Simulating Parallel Trains of Feedwater Heaters Using a Single Train of PEPSE Design-Mode Components

By Gene L. Minner, PhD
SCIENTECH, Inc.

ABSTRACT

Analysis objectives frequently require the use of design-mode feedwater heaters to accurately predict system performance. In many real cycles there are parallel trains of feedwater heaters. For example, the "number 1" feedwater heater actually may be two or three heat exchangers that are in parallel on the feedwater line (FWH 1A, 1B, and 1C). This paper makes recommendations for modeling these parallel heaters as a single PEPSE component that takes the full feedwater, shell steam, and drain inlet flows, instead of half or a third of the flows. Such a modeling simplification would be applicable, only, when the two or three parallel heaters are "identical".

An example application is included.

INTRODUCTION

In the interest of keeping the modeling simple and reducing the amount of work to create the model, it is reasonable to ask whether results will be accurate if three parallel feedwater heaters are represented as a single component. If this simulation is possible, the single component would handle all of the flows that pass to the three separate heaters in the actual system.

It is common practice to use the design mode for feedwater heater calculations in PEPSE. Frequently in modeling, the complexity of three parallel components may be simplified to a single component. Can this be done for the design mode feedwater heater applications?

If this can be done for design mode, what are the requirements needed to assure accurate results?

This paper hypothesizes that the desired simplification is possible and that the results will be accurate. Foundation is proposed and the hypothesis is tested by example application.

TERMINOLOGY

For convenience, the following terminology is defined. “Parallel model” refers to simulation of each feedwater heater as a separate component. “Composite model” refers to simulation of multiple parallel feedwater heaters as a single PEPSE component.

THEORETICAL BACKGROUND

In order to obtain dependable results in simulating parallel heaters by a single PEPSE composite feedwater heater component, it is necessary that the heat transfer results match the heat transfer results that would be obtained from the parallel model. This means that a single component that is used to represent multiple parallel feedwater heaters should produce the same total heat transfer as the combined multiple feedwater heaters.

Heuristic arguments are presented, rather than developing a rigorous set of equations, to show us how to produce this match. These arguments will help us to select workable input parameters for our composite model.

Using conclusions reached here, for testing, a composite model and a parallel model are included in a single model file; see the following section. The results from the calculations for the two different simulations are used to examine the success or failure of the guidelines. Success or failure is checked by running the models at different boundary conditions. If successful, the two separate simulations provide matching results at these differing boundary conditions. Presuming success, logical induction is used to persuade us that similar simple models can represent three or more parallel feedwater heater units. These results give confidence that, for many analysis assignments, a composite model does a good job, saving modeling labor and computational complexity compared to building a parallel model.

Given our knowledge of heat transfer calculations, we would be led to suppose that, for established incoming heater boundary conditions (temperatures, pressures, and flow rates), the desired heat transfer match could be obtained by matching heat transfer coefficients and properly accounting for heat transfer areas in the single versus the multiple parallel modeling choices.

In the general application, PEPSE calculates the heat transfer coefficients as functions of the geometry of the feedwater heater, the flow rates, and the temperatures and pressures.

There is a heat transfer coefficient for the tube wall. This coefficient can be matched by input of the same tube diameters and the same thermal conductivity in the composite model as would be used in the parallel model.

There is a film heat transfer coefficient for the water flowing inside of the tubes. This heat transfer coefficient can be matched by matching the velocity of the water inside of the tubes. If the composite model simulates N (e.g. 2 or 3) separate parallel units, the flow rate for the composite model will be N times the flow rate for the individual parallel component. As stated immediately above, the tube diameters have been matched. Therefore, to match the tube velocity, the number of tubes input to PEPSE for the composite model should be N times the number of tubes that are in the parallel model.

There is a film heat transfer coefficient for the shell-side of the tubes. For a desuperheating or a drain cooling zone, this heat transfer coefficient is determined primarily by the "mass velocity" of the shell-side flow across the tubes and the specified "number of tubes in crossflow". So, it would seem desirable to match these two quantities. Indeed this would also have the desirable effect of helping to match the shell-side pressure drop result as well.

Further addressing pressure drop, to match the tube-side pressure drop, the overall length of the tubes should be matched. If this is done, and having the matched tube diameter and the multiple number of tubes, the overall heat transfer surface area is also matched.

To match the mass velocity, consider the relationship:

$$G = \left\{ \frac{w}{\frac{L}{\#BFL+1}\left[\sqrt{CL_L * CL_T * \#_T}\right]} \right\} BPH$$

In this equation:

G	=	mass velocity
W	=	mass flow rate across the tube bank on the shell side
L	=	overall tube length
#BFL	=	number of baffles
CL	=	SL – Do (longitudinal tube pitch minus outside diameter)
CT	=	ST – Do (transverse tube pitch minus outside diameter)
#T	=	total number of tubes
BPH	=	heat transfer bypass factor (= 1.0 means no bypass)

Tube length and number of tubes have already been addressed above. Note that the flow rate, w, in the composite model will be equal to the number of units represented in the composite model times the flow rate in the parallel model. It is recommended that, to match mass velocity, the number of baffles, the longitudinal pitch and the transverse pitch be matched in the composite model to the real feedwater heater. In the equation above, the unmatched flow rate means that matching the mass velocity will require an adjustment of the bypass factor. In normal applications of the design mode for feedwater heaters, this bypass factor is used as a tuning parameter for matching a benchmark performance. Therefore, its magnitude will be adjusted by the overall tuning of the calculations, and we need not give it further consideration here.

In actual computations, the bypass factors have effects other than those shown here, complicating the arguments on which the hypothesis is based. Indeed, because of this fact, the shell-side heat transfer coefficients will be matched only approximately. Nevertheless, the conclusions drawn above form a structured approach to creating a useful composite simulation.

The heat transfer coefficient on the shell side for the condensing zone is a function of the thermal properties. It will be matched by the composite model as long as the boundary conditions and the shell side pressure drops are matched.

As a final note on matching, the shell-side pressure drops can be matched by setting the flow area around the end of the baffles (the window) for the composite model to obtain the same shell-side flow velocity through the window as is obtained in the parallel model. This is done by multiplying the actual baffle-window area by the number of feedwater heater units being represented. Further, for pressure drop matching, the inlet nozzle areas and the outlet nozzle areas for both the feedwater-side and the shell-side flows are adjusted in the composite model to obtain a match of flow rate per unit area at these locations between the composite and the parallel models.

APPLICATION - EXAMPLE MODEL

Figure 1 shows the schematic for the model that is used to test and verify the ideas that have been suggested above in the section above. Both the composite model and the parallel model are included in a single PEPSE model file. As shown, the submodel on the left, with component ID's 210, and higher, is the composite case, and the remaining portion is the parallel submodel. The boundary conditions are set up in a consistent manner, and the descriptions of the feedwater heater components in the composite and parallel models are set up according to the conclusions of the previous section.

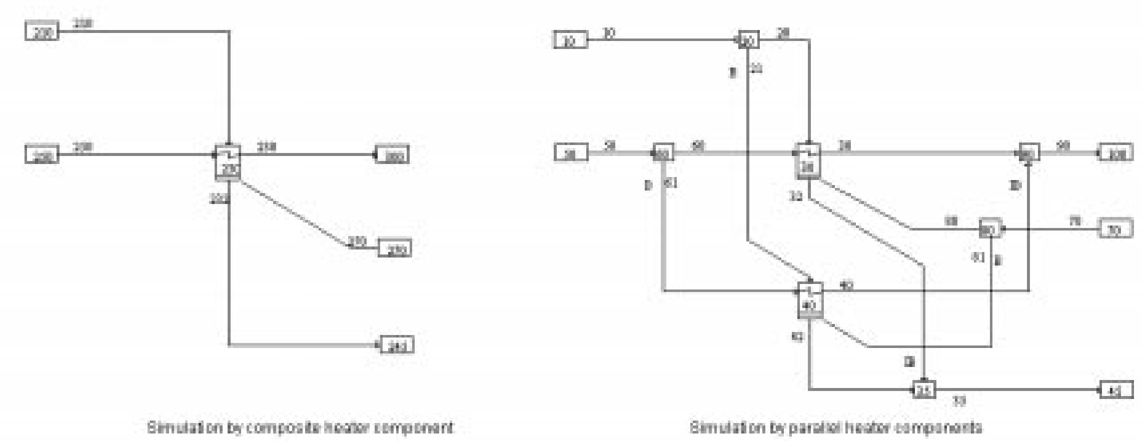


Figure 1 - Schematic including composite and parallel design mode feedwater heaters.

