# MODELING OF GAS TURBINE ENGINES, HEAT RECOVERY STEAM GENERATORS, AND COMBINED CYCLES USING PEPSE®

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## ABSTRACT

Guidance is provided for PEPSE modeling of gas turbine engines, heat recovery steam generators, and combined cycle plants.  Suggestions for modeling are based on experience gained in developing computational coding and in making models of numerous arrangements of combined cycle units.  Some of the details are specific to the latest version of PEPSE that is in development, Version 64 and GT3.0.

## INTRODUCTION

Considerable attention and emphasis is being given to electric power generation systems that include gas turbine (GT) engines, heat recovery steam generators (HRSG's), supplemental firing, and combined cycles (CC's) that include both gas and steam turbines. These systems frequently provide significant improvements in operating efficiencies and reductions of pollutant emissions compared to older "conventional" power generation systems.

The need for computational tools to perform heat balance engineering calculations for these systems has arisen with this new emphasis. Recent enhancements in PEPSE have responded to these needs.

While the ability to analyze HRSG's has existed for over five years in PEPSE, experience has shown difficulties in applications in some cases. These difficulties have been the result of the complexity of the systems and the standard methods (in the industry) of representing the performance of HRSG stages. Understanding these computational hurdles can be a benefit by providing direction and reducing frustration in doing the analyses. In addition, understanding contributes to improvements in the program, devoted to modifying the computations to improve robustness. A compilation of a list of modeling techniques that work has been assembled. This report primarily discusses a group of modeling techniques that we have found useful in HRSG applications. However, occasional reference is also made to coding improvements that have provided significant benefits.

Included in the discussions here are several example models that illustrate the techniques discussed. When these examples are presented in schematic form, the computed results for analysis cases are included on the figures. The necessary details of modeling are described in Reference 1.

Any current PEPSE-GT Version 3.0 customer can access several of the models used here. The combined cycle models that are discussed in this paper are delivered with the installation disk of the PEPSE-GT program. These models are called COMBCY1, COMBCY2, COMBCY3, and COMBCY4, respectively, in the order in which they appear in this paper.

## SYSTEMS FOR CONSIDERATION

The systems involved in GT and CC applications can vary from the simple to the complex. The current versions of PEPSE and PEPSE-GT can be used to model this full range of complexity. Reference 2 gives a wide variety of examples of system arrangements and strategies for CC applications.

The simplest kind of system would be a GT engine driving a generator, with the hot exhaust gases passing out to atmosphere without further processing. A PEPSE model of such a system is shown in Figure 1. The purpose of such a model may be to calculate the electricity generated at design or off-design conditions or to calculate the air pollutant emissions for the GT.

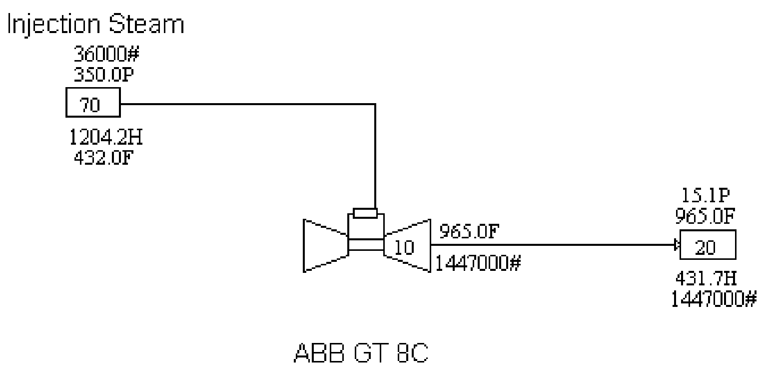
The power generation system becomes more complex if we choose to improve the efficiency by passing the GT's exhaust gases through heat exchangers to extract energy from the gas and reduce the temperature before the gas is discharged to atmosphere. The energy recovered by the heat exchangers can be used for a variety of applications. A few of these include heating of steam for injection into the combustion zone of the GT itself, or heating steam for sendout to some off-site process, or heating of steam for driving a steam turbine cycle. An example system that includes a HRSG for steam turbine applications is shown in Figure 2, which is model COMBCY1. The system has two GT engines having their exhaust gases ducted to a HRSG. In this system the steam turbine is provided "reheat" steam by the HRSG's reheater stages, coupled with steam supplied by the IP (intermediate pressure) HRSG loop. The LP (low pressure) portion of the HRSG

**Figure 1**

**Schematic Diagram Of A Submodel With A Type 77 Component**

**To Represent A Gas Turbine Engine**

GTENG3 - DEMO GLOBAL FACTORS CONTROLS




1.7220259e+008 Btu/hr - Gross wheel power

48.1 MW - generator terminal power

10760B/kWh - engine heat rate

1447000# lbm/hr - exh flow rate

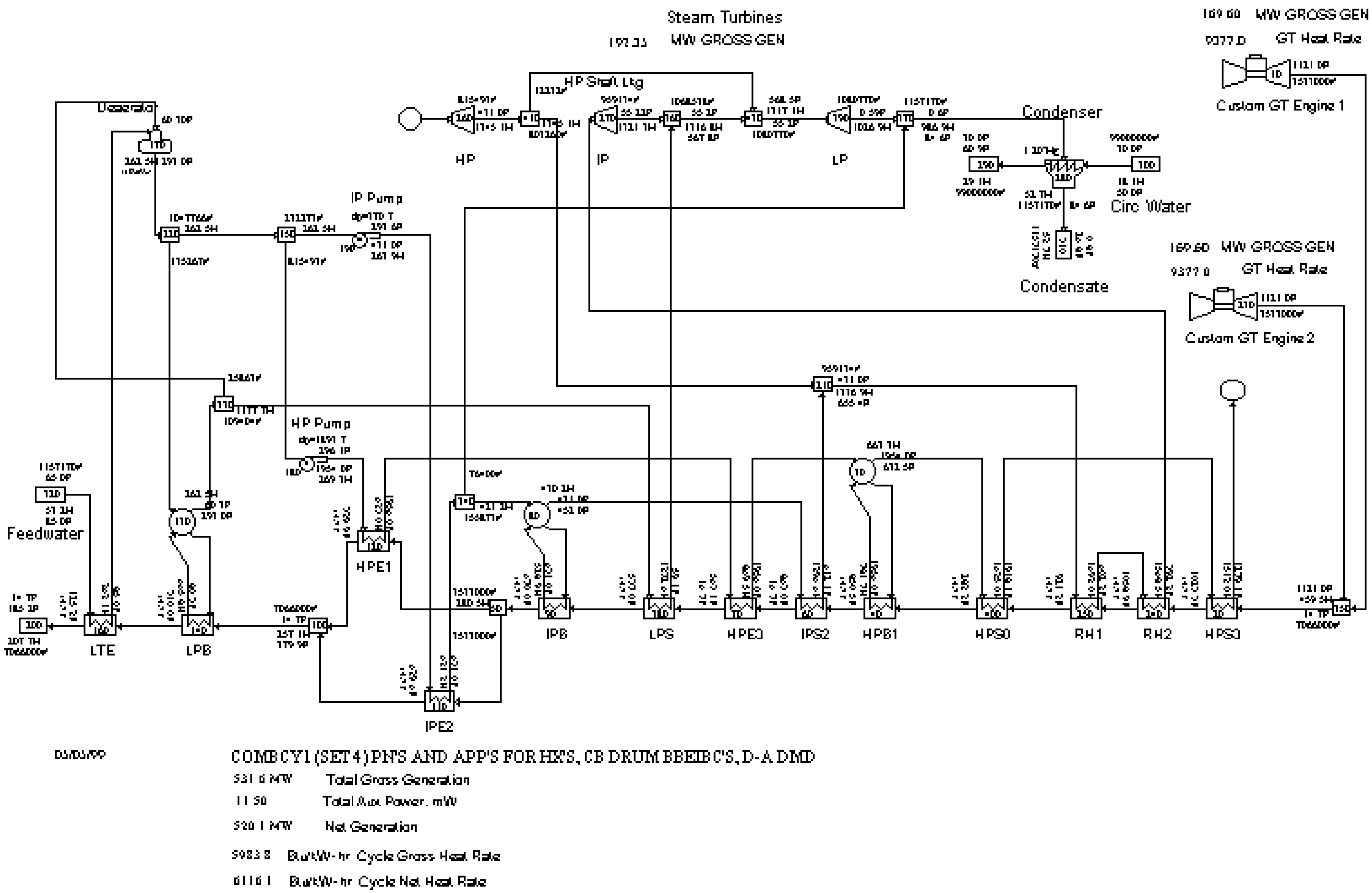
965.0F deg F, exh temp

24069# lbm/hr - fuel flow rate

1422931# lbm/hr - air flow rate

## Figure 2

## Schematic Diagram Of A Combined Cycle Model That Includes A GT Engine Component, A HRSG, And A Steam Turbine, With Process Steam Sendout (COMBCYC1 Model)



provides steam to the LP steam turbine. In addition the coolest gas in the HRSG provides water/steam heating in a drum loop for deaerating the steam.

