Tubular heater/exchanger modeling: conclusions of the case study

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Modelling of Complex Systems

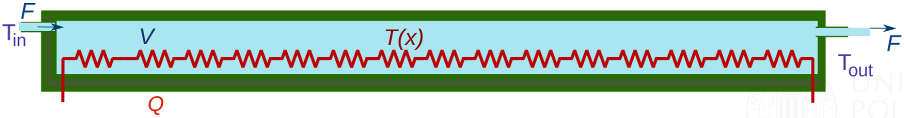
Video-presentación disponible en:

http://personales.upv.es/asala/YT/V/**tubulconcEN**.html

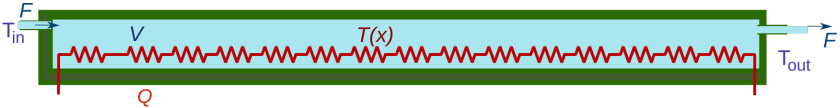
Introduction

Motivation: A physicist would say that the "good" model of the tubular heater needs adding turbulence, Navier-Stokes, pipe conduction, etc. But a technician using it to fill a tank with hot water just needs that "each kW heats 12 degrees Celsius". We, control engineers, are in an "uncomfortable middle ground"... what should we do?

Objectives: Analyzing the drawbacks of excess model complexity given a target application "bandwidth". Stating sensible modelling proposals.



Tubular heater: model complexity choices



We reviewed many model complexity options (and there are even more):

1. Static (nonlinear), Logarithmic Mean Temperature Difference, $T_{out}(t) = g_1(F(t)) \cdot T_{in}(t) + g_2(F(t)) \cdot Q(t)$. **[simplest]**
2. Nonlinear partial differential equation (because of FT) **[most complex]**
3. 1st order approximations (energy balances), with several options for $\bar{T} = \beta T_{out} + (1-\beta) T_{in}$).
4. Finite elements $(N = 2, 3, \ldots, 100, \ldots, 1000, \ldots)$
5. Approximate linearisation of options 1, 2, 3, 4 for linear simulation, Bode diagrams, and Padé approximation.

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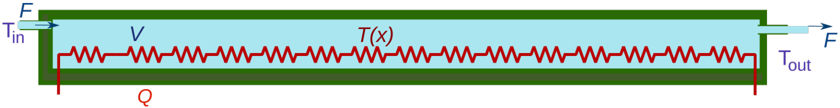

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Drawbacks of excessive model complexity

- Higher computational cost (stiff, high order) and numerical accuracy problems in simulation. Higher staff qualification to understand it.
- Results in complex controllers in quite a few cases (except when optimising fixed-structure setups, of course).
- In realistic applications, there is **a lot** of model uncertainty
  - Tank stirring and turbulence (if it is "elongated" but not truly "tubular", Reynolds number, etc.).
  - Parametric uncertainty in thermal conduction coeffs., outer temp., ventilation/fins, thermal expansion, fouling, resistance changes...
  - Heat capacity of the metallic pipe and of the heating resistance (they are not considered in the models)
  - Limited bandwidth of the system's sensors, if used for feedback.

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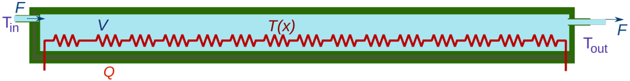
Complicating the model adds development cost that may not yield tangible improvements in performance of actual engineering applications.

*It may be of no practical use <reducing error from PDE of "ideal tubular heater" from 8% (1st-order approx.) to 1% with a 50th-order FE model> if other sources of error amount to 32%.

Recommendations (≈ rule of thumb *if we believe error due to stirring, metal heat capacity, fins, etc. is small enough)



Transient duration is **residence (washout) time**: $\tau_{res} := V/F$.

- If τ_{res} is "*more than 5 times*" smaller (faster) than the time constant of the system in which the heater is a subsystem thereof ($\tau_{res} < 1/15 \cdot$ settling time), then use a static model **(most frequent case)**.
  *usually, only "simulation and control *freaks*" think of something more complicated (and physicists).

- If τ_{res} is "≈ *3 to 4 times*" less than the full system time constant ($\tau_{res} \approx 1/8 \cdot$ settling time), use 1st order models. Heat exchanger in Simscape is 1st order (or 2nd order if wall heat capacity is considered).

- If τ_{res} is "*similar*" ($\tau_{res} > 1/4 \cdot$ settling time) to the application's time constant (e.g. fast feedback output temperature control), then use models of somewhat higher order (finite elements)... or Smith's predictor (internal delay in controller).