It is easy to see in the two separate parts of the schematic that the composite submodel is much simpler. If the composite submodel can be made to produce the same results, it is clearly more desirable for setup and application.

At the boundaries of this model, the source thermodynamic conditions and the flows at 10 and 210, at 50 and 250, and at 70 and 270 are set to the same values. Splitters number 20, 60, and 90 in the parallel heater submodel are set for equal flow splits to the two separate feedwater heaters.

As an aside, we recommend the use of submodels similar to these for tuning design mode feedwater heater computations prior to inclusion in a turbine generator cycle system model.

RESULTS OF EXAMPLE MODEL

In order to check the hypothesis of this paper, the example model is run through several cases here, and the results from the composite side of the model are compared against the results from the parallel side of the model. These cases consider variations of feedwater flow, drain flow, and feedwater temperature to which the feedwater heaters are subjected. If the results for the composite submodel and the parallel submodel, within any one case, are found to match each other, this evidence supports the hypothesis.

For completeness, the input descriptions of feedwater heater 230 and of 30 are included in the Appendix of this paper.

The first case analyzed is a base case, where controls are included in order to tune the heat transfer and pressure drop results to expected values. Specifically, the TTD and DCA in each case are tuned to 5 and 10 F, respectively. The tuning factors used for these purposes are the heat transfer coefficient multiplier in the condensing zone and the heat transfer bypass factor in the drain cooling zone. In addition the drain outlet pressure for the composite submodel is tuned to the same value as the pressure for the parallel submodel. Figure 2 shows the results for this analysis case. Comparison of the results from the composite and parallel submodels shows excellent agreement. So, the starting point for the analysis is a good one.

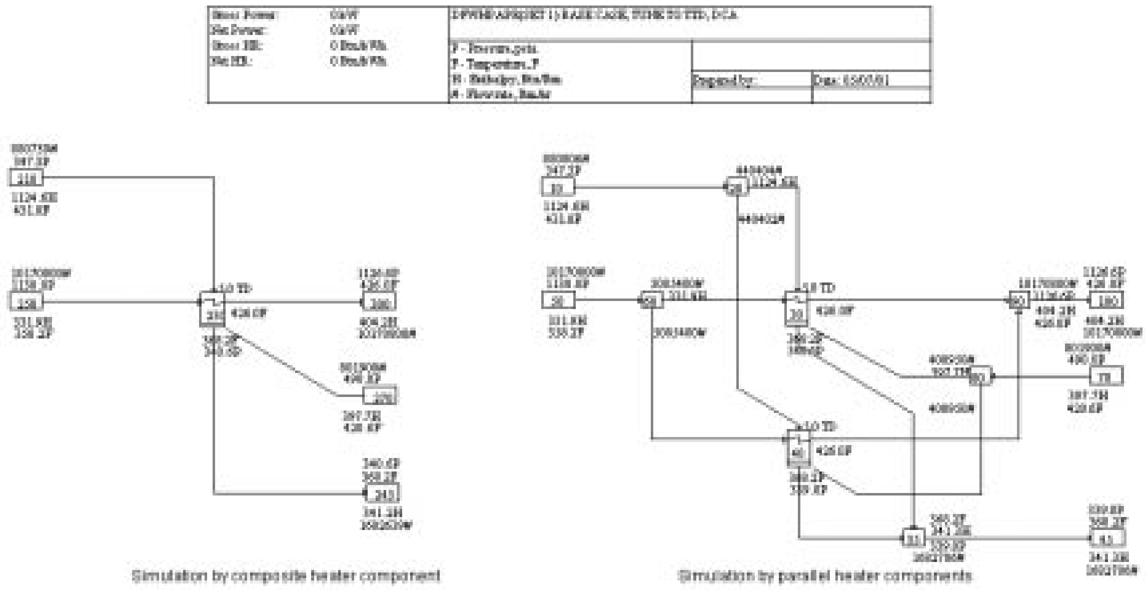


Figure 2 - Base model results, including controls to match TTD and DCA

Critical points to observe in Figure 2 are the TTD values on components 230, 30, and 40. As seen, the match is identical. Using the definition of DCA, it is easy to verify that the DCA is also matched. Additionally, the shell steam flow rates at components 210 and at 10 are a very close match to each other. For further details of the results of the tuning done by the controls, see Table 11 in the Appendix. As seen there, the tuning factors from composite and parallel submodels are quite close to each other, with the exception of the hydraulic bypass factor. No predefined requirement was placed or expected between composite and parallel submodels.

The second case is an important one. Without changing any boundary conditions, but with the controls removed and now using the tuning factors from the base case, the model is run again to verify that the results are those that have been shown for the base case. This was run as a "stacked case" in PEPSE, using the "save case" feature in order to retain the tuning factors from the base case. In fact, all subsequent cases are also run as stacked cases with the save for retaining the tuning factors and passing them down from case to case. The results from this verification case are included here in Figure 3. Comparison of Figures 2 and 3 reveals an exact match. This is verification of the tunings.

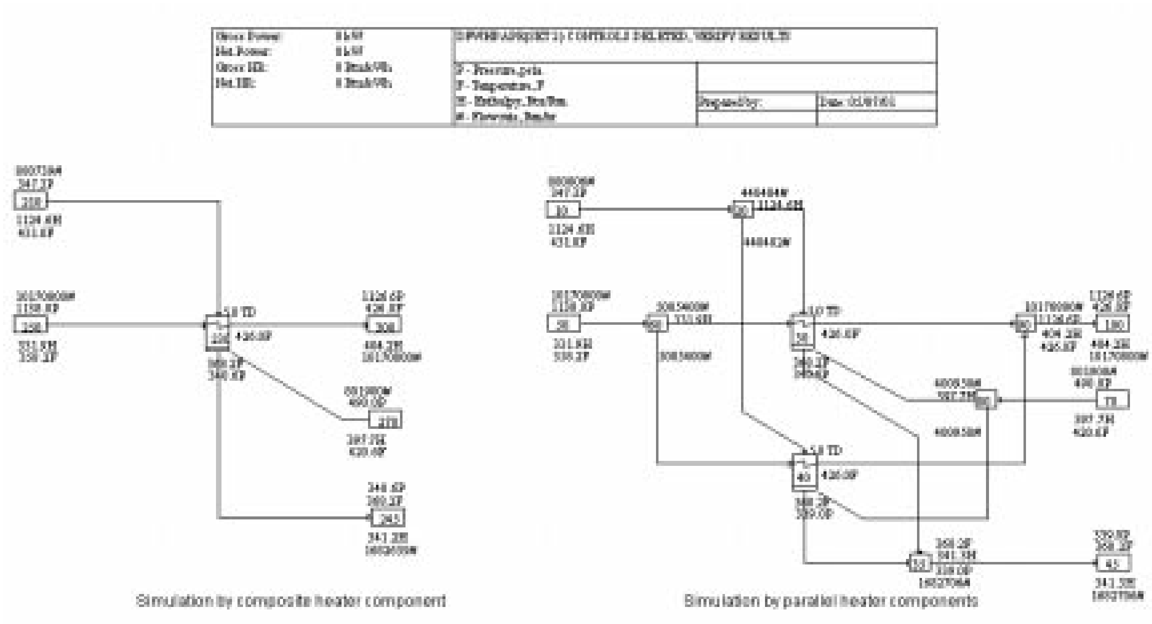


Figure 3 - Model results, base case, controls removed, verification

The third case for analysis is one in which the feedwater flow rate is cut in half, compared to the base case. In all other respects the geometric and flow descriptions are the same from base to this case. In this case, it is expected that the steam flow rate demanded will change in similar fashion to the change of feedwater flow rate. Figure 4 shows the result of this case. Indeed, the demand steam at components 210 and 10 have been reduced, as compared to the base case. It is critical in this case that the 210 component flow rate will be a close match of the 10 component flow rate, if the hypothesis is supported. As seen, the match is quite good. It is also easy to see in Figure 4 that the TTD has changed significantly from the base case, but the composite and the parallel results match each other.

