Design Mode Analysis of Reheaters in Nuclear Steam Secondary Cycles

By

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Abstract

This paper presents a new design mode for use in analyzing nuclear reheater thermal performance. The method applies to reheaters that are commonly available. Schematics are included to demonstrate the several flow path layouts that can be modeled. A calculated result is presented for one example reheater configuration.

Introduction

Many power generation cycles in nuclear plants include moisture separators and reheat heat exchangers located between the high pressure and the low pressure turbines. These are frequently called MSR's, for moisture separator reheaters. As the effluent at the HP turbine's exhaust is wet steam, the purpose of these devices is to reduce and minimize the amount of the liquid-phase component of the steam flow through the LP turbine, in addition to raising its temperature.

Reheaters generally do not increase the thermal efficiency of the steam cycle, compared to a cycle without a reheater. This is so because the heating steam is taken from within the steam cycle itself, with no other external effect occurring. That is, there is no increase of available energy. Since the heating steam is taken from the main turbine flow path, the flow through the turbines is reduced, and this reduces the amount of power that could be generated by the turbines. In addition moisture separators and reheaters inevitably introduce some pressure drop on the main steam path. A consequence of reduced pressure is the reduction of available energy for doing work.

When viewed from a second law of thermodynamics perspective, there are irreversibilities that occur due to transfer of heat across a finite temperature difference within the reheater and due to pressure losses. Thus the thermodynamic efficiency is actually reduced somewhat by the process of reheating. However, by removing liquid from the turbine-line steam and then superheating the remaining steam, the reheater can improve the flow pattern over the LP turbine's blades and in this way improve its performance and efficiency. In addition, since over time liquid wears blades, removal of liquid from the turbine-line steam can improve the longevity of the LP turbine's blading. Poorly performing reheaters have the potential to exert a profound negative influence on the efficiency of the cycle and on the life expectancy of the turbines.

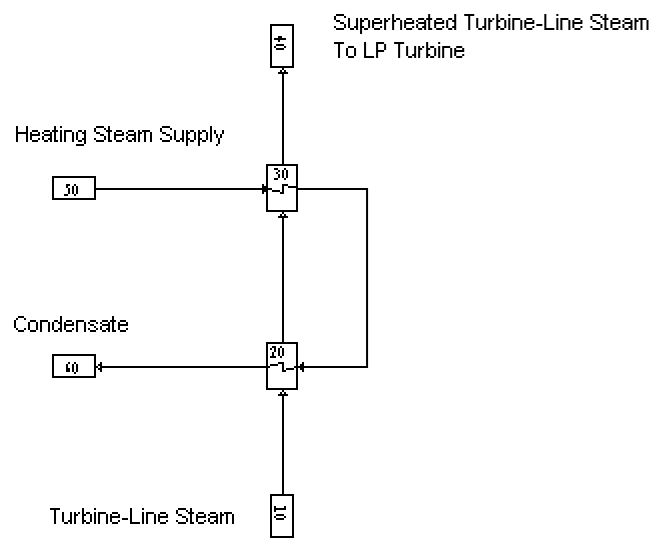
Because of the potential for impact on cost of operation and maintenance, a clear understanding of the performance of these complex devices can provide considerable benefit to the plant performance engineer who has responsibility for maintaining favorable operating conditions and high efficiency, consequently low costs.

This modeling tool, PEPSE, offers an option for improving understanding of the thermal performance of the nuclear reheater and its impact on the power cycle. Effects that can be evaluated include surface fouling, tube plugging, shell-side flow bypass, quantity of excess steam, pressure drops, and others. The tool also addresses moisture separators, but they are modeled as separate devices. The PEPSE software has the ability to analyze the entire power cycle, with the reheater included in the model of the cycle.

