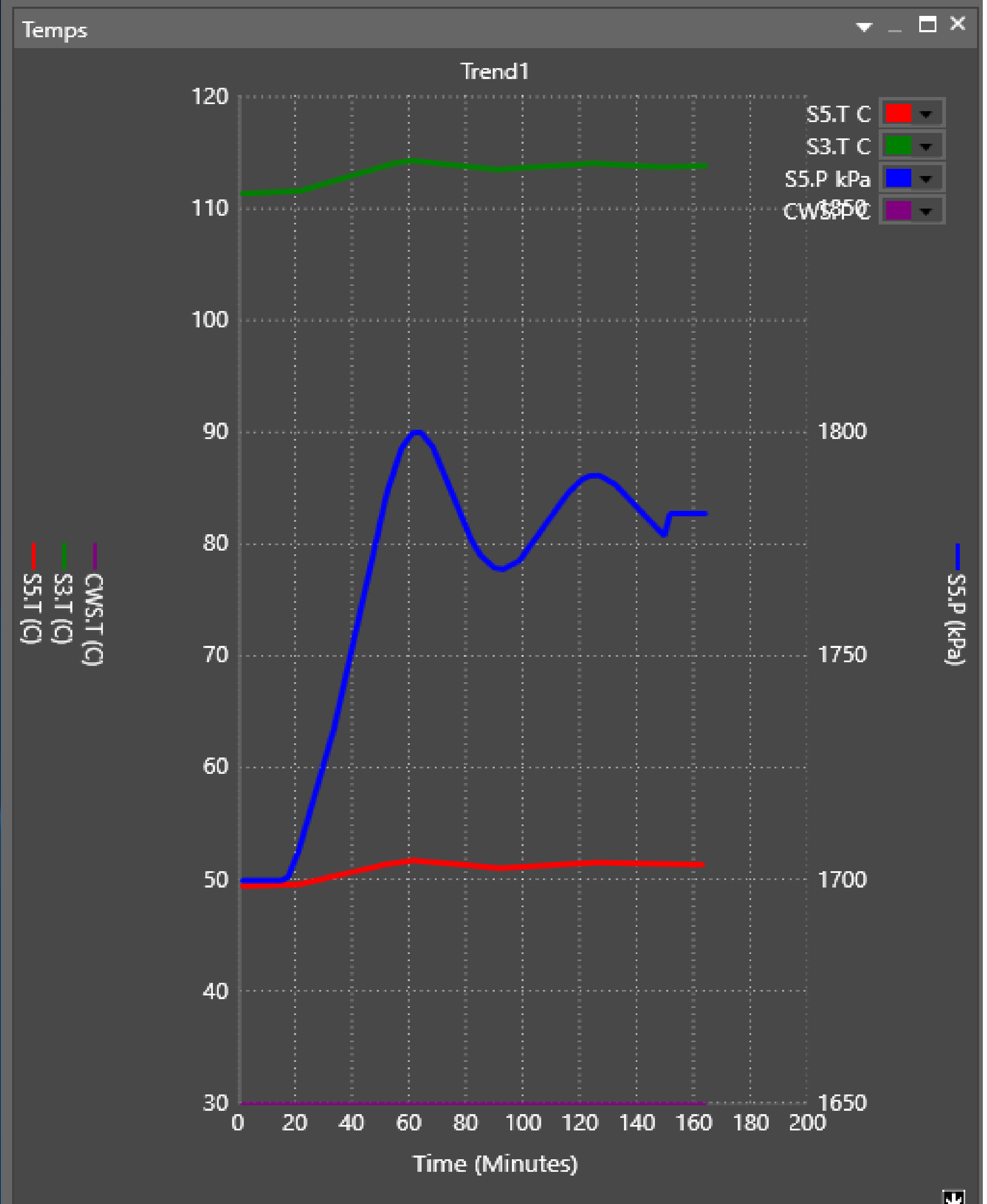
- Operations of plant become easier to follow
- Material balance control of process clearly shown
- Composition control also shown (for top product)
- Pressure control is obvious (2^{nd} question)
- Can also discuss the effect of ambient temperature via cw temperature (3^{rd} question)

