DYNAMIC MODELLING OF A PILOT-SCALE FALLING FILM EVAPORATOR

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MOTIVATION

Industrial evaporation consumes massive energy, yet standard models only cover steady-state operations. To improve control during start-ups or disturbances, a dynamic approach is needed. This work establishes a validated modeling foundation to guide future process optimization.

MODELLING APPROACH

Two Lumped-parameter ODE models were developed and compared

Bojnourd Model

$$\frac{dx_{prod}}{dt} = \frac{\dot{m}_{in}(x_{in}-x_{av}) - \dot{m}_{prod}(x_{prod}-x_{av}) + \dot{m}_{evap}\,x_{av}}{\tau(1-\alpha)\,\dot{m}_{av}} - \frac{\alpha}{1-\alpha}\frac{dx_{in}}{dt}$$

$$\frac{d\dot{m}_{prod}}{dt} = \frac{1}{\tau(1-\alpha)}\left(\dot{m}_{cal,\,in} - \dot{m}_{prod} - \dot{m}_{evap}\right) - \frac{\alpha}{1-\alpha}\frac{d\dot{m}_{cal,\,in}}{dt}$$

Lumped Parameter tube model with residence time τ and mixing parameter α

Sump Model

$$\frac{dM_{sump}}{dt} = \dot{m}_{feed} - \dot{m}_{evap} - \dot{m}_{prod}$$

$$\frac{dx_{prod}}{dt} = \frac{\dot{m}_{cal,\,out}}{M_{sump}}\left(x_{cal,\,out} - x_{prod}\right)$$

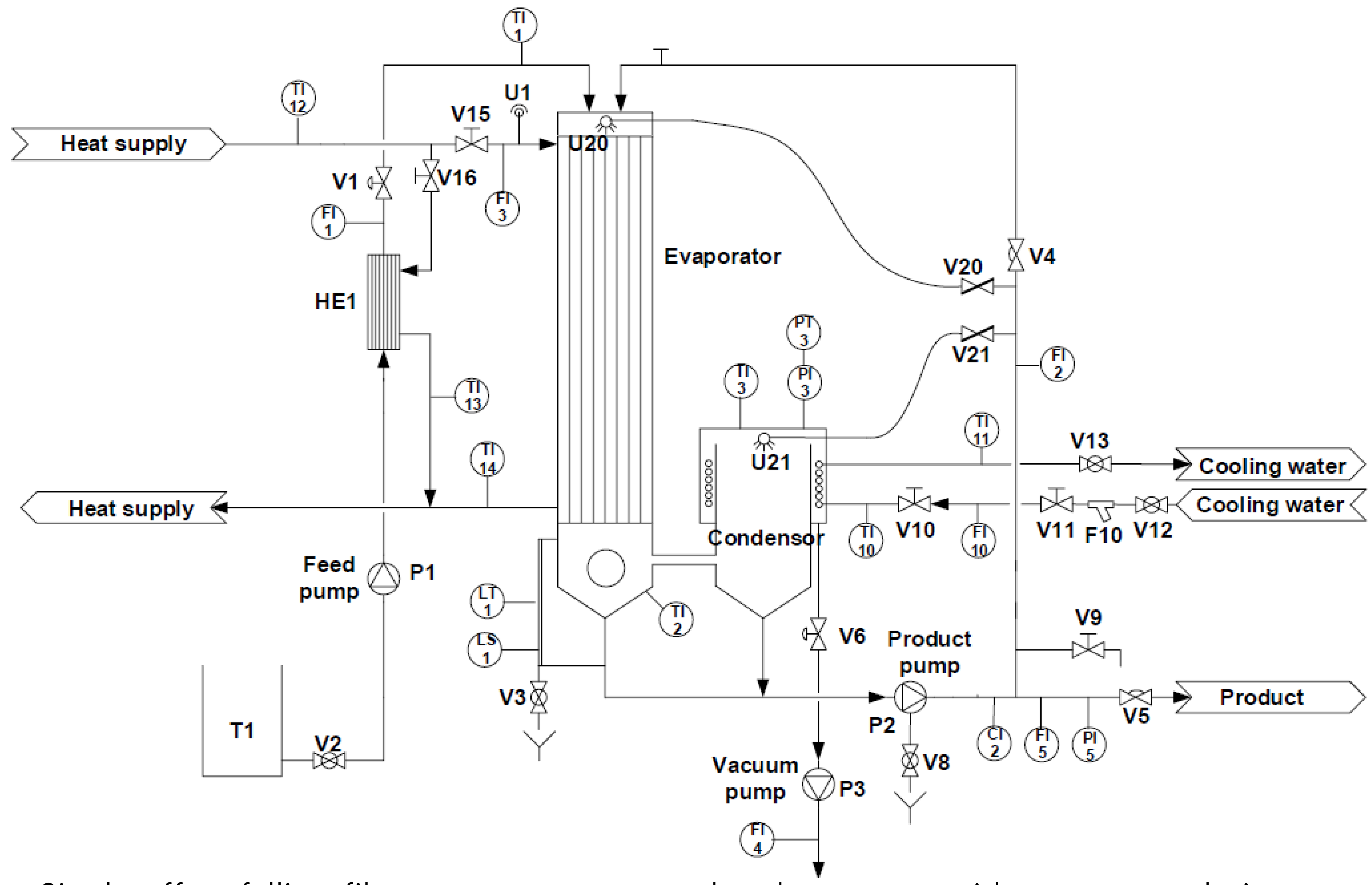
Quasi-steady Calandria; sump treated as CSTR