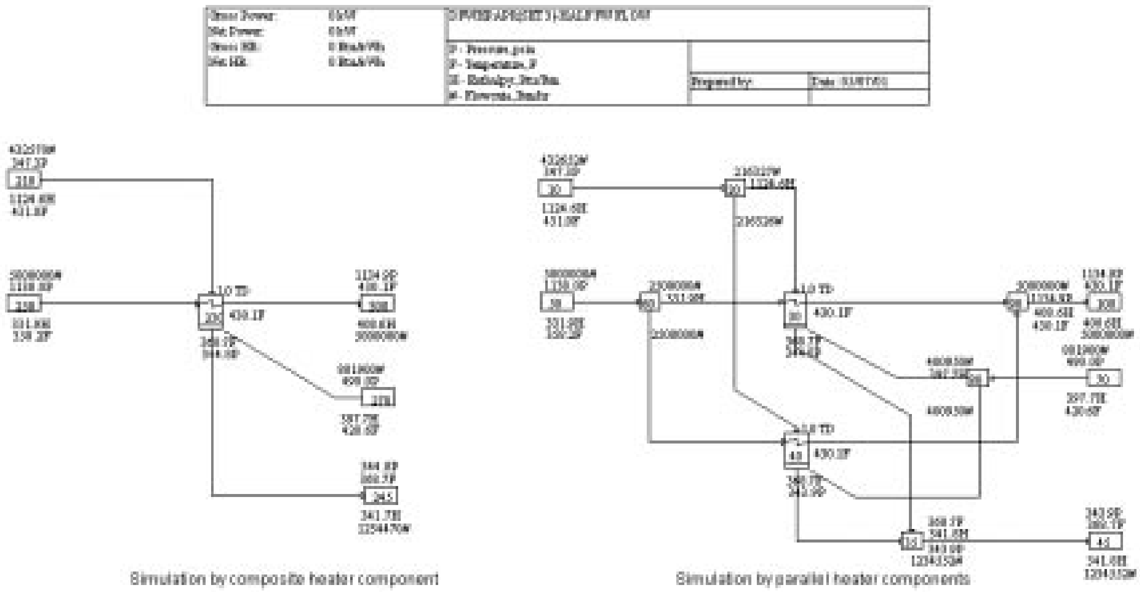


Figure 4 - Model results when feedwater flow is half of base case flow

The fourth case for analysis builds upon the third. Now the drain inlet flow rate boundary condition is reduced to zero, and the feedwater heater is left to depend solely on the steam inlet in order to fulfill its heat transfer objective. As seen in Figure 5, the results have changed relative to the preceding case, but the comparison from composite to parallel submodel in this case is quite good. Of all of the cases that have been run, this one has the largest discrepancy between composite and parallel. This discrepancy shows up in the value of the DCA, which is different by about 0.3°F for the two submodels. Because all other performance aspects are a very good match, this is not considered to be a significant difference.

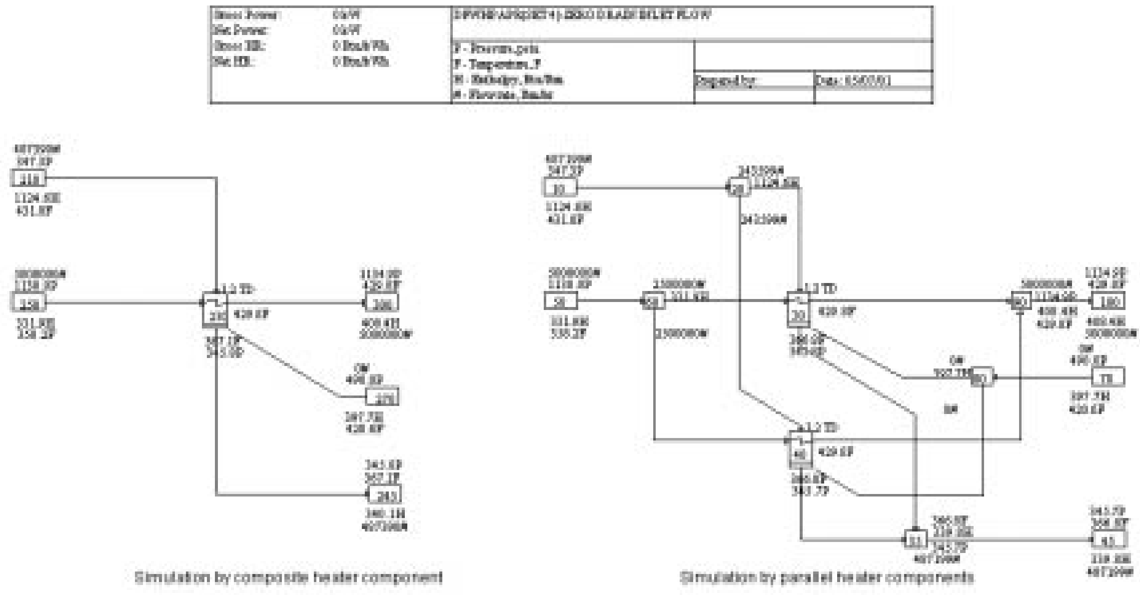


Figure 5 - Model results when feedwater flow is half of base flow and drain inlet flow is zero

In the final case, all boundary conditions are returned to those of the base case, except the feedwater temperature entering. This value is reduced from 358.2 F to 345 F. The results from this case are shown in Figure 6. As would be expected, the demanded steam flow increases compared to the base case. Furthermore, the TTD is larger than the TTD in the base case. The match between the results of the composite submodel and the parallel submodel are again excellent.

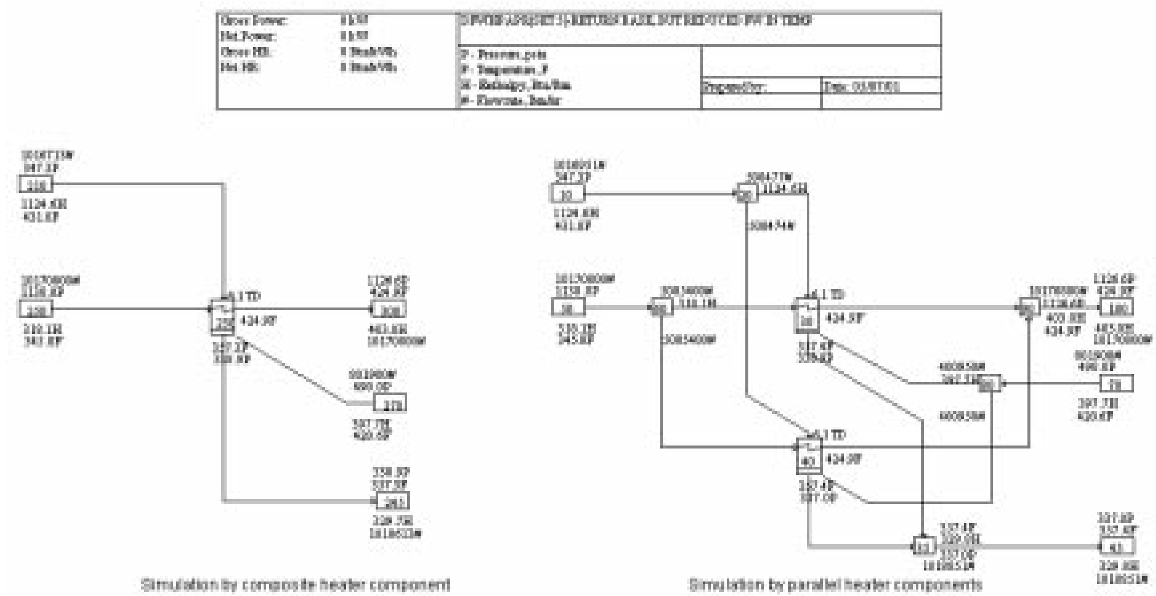


Figure 6 - Model results when feedwater temperature is reduced to 345 F, otherwise base description.

CONCLUSION

Heuristic considerations based on knowledge of the computation of heat transfer and flow in a design mode feedwater heaters have provided guidance for simplifying the modeling work. This simplification means representing two, three, or more parallel feedwater heaters as a single design mode component. The example application has shown that accurate results are obtained when these steps are taken.

ACKNOWLEDGMENT

This paper was inspired by a question asked by Mr. Toshi Maeda of CSAJ, Tokyo, Japan.

BIBLIOGRAPHY

G. Minner, et al, “PEPSE Manual Volume II, Engineering Model Description”, Halliburton NUS Corporation, 1995.

APPENDIX

This appendix provides additional information about the inputs to the example PEPSE model and the results from the model. The data are the descriptions of the composite and the parallel representations of the design mode feedwater heater. The results are contained in the control table from the tuning of the model.

