Improving the operation of a vinyl chloride monomer (VCM) purification plant

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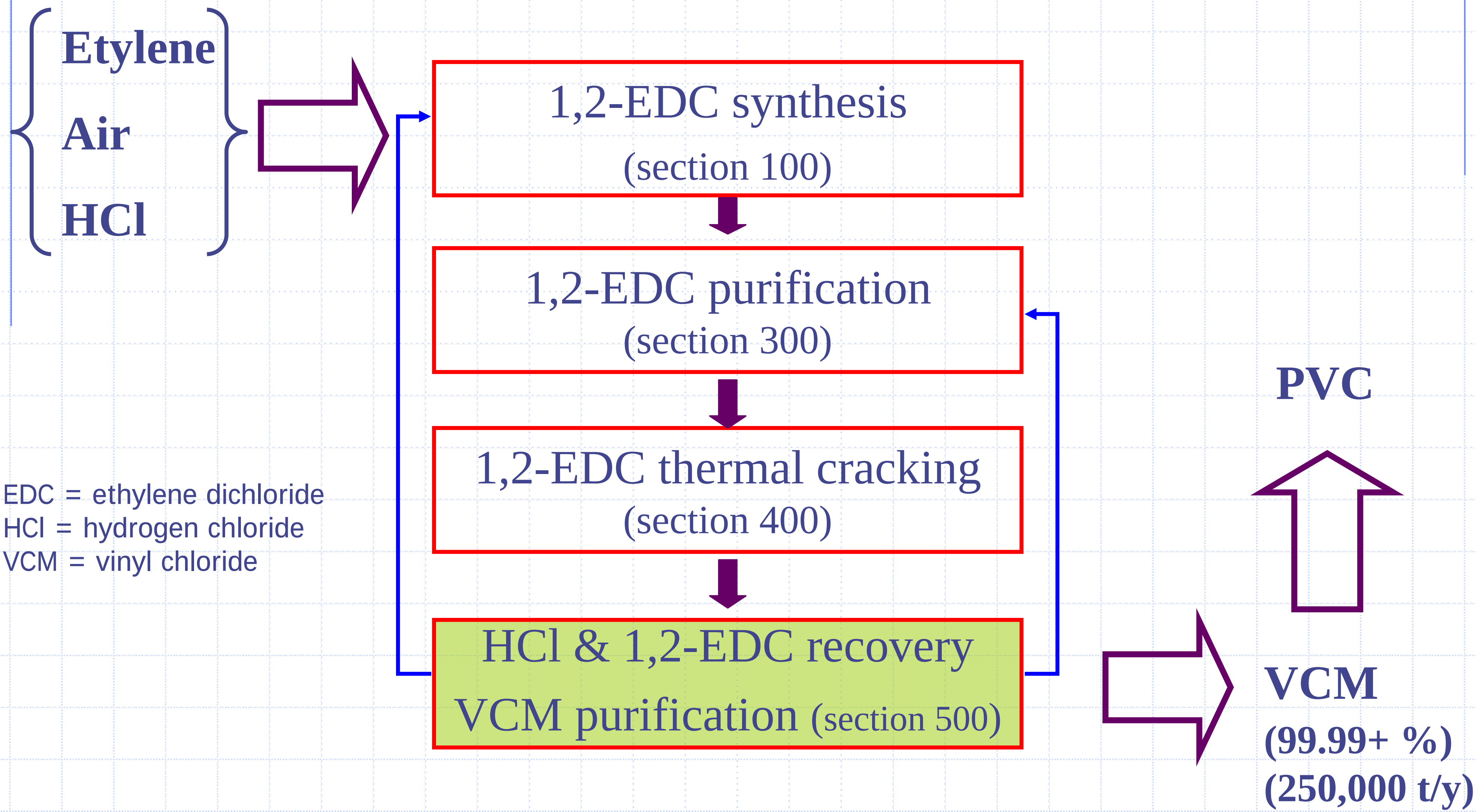
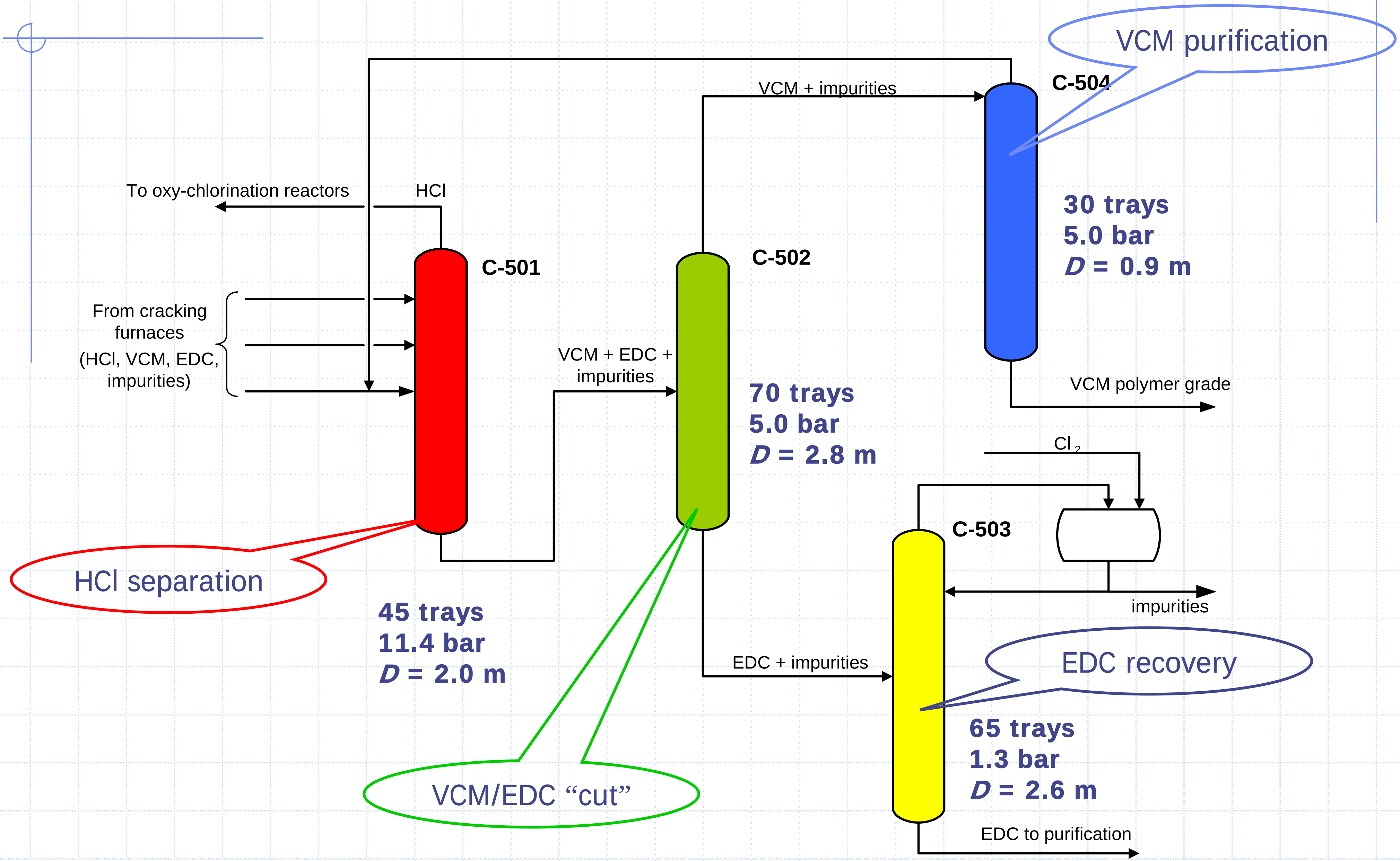
VCM production in Porto Marghera (Italy)