Depropanizer

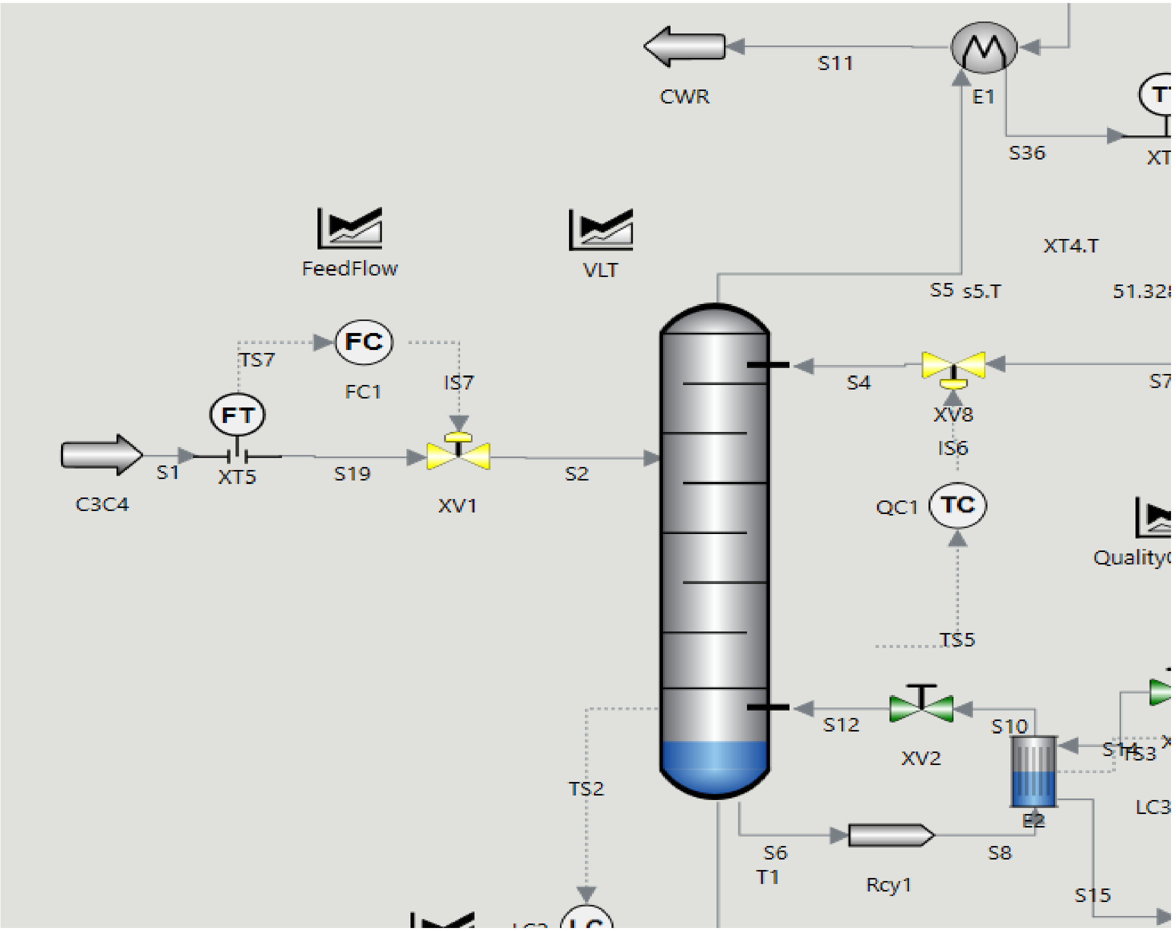


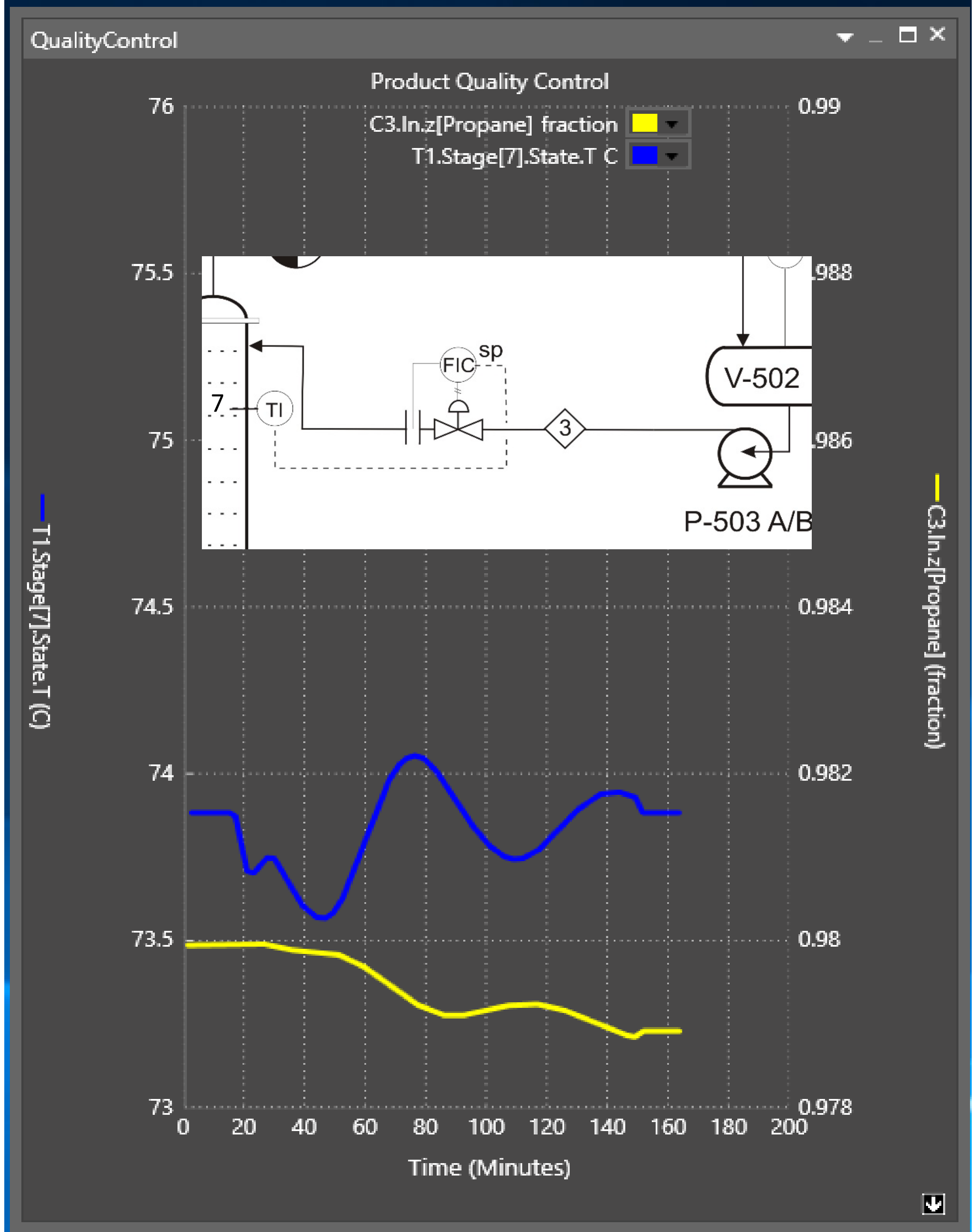