Computational models of these kinds of systems and others have used the modeling techniques that are discussed in this report.

The models that appear in this paper as illustrations, include several “SET’s” of descriptions. These sets show varying ways of describing components and varying methods of applying controls to meet modeling objectives. These sets are arranged in the model “RUN” menus for multiple analysis “stacked” cases. Some of the cases use the performance mode parameters, pinches and approaches; and some use the simplified design mode heat transfer coefficients. Most of the techniques discussed in the balance of this report are applied in these models.

**GAS TURBINE MODELING**

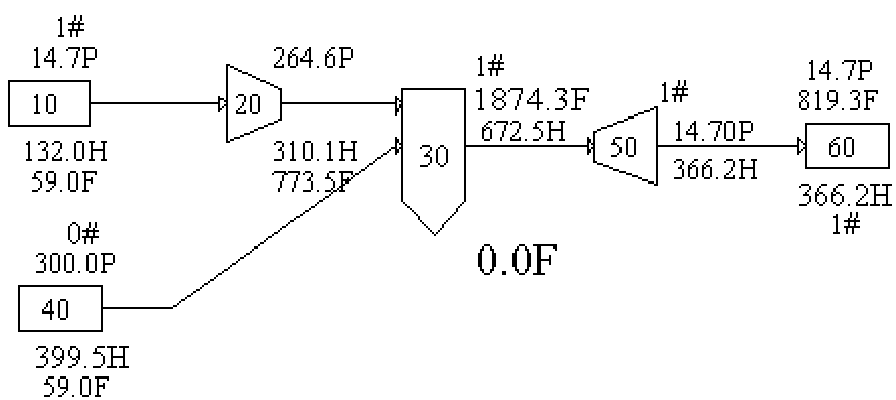
PEPSE Version 64, and older versions as well, provides tools for modeling GT engines in detail. Figure 3 shows a model that could be used on these PEPSE versions to analyze a GT. As seen in the schematic, the model consists of a source of air flow, a source of fuel flow, a Type 44 compressor component, a Type 70 combustor component, a Type 9 “gas turbine” (expander) component, and a sink to receive the exhaust gas flow. Also included in the input data for the model description would be a generator.

This model provides the opportunity to do detailed analysis of the effects of compressor pressure ratio, of bleed flows from the compressor to turbine, of intercooling or regeneration, and other assorted internal effects of the engine. User inputs for this model would include pressure and heat losses, if any, compressor pressure ratio and efficiency and turbine efficiency, and so forth. PEPSE Version 64 does not include built-in correlations for the component parts’ efficiencies or pressure ratios of any specific engines. Such information is proprietary to the engine manufacturers, generally closely

**Figure 3**

**Schematic Diagram Of A Submodel To Represent A Gas Turbine Engine By Compressor, Combustor, And Expander Components.**

Simple Gas Turbine - modeled in parts

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guarded for their competitive benefit. However, PEPSE includes the tools that enable a user to input these characterizations, in the form of performance “maps”, using schedules, operations, curve fits, and compiled algorithms when the user is able to obtain such proprietary information from a vendor.

Models such as this one can be used as shown, for analyzing the GT as a stand-alone, or the significant parts could be included in a model of a larger system for more extensive analyses.

The PEPSE-GT program provides the methods discussed above and additional GT modeling capabilities. The schematic diagram shown in Figure 1 illustrates a submodel of a GT engine, where a Type 77 component represents the complete engine. In addition to this model, which focuses attention on the engine as a single entity, it is also possible to use the Type 77 component in a larger system model, as shown in Figure 2.

The Type 77 component includes the compressor, combustor, and expander items within a single PEPSE module. This GT engine component can be used to compute net electrical generator power, the heat rate, the associated fuel and air inflow, the water or steam injection flow, as applicable, and the exhaust gas flow and temperature. Performance descriptions of over 400 available vendor GT engines are built into PEPSE. For the most part, these descriptions have been extracted from the literature, such as reference 3. Data also have been provided directly to us by vendors.

It is a simple matter for a modeler to select a specific vendor’s engine from a pick-list in the PEPSE graphics program; whereupon the design-point key parameters are automatically employed. These are: generator power, heat rate, engine flow rate, and exhaust temperature. Calculations automatically account for operation at off-design conditions. In addition to the built-in GT engine descriptions, it is possible for a modeler to specify the key parameter values and the effects due to off-design operation for any engine.

In addition to these tools, additional tuning factors are provided for use in closely matching a specific calculation's results with a tested or claimed performance item. In addition, these tuning parameters can be used in order to obtain an energy balance for the GT engine component in the results. We have found that energy balance tuning may be needed because of difficulties in obtaining an exact energy balance based on the data provided by the vendors. This may be a consequence of assumptions that we had to make in obtaining closure of our calculations. Among these assumptions are: location of the point where the engine flow rate is reported (the air inlet or the engine exhaust, the heating value for the fuel, losses in the generator and its drive system, and others. There are uncertainties and ambiguities about these and other points in the Reference 3 information.

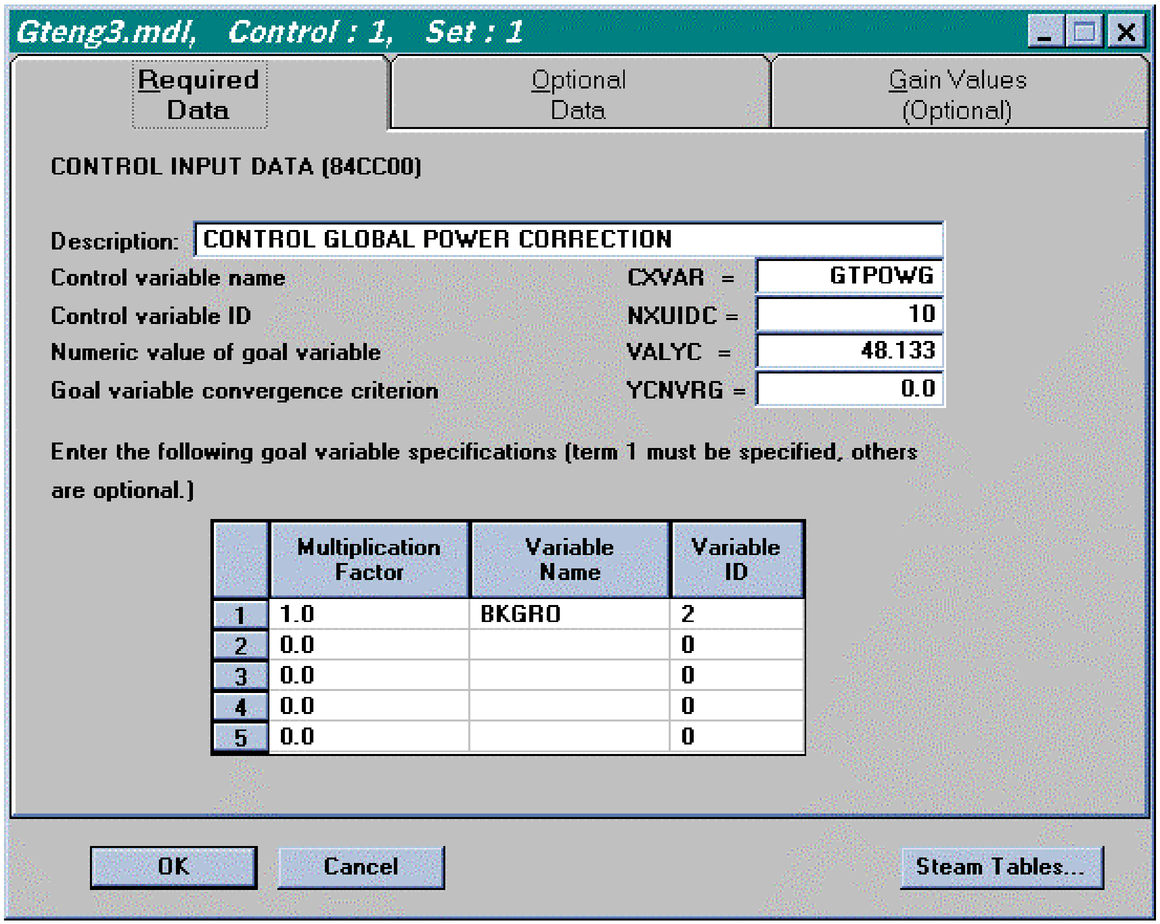
An example of a completed form for a control used to tune a gas turbine engine's generation factor is shown in Table 1. The control variable is GTPOWG, for turbine component 10, with a goal value of 48.133 mW. The goal variable is BKGRO, for generator number 2 in the model. The model includes similar controls for tuning the other global factors to obtain heat rate, temperature, and flow. In this model all of the controls were placed in a control block in order to account for the interdependencies of the controls. Convergence was straightforward.

## SIMPLE HRSG MODELING APPLICATION

A diagram of a simple HRSG modeling application is shown in Figure 4. In this system, hot exhaust gases from the GT engine (not shown, but represented by a gas source component) are passed through several stages of water and steam heat exchangers in a heat recovery boiler. The heating provides evaporation for a deaerating loop and for a single-pressure steam sendout to a process customer.