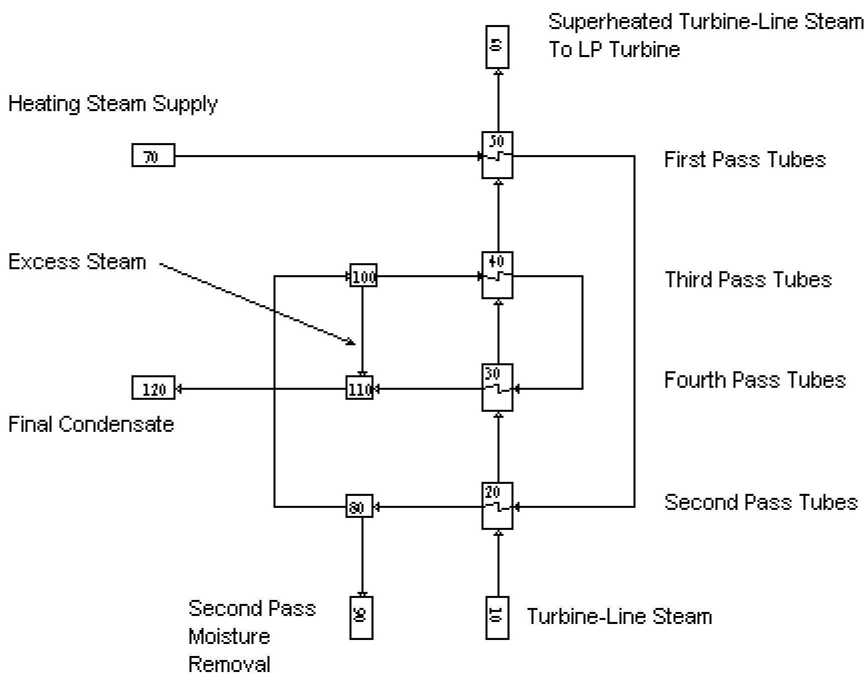
Details of the Model

Basic principles of thermodynamics and heat transfer are applied in the analysis of a nuclear reheater. In addition correlations for coefficients of heat transfer come into play. This heat balance analysis is done for steady state operation. The flow rates entering the device and a detailed description of the internal structure and flow arrangement of the device must be known in order to apply these principles to predict thermal performance.

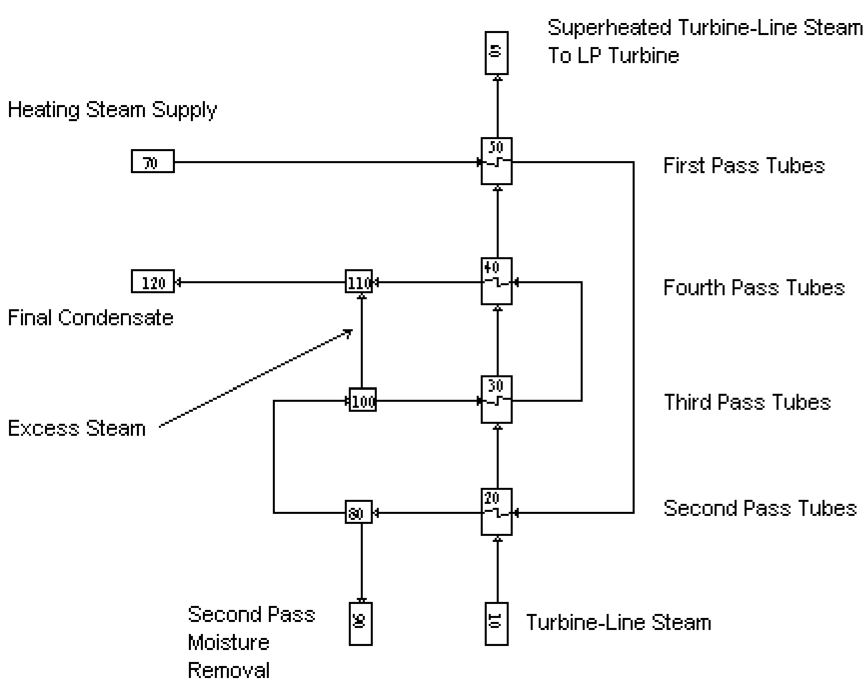
There are several arrangements of tubes in current use in reheaters. Schematic diagrams below show conceptual views of some variations of flow arrangements.