EDC = ethylene dichloride
HCl = hydrogen chloride
VCM = vinyl chloride

VCM purification train (section 500)



Objectives of the project

- Improving the plant understanding
- Improving the plant operating conditions
  - can throughput be increased?
- Evaluating the approach to equipment hydraulic limits
  - current operating conditions are quite different from the design ones

steady state

- Assessing the performance of the current control system
  - any improvements in the control system performance?
  - switching to minimum plant capacity currently performed manually
- Evaluating the plant dynamic response to abnormal operating conditions
  - oxy-chlorination reactors may run out of service
  - safety issues

dynamic

The simulation path

1. **System thermodynamics**
   - how many components?
   - which thermodynamic model(s)?
   - any parameters lacking?
2. **Steady state simulation**
   - set up the process flow diagram (PFD)
   - validate the steady state model
3. **Improving plant performance at steady state**
   - evaluate equipment loads
   - change operating conditions (sensitivity studies)
   - change PFD configuration
4. **Dynamic simulation**
   - which level of detail on the equipment modeling?
   - validate the dynamic model
5. **Control system performance**
   - control configurations OK?
   - tunings OK?
   - any improvements possible? devise alternative control configurations
6. **Safety issues**
   - handling abnormal events
   - hazard analysis

Components in the feed

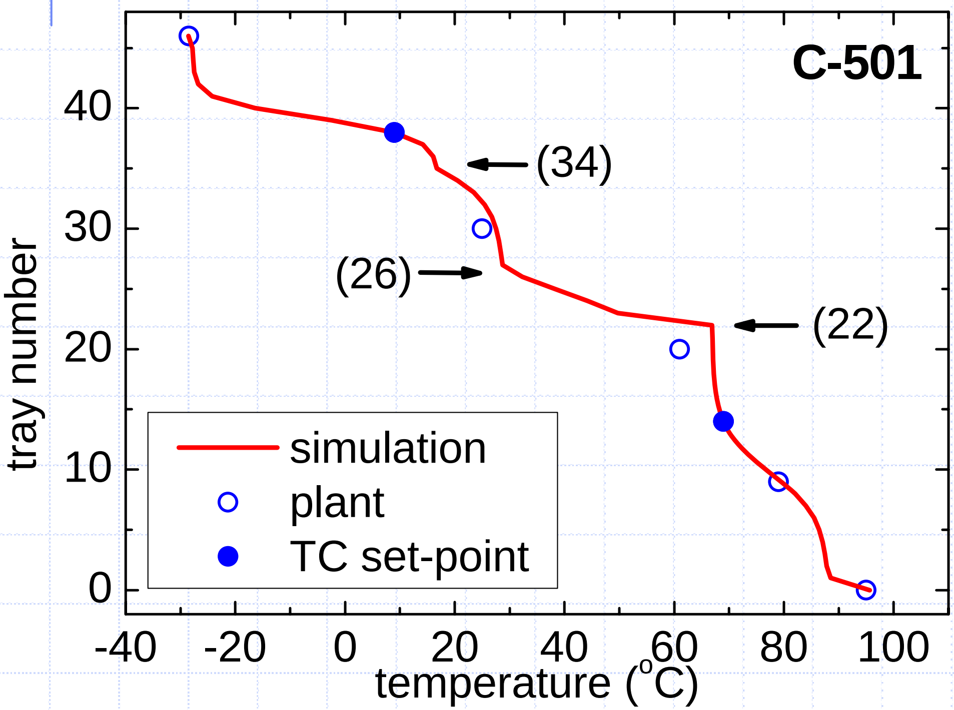
- Keep the number of components as low as possible (but not **too** low)
- *Always discuss your choice with the plant engineers*
- Lump components together whenever possible
- Include trace components (they are useful for model validation)
  - discuss with plant personnel