# Table 1

## Completed Forms Showing The PEPSE Control Used For Tuning The GT Engine, Type 77 Component, Results To Match Available Data



Gteng3.mdl, Control : 1, Set : 1

Required Data | Optional Data | Gain Values (Optional)

CONTROL INPUT DATA (84CC00)

Description: CONTROL GLOBAL POWER CORRECTION

Control variable name CXVAR = GTPOWG

Control variable ID NXUIDC = 10

Numeric value of goal variable VALYC = 48.133

Goal variable convergence criterion YCNVRG = 0.0

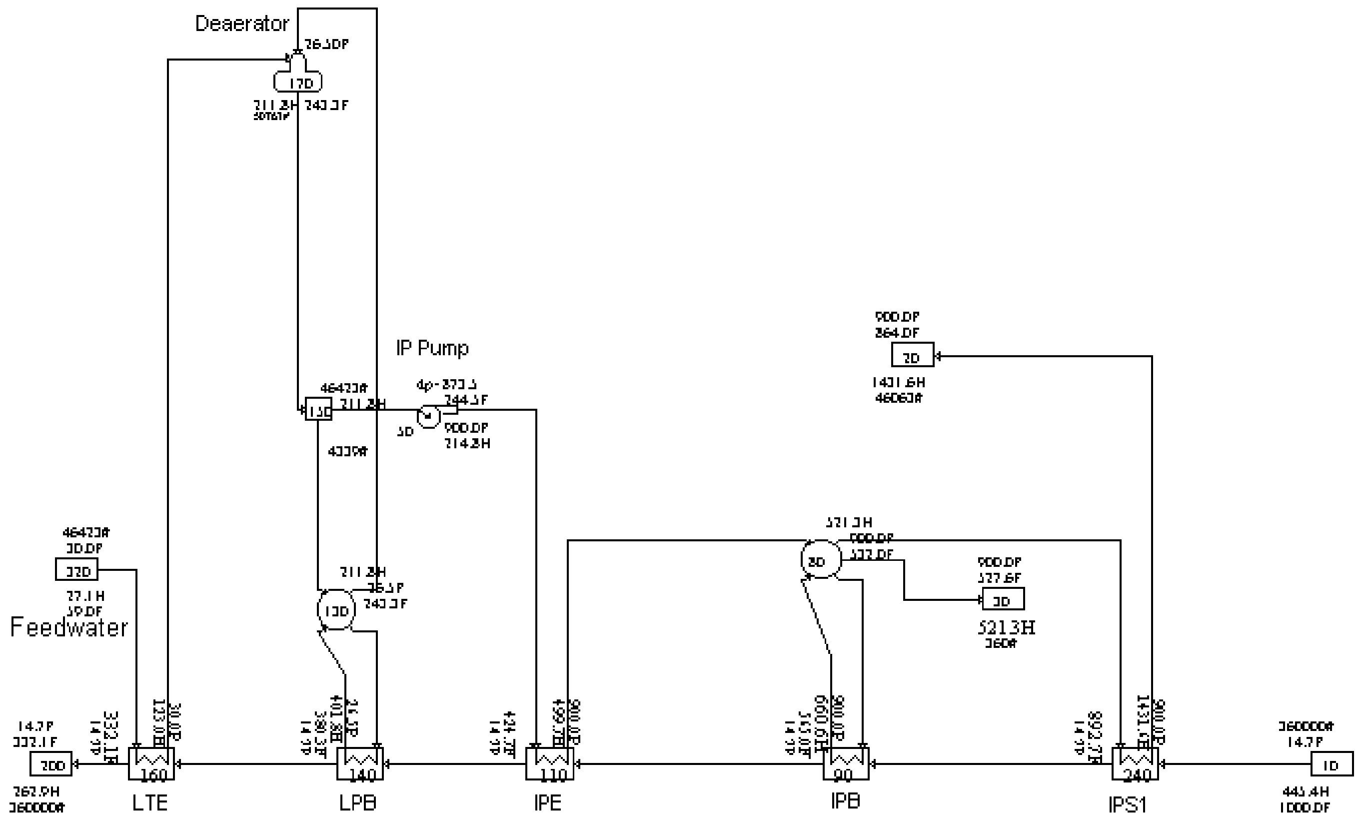
Enter the following goal variable specifications (term 1 must be specified, others are optional.)

| | Multiplication Factor | Variable Name | Variable ID |
|---|---|---|---|
| 1 | 1.0 | BKGRO | 2 |
| 2 | 0.0 | | 0 |
| 3 | 0.0 | | 0 |
| 4 | 0.0 | | 0 |
| 5 | 0.0 | | 0 |

OK Cancel Steam Tables...

**Figure 4**

**Schematic Diagram Of A Heat Recovery Boiler To Provide Process Steam Sendout**




05/05/99 TB19F1A (SET 3) - CNTRL TO MATCH IP PINCH

The significant components used in this model are the Type 28 heat exchangers to represent the HRSG economizer, evaporator, and superheater stages, the Type 74 drum to separate the steam and liquid, the Type 15 deaerator component, and the pump. It is typical that the performance of the HRSG heat exchangers is represented by "performance mode", using a pinch value for the evaporator component and approach values for the economizer and superheater components. Over some limited range of operation it is common to assume that these performance parameters remain fixed. Note that the pinch for the evaporator is a relation between the steam saturation temperature and the gas exit temperature. The approach for the economizer is a relation between the steam saturation temperature and the liquid-exiting temperature. For the superheater, the approach is the difference between the gas entering temperature and the steam exiting temperature.

Use of the pinch for an evaporator in doing calculations can be especially troublesome. This is because the pinch applies strictly at the operating point at which it was derived. If excursions of steam-side pressure, or of gas incoming temperature, or of flow proportions occur due to significant changes of operating point or due to iteration effects, the fact that pinch dictates the gas outlet temperature can drive steam-side energy to unreasonable values. This can abort the computation directly in the evaporator, or it can cause non-physical results in a receiving component. Behavior of an evaporator in a computation should be examined/monitored, especially in cases where there are difficulties in obtaining a converged solution. Use of our suggested modeling techniques can be helpful in resolving these troubles.

Also available in PEPSE are other, "design mode", methods of characterizing the thermal performance of the heat exchangers. The first of these is a simplified design-mode calculation, where the heat transfer is characterized by an overall heat transfer coefficient, which has a built-in adjustment according to flow rate. This mode can be useful for more accurately predicting heat transfer over a wider range of operation than would be reasonable for the pinch and approach method. The second method offers the opportunity to perform a full design mode calculation, using the Type 28 component description much as it is frequently used in modeling fossil boiler “convective stages”. In this method, the user gives details such as tube diameters, lengths, thermal conductivities, and so forth. From this information, the built-in hydraulic and thermal correlations, and the local incoming conditions, PEPSE calculates the heat and hydraulic performance. This latter method is more versatile and adaptive than the other two methods, but accumulating the needed data is time consuming and is less commonly used in modeling combined cycle systems.

A control was written for this model to match a pinch value by adjusting the water-side flow. The completed input form for this control is shown in Table 2. The control variable is WWVSC, the flow at source component 320. The goal pinch value is 33.0 degrees, and the goal variable is PNEVU, for component 90, the IP evaporator.