Depropanizer – increase tower pressure



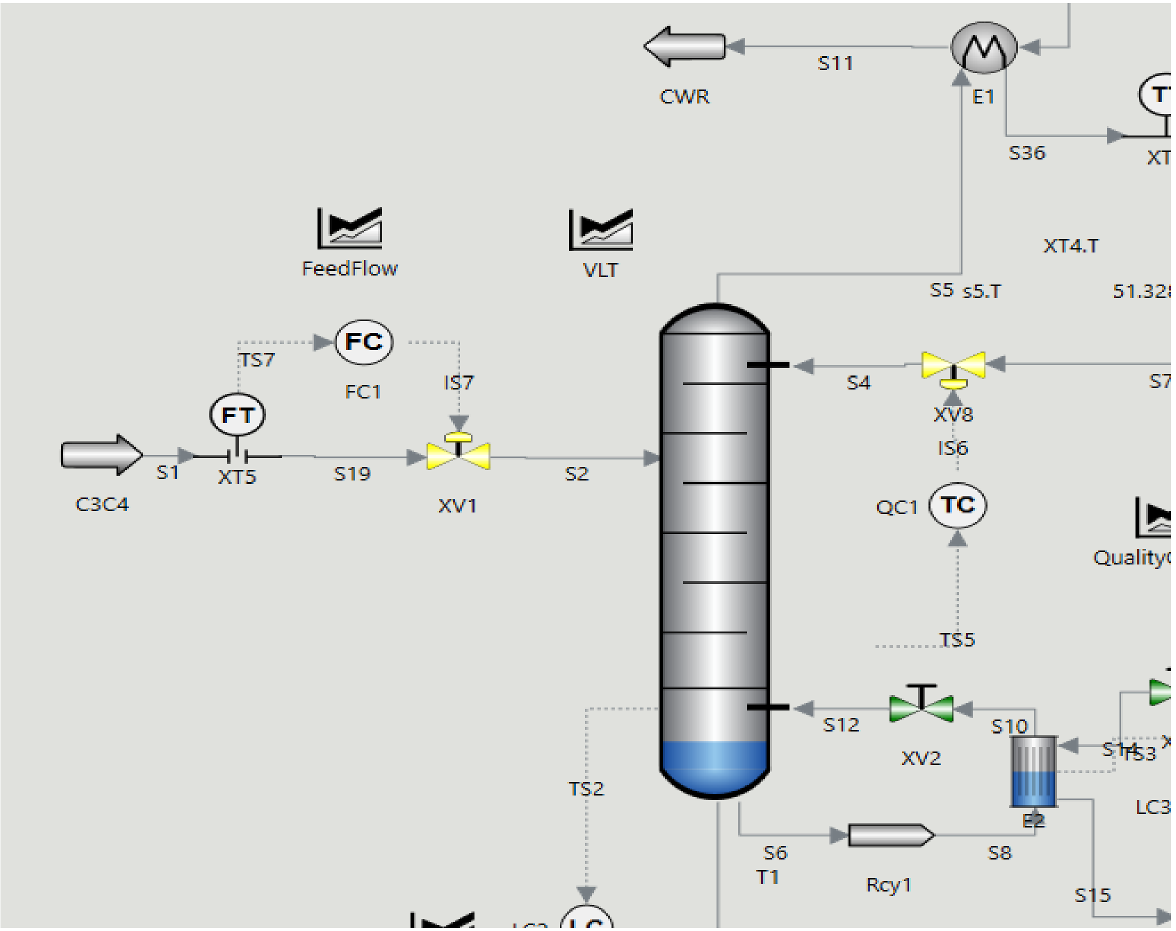


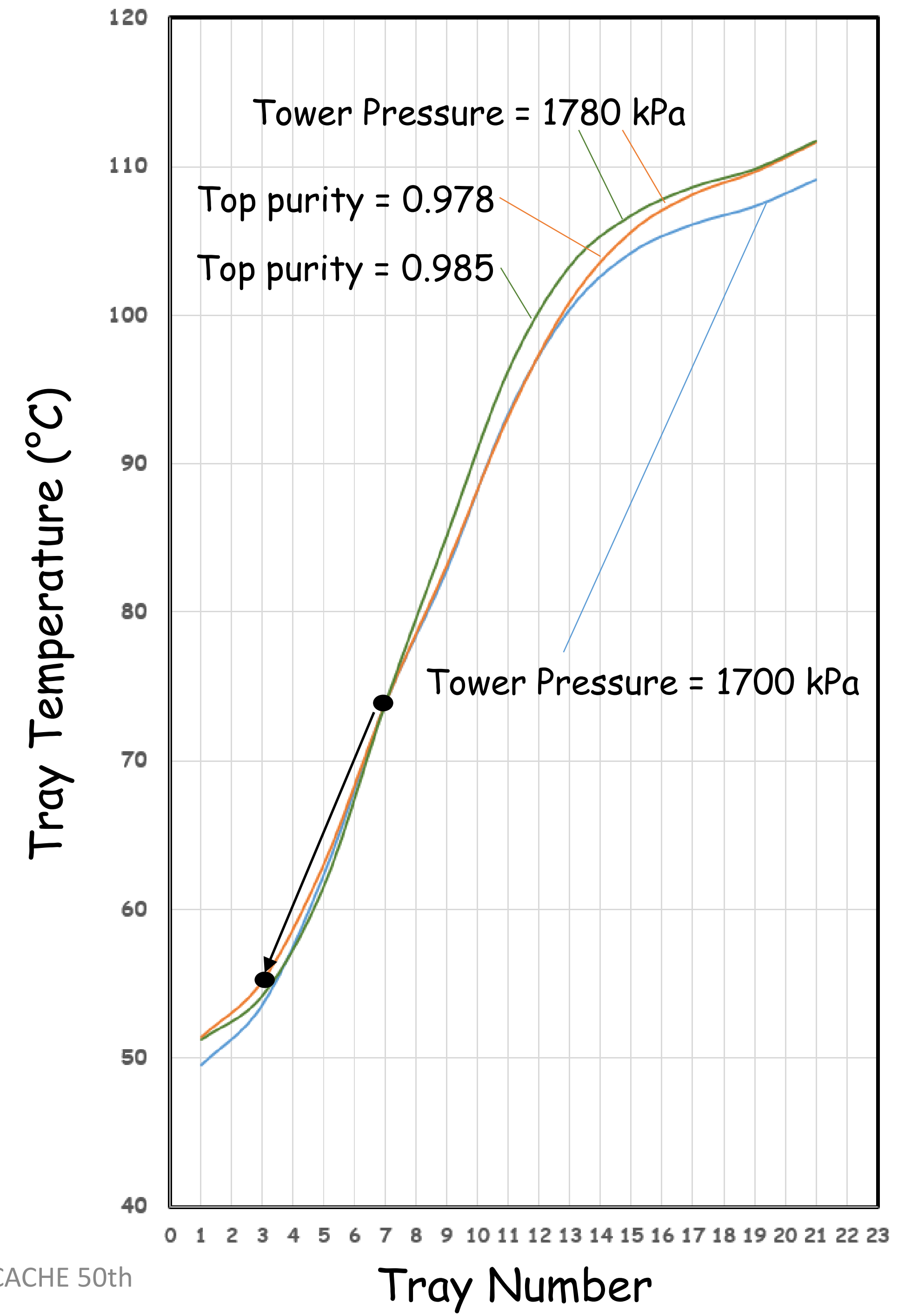
