USE OF AN ENERGY BALANCE COMPUTER PROGRAM IN THE PLANT LIFE CYCLE

William C. Kettenacker

Central and South West Services, Inc.

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INTRODUCTION

The thermodynamic evaluation of a power plant throughout its life leads to increased efficiency, availability, and reliability. A thermodynamic evaluation, such as an energy balance, locates design flaws, pinpoints malfunctioning equipment, evaluates new operating procedures, and predicts future performance from current conditions or proposed changes.

Eight key steps in the plant life cycle benefit from an energy balance evaluation. These steps are:

(1) Initial plant design,

(2) Evaluation of vendor plant design proposals,

(3) Acceptance test evaluation,

(4) Daily operations support,

(5) Periodic performance test evaluation,

(6) Troubleshooting,

(7) Redesign of existing equipment and systems, and

(8) Prediction of future performance.

For the past eight years, the operating companies of the Central and South West Corporation (Central Power and Light, Public Service Company of Oklahoma, Southwestern Electric Power Company, West Texas Utilities Company) have used an energy balance computer program for the thermodynamic evaluation of their units. All of the steps in the plant life cycle listed above (except initial plant design) are included in their evaluation studies. A commercially available computer program, PEPSE [1] (Performance Evaluation of Power System Efficiencies), is the tool used to perform these evaluation studies. Thirty-four of CSW's largest units comprising 65% of the 13,500 MW installed capacity are modeled on PEPSE.

This paper describes the use of PEPSE in the life cycle evaluation process at the CSW operating companies. A specific example of the use of PEPSE is presented to demonstrate the benefit of an energy balance cycle evaluation.

THE ENERGY BALANCE

An energy balance calculation is vital in determining how well a steady flow process is performing in comparison to a standard. The steam and gas sides of a power plant represent steady-flow processes. Where the energy comes from, where it goes (in terms of losses and useful work), and how each component in the plant is contributing to this process must be determined. This is necessary to measure the efficiency of the individual components and the entire system. The system standard may be the original plant design. If the system has been in service for several years, the standard may be last year's performance test.

By evaluating a system using an energy balance, one can make decisions in the areas of design, performance, or operations. In the area of design, the most efficient (and economical) combination of system components is chosen by evaluating their combined effect on the overall system before building the system. In the performance area, evaluation of test data using an energy balance can pinpoint malfunctioning hardware. Operations are improved by simulating proposed operating scenarios before they are actually used in the plant.

An energy balance is a comprehensive term to describe both the heat and mass balance around an individual component, a subsystem comprised of several components, or an entire plant. In the steady-state, a mass balance is expressed as follows:

$$\Sigma m_i = \Sigma m_o \qquad (1)$$

where:

- m = mass
- i = in
- o = out

In the steady-state, the energy balance for a flowing stream (as found in power plants) is as follows [2]:

$$\delta[(H + u^2/2g_c + zg/g_c)dm] = \Sigma dQ - dW \qquad (2)$$

where:

- H = enthalpy (U + PV)
- u = internal energy
- z = elevation
- Q = heat added
- W = work performed

If changes in kinetic energy ($u^2/2g_c$) and potential energy (zg/g_c) are neglected, a common assumption in energy balance calculations, Equation (2) reduces to:

$$\delta(Hdm) = \Sigma dQ - dW \qquad (3)$$

Equations (1) and (3) are the basic equations for balancing mass and energy in every piece of equipment or length of pipe in a power plant. In Equation (3), the work term, W, and the heat term, Q, vary from component to component; however, the basic equation applies universally.

A plant steady-state energy balance, whether performed by hand or done on the computer, follows an iterative pattern. This pattern constitutes applying Equations (1) and (3) one component at a time around the cycle. The process is iterative because assumptions made when applying these equations to one piece of equipment may not hold true when solving the equations for a downstream component. A trial and error process is the rule in energy balance calculations. Because of this, computer calculated energy balances are far more efficient than hand calculations. This is especially true if the entire plant is being analyzed. Several good computer programs are available to do these calculations. CSW has used the PEPSE computer program since 1980.

PEPSE

PEPSE is a modular steady-state energy balance computer program. Any arbitrary system geometry is allowed. This includes boilers, turbine cycles, combined cycles, NSSS systems, plant subsystems, or any fluid process system. A model is prepared by interconnecting the components, chosen from PEPSE's component library, as they appear in the actual or proposed plant. The component library includes steam and gas turbines, feedwater heaters, condensers, general heat exchangers, valves, pumps, fans, boilers, combustors, and flow merging and diverting devices (mixers and splitters). Components are joined through streams which act as pieces of pipe or simulate thermodynamic connections in the plant model.