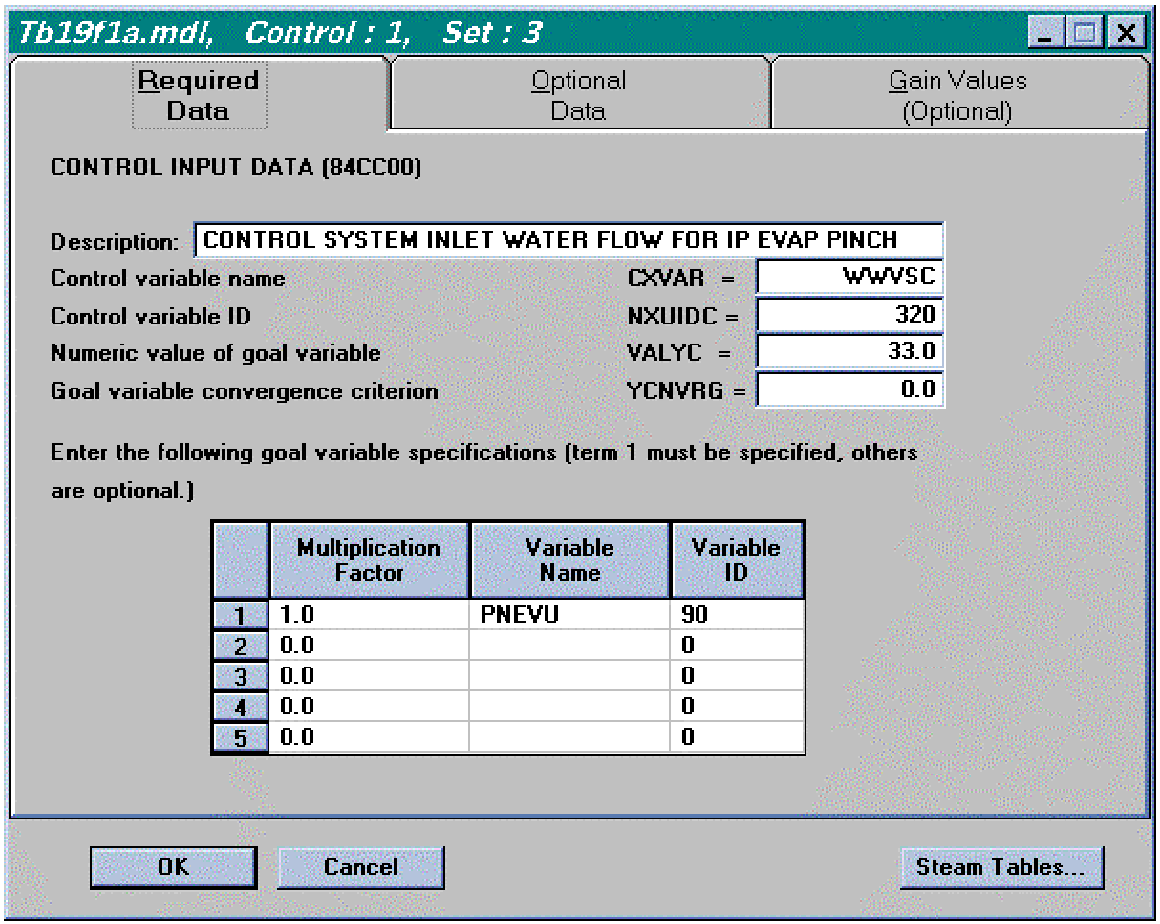
## COMBINED CYCLE SYSTEMS INVOLVING GT, HRSG, STEAM TURBINE, AND PROCESS SENDOUT STEAM

Combined cycle example systems are shown in schematic form in Figures 2, 5, 6, and 7. The COMBCY1 cycle of Figure 2 has already been discussed in a previous section. Mentioned here is the fact that this model includes an explicitly specified control to calculate the flow needed to balance the HP drum, component 30. The completed input form for this control is shown in Table 3. The control variable is WWFIXB for splitter component 150. The goal value is zero, and the convergence criterion is a band of width 3000 Btu/hr. The goal variable is BBEIBC for component 30, the energy imbalance variable.

The system of Figure 5, COMBCY2, shows results in SI engineering units. The principal feature demonstrated by this system is that the steam turbine is a “back-pressure” application. That is, there is no condenser present. Sendout steam is provided by the IP HRSG drum loop and by the exhaust of the steam turbine. In addition the model provides an option for supplemental duct firing to increase the heat available for use by the HRSG.

## Table 2

## Completed Input Form For Control To Adjust Flow To Match Pinch Value For IP Evaporator In Simple HRSG Model Of Figure 4



Tb19f1a.mdl, Control : 1, Set : 3

Required Data | Optional Data | Gain Values (Optional)

CONTROL INPUT DATA (84CC00)

Description: CONTROL SYSTEM INLET WATER FLOW FOR IP EVAP PINCH

Control variable name CXVAR = WWVSC

Control variable ID NXUIDC = 320

Numeric value of goal variable VALYC = 33.0

Goal variable convergence criterion YCNVRG = 0.0

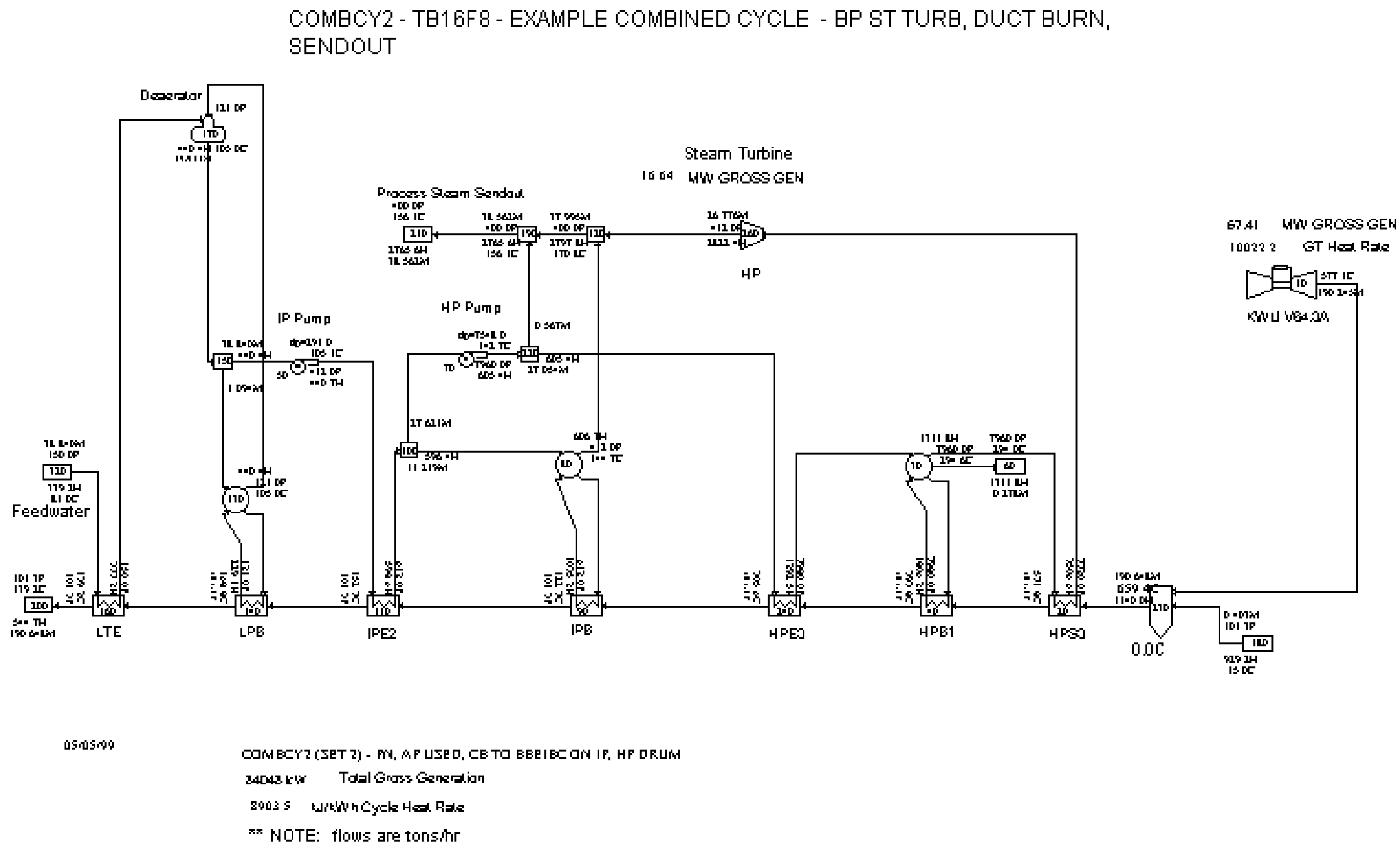
Enter the following goal variable specifications (term 1 must be specified, others are optional.)

| | Multiplication Factor | Variable Name | Variable ID |
|---|---|---|---|
| 1 | 1.0 | PNEVU | 90 |
| 2 | 0.0 | | 0 |
| 3 | 0.0 | | 0 |
| 4 | 0.0 | | 0 |
| 5 | 0.0 | | 0 |

OK Cancel Steam Tables...