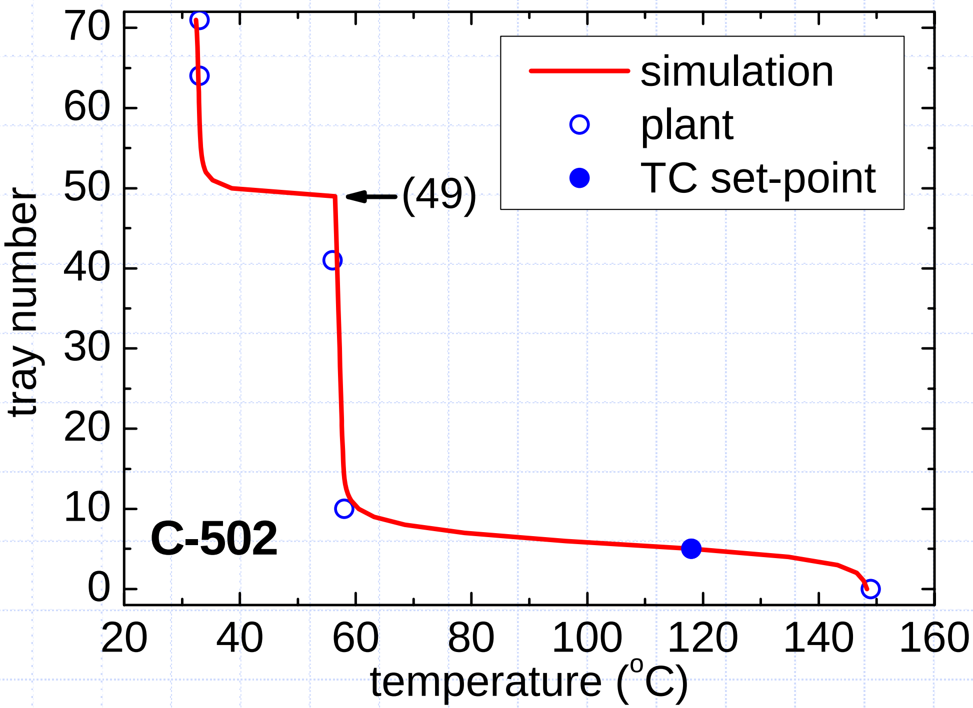
Component
hydrogen chloride
vinyl chloride
ethylene 1,1-dichloride
ethylene 1,2-dichloride
1,3 butadiene
benzene
ethyl chloride
methyl chloride
acetylene
tetrachloroethylene
trichloroethylene
carbon tetrachloride

Model validation (steady state) 1/2

- *Several checks can be carried out, depending on the measurements available from the plant*

1. **Temperature profiles** inside the columns (where the ΔT between bottom and top is large enough)





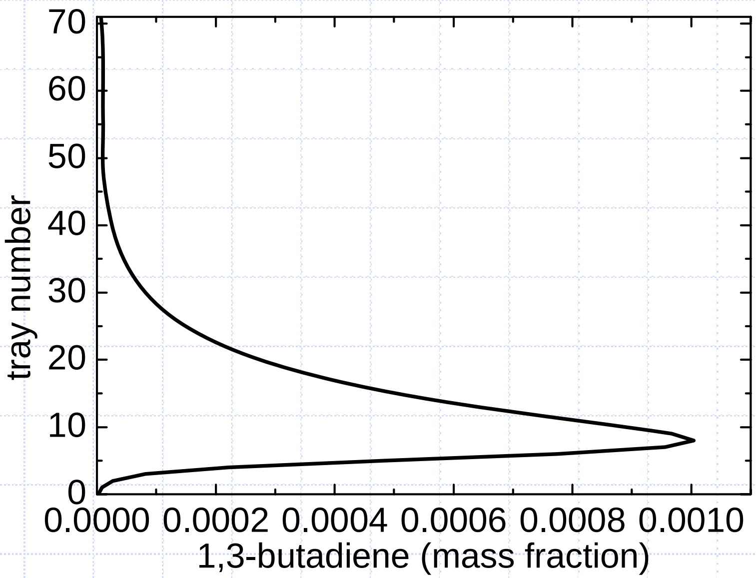
Model validation (steady state) 2/2

2. Reboiler / condenser duties

- this is and indirect verification of the closure of energy balances
- taking into account measurement inaccuracies, a match within ~10% is enough