Depropanizer – increase tower pressure



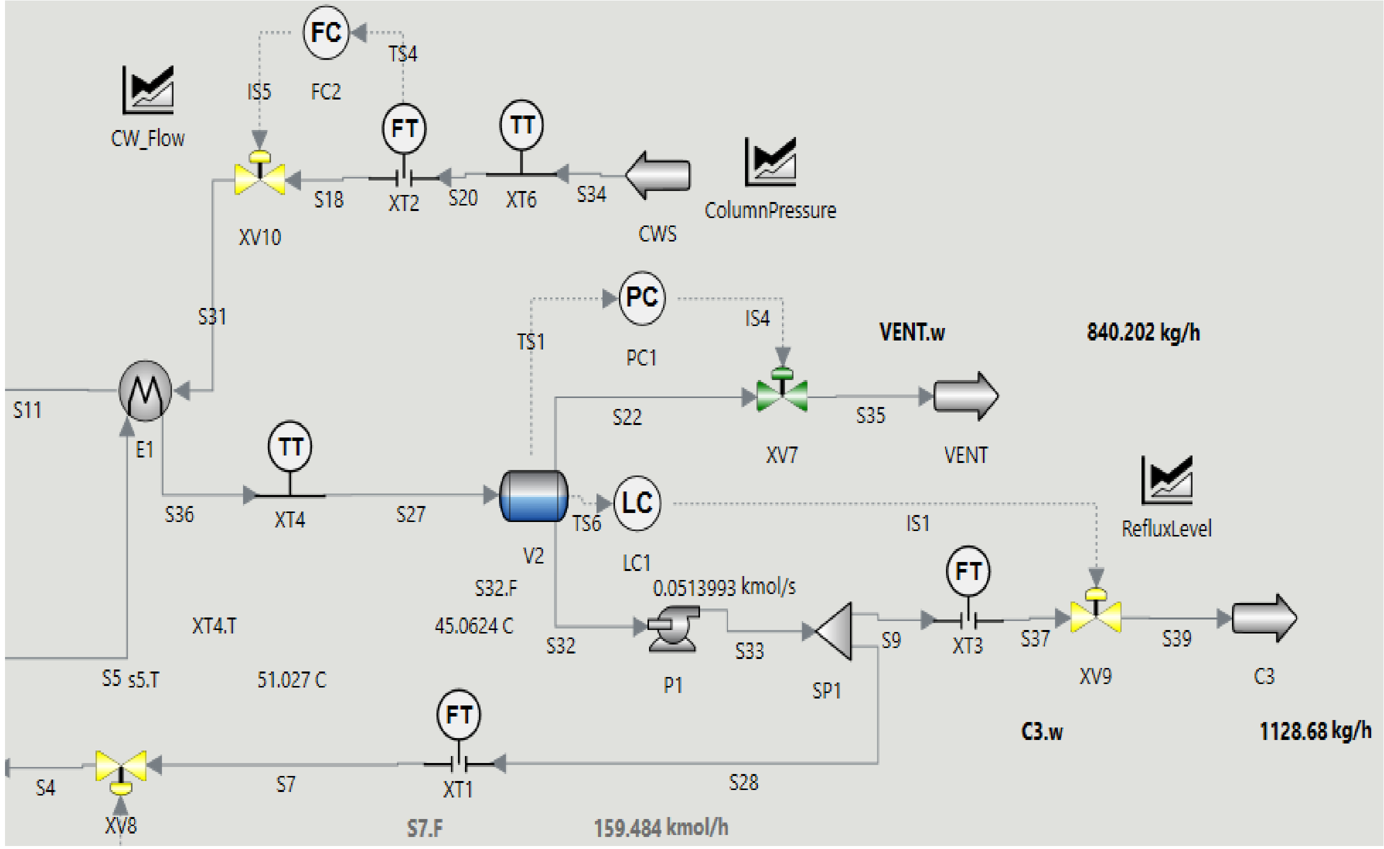