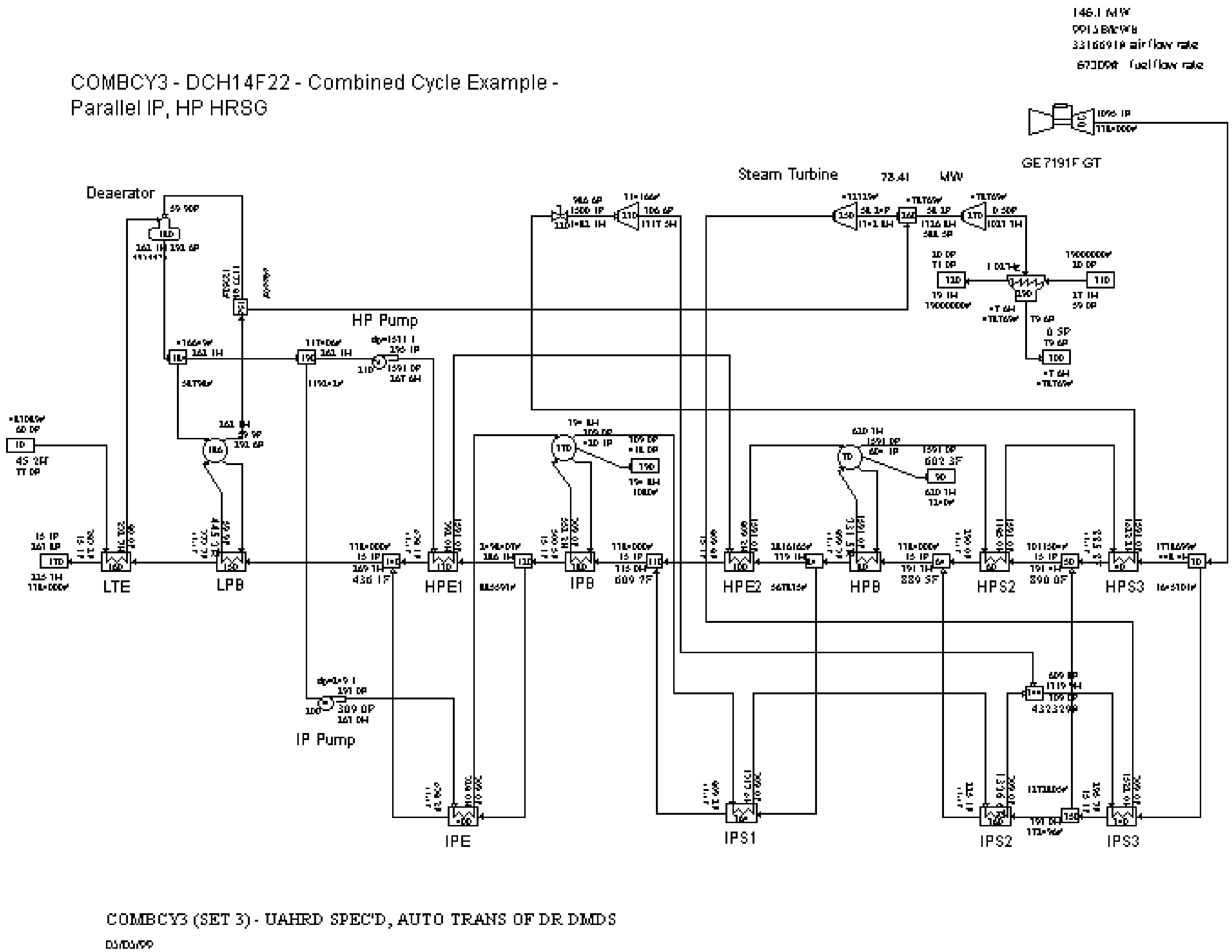
# Figure 5

## Schematic Diagram And Results In SI Engineering Units For A Combined Cycle With A Backpressure Steam Turbine And Supplemental Duct Firing. (COMBCYC2 Model)



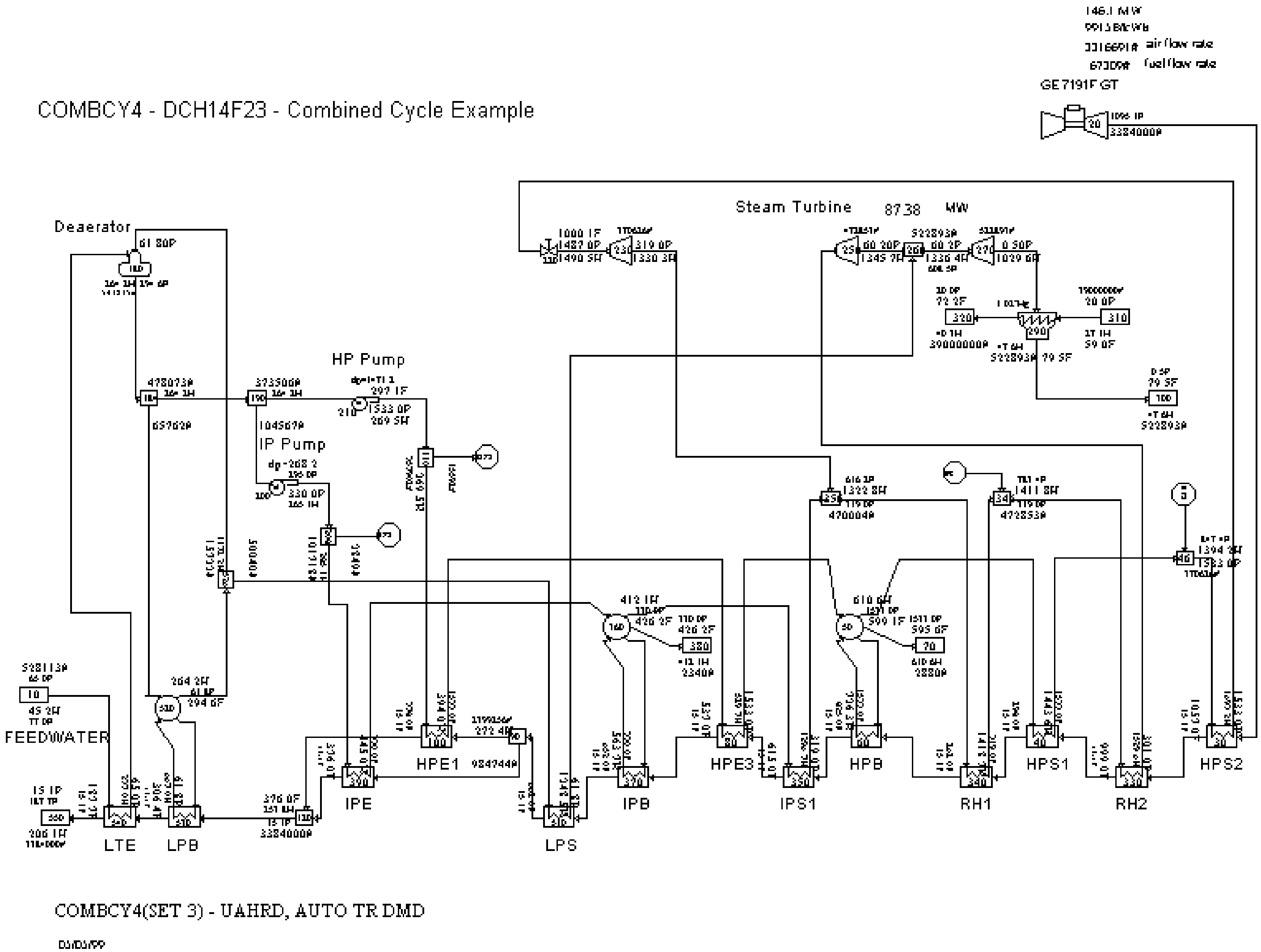
# Figure 6

## Schematic Diagram And Results For A Combined Cycle With A Reheated Steam Turbine. (COMBCYC3 Model)



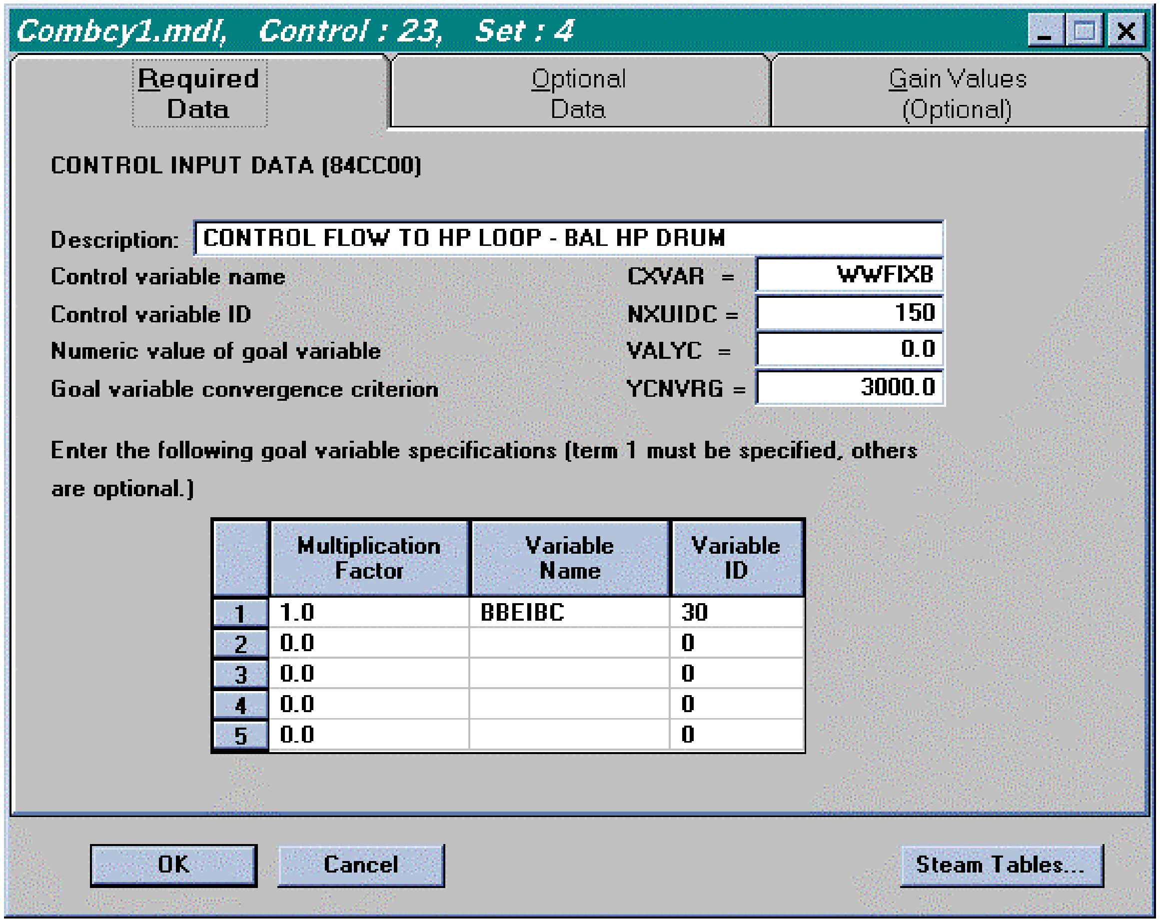
# Figure 7

## Schematic Diagram And Results For A Combined Cycle With A Reheated Steam Turbine. (COMBCYC4 Model)



## Table 3

## Completed Input Form For Control To Adjust Flow To Balance HP Drum In Model COMBCY1



Combcy1.mdl, Control : 23, Set : 4

Required Data | Optional Data | Gain Values (Optional)