3. Reflux rates

4. Trace components



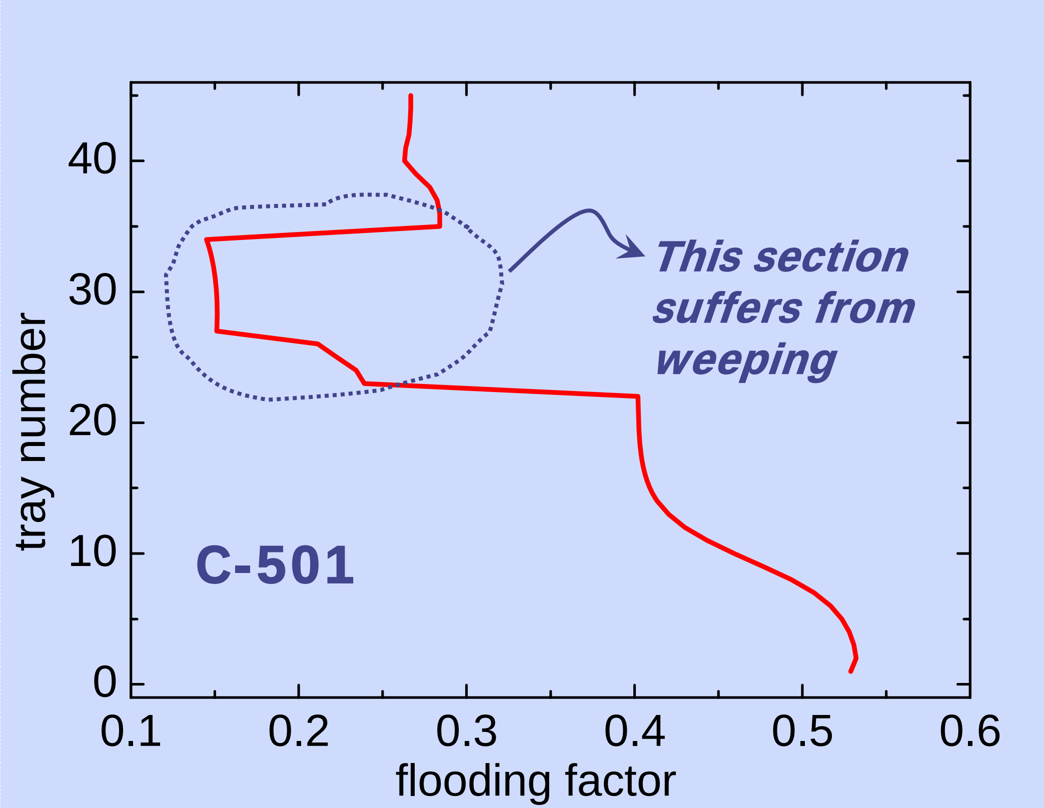
<u>Interaction with the plant operators is of paramount importance</u>

They can:

- guide you through the analysis of process data sheets
- highlight which measurements can be trusted and which cannot
- show you their ‘tricks’ to make the plant perform better

Improving the plant performance 1/3

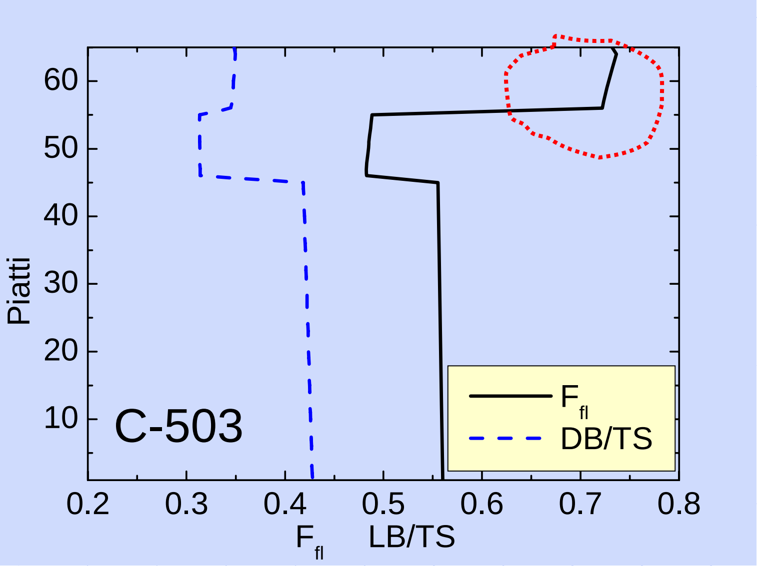
- **How far are the columns being operated from flooding or weeping?**
  - the plant is run at operating conditions quite different from the original design ones



- The separation performance is severely reduced in the presence of tray weeping
- ***Solution***: lock some valves to increase the vapor velocity

Improving the plant performance 2/3

- **More on flooding / weeping**
  - top C-503 trays may suffer from flooding is the load is increased
  - ***Solution***: change top trays (originally they were sieve trays)



- **Can the operating conditions be changed to save energy?**
  - sensitivity study: C-502 reflux ratio can be slightly decreased (from 0.5 to 0.4)
  - no changes in the separation performance (number of trays is large enough)
  - energy consumption was reduce by an amount equivalent to a **saving of ~50,000 €/year** (year 2000; ~63,000 €/y in 2008)