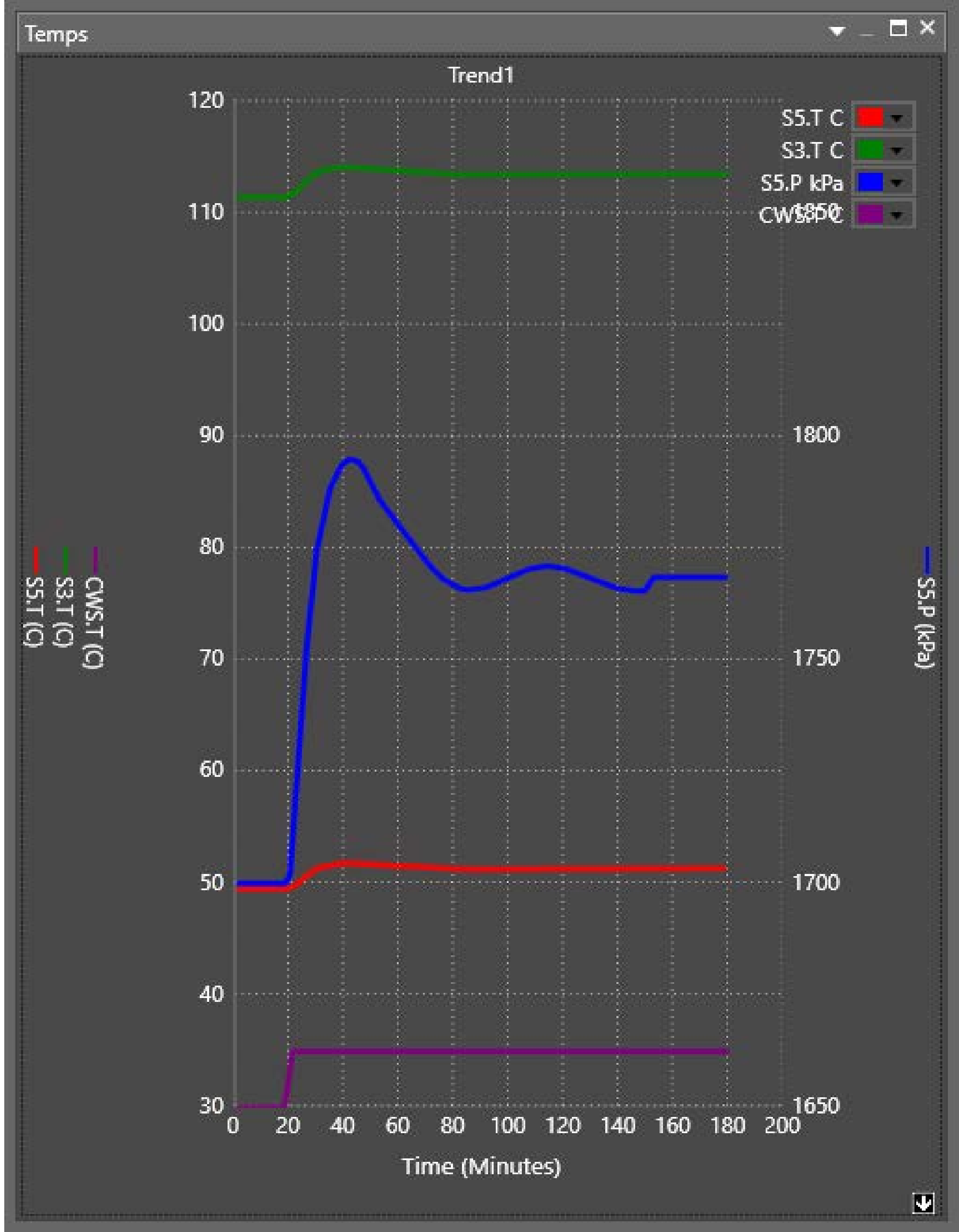
Depropanizer – product purity control for increase in tower pressure