Table 1 - “Minimum Data” form for composite feedwater heater submodel

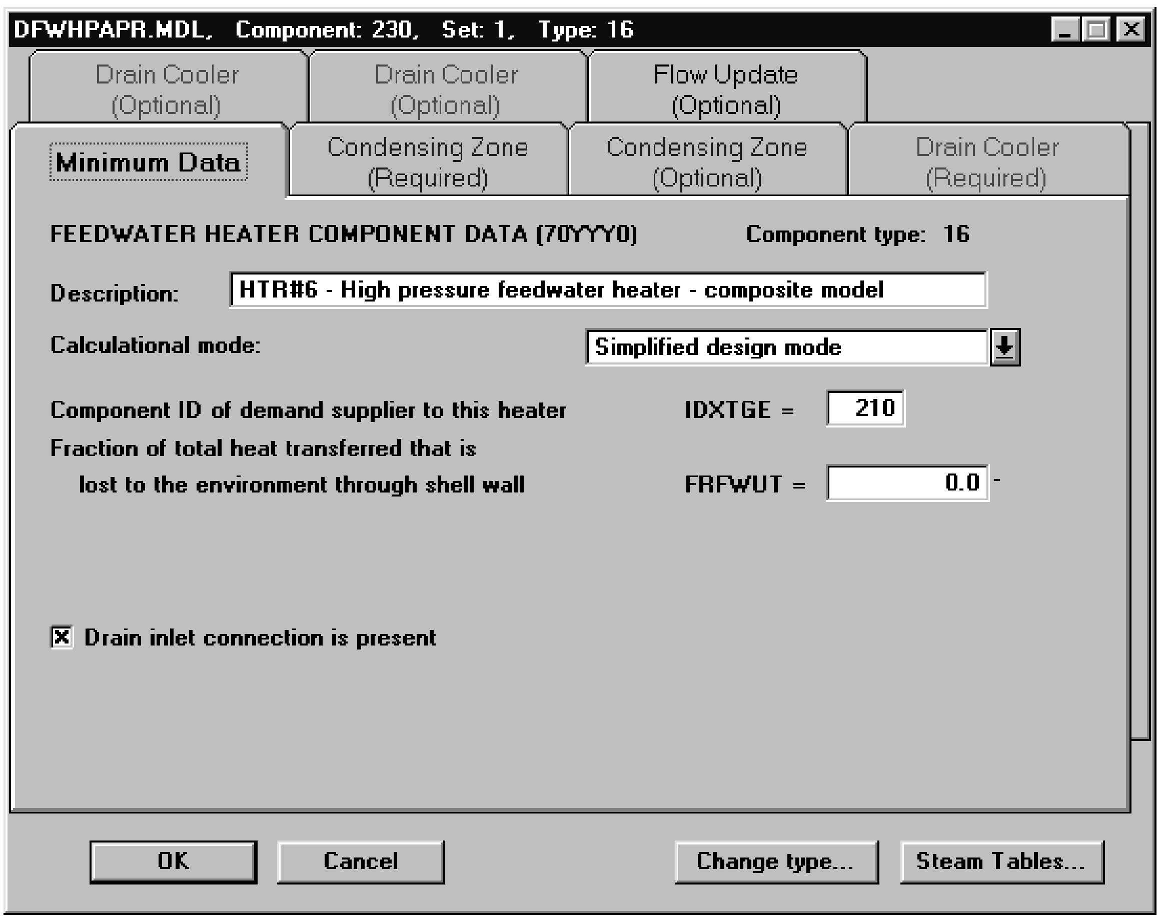


Table 2 - “Minimum Data” form for parallel feedwater heater submodel

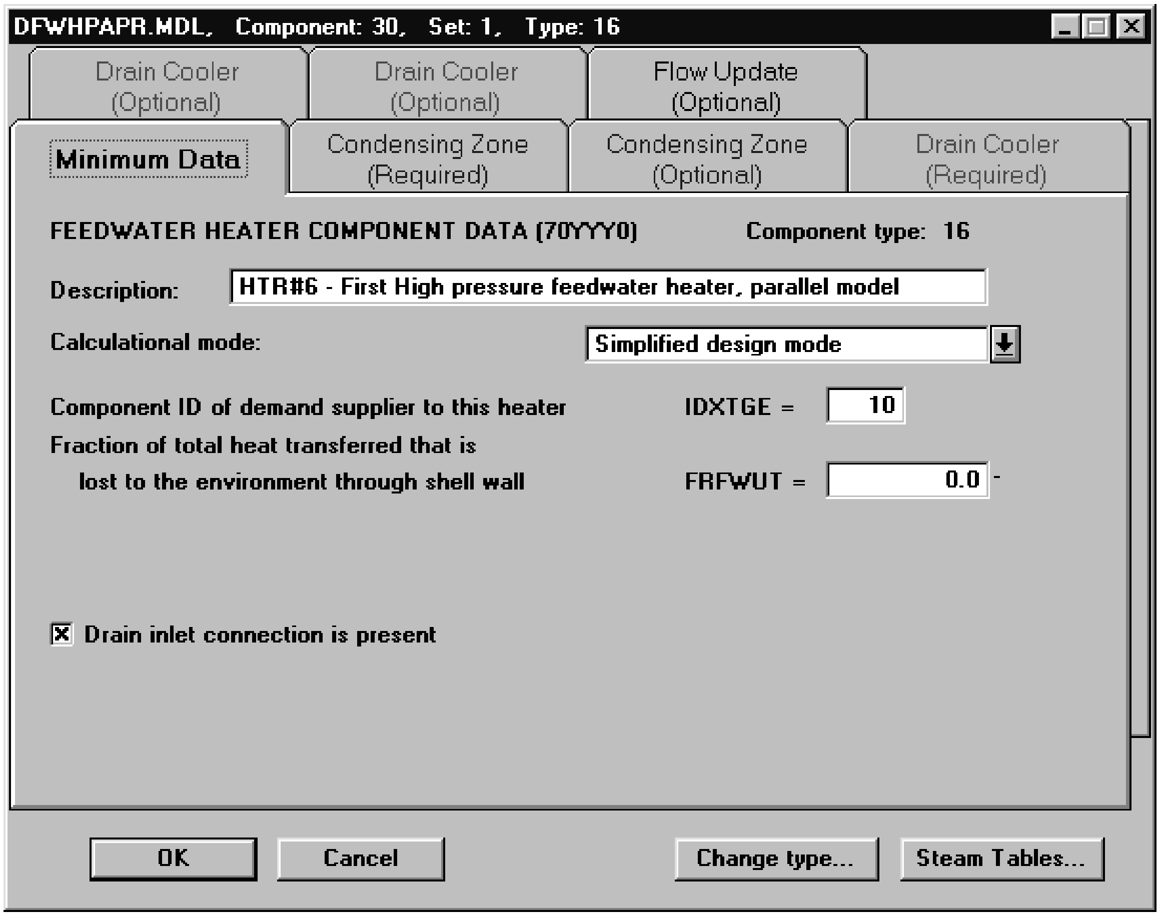
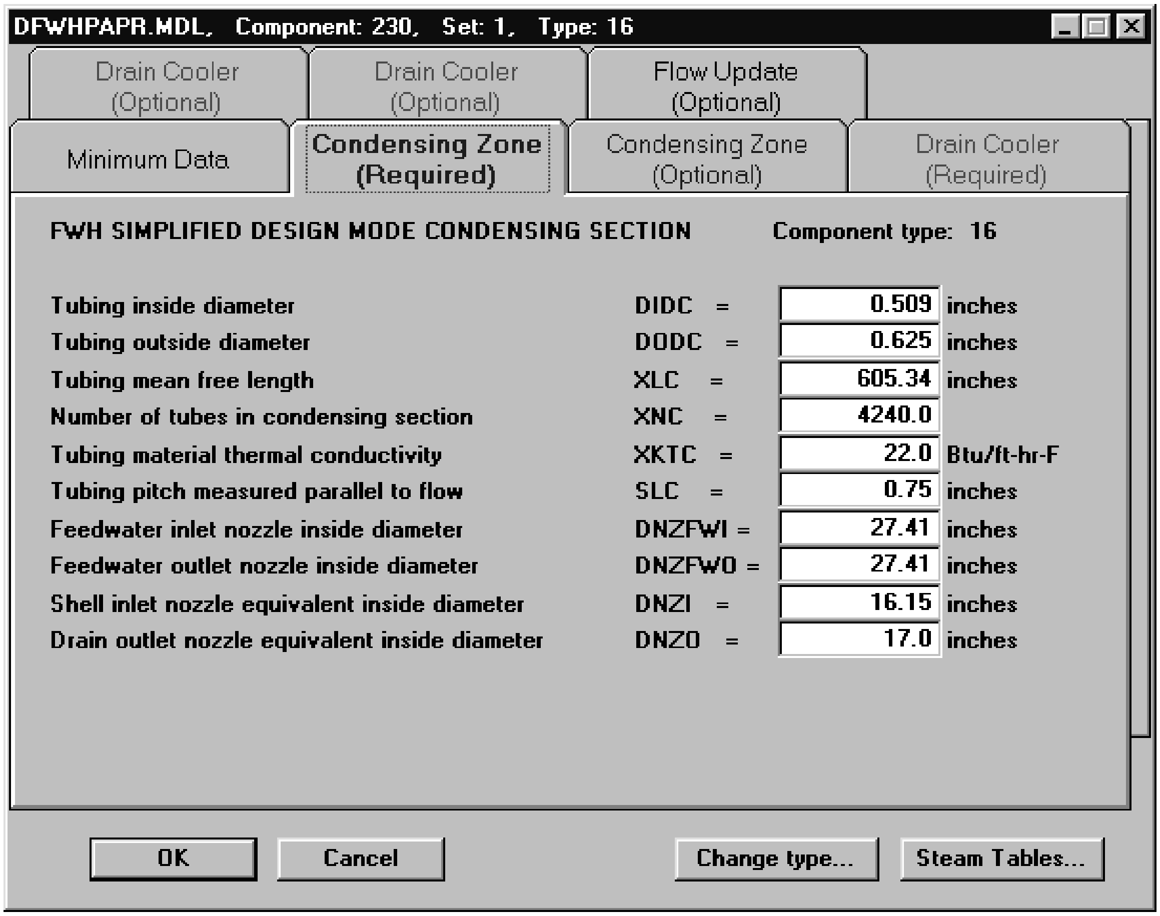


