Preliminary design of a heat exchanger and its feed system using Simscape and multiobjective optimization

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Summary

This UROP project aimed to investigate and demonstrate Simscape's and MATLAB's capability to simultaneously size multiple components in accordance with the physical design parameters for the entire system. This paper presents an initial validation of this idea.
In my research, I concentrated on developing Simscape components to model a heat exchanger and its feed system. The key design parameters included heat transfer and pressure drop across the entire system. Once the model was built, multiobjective optimizer was utilized to streamline the design process and identify optimal solutions that minimize both, the length of the heat exchanger and the pressure drop across all components.
Looking ahead, the move toward carbon-neutral cycles requires systems to be complex. They are often challenging to integrate as the design of each component is done independently based on assumed input and output conditions. However, the cycle's theoretical performance is frequently not met once the system is interconnected. Simscape and MATLAB have the potential to assist engineers in this endeavor by concurrently sizing various parts of the plant. The critical objectives and constraints can be defined within the multiobjective optimizer, which can then analyze the trade-offs between important factors such as efficiency, weight, and size, among others.

Objectives

The main aims for this UROP project were to:

1. Design a tube-in-tube Heat Exchanger (TL_TL) that could be sized based on the desired performance.

2. Design a sizeable Pipe (TL) so that a HX and its feeds system could be created in Simscape.

3. Solve a multiobjective optimization problem to find tradeoffs within the entire system whilst ensuring constant heat transfer.

Design Parameters & Variables

When the conventional Simscape block is used to simulate a heat exchanger based on the E-NTU model, the design parameters include mass flow rate, pressure, and temperature at the source, the geometry of the tubes inside the heat exchanger and pipes connecting it to the reservoirs.
As Simscape components consist of parameters and variables for which simultaneous equations are being solved, it is relatively simple to replace the inputs with outputs. Once I had written the source code that replicates the behavior of the conventional Simscape heat exchanger block, I was able to set pressure drop and heat transfer across the tubes as the inputs to the block and the feasible geometry as the output. This process was then repeated for a pipe block. The showcase of the modified blocks and their interface is attached in the appendix.

Combined Model

Once both components were modified so they could be sized based on the performance parameters it was possible to build a simple model of a plant that MATLAB optimizer could interact with. The figure of the plant is attached in the appendix.

Multiobjective Optimization

The utilization of a multiobjective optimizer streamlined the design process by identifying optimal solutions that reduce both the heat exchanger's length and the pressure drop across the entire system whilst achieving the desired value of heat transfer. I used Pareto search with constraints on total pressure drop and geometry to restrict the problem to a feasible design space. The optimization variables were the radii of the tubes inside the heat exchanger and the radius of the pipe representing the feed system. The optimizer interacted with the Simscape model during each function evaluation and retrieved the results using Simulink.SimulationInput(...) and SimOut(...) syntax.

Limitations and Future Improvements

Because the timeframe of this project was limited to 8 weeks, the following assumptions were made to achieve the objectives. The possible improvements are listed below.

1. The bespoke Simscape block for HX (TL –TL) only models a tube-in-tube heat exchanger. It assumes a constant heat transfer coefficient and neglects the transient effects and therefore solves in one instance.

   (a) A Wide range of HX can be implemented using the E-NTU method. However, obtaining the size estimates for them will be more challenging due to complex geometry.

2. The internal node has not been included in the HX block.
   (a) The internal node would have to be included in the HX code if the transient response is desired.

3. Dynamic compressibility has not been included for the HX block, which depending on the type of fluid can be significant.

4. The blocks only work for thermal liquids.
   (a) A separate code for other liquid domains, (e.g. gas or two-phase) can be easily implemented without great changes to the code.

5. The liquid that flows through the larger tube should be connected to branch 1.

6. There is no heat exchange with the environment.

7. Both the pipe and heat exchanger block use industry-standard calculations for pressure loss based on the correlations for tubes.
   (a) Other options for pressure drop calculations, for example, based on tabulated data, could be implemented.