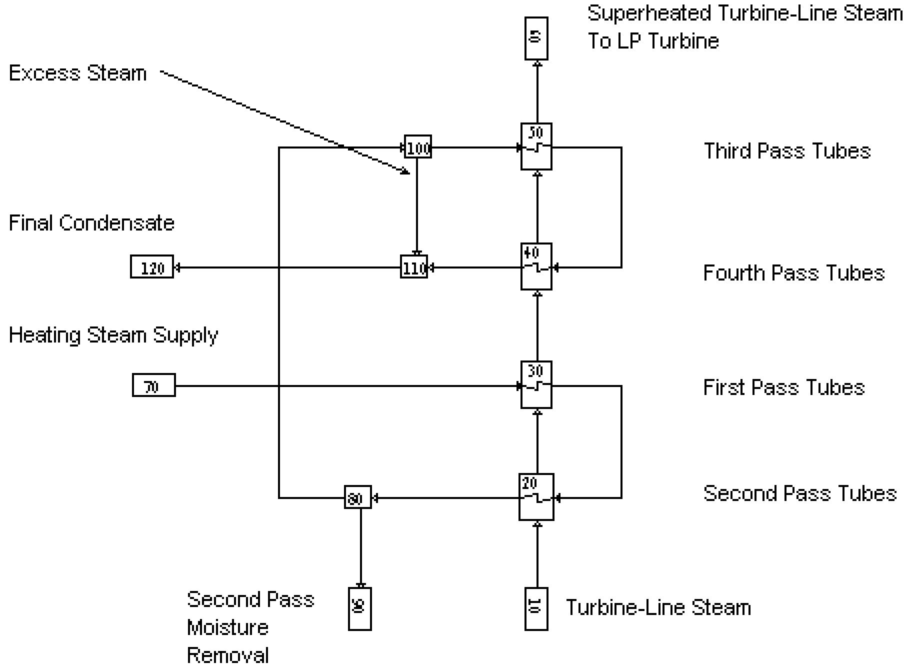
U-Tube Two-Pass Reheater



1-3-4-2 U-Tube Four-Pass Reheater



1-4-3-2 U-Tube Four-Pass Reheater



3-4-1-2 U-Tube Four-Pass Reheater

In common among these is upward flow of turbine-line steam across tube banks on the shell side. Heating steam flows inside of the tubes. The heating steam condenses, and the turbine-line steam becomes superheated.

The coded modeling tool provides calculations for each of the configurations above and any others that may be in use.

Modeling of any one of the various arrangements uses PEPSE "components" that can be interconnected in a way similar to the schematic diagrams above. Each component represents half of a U-tube in the actual reheater. The heat transfer within an individual component is analyzed as pure crossflow with condensing heat transfer occurring inside of the tubes and superheating of steam on the outside of the tubes. Generally the tubes have fins on the outer surface, and these fins are accounted for in the model.

In a 4-pass reheater, tube-side condensate is drained away following the second pass. The model accounts for this moisture removal.