Shared Evaporation Rate

$$\dot{m}_{evap} = \frac{U\,A_{cal}\,\Delta T_{LMTD}}{\Delta h_v}$$

heat transfer coefficient U modelled data-driven

DTU PILOT PLANT



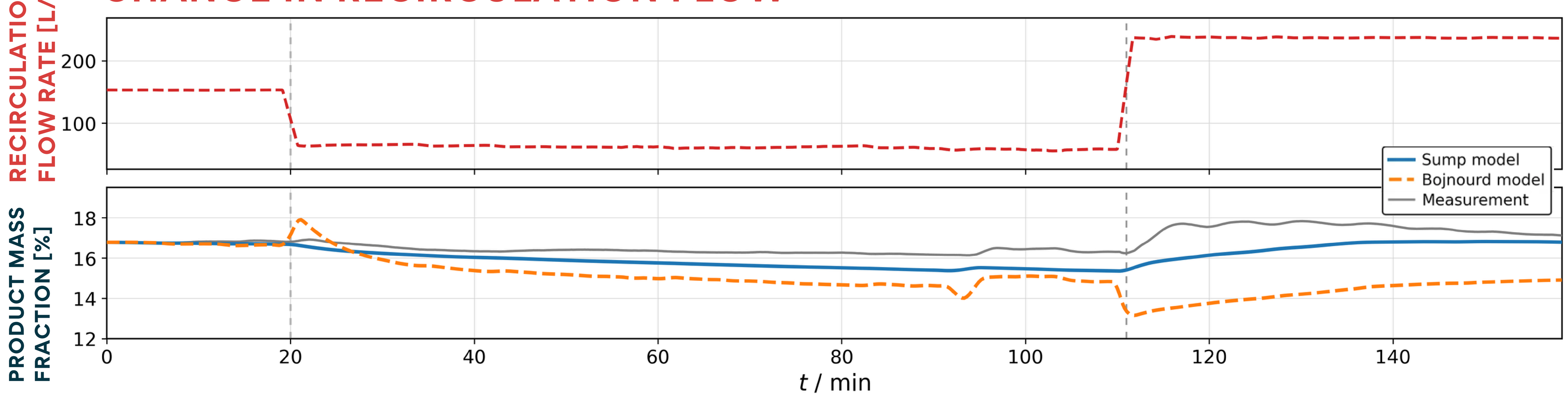
Single-effect falling-film evaporator, operated under vacuum with a sucrose solution; concentrate is recirculated to the top

Flows, temperatures, pressure and conductivity are logged automatically via SCADA

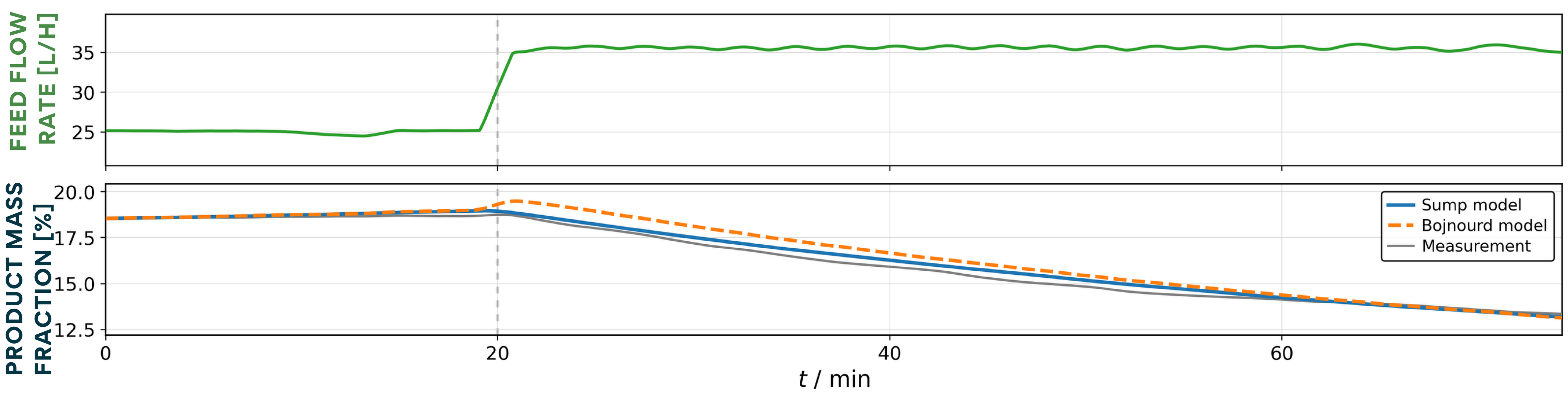
DYNAMIC VALIDATION

- Two dynamic models developed and compared, starting from the Bojnourd tube model
- Bojnourd reproduces the transients only with a fitted τ — no longer a physical tube residence time → dynamics not captured structurally
- This motivated the sump model: its time constant follows from the measured holdup, not a fit
- Validated on two disturbances — a recirculation step and a feed step
- The sump model tracks the mass fraction through both steps better
- The heat-transfer coefficient U is corrected data-driven from the runs, so the evaporation duty matches across load

CHANGE IN RECIRCULATION FLOW



CHANGE IN FEED FLOW



CONCLUSION & LEARNINGS

The observed dynamics are set by the sump holdup, not the film transport, so the sump model, with its time constant from the measured holdup, is the more trustworthy basis for this plant. Which structure to prefer is set by the plant, and getting there required careful data screening to turn plant records into a consistent basis for modelling. Such a validated dynamic model can serve as a basis for real-time monitoring and control of the concentrate, and as a foundation for modelling larger evaporators in industrial plants.

REFERENCES

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