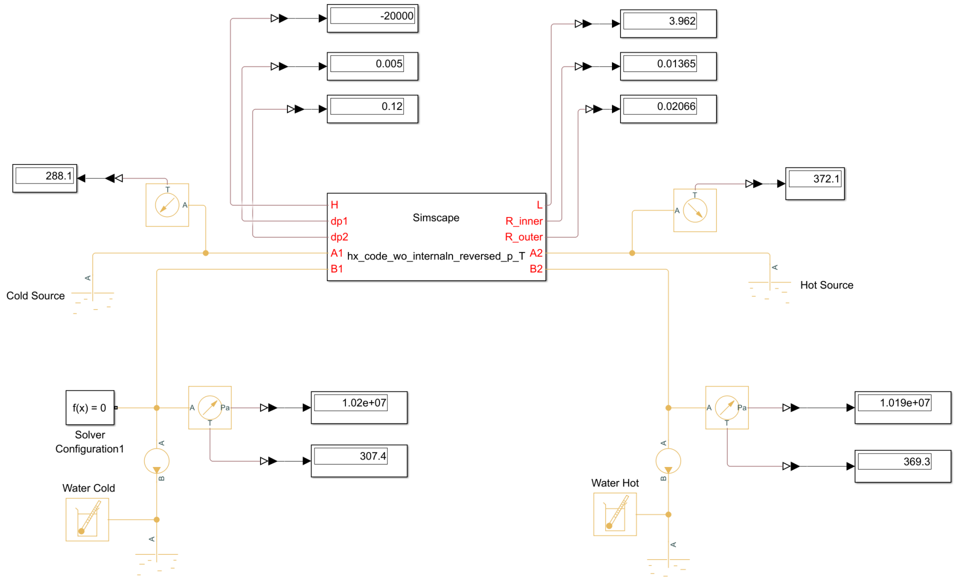
Conclusions

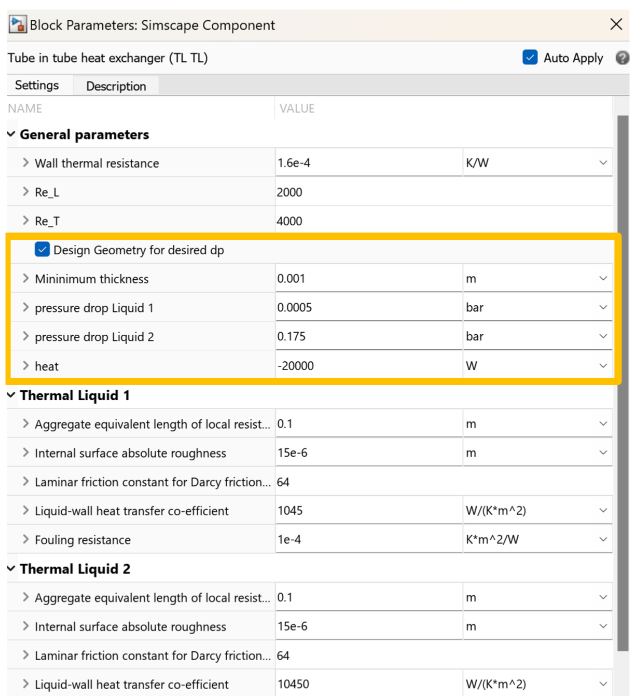
This paper presents the outcomes of the UROP project, which aimed to validate the use of Simscape for sizing multiple components simultaneously. Simscape blocks for a heat exchanger (TL TL) and a pipe (TL) were successfully created by modifying the source code to set performance parameters as inputs and geometry as output. Multiobjective optimization techniques were employed to streamline the design process and achieve performance targets while considering trade-offs between factors like heat exchanger length and pressure drop across the entire system.

In conclusion, this research showcases Simscape and MATLAB's potential in aiding engineers with simultaneous component design for complex systems. Future work can address the identified limitations and expand the library of sizeable components; in aim to model a complex plant and maximize its efficiency while considering other factors like overall weight and size, among others.

Appendix 1

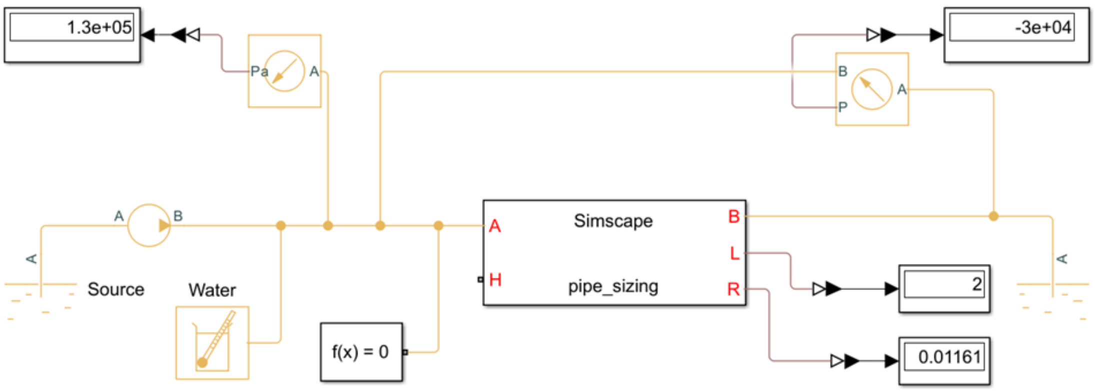
Modified tube-in-tube heat exchanger (TL TL) block and its interface