CONTROL INPUT DATA (84CC00)

Description: CONTROL FLOW TO HP LOOP - BAL HP DRUM

Control variable name CXVAR = WWFIXB

Control variable ID NXUIDC = 150

Numeric value of goal variable VALYC = 0.0

Goal variable convergence criterion YCNVRG = 3000.0

Enter the following goal variable specifications (term 1 must be specified, others are optional.)

| | Multiplication Factor | Variable Name | Variable ID |
|---|---|---|---|
| 1 | 1.0 | BBEIBC | 30 |
| 2 | 0.0 | | 0 |
| 3 | 0.0 | | 0 |
| 4 | 0.0 | | 0 |
| 5 | 0.0 | | 0 |

OK | Cancel | Steam Tables...

The cycle model, COMBCY3, in Figure 6 shows HRSG arrangements where there are heat exchanger stages modeled in parallel on the gas path. For example, HP economizer 2, component 100, is in parallel with IP superheater 1, component 364. In such instances, it may be a little tricky to determine the correct amount of gas-side split to send to the two branches. PEPSE controls can be used for this purpose when the vendor heat balance has provided waterside performance information. Recognize that, in the real system, the gas flow does not actually split; rather, the two heat exchangers are immersed in the gas stream at the same longitudinal position of the gas flow.

This model illustrates one of the suggestions listed in the following section, the use of the automatic transformation of drum demand into a control and subsequently into a control block. This occurs in Set 2 of the data. Table 4 shows the completed data form for the HP drum component 70 for this purpose. The minus sign on input IDXFWF provides the signal to PEPSE for the transformation.

The cycle shown in Figure 7, model COMBCY4, shows additional variations of arrangement that include HP steam for the steam turbine, IP and reheat steam, an LP loop to the LP steam turbine, and a deaerating loop at the cool end of the HRSG's gas path.

Table 5 is an example of a completed form for a heat exchanger, evaporator component 370 in Set 3 to show the specification of the heat transfer coefficient, input UAHRD. This variable overrides the pinch that appears earlier on the form.

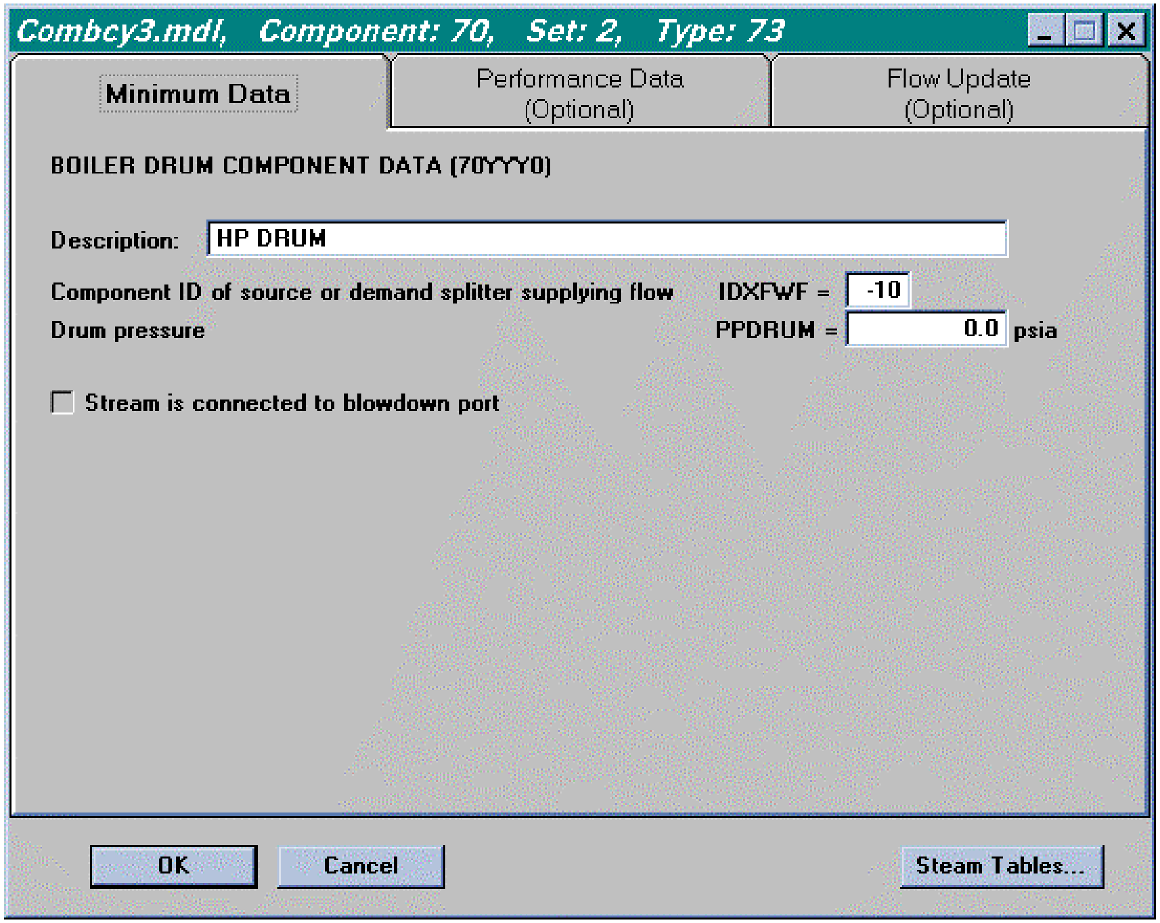
## SPECIFIC TECHNIQUES ADVISED FOR MODELING COMBINED CYCLES

.

The following lessons have been learned in our experience modeling HRSG's using PEPSE and PEPSE-GT. More details are given to explain these items in the Appendix.