Improving the plant performance 3/3

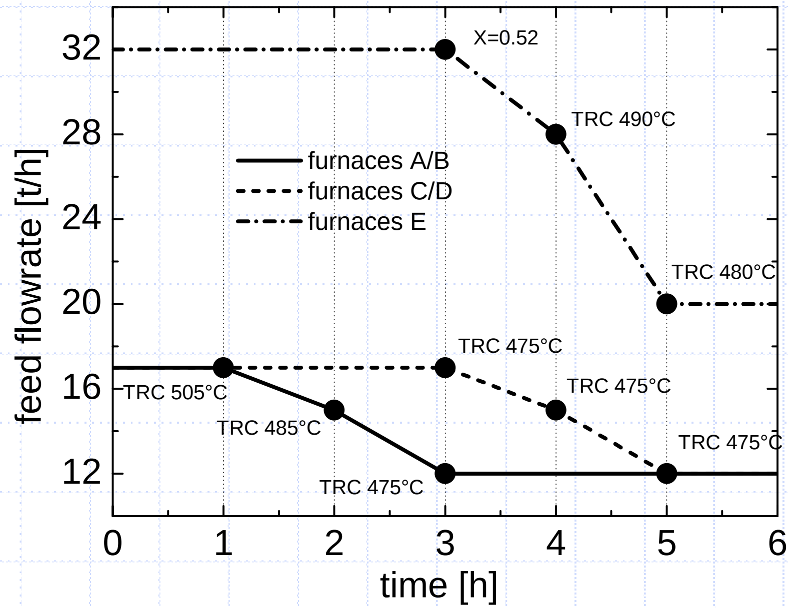
- Other results from the steady state simulation
  - the **throughput can be increased**: from 250,000 $tons_{VCM}$/year to 291,000 $tons_{VMC}$/year (provided that the top C-503 trays are changed)
  - the feed tray of C-503 should be shifted down
    - EDC **purity increases** and **energy consumption decreases**

Dynamic simulation

- **The basis is the steady state PFD**; however, a number of parameters need to be specified to run the model in dynamic mode
  - actual size of columns and ancillary equipment
  - hold-ups (they affect the dynamic response **very markedly**)
- **A balance must be struck** between the level of detail included in the model and the model speed of running
  - too detailed a model may be impractical or even impossible to run in a reasonable time at the plant level
  - pressure losses due to pipe friction can be omitted in a first instance, as well as pump characteristic equations
  - pipe holdups can be neglected (if reaction does not occur)
- The **specification of the tuning constants** of the control loops is critical
  - use the same values as in the plant but double check the unit dimensions of gains, integral times and derivative times
  - errors may arise from incorrect evaluation of transmitter spans and valve gains
  - check valve actuation (direct or reverse acting)