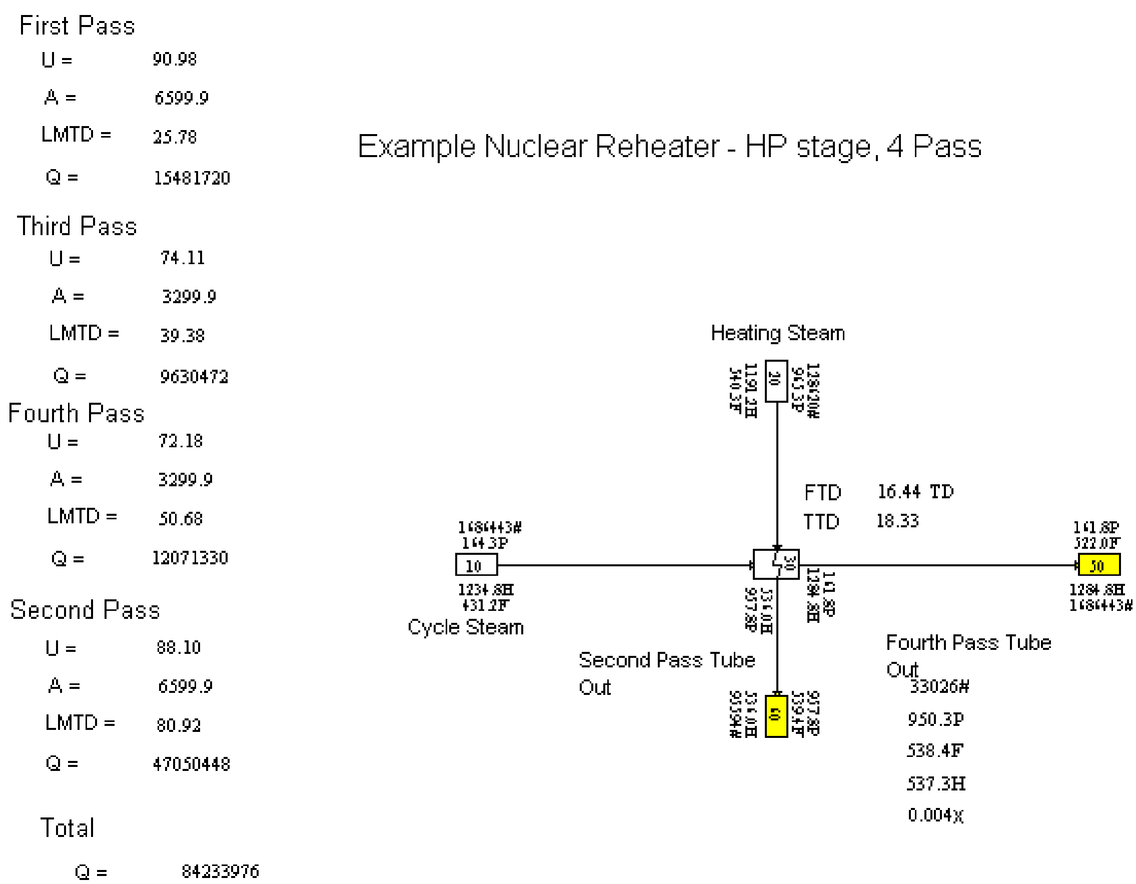
There is an available alternative single reheater component that can be selected to represent the entire reheater. This component has been programmed so that the modeler can indicate which one of the flow arrangements, of the set shown above, is represented by the single component. Thus, there is modeling flexibility in the tools available. This latter alternative is probably the easier to use of the two alternative approaches.

Results Produced by Calculations of the Model

The results of computations include general performance descriptors of the reheater - the final temperature difference, the amount of heating steam, the amount of heat transferred to the turbine-line steam (passing onward to the LP turbine), the quantity and state of the fluid that exits the drains, and the integrated impact of the reheater on the balance of the turbine cycle. Thereby, the effects on system generation and efficiency and on components that receive the effluent are quantified. These results can then be used in subsequent financial evaluation of current operating state and the benefit to be gained by considered modifications of the reheater or modifications of its operational controls.

Example Results

The schematic diagram below, including computed results, provides a demonstration of most of these parameters for a small model that focuses only on the reheater.



The results shown on the schematic compare favorably with the performance that was reported on the vendor's specification sheets for this reheater.

Conclusions

A new modeling component within the modeling tool is available to perform detailed calculations for nuclear reheater components. This module can be configured to represent any cross-flow reheater that is in current use. Specification of the inputs to describe the reheater is straightforward. The results from example calculations that have been performed for a limited collection of several reheater arrangements have compared well with the performance claims of the vendors. The module includes factors that can be used to tune the calculations to match vendor claims or tested performance.

Bibliography

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