Two input modes are available; the performance mode and the design mode. The performance mode requires the input of test data or parameters that describe the overall performance of a component. An example of an overall performance parameter is the terminal temperature difference of a feedwater heater. This parameter describes nothing of the internal characteristics of the heater, only the results of those characteristics. In contrast, the design mode requires detailed information on the internal characteristics of a component, such as the tube geometry and material in a heater. These input modes are on a component-by-component basis (not the entire system), therefore, the two modes may be combined in a model.

Output from PEPSE includes seven thermodynamic parameters at each port of every component in the cycle. Mass flow, temperature, pressure, thermodynamic quality, enthalpy, entropy, and specific volume are the included parameters. In addition, a table for each type of component class (e.g., turbines, feedwater heaters, boilers) is printed. These special tables present the unique parameters of each component type. Finally, PEPSE prints a system-wide 1st Law of Thermodynamics and 2nd Law of Thermodynamics energy balance table.

Of the thirty-four CSW units modeled on PEPSE, five are coal-fired and the remainder are gas-fired. All thirty-four have their turbine cycles modeled, and six have PEPSE boiler models constructed.

LIFE CYCLE EVALUATION PROCESS

The eight steps in the plant life cycle represent key areas for efficiency evaluation. At the CSW operating companies, an energy balance evaluation using PEPSE has been performed on many units for each of these steps (except initial plant design) to assure improved efficiency of the units.

Initial Plant Design

Initial plant design is the first and probably most important area of efficiency evaluation. Component sizing, steam conditions, fuel type, and system configuration can be evaluated for greatest efficiency before the plant is built. Because the CSW operating companies do not design their own plants, this is the one area in which an energy balance evaluation is not used. However, the plant design vendor uses an energy balance program in designing the plant.

Evaluating Vendor Designs

Using an energy balance to evaluate and confirm a plant design proposed by a vendor provides a two-fold benefit. First, the reasonableness and accuracy of the vendor's calculations and assumptions are checked. Secondly, a baseline calculation is established to compare future performance evaluations. Three currently operating plants and one proposed plant in the CSW system were evaluated at this stage. Northeastern Units 3 and 4 and Oklaunion Unit 1, all currently operating coal-fired plants, were evaluated using PEPSE to confirm vendor calculations. A proposed coal-fired unit, Coleto Creek Unit 2, has also been evaluated.

Acceptance Test Evaluation

Acceptance test data analysis by a utility is crucial in determining whether the system has met guarantee levels. Simply relying on the vendor evaluation of the acceptance test results may not be in the utility's best interest. The utility's analysis should focus on the proper correction to standard conditions and the isolation of those areas in the plant system which do not meet contractual guarantees. At CSW, an acceptance test energy balance evaluation using PEPSE will be performed on the newest unit in the system, Oklaunion Unit 1, this year.

Operations Support

An on-going application of an energy balance program is its use in evaluating various operating scenarios. The plant response to changing controllable parameters, such as main steam temperature or excess air, is evaluated before implementing any operating change in the plant. The applications in this area at CSW are many. One specific application at J. L. Bates Unit 2 included evaluating the effect of different combinations of boiler back-pass damper settings in an attempt to reduce reheat attemperation flow. The split back-pass has one pass containing the primary reheat stages and one pass containing the primary superheat stages. Routing more flow over the superheat pass reduces the heat transferred to the primary reheaters. This reduces the required reheat attemperation flow. A study of this unit using PEPSE showed that reheat attemperation flow is reduced by properly setting the backpass damper position. Savings over 100 BTU/KW-HR were calculated by PEPSE.

Performance Test Evaluation

The most common use of PEPSE at CSW is in the evaluation of test data from periodic performance tests. These tests may take place monthly, yearly, or during pre- and post-outage. They involve either the entire plant, both boiler and turbine cycle, or cover a component or series of components. Unlike the acceptance test evaluation, intended to confirm or refute the vendor guarantee, periodic performance tests pinpoint malfunctioning hardware and/or uncover degraded plant performance. In some cases a pre-outage test points to problem areas in the plant. A post-outage test shows the effect of outage maintenance. A common use of an energy balance program in the test data evaluation mode is to correct the test results to standard conditions. A test is rarely run at the same boundary conditions as the previous benchmark or standard (i.e., vendor design, acceptance test, last year's test). Therefore, the current test results must be corrected to the same boundary conditions that existed for the standard.