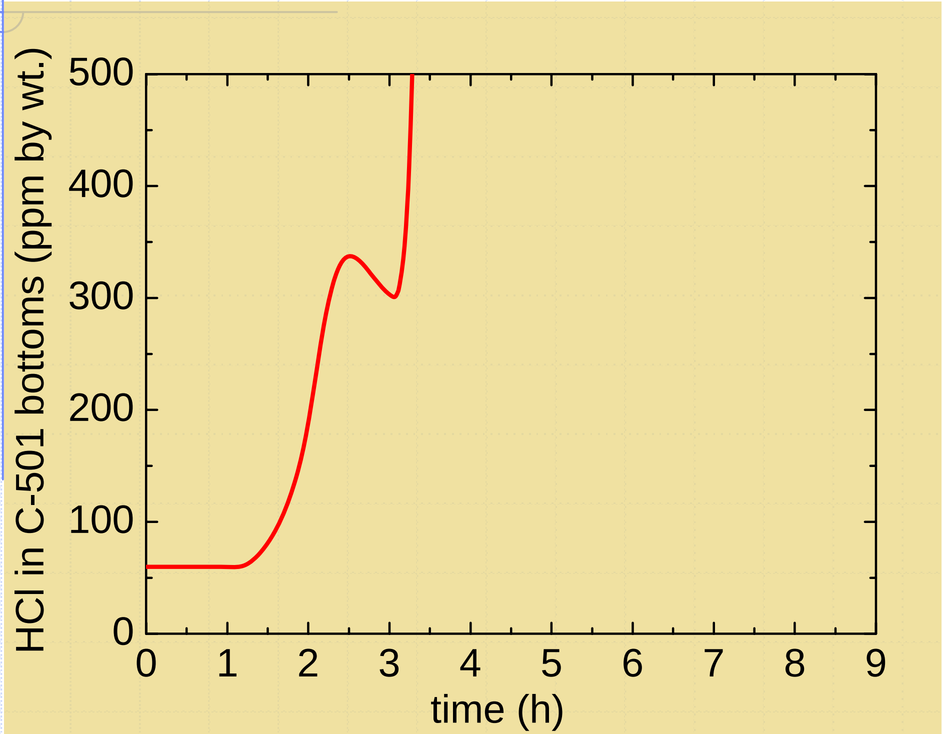
Handling abnormal events

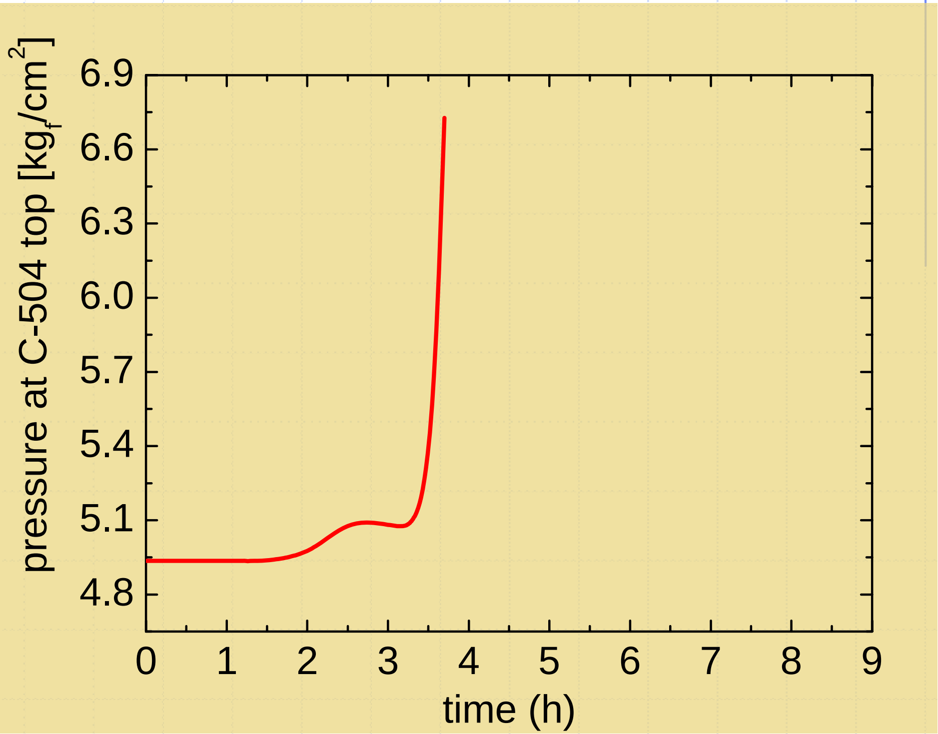
- **Plant capacity is sometimes switched to the minimum** (e.g. for maintenance; strikes)
  - the feed to the cracking furnaces and the conversion through the furnaces change dramatically
- The switching was carried out **manually**, because the control system "**doesn't work**" in automatic mode



What happens?

1. Switching to minimum capacity



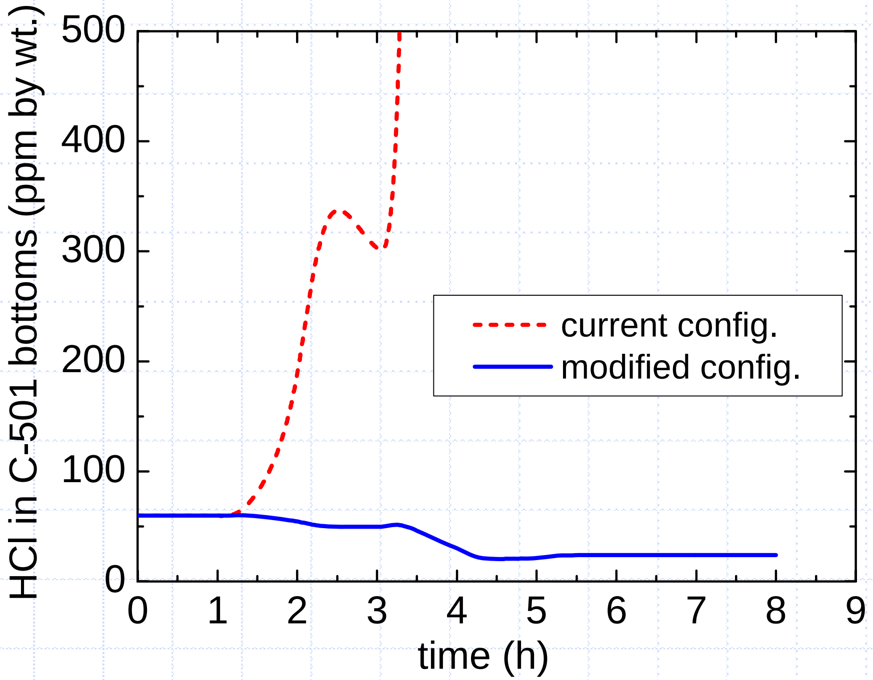


- The HCl losses from the bottom of C-501 markedly increase
- The HCl "travels" along the train, and eventually reaches C-504, and pressure increases in this column
  - after 4 hours the **pressure is unacceptably high**, and the **VCM product is contaminated**

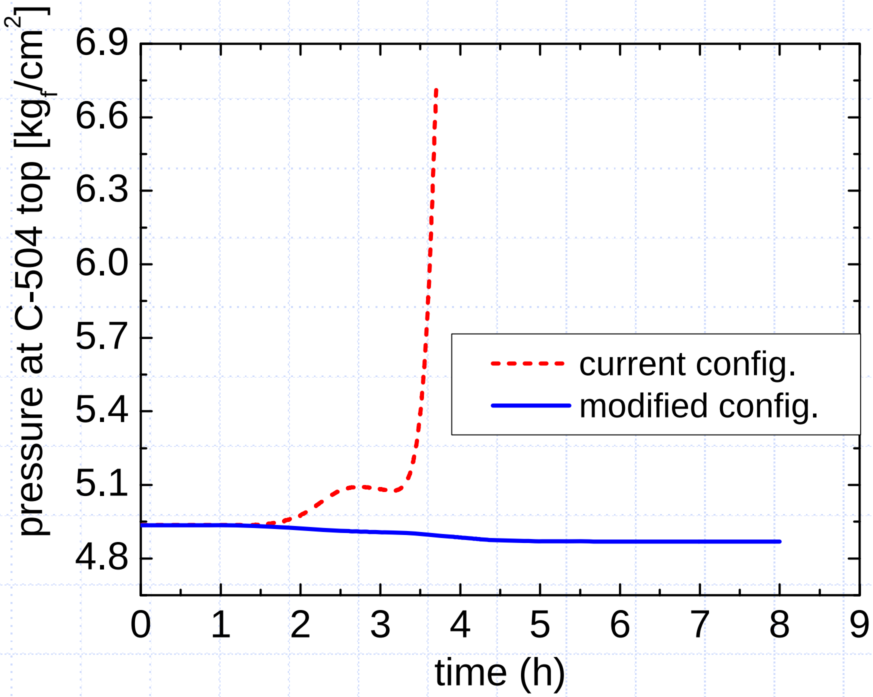
Results after dynamic simulation

(1. Switching to minimum plant capacity)