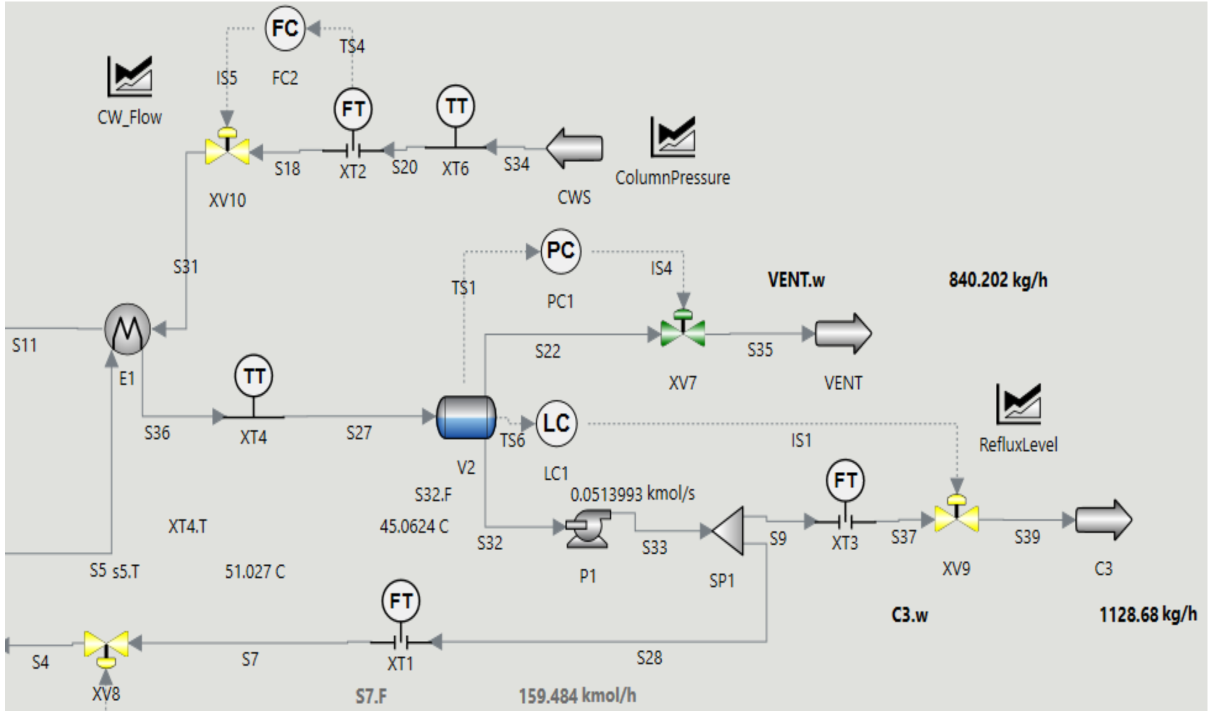


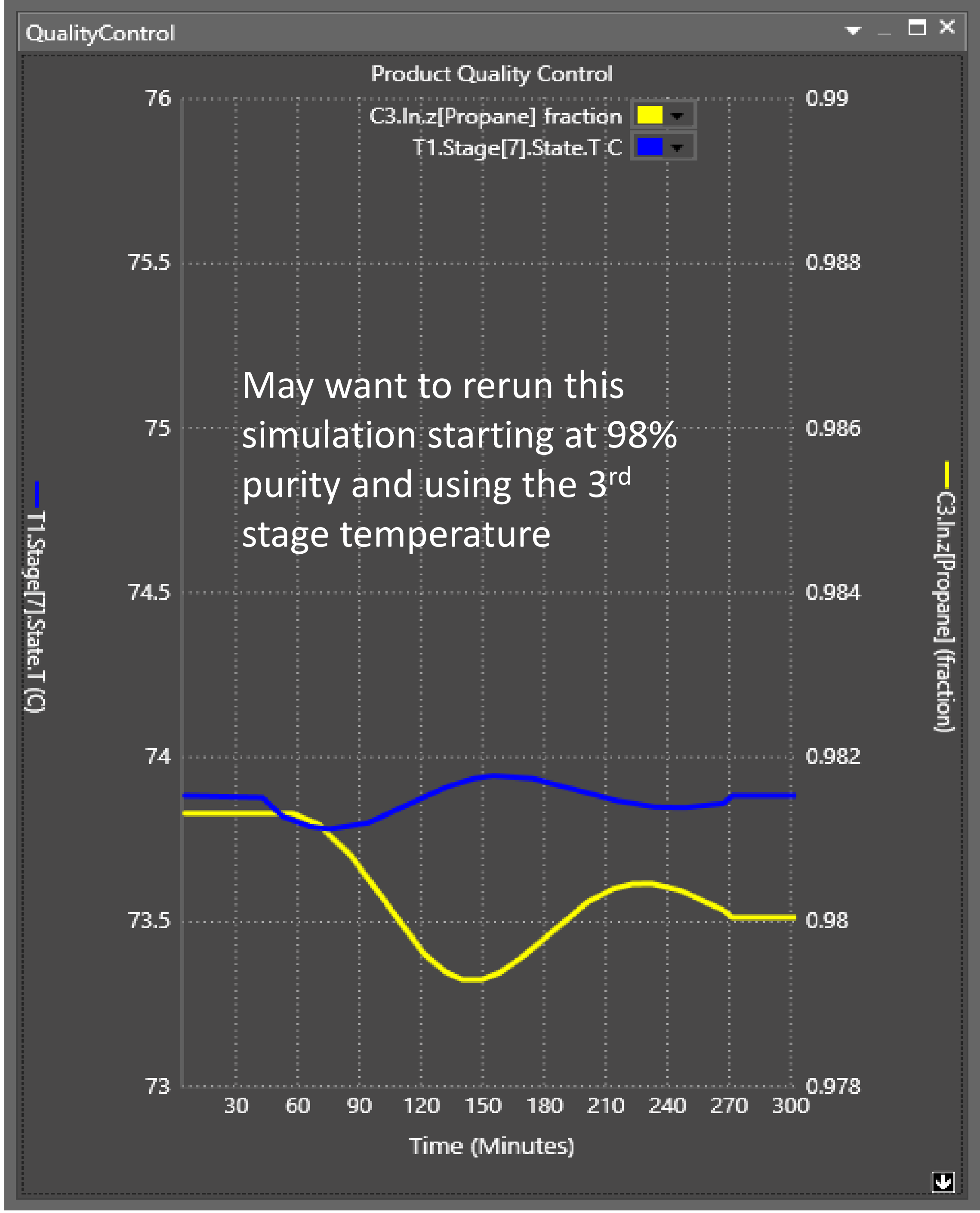
Depropanizer – Change from Winter to Summer Operation (increase in cw temperature)





Depropanizer – increase cw temperature





Again the top purity starts to drift - solution is the same as previously mentioned – move the location of the temperature to the 3rd plate/stage.

(This causes the reflux to decrease from 169.9 to 163.4 kmol/h

Conclusions So Far

- Steady state simulators used in "typical" senior or capstone design courses do a good job of providing:
  - M&E balances
  - Basic equipment design parameters – heat exchanger area, reactor volume and dimensions, column dimensions, tray characteristics, flooding factors, etc.

- Demonstrations of some typical process upsets are relatively easy to do but must use dynamic simulators as the engines for the process model

Future Trends - What tools are available to help explain Plant Operations?

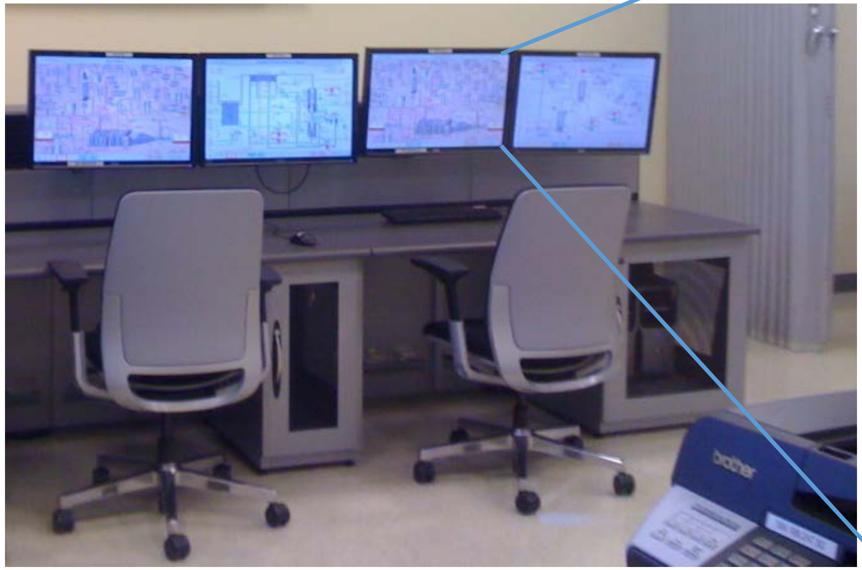
- Dynamic Simulators – many available, some more robust than others and more suitable for plant start-up problems
- Operating Training Systems (OTS)
- Immersive Training Systems (ITS)

Operator Training System (OTS)

