Closed Feedwater Heaters with Cascaded Drains

Introduction

The role of feedwater heaters is to preheat the feedwater to reduce the temperature difference within the economizer. In high-capacity power plants, there are a large number of feedwater heaters, from which condensates are extracted at increasingly higher temperatures and pressures as the feedwater is heated.

Rather than directly returning these condensates to the feedwater tank or the condenser, it is more thermodynamically efficient to use the hotter water exiting a downstream feedwater heater to preheat the water entering an upstream feedwater heater, thus achieving a counterflow of condensates relative to the feedwater (Figure 1).

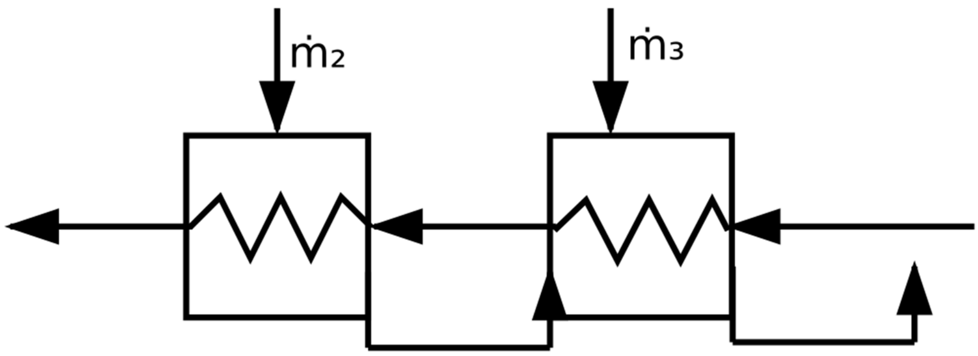


Figure 1: Feedwater heaters with cascaded drains

The heat exchangers that enable this are of a particular type, as they receive two liquid flows and one steam flow. This configuration, called cascaded drain reheaters, is used in a large number of power plants, both nuclear and fossil-fueled.

Modeling Principle

The diagram in Figure 2 shows the internal operation of such a feedwater heater. The cold feedwater enters at the bottom left and flows inside the tube shown in black. It is first preheated by the condensate from the downstream feedwater heater, then by heat exchange with the steam, and exits at the top left of the figure. The steam that condenses mixes with the downstream condensate, with the total flow exiting at the bottom right (drain).

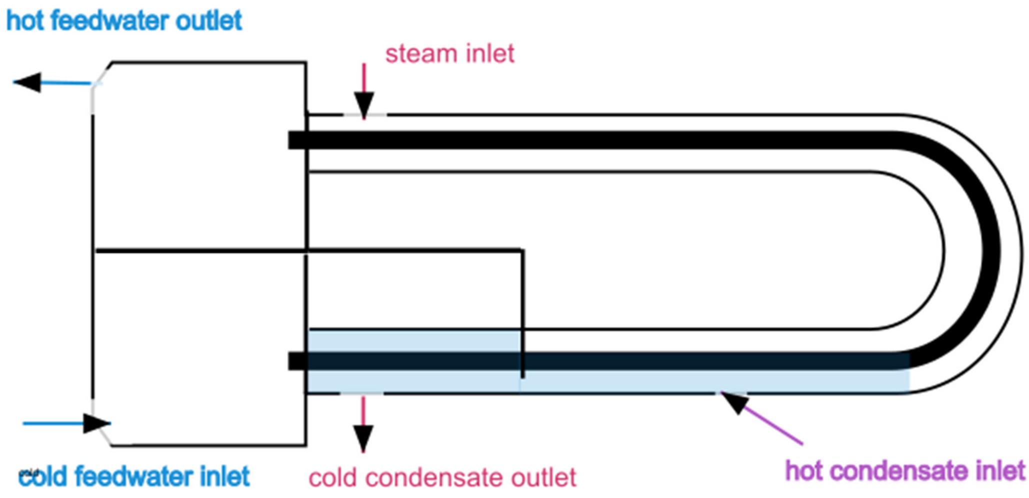


Figure 2: Internal sketch

From a functional perspective (Figure 3), the steam may be considered to fully condense in one heat exchanger before mixing with the condensates to preheat the main flow in another.