HCl losses from C-501



C-504 pressure



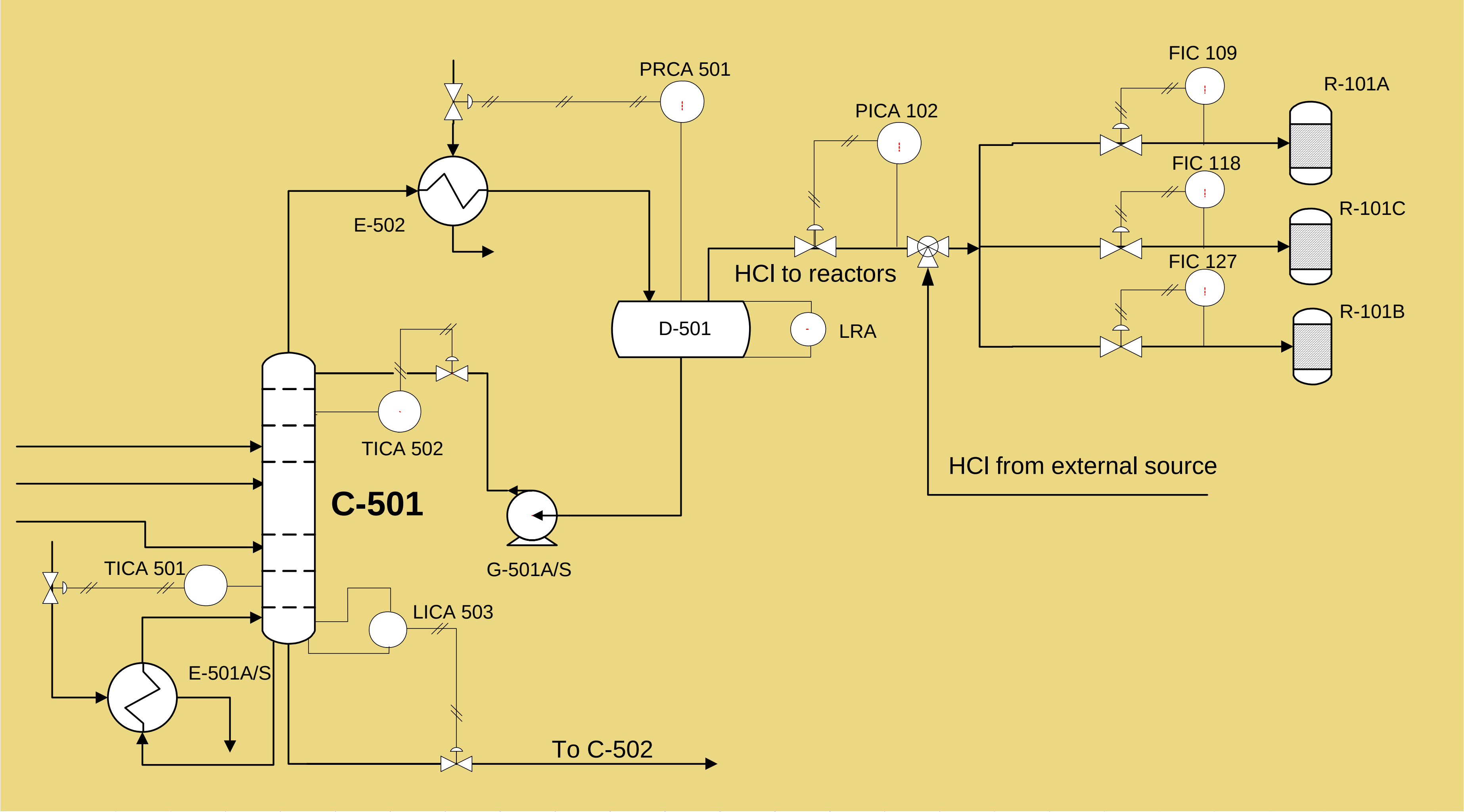
- The new control configuration is able to:
  - **automate the switchover** to minimum plant capacity
  - **keep the process production within specification** at nominal plant capacity too

2. Hazard analysis

- **Plant data cannot be obtained by pushing the plant close to unsafe operating conditions!**
- **Dynamic simulation** can be exploited to:
  - verify how the plant responds to “heavy” disturbances
  - assess (and possibly improve) the effectiveness of installed safety procedures
  - estimate the plant characteristic response times to foresee the time available for intervention before a breakdown appears
- A load reduction/breakdown on the downstream oxy-chlorination reactors was simulated
  - how does the control systems work? which is the rationale?
  - how effective is the control system?
  - how safe is the plant?