As an example, Northeastern Unit 3 was recently tested following a major outage. The test was conducted at slightly different conditions than the original acceptance test performed in 1981. Thus, a comparison of the current performance to the performance during the acceptance test could not be made. However, by using PEPSE, the test results were corrected to the original acceptance test conditions, allowing a valid comparison of performance. This comparison showed a current turbine heat rate 3.5% higher than during the acceptance test. The evaluation pointed to HP and IP turbine efficiency decreases, a boiler feed pump turbine efficiency decrease, and increased seal leakages as the reasons for the increased heat rate. When the uncertainty of measuring the condensate flow was factored in, the heat rate increase was estimated to be 2.5%.

Plant Troubleshooting

Plant troubleshooting is made easier by performing an energy balance calculation. This calculation includes evaluating data from the suspected area in the plant and comparing the results to a previous performance level. Or the problem is determined by simulating various causes using an energy balance to determine which best matches the symptoms in the plant. The application of PEPSE to plant troubleshooting is widespread in the CSW system. As an example, at Coleto Creek Unit 1, the HP turbine exhaust pressure increased following an outage. Several PEPSE cases were run to determine the cause. One case involved increasing the N2 packing leakage to reproduce the effect in the plant. This showed a decrease in HP exhaust pressure, not the increase noted in the data. Finally, a case was run which simulated flow bypassing the HP turbine completely. The results matched the symptoms in the plant. Discussions with the turbine manufacturer reinforced the results. Actual causes will be checked during the next outage.

Redesign

After remaining in service for a period of time, the components and systems of a plant begin to deteriorate. In addition, operating history may show that certain components and systems are not operating as designed or do not meet original expectations for performance and function. An energy balance on the cycle will show the effect of continued operation in a degraded mode. If continuing to operate in this mode proves economically unfeasible, the degraded components or systems may be replaced with either identical equipment or with equipment which represents newer technology. If newer technology is chosen, it is likely that its performance is different from that it is replacing. This requires an investigation as to its impact on the performance of the rest of the system. This, too, can be evaluated with a cycle energy balance.

As an example, at Riverside Unit 1, a supercritical gas-fired unit, the start-up bypass valve was leaking. This caused about 20,000 lb/hr of steam to dump to the condenser during normal operation. An energy balance on the unit using PEPSE showed that this leak resulted in a 40 BTU/KW-HR increase in the turbine heat rate. Two changes were proposed. One change involved fixing the valve only. This was considered the best solution, but the possibility exists that the leak will return. As an alternative, a design change which would dump the bypass flow to the deaerator was proposed in combination with replacing the valve. Then, if the valve begins to leak again, the leaking steam will dump to the deaerator. A PEPSE study of this alternative showed a turbine cycle heat rate increase of only 16 BTU/KW-HR over the no-leak heat rate. The valve was replaced, but is being watched closely. If the leak returns, the plant modification alternative will be considered.

Prediction of Future Performance

An energy balance program can predict future performance of a unit based on current performance levels. By varying certain component parameters while holding the rest of the system constant at current levels, one can determine the performance due to the changing component parameters. These changes may involve planned modifications or may represent anticipated equipment performance changes due to age. At Fort Phantom Unit 2, PEPSE was used to predict the performance of the unit to anticipated changes in feedwater heater terminal temperature differences and drain cooler approach temperature differences.

EXAMPLE

In 1987, West Texas Utilities Company (WTU) and Central and South West Services (CSWS) undertook a joint study to determine the effects of various boiler parameters on cycle performance [3]. The unit chosen for the study was Paint Creek Unit 4. One aspect of the study involved determining how the amount of excess air affects the net unit heat rate (NUHR).

Figure 1 shows the vendor turbine cycle schematic and Figure 2 shows the vendor boiler schematic of Paint Creek 4. The turbine, rated at 105 MW, is a General Electric tandem-compound with a double flow LP. It is a reheat unit designed for 728,000 lb/hr, 1800 psig, and 1000 F/1000 F. The cycle has five feedwater heaters. The boiler is a Riley reheat steam generator type designed with front firing and pressurized operation using natural gas as the fuel. It is capable of producing 765,000 lbs of steam per hour continuously at 1875 psig and 1005 degrees F at the superheater outlet. The unit is a drum unit and has a furnace volume of approximately 29,000 cubic feet. The water capacity is 13,500 gallons. Figure 3 shows the PEPSE model developed for this unit.