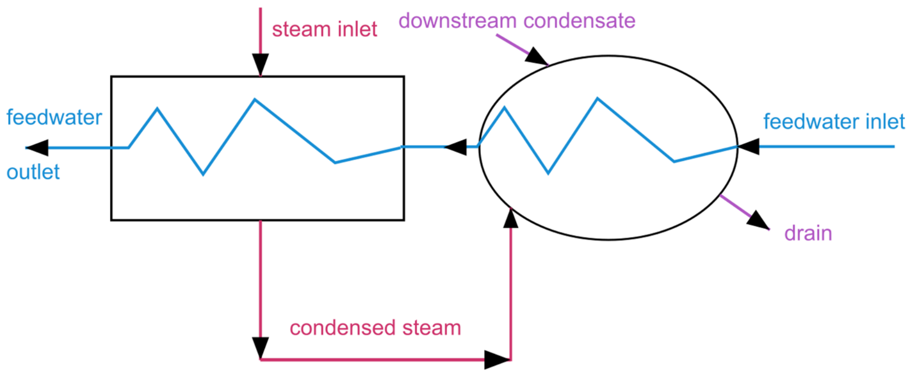


Figure 3: Closed feedwater heater with cascaded drain

A Thermoptim model of such a component has been developed in the form of two external classes (FeedWaterReheaterInlet.java and FeedWaterReheater.java).

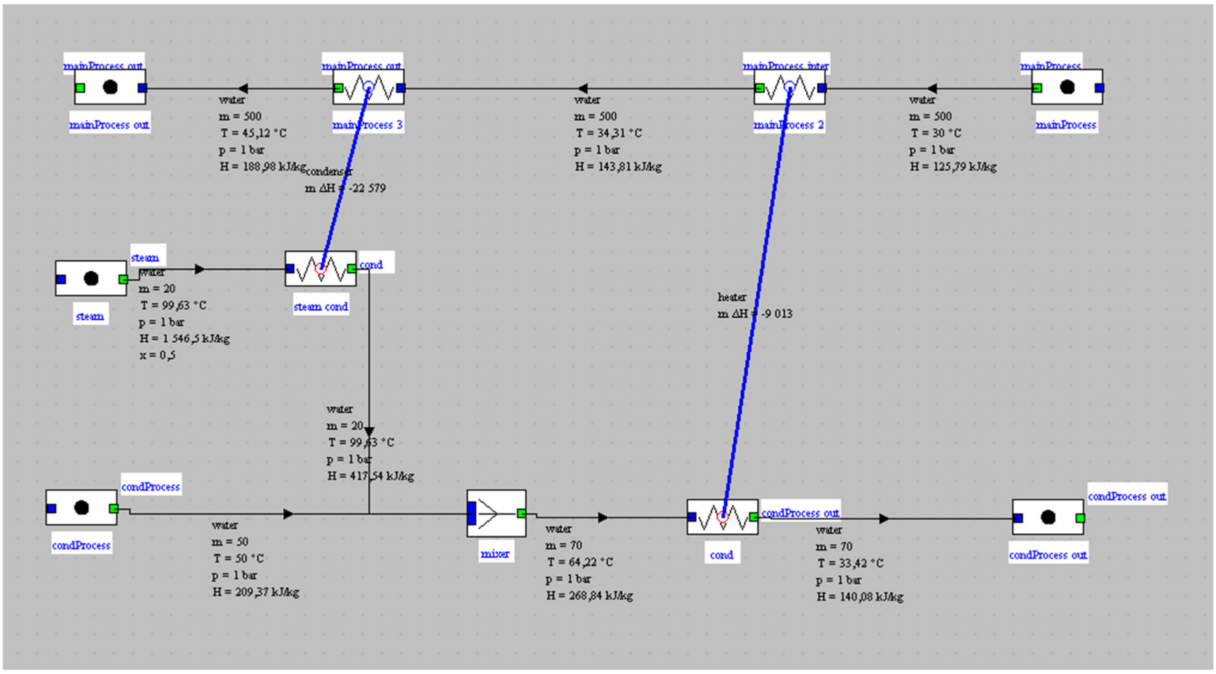
It includes an external three-branch inlet mixer and an external two-branch outlet divider.