Back to the control system

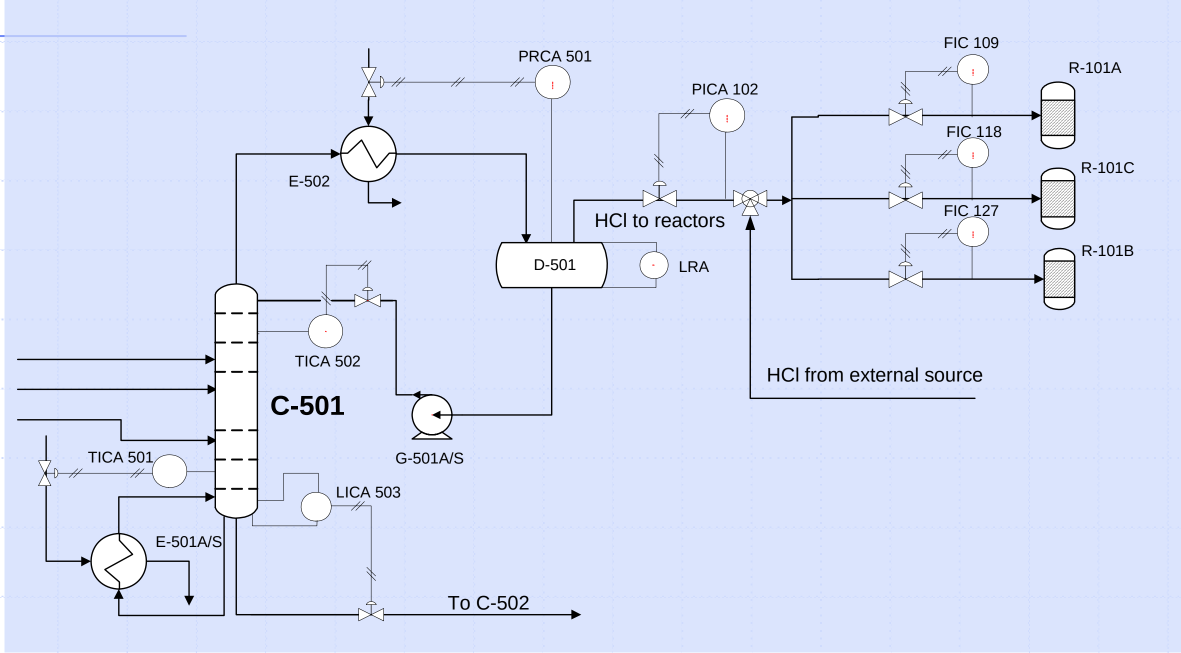
(2. Hazard analysis)



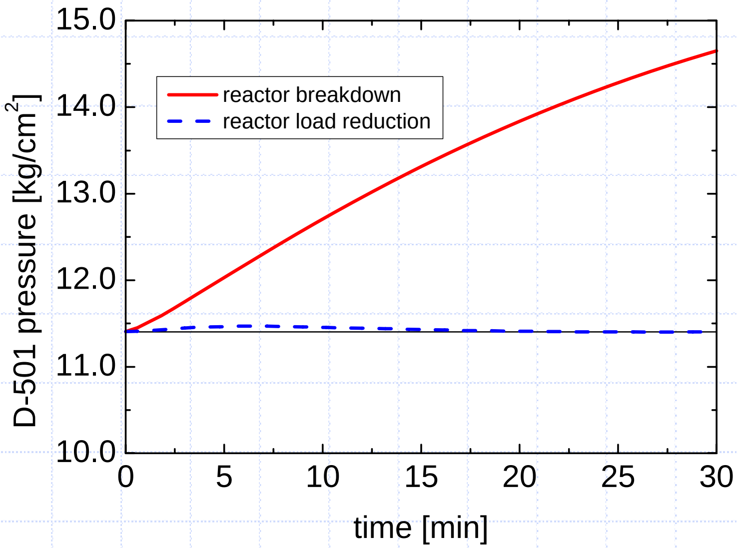
What happens if R-101A breaks down?

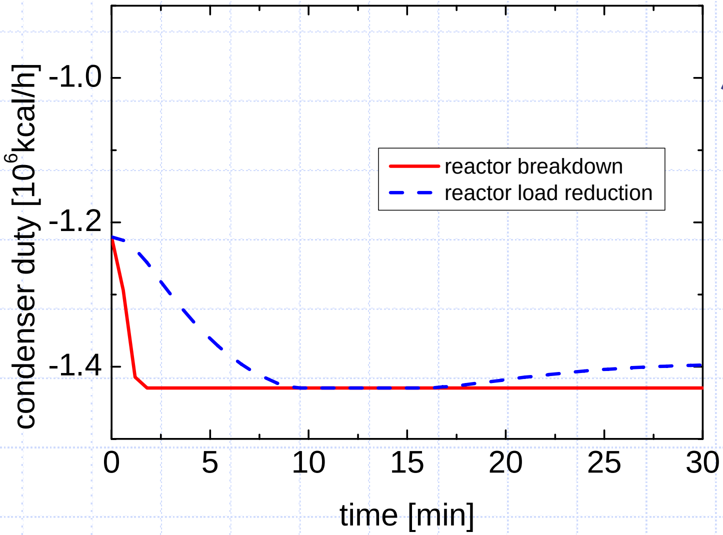
Breakdown in one oxy reactor

(2. Hazard analysis)



- The condenser duty may be not enough!
- Safety can be improved by using a larger condenser





Concluding remarks

- Main benefits from **steady-state** simulation
  - a plant representation consistent with the actual one, and ready to be used directly by the plant engineers as a part of their daily routine
  - assessment of process equipment performance
  - evaluation of production capacity
  - improvement of process operating conditions
  - quick evaluation of potential benefits and pitfalls of modified plant setups

- Main benefits from **dynamic** simulation
  - assessment of the control system performance
  - design of alternative control configurations for automating specific operating procedures
  - hazard analysis to evaluate the plant dynamics and the control system response in the case of abnormal events

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