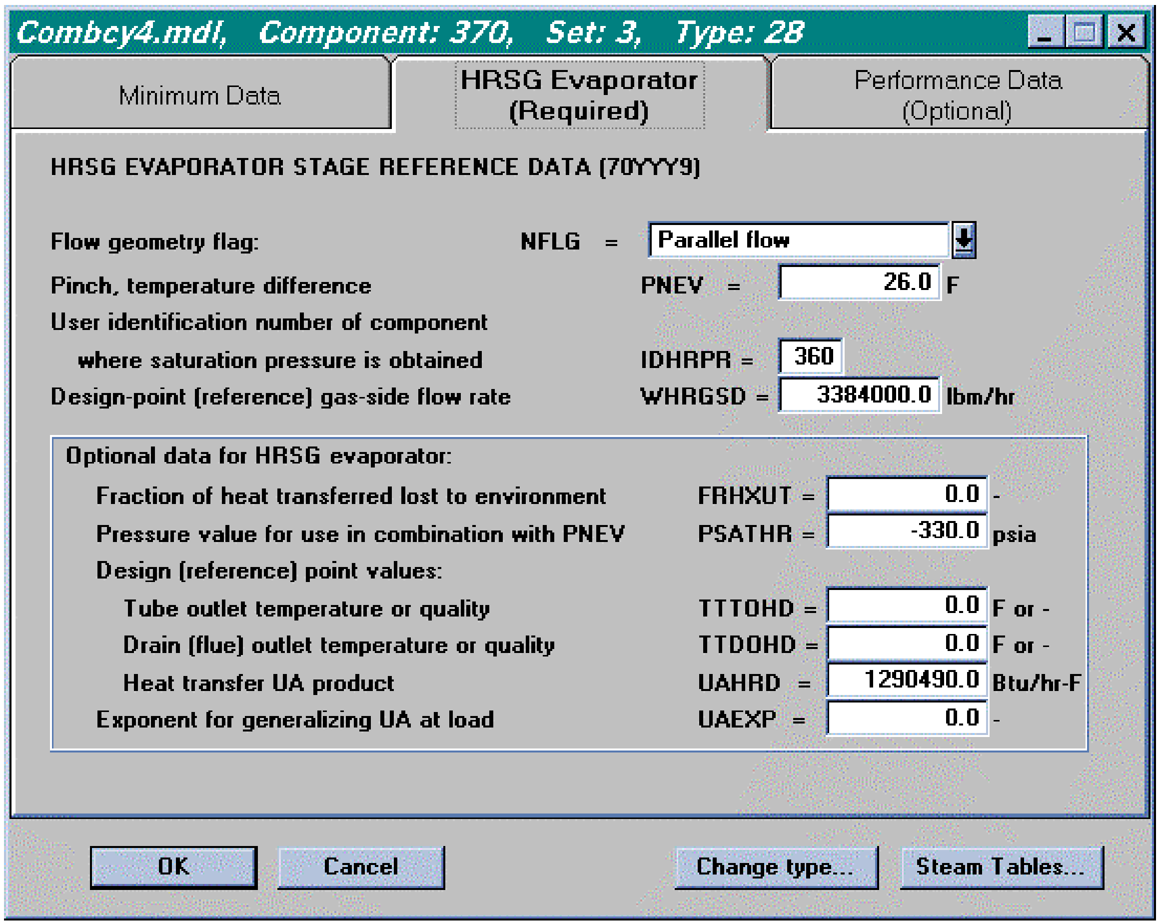
**Table 4**

**Input Form For Drum Showing Switch For Automatic Transformation Of Demand In Model COMBCY3**



# Table 5

## Completed Input Form For IP Evaporator Component 370 In Model COMBCY4 To Illustrate The Use Of Simplified Design Mode



1. Develop models starting from a heat balance or conceptual design.
2. For GT, make a submodel at design load. Tune the model. Incorporate in a system model if desired.
3. Get your first experiences by modeling simple systems, e.g. HRSG submodel.
4. The success of initial run is enhanced by fixing flows and temperatures in your input.
5. Use a large ITRMAX.
6. Convergence is difficult. Loosen the mass and energy convergence criteria.
7. Caution - Be aware that some combinations of flows and heat transfer in systems are not physically possible. Abnormal terminations or failed cases can result if you try to specify such cases.
8. Including a drum component in the LP/D-A loop may help stability of numerics.
9. Always enter values for HRSG HX pinch or approach.
10. Include heat loss to environment in the input.
11. Obtaining drum energy balance is difficult. A control block is the best tool.
12. There is an automatic way available to set up a control block for drums.
13. You can write your own controls. This is more versatile than the automatic approach.
14. Subtle effects can occur in evaporator/drum loops, even in design mode.
15. Beyond min data info is frequently needed for evaporators and economizers.
16. Initiating runs with small flow values can cause steam and gas tables failures.
17. Deaerator loops are common at the LP end. Application of demand updating of the D-A is generally successful.
18. Variations during iterations can erroneously indicate steam inlet to pumps. This can produce calculation of unrealistic, large energy inputs to the water.
19. Systems that have low values of flow in any loop may be difficult to converge.
20. Parallel HX’s in the gas duct of a HRSG can present special modeling challenges.
21. Built-in backpressure calculations work well for HP and IP drums.
22. Alternative backpressure calculations may be required for LP drums.
23. Use Special Option 10 and a Type 34 valve at “automatic extractions”.

24. Some combinations of optional inputs (TTTOHD and TTDOHD) are inherently numerically unstable.

See the Appendix for discussion of the details of these points.

## SUMMARY

This report has discussed thermal, heat balance, modeling of gas turbine engines, heat recovery steam generators, and combined cycles in electric power generation applications. Many key recommendations have been made as guidance for use in developing these types of models. These techniques have been shown to be successful in providing robust and stable computational models. These efforts have been aided considerably by recent numerical improvements in the PEPSE program itself.

## REFERENCES


1. PEPSE and PEPSE-GT Volume 1 – User Input Description, G.L. Minner, et al, 1998.
2. R.W. Haywood, Analysis of Engineering Cycles, Fourth Edition, Pergamon Press, Oxford, 1991.
3. Gas Turbine World 1998-99 Performance Specs, Volume 18, For Project Planning, Engineering, Design and Procurement, Pequot Publishing, Inc., Southport, CT, December 1998.

# APPENDIX

This Appendix provides detailed discussions about the individual modeling recommendations that were summarized in the main body of the paper.

1. In many cases, the modeling effort will begin by mimicking a heat balance that has been provided by a vendor. This is similar to other PEPSE applications, such as steam turbine cycle modeling, fossil boiler modeling, and nuclear steam generator modeling.
2. This discussion assumes that you are using a Type 77 component to model the GT engine. PEPSE-GT includes built-in descriptions of GT engines as a single modeling icon. These descriptions are available for over 400 machines. Design point and off-design data are included. Make a submodel of the GT engine and choose the specific model of interest from the pick-list in the graphics interface program. Run the submodel and compare the results against information available to you. Pay particular attention to the primary results variables -- generator power, heat rate, engine flow rate, and engine exhaust temperature. Also look at the printed value of energy imbalance. If there are significant differences, reconcile the differences. This may involve toggling the input switch that selects front or rear of the engine as the point where flow is calculated. It also may involve checking the sensitivity to the heating value of the fuel. You may need to use PEPSE controls on the global tuning factors for the GT engine component to match known values of the primary results variables. Once you have tuned for the design load, run cases at off-design conditions and compare the results to any information available to you. Perform tuning if necessary. Tuning factors can be scheduled. If you have "correction factors" provided by the vendor for the specific GT engine being analyzed, you can input these correction factors for use by PEPSE-GT.
3. It is sometimes a good idea to get experience in this work by starting with simple models. We have found it helpful to first build a submodel of the gas-turbine component, as specified by the GT vendor, and to exercise the model to tune it to emulate the vendor's performance claims for the engine or as-tested performance. In

similar fashion, one can develop a stand-alone HRSG model and exercise it to learn its characteristics. Sometimes one can learn important facts about these items, and one can apply controls that are easy to understand in the submodel context. Such controls might be harder to diagnose in a more complex full system model as a starting modeling effort. Once the simpler system has been mastered, it is a natural step to move on to the more complete system model.

4. Once you are modeling the full combined cycle, develop a base case that is simple. This is a very useful way to gain confidence in the physical realism of the model. Here "simple" means to include all of the necessary layout of the schematic, but to simplify the input data. Specifically, helpful simplifications can include fixing the flows throughout the system and fixing the pressures at the drums in the HRSG model, rather than jumping immediately to the general case where these "float". In order to obtain a converged solution for this model, the energy results for the HRSG evaporators will need to be auto-balanced. This balancing is done by specifying the tube outlet quality in the input. The value of quality to use is (at the pressure of the drum) the reciprocal of the circulation ratio in the drum loop (note that the ratio defaults to 5.0). To accomplish this, in the performance mode, specify the tube outlet temperature and use the "alternate meaning" as quality (input variable TTTOHD). This is optional input data In this case, in order to have the flows fixed, the drum demand references are entered as zeros A typical value of quality is 0.2.
5. Use a large ITRMAX (the maximum allowance of iteration counter). Several of our models have required between 100 and 200 iterations to converge. Some may require more 200.
6. Loosen the system convergence criteria (generic input EXTERR, CIRERR, and ENEROR) to approximately 10 lbm/hr (.0013kg/s), 10 lbm/hr, and10,000 Btu/hr (3000 W).
7. Combined cycle design is complex, and analysis is also complex. Sometimes, a combination of conditions that you are trying to analyze may not be physically possible. This can happen especially in relative miss-matches of water-side and gas-side flows and water-side pressures, combined with selected values of pinches and

approaches for the heat exchangers in heat recovery steam generators. Therefore, if you have an analysis case that will not converge, the cause may be a combination of unattainable conditions. PEPSE does not tell you this directly, except by failing to converge or by producing a steam table failure. On the other hand, some cases may not converge because of selection of initial conditions that are too far away from the final answer; this is an intrinsic hazard of numerical analyses where the calculations begin with a guessed set of starting conditions. The example models that accompany the PEPSE GT installation show several variations of techniques that we have found successful in modeling combined cycles.

8. In our experience the calculations work best when the deaerator (D-A) drum loop in the model includes a drum component. This improves the stability of the calculations. You CAN exclude the drum, and you can make it work, but we have found this to be more difficult.
9. HRSG HX's should be declared as "economizer", "evaporator", or "superheater", and a non-zero value of pinch or approach should be entered, even if the intent is that one of the later-appearing inputs, such as TTTOHD overrides the pinch or approach.
10. It is common to specify some heat loss to the environment for each HX. This represents the heat loss from the HRSG duct. Specification is done as a fraction of the gas-side heat transfer in the HX. Typical values of this fraction (input variable FRHXUT) are in the range .01 to .02.
11. When drum (Type 73) components are involved in HRSG's, the drum demand reference, input variable IDXFWF, will generally be successful to analyze fairly simple cases. The demand supplier for this purpose will typically be a source component or demand splitter at the originating location for the water-side flow for the affected drum. Intervals, input variable IUPD07, in the range of 5 to 10 are typically required. This is the easiest case to set up to run an analysis If a system is complex, most cases will not be solved by this approach, and abnormal terminations will result. Greater sophistication is needed for these systems.