Table 3 - “Condensing Zone (required)” form for composite feedwater heater submodel


DFWHPAPR.MDL, Component: 230, Set: 1, Type: 16

Drain Cooler (Optional) | Drain Cooler (Optional) | Flow Update (Optional)

Minimum Data | Condensing Zone (Required) | Condensing Zone (Optional) | Drain Cooler (Required)

FWH SIMPLIFIED DESIGN MODE CONDENSING SECTION   Component type: 16

Tubing inside diameter	DIDC =	0.509	inches
Tubing outside diameter	DODC =	0.625	inches
Tubing mean free length	XLC =	605.34	inches
Number of tubes in condensing section	XNC =	4240.0	
Tubing material thermal conductivity	XKTC =	22.0	Btu/ft-hr-F
Tubing pitch measured parallel to flow	SLC =	0.75	inches
Feedwater inlet nozzle inside diameter	DNZFWI =	27.41	inches
Feedwater outlet nozzle inside diameter	DNZFWO =	27.41	inches
Shell inlet nozzle equivalent inside diameter	DNZI =	16.15	inches
Drain outlet nozzle equivalent inside diameter	DNZO =	17.0	inches

OK | Cancel | Change type... | Steam Tables...

Table 4 - “Condensing Zone (required)” form for parallel feedwater heater submodel

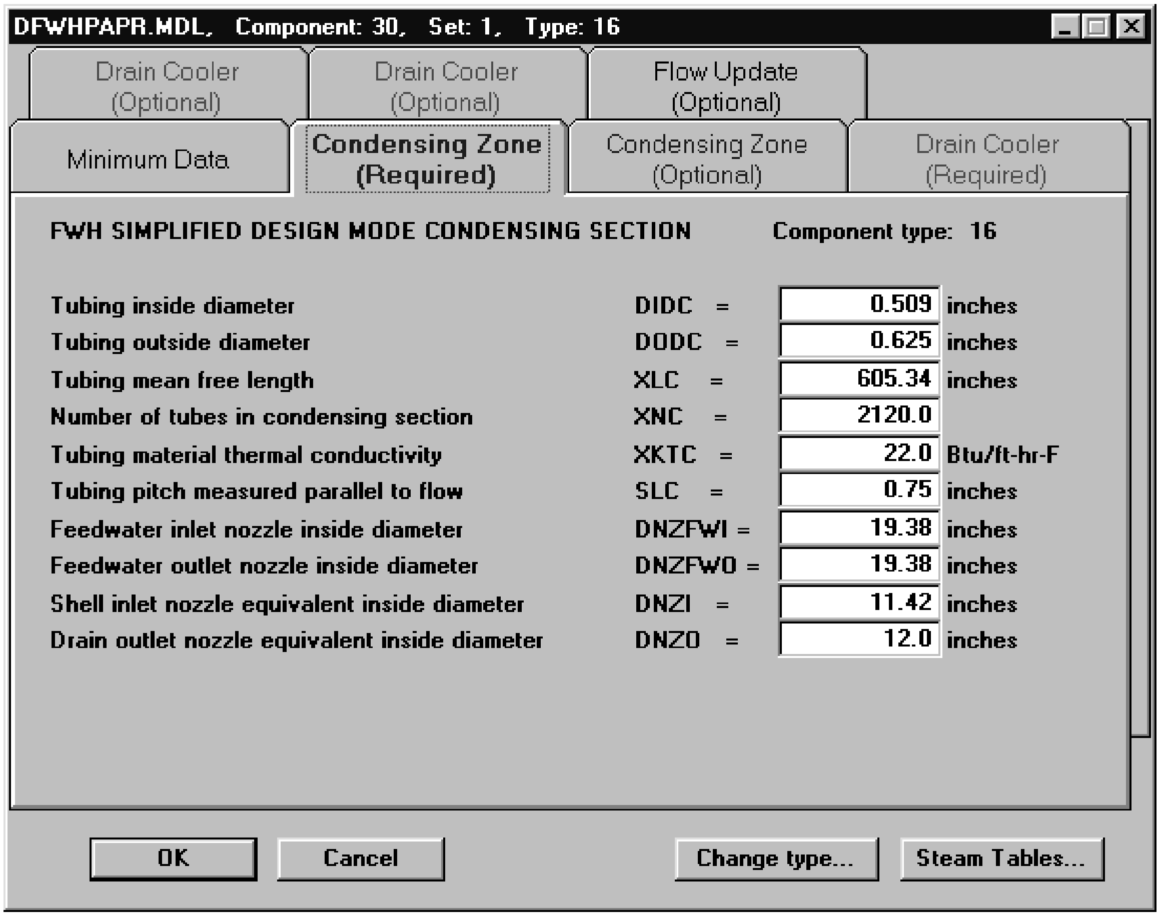
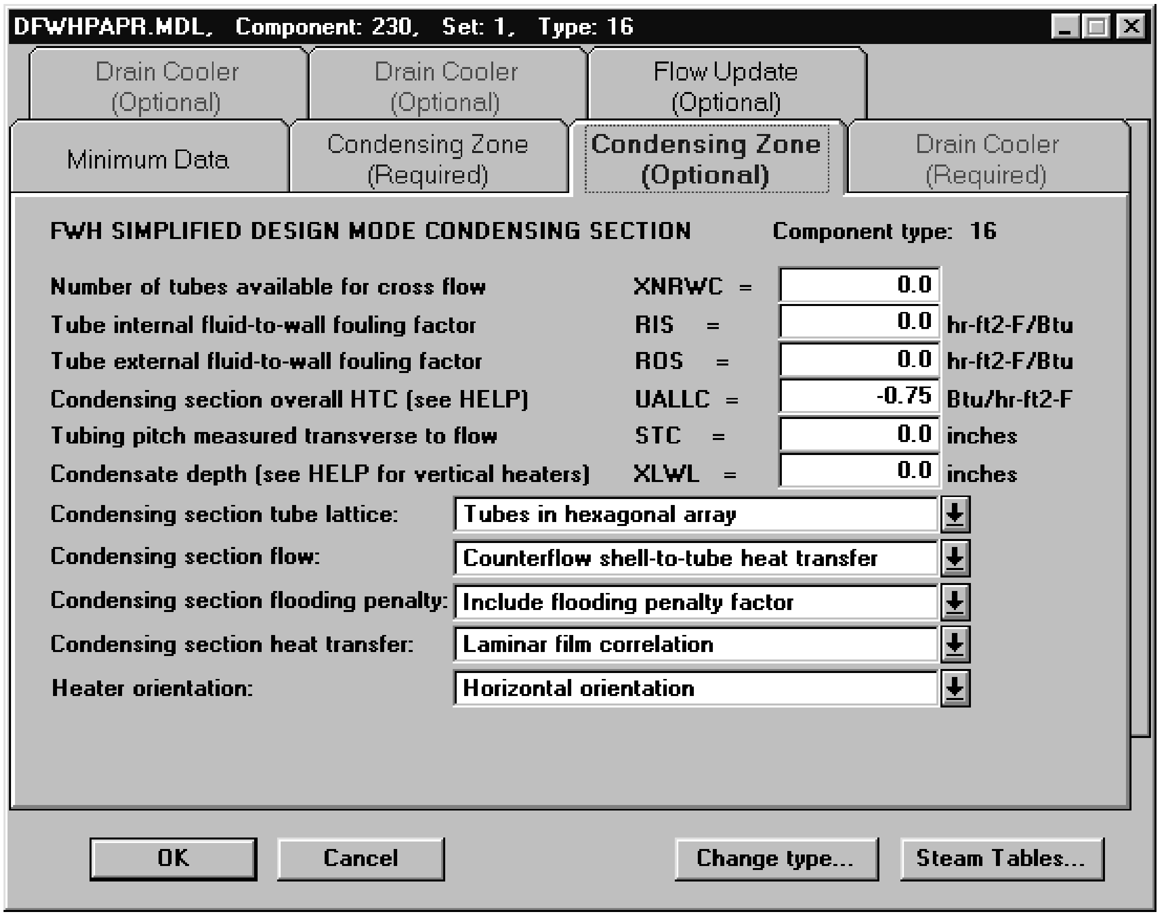