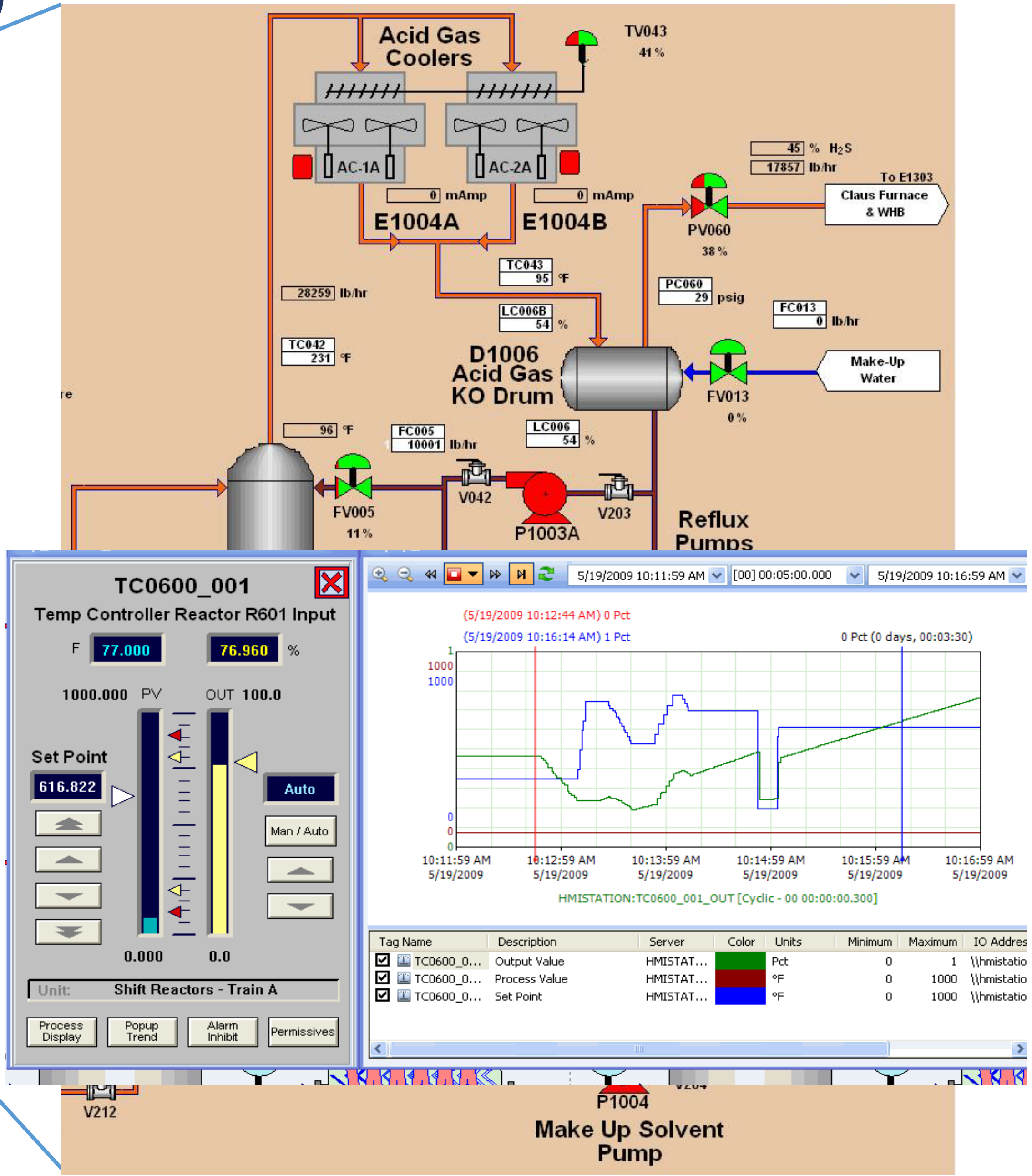
- OTS = Basically a “flight simulator” for process engineers
- Used to train operators (+ engineers + managers) on how to operate the plant under “normal” and adverse (through planned malfunctions and scenarios)
- Used to check the sequence of start-up procedures
- Dynamic model of plant drives simulation and sends continuous process data to an historian and the human machine interface (HMI)
- Operators interact with HMI (not the model *per se*)
- Instructor (instructor station) can change operating conditions, initiate scenarios, etc.

Operator Training System (OTS)

Operator Station



HMI



Instructor Station – runs dynamic model of process and provides data to update the HMI also receives input from operators to change model

Operator Training System (OTS)

Key features of HMI

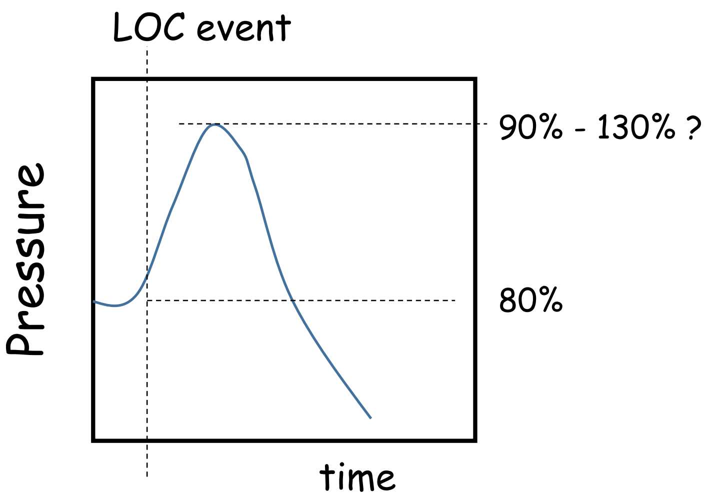
- Has look and feel of control room display
- Only instrumentation that can be manipulated by operator/engineer are shown
- Remote function (local operation in plant) valves can be manipulated on instructor station
- Start-up sequence for plant can be simulated

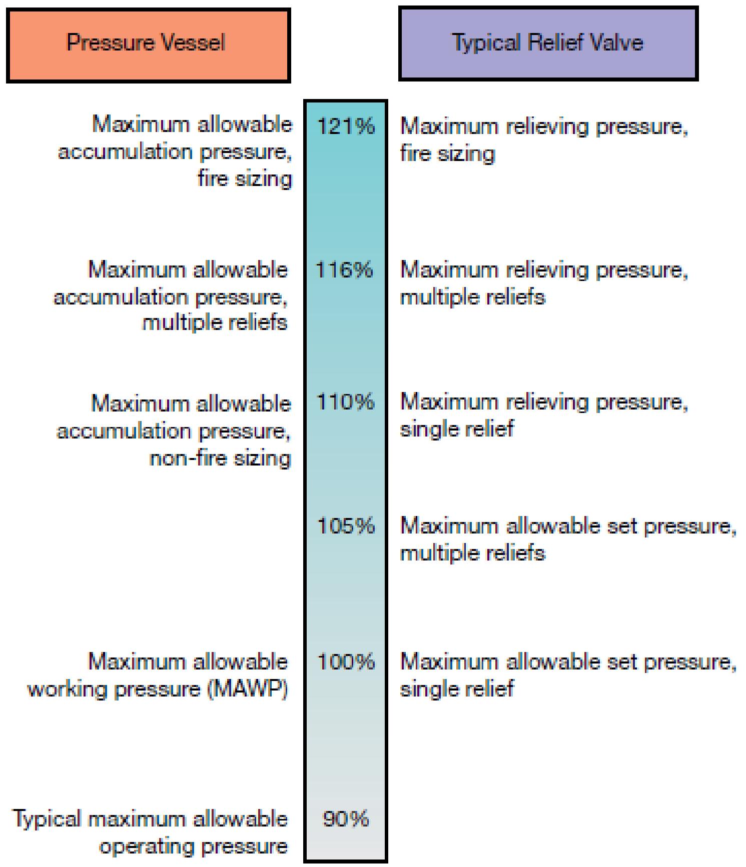
24.3.3 SRU S/U PREPARATION SEQUENCE - All steps mentioned in this sequence pertain to Area 1300				
293.	OPEN RF010 valve to the Incinerator and block the flow to the TGTU by closing the RF011 located at the outlet of the third sulfur condenser E1309.	1300-SRU-002	Remote Function	A1305_Third_Sulf_Cond FS This ensures gas flow is set to go to the incinerator and not to the hydrogenation unit.
294.	Make sure all the motor valves are in AUTO mode on both Claus Furnace 2 WHB.		Claus Furnace and Waste Heat Boiler Claus Plant S2 Converter/Condenser	MV001, MV002, MV006, MV007, MV008, MV009, MV010, MV015, MV016, MV017, MV018, MV019 & MV030
295.	Make sure all the Permissive are met to start the R1300. PRESS the R1300 STARTUP RESET Button.	1300-SRU-001	Claus Plant S2 Converter/Condenser	