12. Many system analyses will not converge, i.e. they will give ABNORMAL TERMINATION at the end of the run, with the use of the drum demand reference, input IDXFWF. When this occurs, alternative, more robust, computational tools are required in order to attain a converged solution. Generally, non-convergence of the drum demand calculations is caused by the interdependencies of effects among drum loops and multiple HX's, whereas the demand calculations are not effective in accounting for these interdependencies. PEPSE's Control Block feature is effective. The next easiest way to do this is to flag automatic setup of controls and a control block via your input of word IDXFWF for the drum. This is a feature added to the program during the development of Version 64 and GT3.0. The flag is set by placing a minus sign in front of the ID entered in the IDXFWF space As long as you have cited a valid demand component ID, PEPSE will do all the rest of the work of creating the needed controls and the control block. If you have other controls in your model, the run will be best-behaved if ALL of the controls in the model are included in the control block. You can place your specified controls in a control block via the standard mechanism for creating a control block. Any controls created automatically by PEPSE will be automatically added to the control block that you have created.
13. At the next level of complexity in usage is writing your own controls and your own control block, instead of using the drum demand as described above. In doing this, you have more options relative to the way that you specify the controls and the block. First of all, the drum demand, IDXFWF; is to be zero. The automated process would have written a control on flow rate to minimize the energy imbalance, BBEIBC, for the drum component. If you set up your own control to balance a drum, you could choose to make the pinch of the evaporator the control variable, or some other choice. NOTE THAT, whether you set up your control as described here or use the automated option in the item immediately above, the evaporator in the drum loop must NOT be auto-balanced. That is, do NOT specify a value of quality (TTTOHD) at the tube outlet of the evaporator. Instead, use pinch, or TTDOHD, in performance mode, or use UAHRD in design mode for the evaporator specification. You do, of course, also have the option to represent the HX in full design mode, Type 28 component. In

the event that you choose to write your own control block, some cases may be helped by specifying optional data word IBGCBL with a value of 20 or 25 (the automated control block sets this by default). This will start the control block calculations later than might occur by default. We have found in some cases that starting the control block early (by default) can cause troubles in the numerical solution of the control block.

14. Just for your information, be aware that, in any application of a drum-evaporator loop, where the UAHRD has been specified for the evaporator and where the water-side pressure is fixed and the incoming gas flow and temperature are fixed, the amount of steam production will be fixed and the pinch will be fixed. Even if you vary the water-side flow, the amount of steam produced will not change, and the pinch will not change. This is a consequence of the heat transfer calculation, which is Q = UA * LMTD.
15. For economizers and evaporators, it is advisable to enter a reasonable value for input variable PSAHTR, preceded by a minus sign. This causes the value to be used initially and for any fixups that may be required during later iterations.
16. If you specify a pinch (or a gas-side outlet temperature) value for an evaporator, you need also to specify a reasonable value of water-side flow through the evaporator. Failing to do so is susceptible to trouble because the gas-side temperature specification determines the amount of energy that will be passed from the gas side to the water side. A small amount of water flow would produce an inordinate rise in enthalpy and temperature and result in probable steam table troubles. While PEPSE has been coded to catch and fix up many such troubles, there is still potential for unexpected results to occur. Among other things, repeated use of fixups can lead to bogus values of “gains” calculated for control blocks, leading to difficulties of convergence of this feature.
17. If there is a deaerator component (D-A) associated with the HRSG, it is appropriate to use a PEPSE Type 15 component to represent this item. The demand ID, IDXTGE, for the D-A can be used to point to a demand splitter, where the flow will be adjusted in order to attain an energy balance for the D-A. Typically, the D-A is included in a low pressure drum loop at the back end (gas-side) of the HRSG. Because this is a

closed loop, PEPSE would have trouble choosing an order of solution without your help. You can help PEPSE by making one of the streams in the loop a Type 6, for impasse resolution. At this stream you will need to enter initial-guess values of pressure, temperature (or quality), and flow rate. In some instances, the guessed value of pressure will be the value that is retained throughout the solution in the LP loop. There are two specific streams that seem to work well for this, either the steam inlet to the D-A or the drain outlet from the D-A. In both cases, it is an easy matter to specify the quality (1.0, and 0.0, respectively). We have had success with two different scenarios in the LP drum loop. In the first you can actually use a Type 73 drum component and a Type 28 evaporator component (with the tube exit quality set to the inverse of the circulation ratio – typically .2). In the second you can use a simpler arrangement with a Type 20 heat exchanger where the tube exit quality is set to 1.0. In either case, the drum will be automatically balanced, and no drum updating need be considered, either by the "traditional" demand method or by the control method. Sometimes you can help the D-A's demand calculations by specifying a relaxation factor (optional data, RELAXF) of about .75 and a limiter (optional data, FUPMXF) of about 0.1.

18. In some cases pumps for the IP and HP drum loops may receive some amount of steam in the inlet water, especially due to variations during iterations. This can cause difficulties in the calculations. Pump calculations involve use of the value of specific volume incoming. If steam is present, the specific volume is incorrectly elevated, and this produces a very large calculated enthalpy rise for the pump. When this occurs, warnings are printed. You are advised to look at the PEPSE printout (.out file) to check for this. If this occurs, you probably should make a modeling change in order to eliminate the steam at the pump inlet. For example, you could modify the description of the component, perhaps a heat exchanger, that supplies the flow to the pump such that liquid is supplied to the pump.

19. Any time that the flow in one of the pressure loops, e.g. the IP loop, is very low (a few hundred to a few thousand pounds per hour), there is a high risk of computational trouble, especially if flows are being adjusted as part of the solution process. If you have a troublesome, nonconvergent, run, you should look for this possibility in the results. This is an indication that this loop is attempting to do physically impossible things, or marginally so. In a real system, it may not be practical to operate such a loop in these circumstances. If PEPSE is driving the flow very low, you can do some "exploration" with the model to diagnose the situation by shutting off the feature that drives the low value and simply setting some very low flow rate as a fixed value. Temporarily you can make the evaporator in the loop converge by setting the tube exit quality (TTTOHD) to the inverse of the circulation ratio (typically .2). You can look at the converged results and examine the printed pinch value and compare that to the value that your earlier run was trying to attain.
20. Some HRSG arrangements are complex, having HX's that are in parallel on the gas path. You can model this by placing a gas-side splitter prior to the parallel HX's. It becomes a tricky matter to decide how much gas flow to send each direction. Realize that in the real system the gas side is actually flowing in a single duct and there just happen to be both IP and HP HX tubes at a particular axial position. One way to determine the effective gas split is to place a control on the gas split fraction (Type 63 splitter), control variable, to produce equal values of gas temperature exiting the two parallel heat exchangers. Of course, to do this, often other quantities in the model may have to be fixed (known or assumed); among these may be water-side flow rates.
21. In a HRSG, the drum pressure (hence pressures in the HX's) can be calculated by PEPSE by your setting the built-in backpressuring switch. This is a Version 64 and GT3.0 feature. This is activated by inputting a switch (minus sign) when specifying a value for PPDRUM for the drum. This feature uses the flow coefficient at an eligible receiver, i.e. downstream valve or steam turbine component in the calculation. The method works well for HP and IP drums. Some schematic arrangements of LP drums will not work, due to the method used by PEPSE to locate the eligible receiver. This tracing method follows the main flow path downstream from the drum until the

receiver is found. Such tracing in LP loops may lead to a deaerator component and ultimately back to the LP drum.

22. When the LP drum backpressure cannot be calculated successfully by the built-in method described above, it is possible to use an alternative, wherein the user writes operations to set the drum pressure (variable PPDRUM) according to the pressure in the receiver and accounting for any intervening pressure drop.
23. If the system includes process sendout steam (“cogeneration”) at a fixed pressure from an intermediate point in the steam turbine expansion line, use Special Option 10 to analyze the fixed pressure point correctly. Take this “automatic extraction” off from the turbine component’s “E” port or from a splitter downstream of the turbine component. Also place a Type 34 valve in the line downstream next, to represent the pressure regulation device.
24. HRSG (Heat Recovery Steam Generator) modeling. Some combinations of performance mode inputs for HRSG heat exchanger strings make the marching numerical solution inherently unstable. Such cases cannot reach a converged solution. One situation that exhibits this behavior is one where the gas path is routed through an evaporator heat exchanger, thence to an economizer heat exchanger, wherein the water from the economizer flows to the drum loop for the just-mentioned evaporator. This is nearly pure counter-flow. Calculations for this arrangement are rendered unstable in a performance mode calculation, if the evaporator is modeled by specifying a variable that sets the tube outlet condition, e.g. a temperature or a quality in TTTOHD, while the economizer has a specified gas outlet temperature, TTDOHD. This combination of inputs should be avoided. Note that this is not a PEPSE shortcoming; rather, it is an intrinsic characteristic of such an arrangement. There is not yet adequate experience to make a generalization, but it may be the case that a HRSG that uses TTDOHD for any heat exchanger needs to have TTDOHD specified for all heat exchangers in the HRSG in order to be stable