Several PEPSE cases were run, varying the excess air from 4% to 18% (0.7% to 2.1% excess stack O2). Superheat and reheat attemperation flows were adjusted to give constant superheat and reheat outlet temperatures of 1005 degrees F. Figure 4 presents the results of this study. They show that the lower the O2, the better the NUHR. Boiler efficiency improves as excess O2 decreases. Forced-draft fan input amps decrease. This is partially offset by increased attemperation flows, but not enough to override the positive effects. Overall performance is improved.

CONCLUSIONS

All phases of the plant life cycle can be investigated and improved with the use of an energy balance computer program. An energy balance traces the flow of work and energy in the cycle. This allows comparisons to an ideal (e.g., design) or a norm (e.g., last year's test) and may show poorly designed or inefficient plant components.

In addition, an energy balance shows improved methods, procedures or conditions for operating the unit. The companies of the Central and South West Corporation recognize these advantages. They have successfully utilized an energy balance computer program to evaluate their units in the life cycle process.

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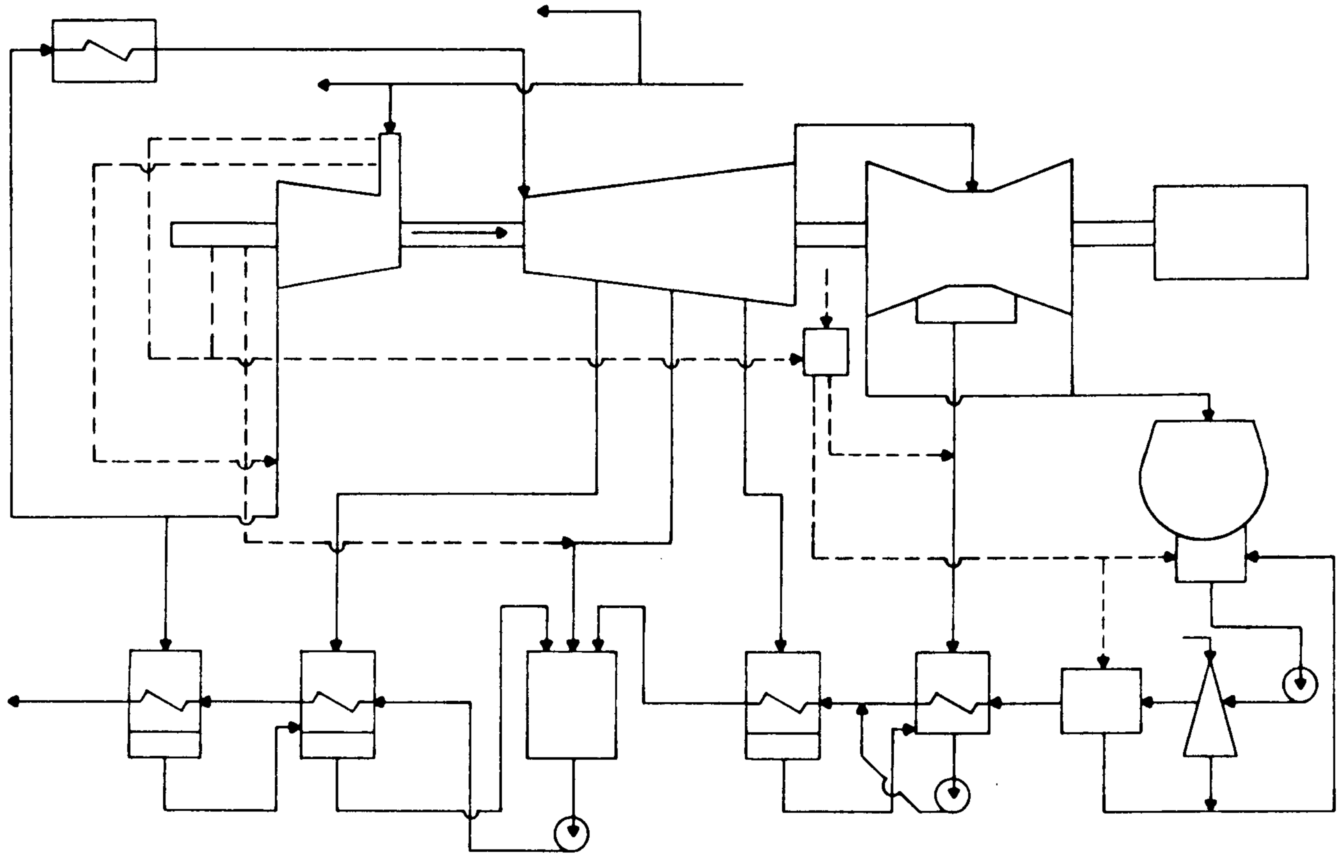