Table 5 - "Condensing Zone (optional)" form for composite feedwater heater submodel



DFWHPAPR.MDL, Component: 230, Set: 1, Type: 16

Drain Cooler (Optional) | Drain Cooler (Optional) | Flow Update (Optional)

Minimum Data | Condensing Zone (Required) | Condensing Zone (Optional) | Drain Cooler (Required)

FWH SIMPLIFIED DESIGN MODE CONDENSING SECTION   Component type: 16

Number of tubes available for cross flow	XNRWC =	0.0	
Tube internal fluid-to-wall fouling factor	RIS =	0.0	hr-ft2-F/Btu
Tube external fluid-to-wall fouling factor	ROS =	0.0	hr-ft2-F/Btu
Condensing section overall HTC (see HELP)	UALLC =	-0.75	Btu/hr-ft2-F
Tubing pitch measured transverse to flow	STC =	0.0	inches
Condensate depth (see HELP for vertical heaters)	XLWL =	0.0	inches

Condensing section tube lattice:	Tubes in hexagonal array
Condensing section flow:	Counterflow shell-to-tube heat transfer
Condensing section flooding penalty:	Include flooding penalty factor
Condensing section heat transfer:	Laminar film correlation
Heater orientation:	Horizontal orientation

OK | Cancel | Change type... | Steam Tables...

Table 6 - "Condensing Zone (optional)" form for parallel feedwater heater submodel