Operator Training System (OTS)

Key features of HMI

- Malfunction scenarios can be programmed – e.g., drain line left open and feed tank empties causing a pump motor to trip – initiated on instructor station
  - Operator or Engineer only observes the motor tripping and has to diagnose and suggest remedy to solve the problem
- Safety scenarios can be simulated, e.g., loss of cooling events - API RP 521 and 520 – RV sizing





▲ **Figure 1.** The ASME Boiler and Pressure Vessel Code Section VIII sets out requirements for standard pressure vessels (left) and the relief valves protecting them (right) as a percentage of the maximum allowable working pressure (MAWP).

Crowl, D.A. and S. A. Tipler, Sizing Pressure-Relief Devices, CEP, Oct 2013, 68 - 76

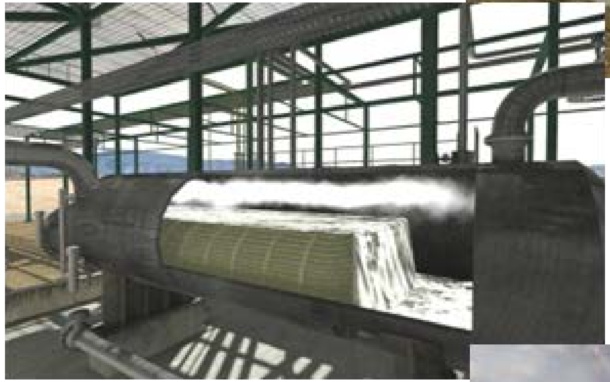
Immersive Training System (ITS)

What is an ITS

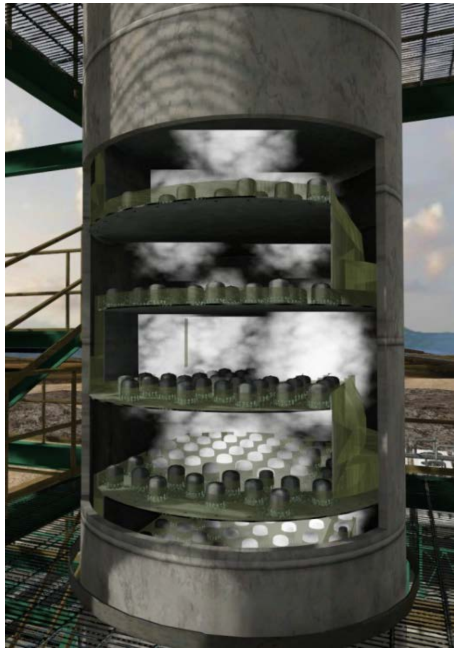
- Visual rendering of the complete plant in a virtual environment
  - Start with engineering CAD drawings – equipment and piping
  - Use actual equipment photos to wrap around objects
  - Add texturing and shadowing
  - Add animations for valve and pump operation
  - Add enhanced reality features – peel away walls of equipment and look at what is happening inside
- Navigation can be done through an Avatar (operator) or as a 3rd person viewer
- ITS can be connected to OTS to enable two-way communication between field and control room operations

Immersive Training System (ITS)

- Benefits to new generation of students
  - View plant design in familiar virtual world
  - Appreciation of 3D structure of Chemical Plants
  - Experience virtual plant tour
  - Enhanced reality and improved understanding of equipment operation
  - Experience emergency situations and respond to plant malfunctions



OTS/ITS Educational Opportunities



How can educators maximize OTS and 3D immersive capabilities in the class room?

- Unit Operations laboratory
  - Run “virtual” experiments on large-scale equipment, collect data, observe dynamics.
- In Classroom
  - Experience troubleshooting problems through programmed malfunctions
  - Appreciation for “performance” problems (design vs. performance)
  - Engage students in seemingly “dry” course work
  - Improve 3D appreciation of equipment
  - Teach safety courses interactively
  - Others…….

What about the Future?

Internet of Things

Digital Twins – virtual representation of a product, process, physical assets, process, people, systems – using real time and historic data

Data Mining/Process Mining – noisy/time-varying/non-linear/discontinuous/temporal – leads to improvements not possible until now

AI – Global data integration, speed-up product development, machine learning, better operations and "uptime",

Conclusions

- Process simulation tools continue to grow in sophistication and speed
- We produce students with remarkable aptitudes to embrace the digital world, use advanced technology, and apply a multitude of sophisticated tools to solve problems – but their appreciation for the physical world is diminishing
- Currently available tools for understanding and demonstrating process engineering principles are also abundant but are they being used to teach students?
- Plant operations is what ChEs do

Something to Think About

- As a profession we have struggled to provide hands-on ChE experience in the class room – unlike ME, EE, CE, etc.
- We have ChE Car? ChE Design Competition?
- Maybe we should have a competition based around a OTS with a set of process problems to be solved by a team?