The distinction between the incoming fluids can be made based on two criteria:

- The vapor quality greater than 0 for the incoming steam
- The flow rate and temperature for both liquids

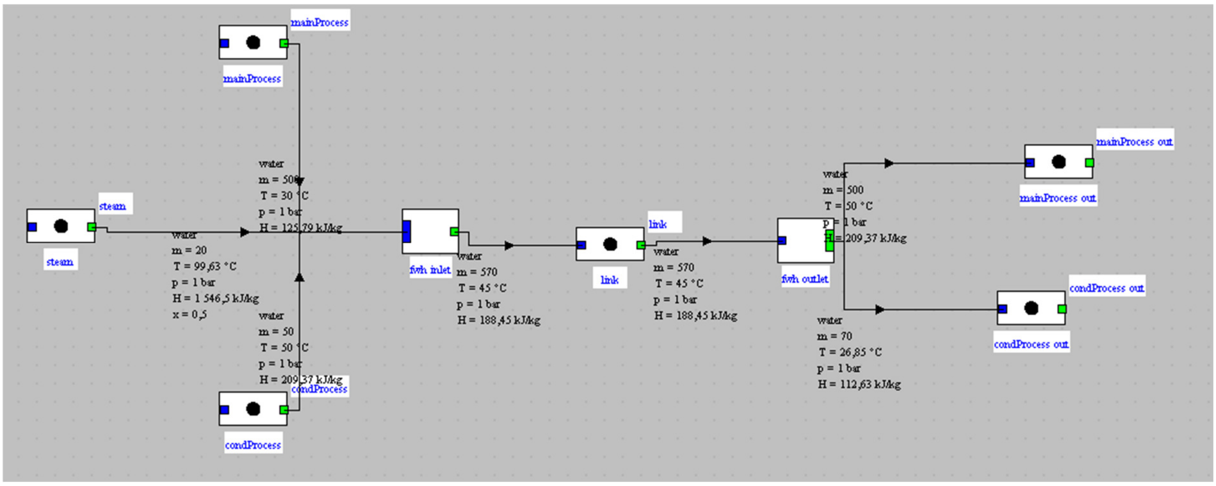
The distinction between the outgoing fluids can be made based on flow rate or temperature. Tests must be conducted on the temperature gradient, which must be respected. They can be disabled during the solution search phase.

The calculation principle is illustrated by this Thermoptim diagram:



It is assumed that the steam first condenses completely in an initial heat exchanger, which determines its state, and then is mixed with the condensates to heat the main flow in a second heat exchanger.

In the model, this second heat exchanger is not explicitly modeled: the outlet temperature of the main flow is determined by assuming that it receives all the heat released by condensation. A problem can occur if the steam flow rate is too high, as this temperature may exceed that of the steam. In such cases, it is essential to reduce the flow rate.



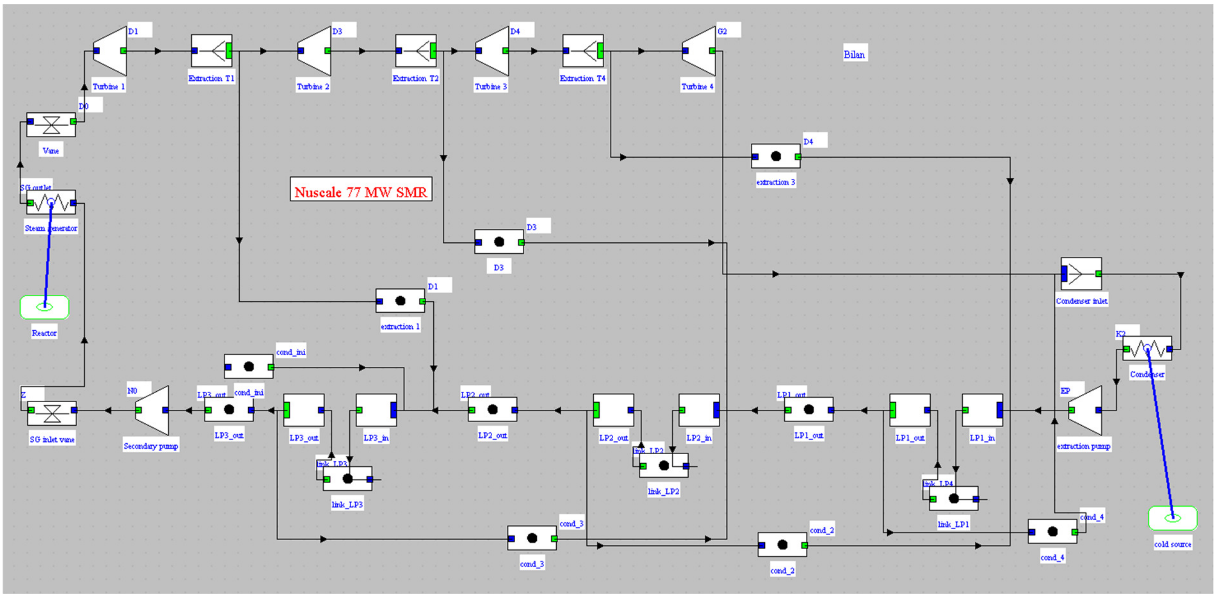
However, it may be preferable not to interrupt the calculations in such a case if there are several heaters in series, waiting until an initial convergence is achieved, because the condensate circuit is countercurrent to the main flow, which complicates finding a stable solution.