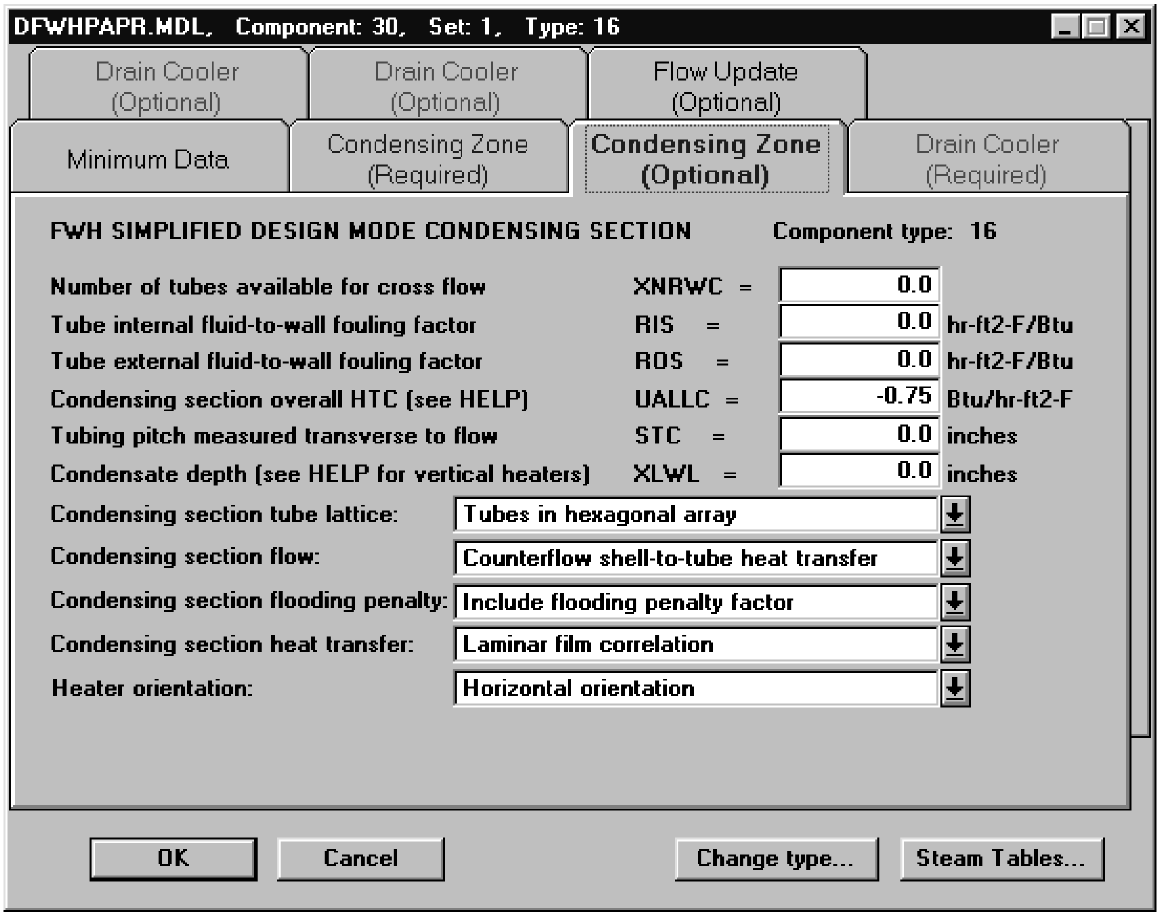


Table 7 - “Drain Cooler (required)” form for composite feedwater heater submodel

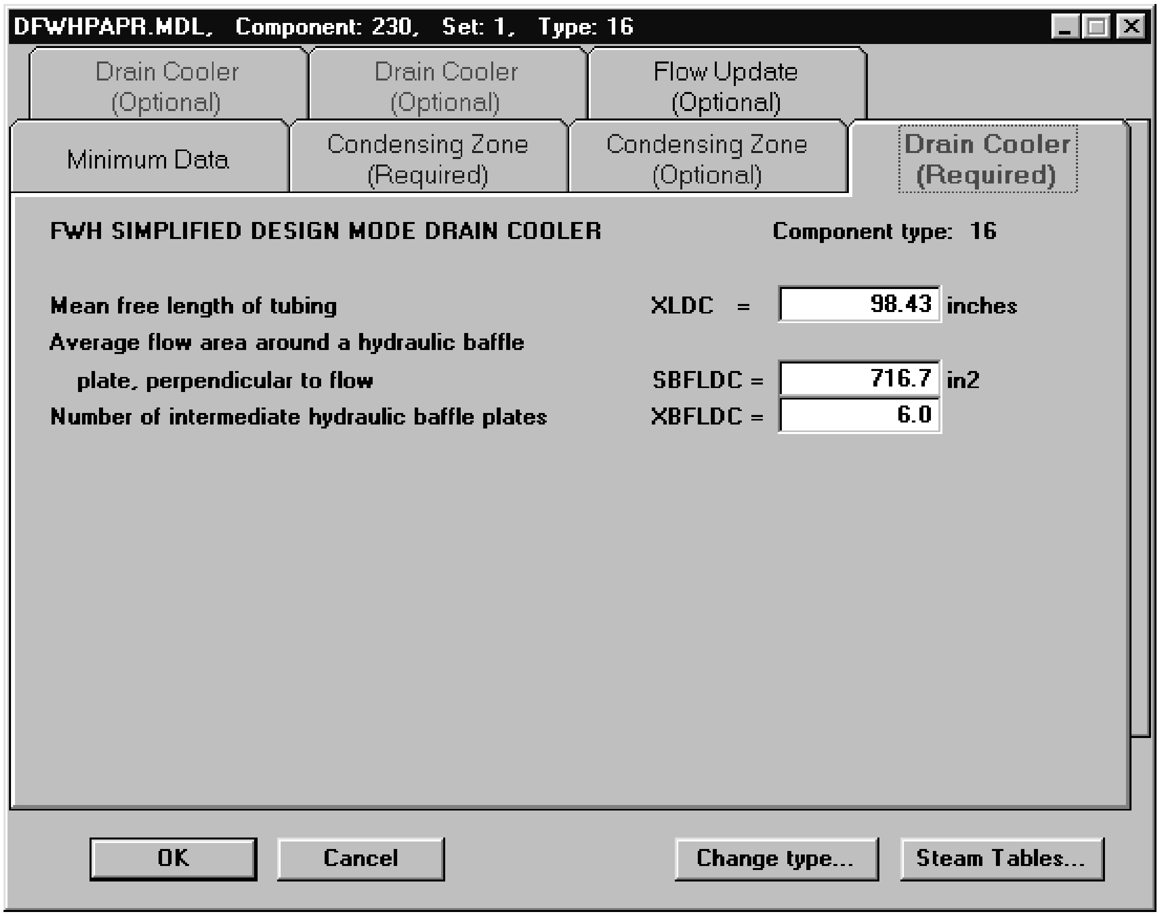


Table 8 - "Drain Cooler (required)" form for parallel feedwater heater submodel

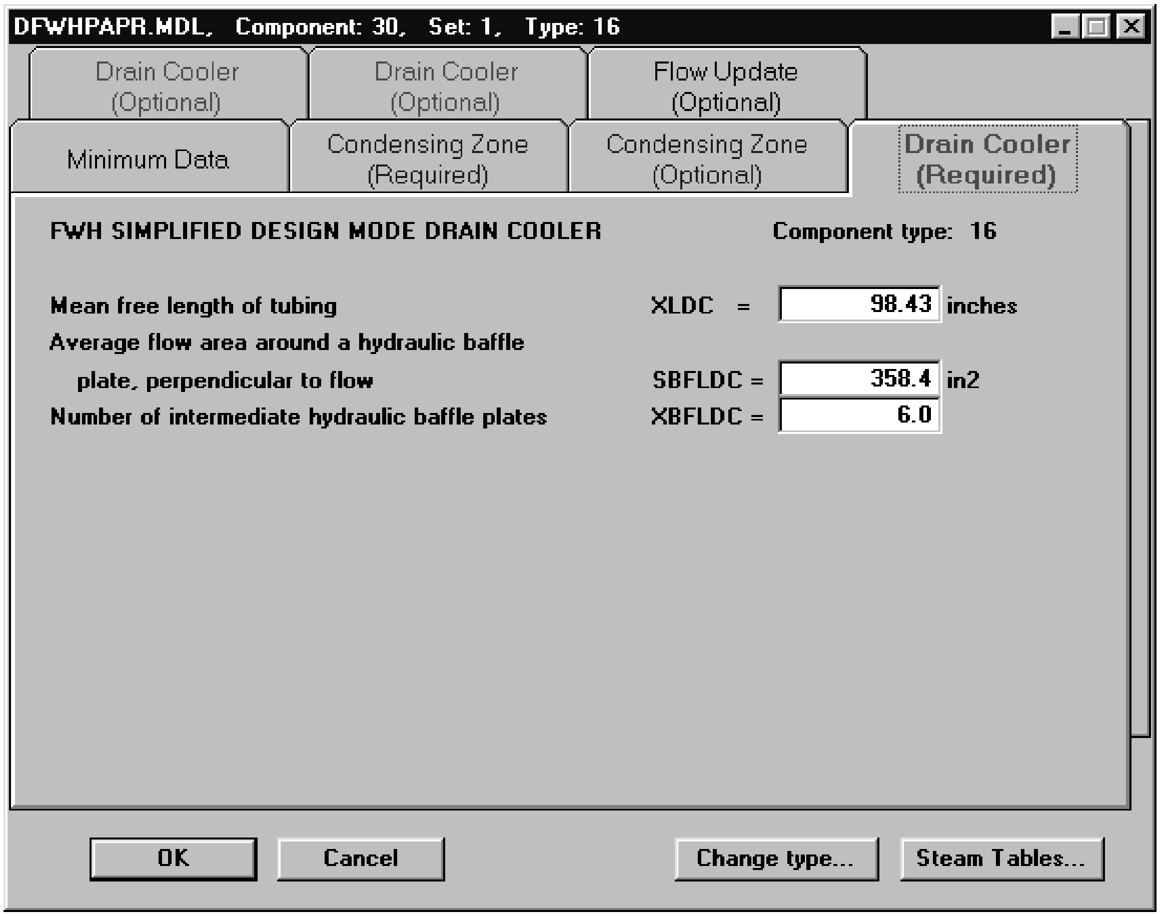
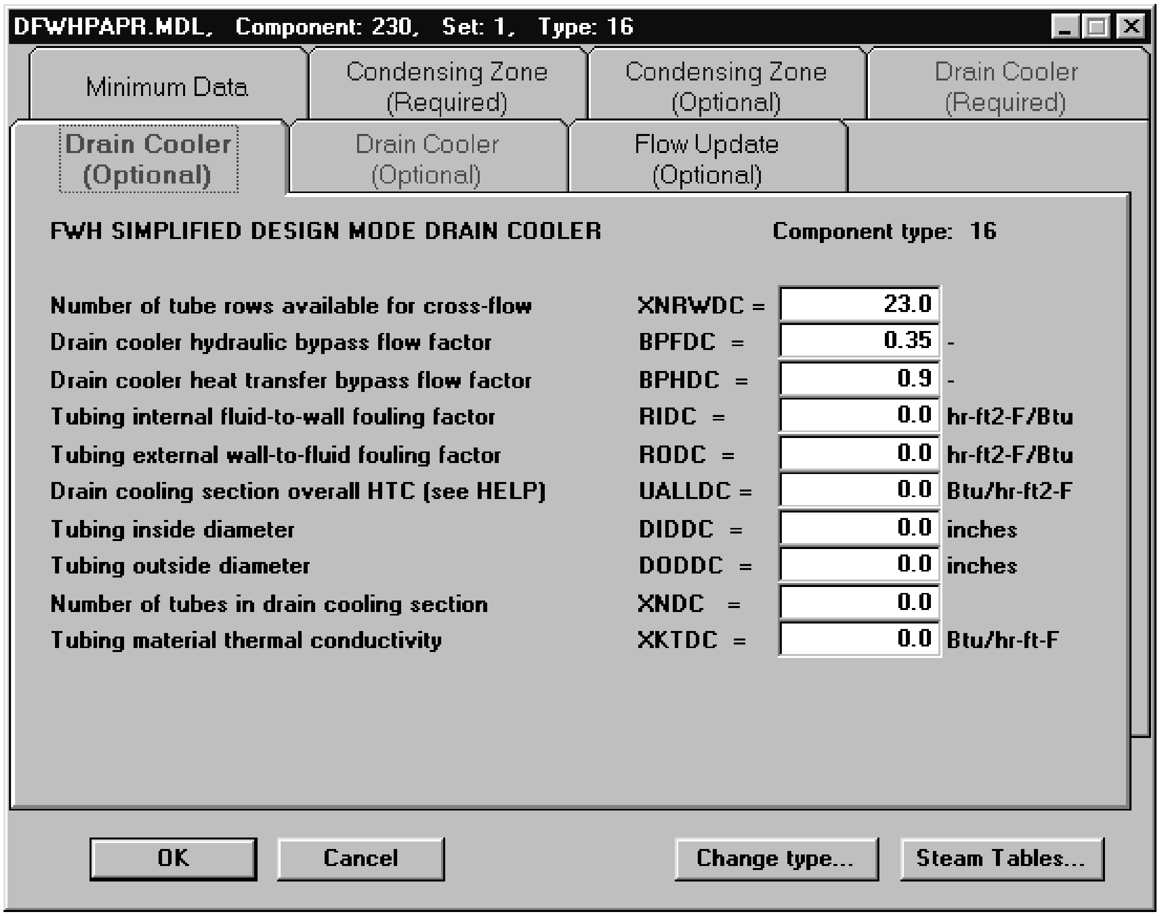