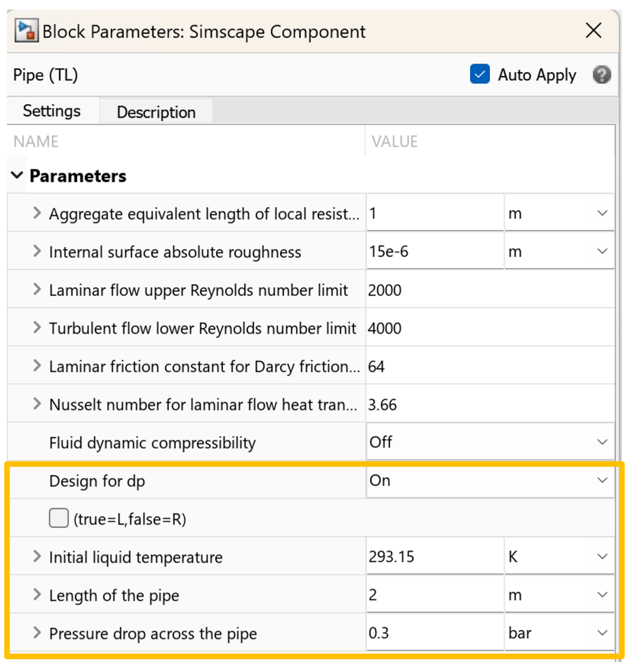




Appendix 2

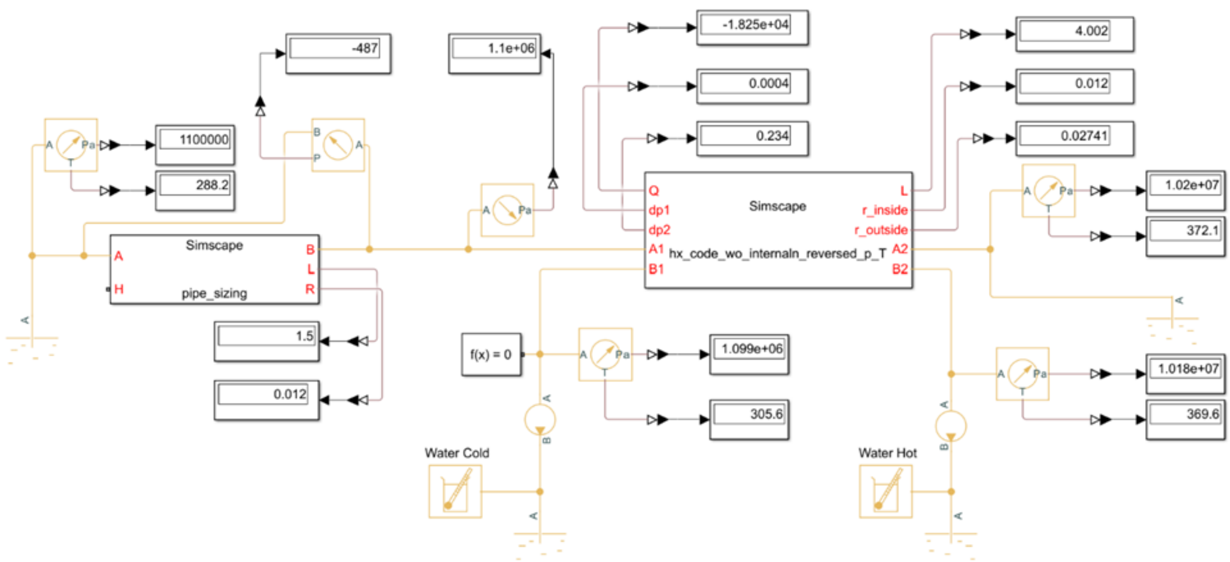
Modified pipe (TL) block and its interface.





Appendix 3

Combined model used for multiobjective optimization



Appendix 4

Multiobjective optimization results