To avoid problems distinguishing between steam and condensate, by forcing the latter to remain in the liquid state, it is preferable to start setting a pressure of 100 bar for them and a subcooling of 0.1°C. Subsequently, when the temperature test is performed, the pressure of the outlet condensate is recalculated to be equal to that of the incoming steam. There is no test to verify whether the incoming condensate actually has a pressure equal to or higher than that.

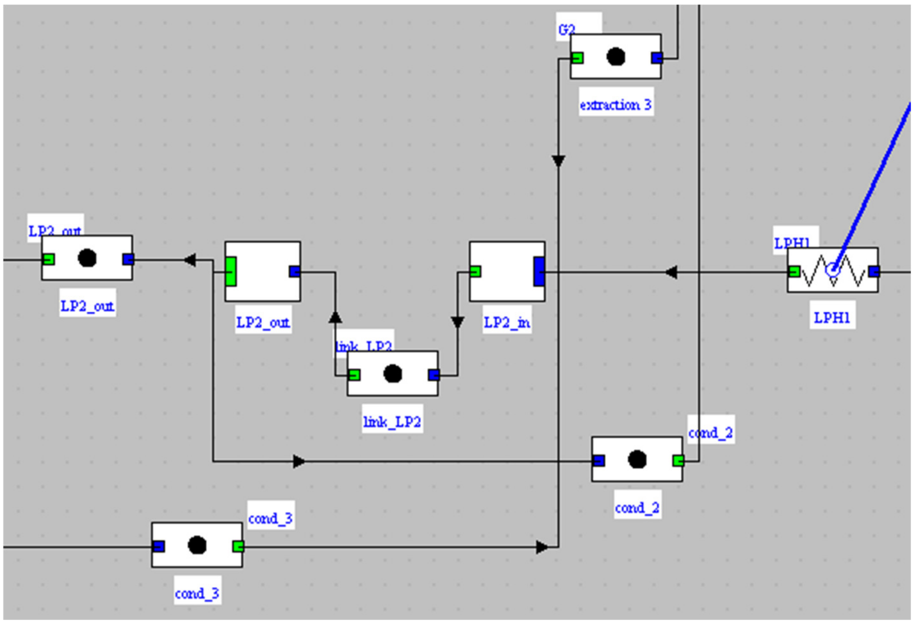
Example of NuScale 77 MW module

Let us now give an example of the use of these classes, for the cycle of the 77 MW module of NuScale.

The NuScale 77 model is particularly simple and serves as an easy-to-understand example (Figure below). It includes four Turbine Stage Groups (TSGs), three extractions, and three feedwater heaters. We will now explain how these are connected to the rest of the schematic and parameterized.



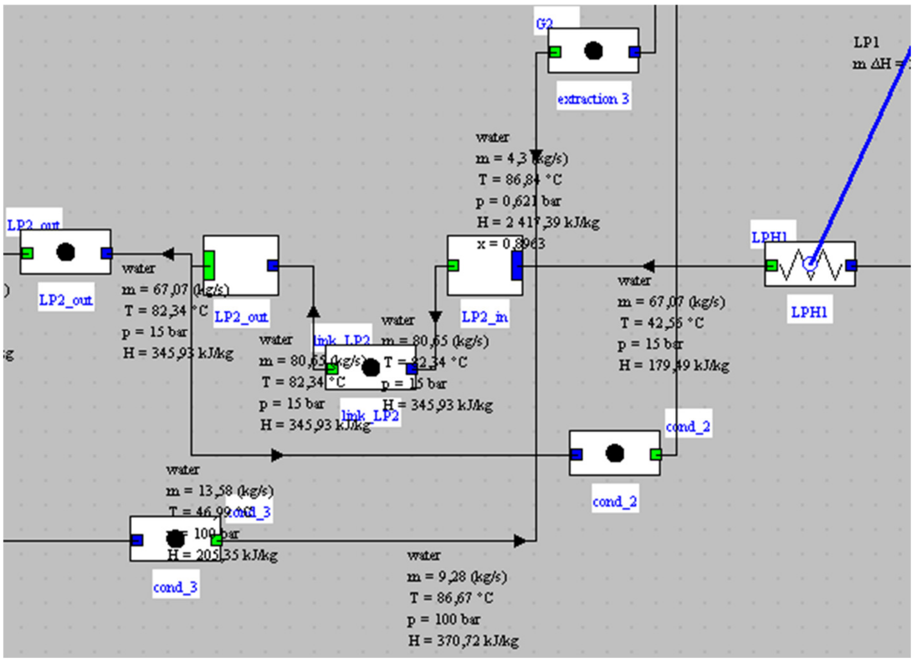
A zoom on the second feedwater reheater gives, the components being slightly moved for clarity:



Here's how such a heat exchanger can be modeled in Thermoptim: an external mixer LP2_in receives the three fluids as inlets: 'extraction 3' steam, feedwater coming here from a conventional LPH1 exchanger, and condensate cond_3 coming from the downstream feedwater.

The internal calculation starts by determining the internal temperature Tint corresponding to the heating by cond_3 of LPH1, then determines the outlet temperature Ts corresponding to the heating of the feedwater to this internal temperature by extraction steam 3. The feedwater flow rate remains unchanged and enters the LP2_out process at Ts. The steam is condensed, and its flow is added to that of cond_3 to enter the cond_2 process at a temperature slightly higher than Tint.

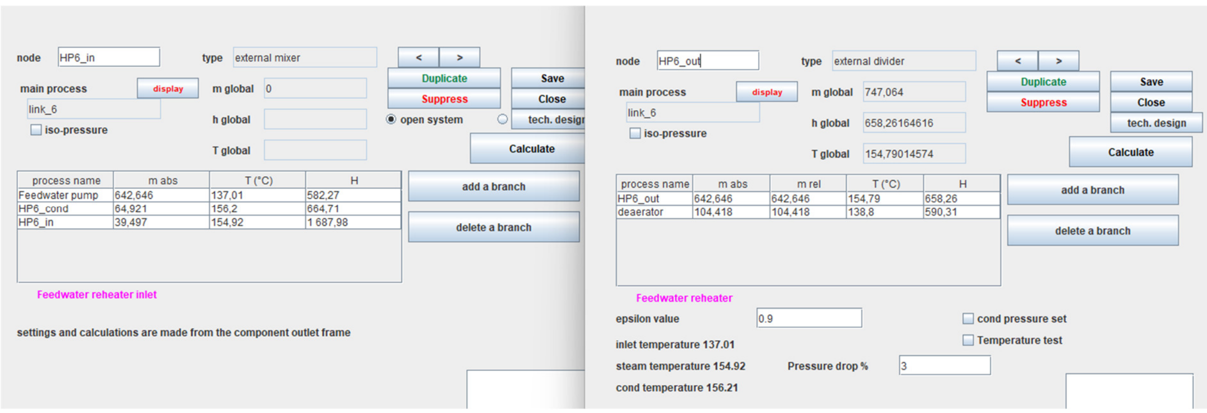
Everything happens somewhat as if there were two counterflow exchangers, the first between the feedwater and the incoming condensate, and the second between the steam and the preheated feedwater. The condensates exit at the temperature resulting from the mixture of the cooled incoming condensate and the condensed steam.



The initialization of the component must be carried out carefully; otherwise, it cannot be computed. The problem is all the more complex due to the coupling between the two counter-flowing fluid lines, namely the feedwater and the condensate lines.

To ensure that the node structure is consistent, a zero-flow process-point must be connected to the most downstream heater. Its temperature must be higher than that of the feedwater; otherwise, a temperature cross will be detected.

For the other process-points representing the condensates, they must be set with a high pressure (typically 100 bar), the point being at saturation, with dTsat = -0.1 °C to force the liquid state. After recalculation, the pressure is set equal to that of the incoming steam.



In order for the node to be constructed, the main upstream stream must have a flow rate higher than that of the condensate stream. During the first calculation, a temperature-related alert is often displayed. It usually disappears once the downstream heaters are calculated.

On the other hand, messages regarding excessively high steam flow must be taken into account; otherwise, the calculations will be nonsensical.

It should be noted that only actual steam extractions should be connected as steam, while condensates, such as the outlet from the heaters, can either be connected directly or routed to a mixer where the condensates from downstream heaters are also collected.