Table 9 - “Drain Cooler (optional)” form for composite feedwater heater submodel



DFWHPAPR.MDL, Component: 230, Set: 1, Type: 16

Minimum Data | Condensing Zone (Required) | Condensing Zone (Optional) | Drain Cooler (Required)

Drain Cooler (Optional) | Drain Cooler (Optional) | Flow Update (Optional)

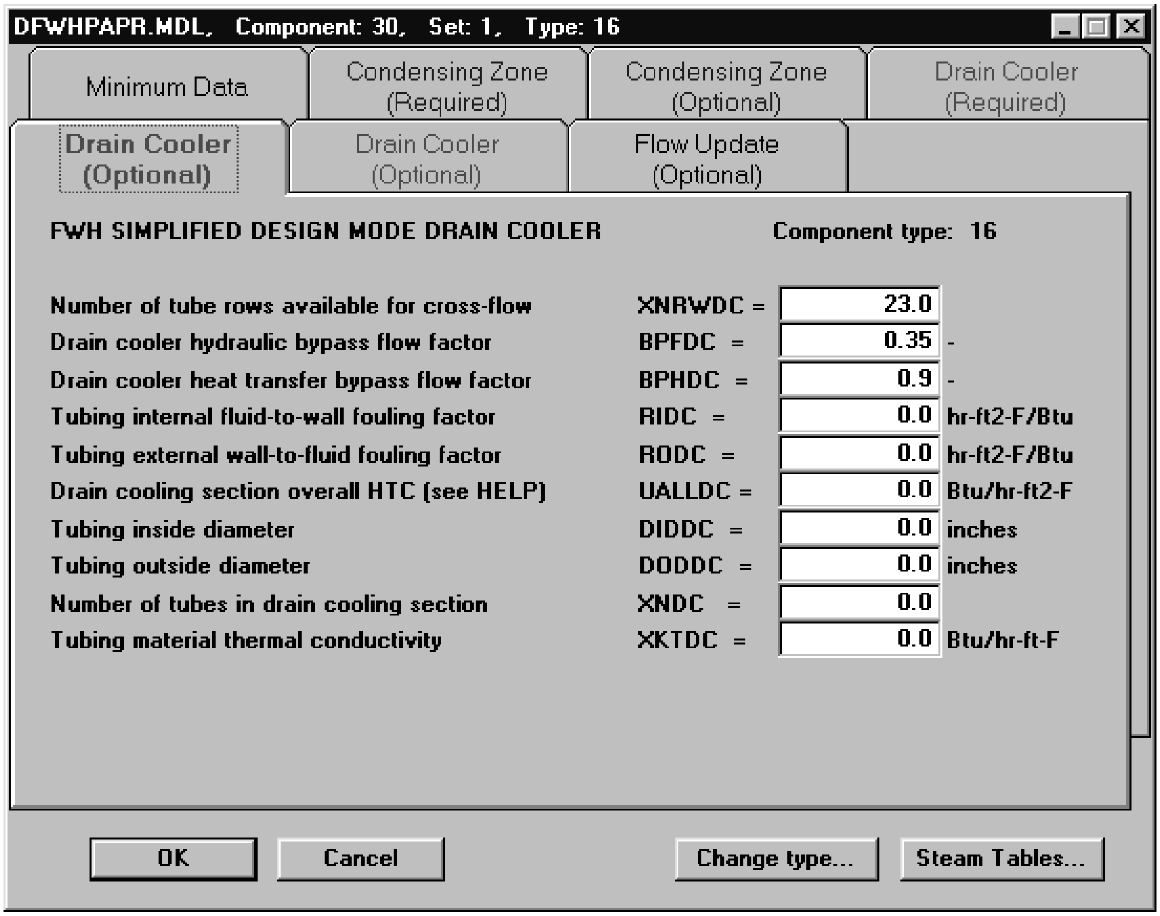
FWH SIMPLIFIED DESIGN MODE DRAIN COOLER

Component type: 16

Number of tube rows available for cross-flow	XNRWDC =	23.0	
Drain cooler hydraulic bypass flow factor	BPFDC =	0.35	-
Drain cooler heat transfer bypass flow factor	BPHDC =	0.9	-
Tubing internal fluid-to-wall fouling factor	RIDC =	0.0	hr-ft2-F/Btu
Tubing external wall-to-fluid fouling factor	RODC =	0.0	hr-ft2-F/Btu
Drain cooling section overall HTC (see HELP)	UALLDC =	0.0	Btu/hr-ft2-F
Tubing inside diameter	DIDDC =	0.0	inches
Tubing outside diameter	DODDC =	0.0	inches
Number of tubes in drain cooling section	XNDC =	0.0	
Tubing material thermal conductivity	XKTDC =	0.0	Btu/hr-ft-F

OK | Cancel | Change type... | Steam Tables...

Table 10 - “Drain Cooler (optional)” form for parallel feedwater heater submodel



DFWHPAPR.MDL, Component: 30, Set: 1, Type: 16

Minimum Data | Condensing Zone (Required) | Condensing Zone (Optional) | Drain Cooler (Required)

Drain Cooler (Optional) | Drain Cooler (Optional) | Flow Update (Optional)

FWH SIMPLIFIED DESIGN MODE DRAIN COOLER

Component type: 16

Number of tube rows available for cross-flow	XNRWDC =	23.0	
Drain cooler hydraulic bypass flow factor	BPFDC =	0.35	-
Drain cooler heat transfer bypass flow factor	BPHDC =	0.9	-
Tubing internal fluid-to-wall fouling factor	RIDC =	0.0	hr-ft2-F/Btu
Tubing external wall-to-fluid fouling factor	RODC =	0.0	hr-ft2-F/Btu
Drain cooling section overall HTC (see HELP)	UALLDC =	0.0	Btu/hr-ft2-F
Tubing inside diameter	DIDDC =	0.0	inches
Tubing outside diameter	DODDC =	0.0	inches
Number of tubes in drain cooling section	XNDC =	0.0	
Tubing material thermal conductivity	XKTDC =	0.0	Btu/hr-ft-F

OK | Cancel | Change type... | Steam Tables...

Table 11 - Computed results of controls from tuning to feedwater heater TTD and DCA in base case model

CONTROLLED VARIABLE VALUES CALCULATED

CONTROL SET	Y VARIABLE/ VALUE FROM ITERATE 11	FRAC(ABS) DEVIATION FROM GOAL	Y VARIABLE GOAL VALUE	X VARIABLE/ VALUE USED AT ITERATE 11	CONVG	LAST ITN X LIMTD
1	1.0E+00 * TTDOUT(230)			UALLC (230)		
	4.99977E+00	4.7E-05	5.00000E+00	-7.47648E-01	YES	
2	1.0E+00 * TTDOUT(30)			UALLC (30)		
	4.99992E+00	1.6E-05	5.00000E+00	-7.47596E-01	YES	
3	1.0E+00 * TTDOUT(40)			UALLC (40)		
	4.99991E+00	1.8E-05	5.00000E+00	-7.47595E-01	YES	
11	1.0E+00 * DCAOUT(230)			BPHDC (230)		
	9.99386E+00	6.1E-04	1.00000E+01	8.80485E-01	YES	
12	1.0E+00 * DCAOUT(30)			BPHDC (30)		
	9.99375E+00	6.2E-04	1.00000E+01	8.84662E-01	YES	
13	1.0E+00 * DCAOUT(40)			BPHDC (40)		
	9.99394E+00	6.1E-04	1.00000E+01	8.84662E-01	YES	
21	1.0E+00 * PP(-232)			BPFDC (230)		
	3.40603E+02	-8.5E-06	3.40600E+02	1.93957E-01	YES	
22	1.0E+00 * PP(-32)			BPFDC (30)		
	3.40597E+02	7.6E-06	3.40600E+02	2.74266E-01	YES	