Figure 1 - Paint Creek Unit 4 Turbine Cycle Schematic

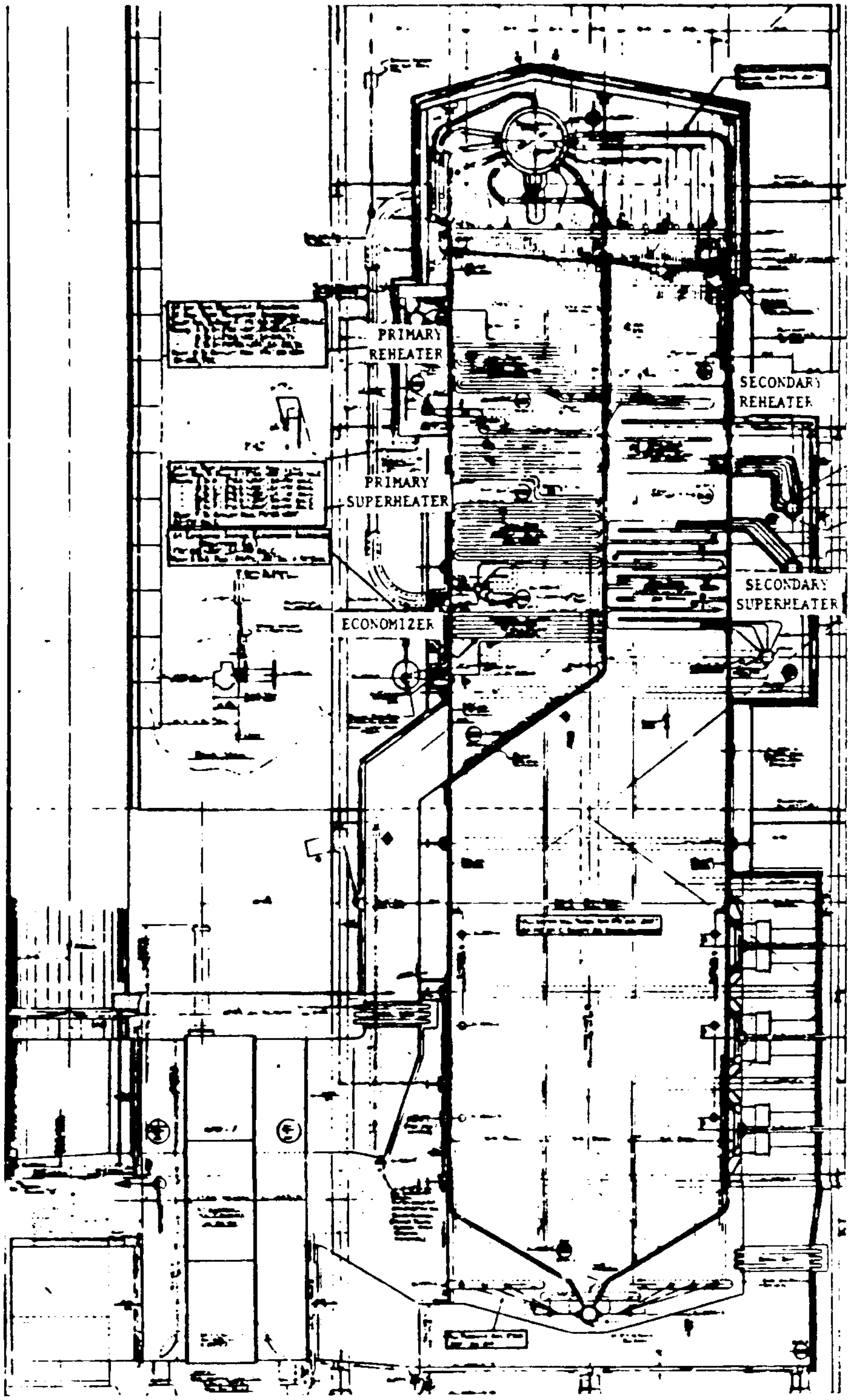

Figure 2 - Paint Creek Unit 4 Boiler Schematic

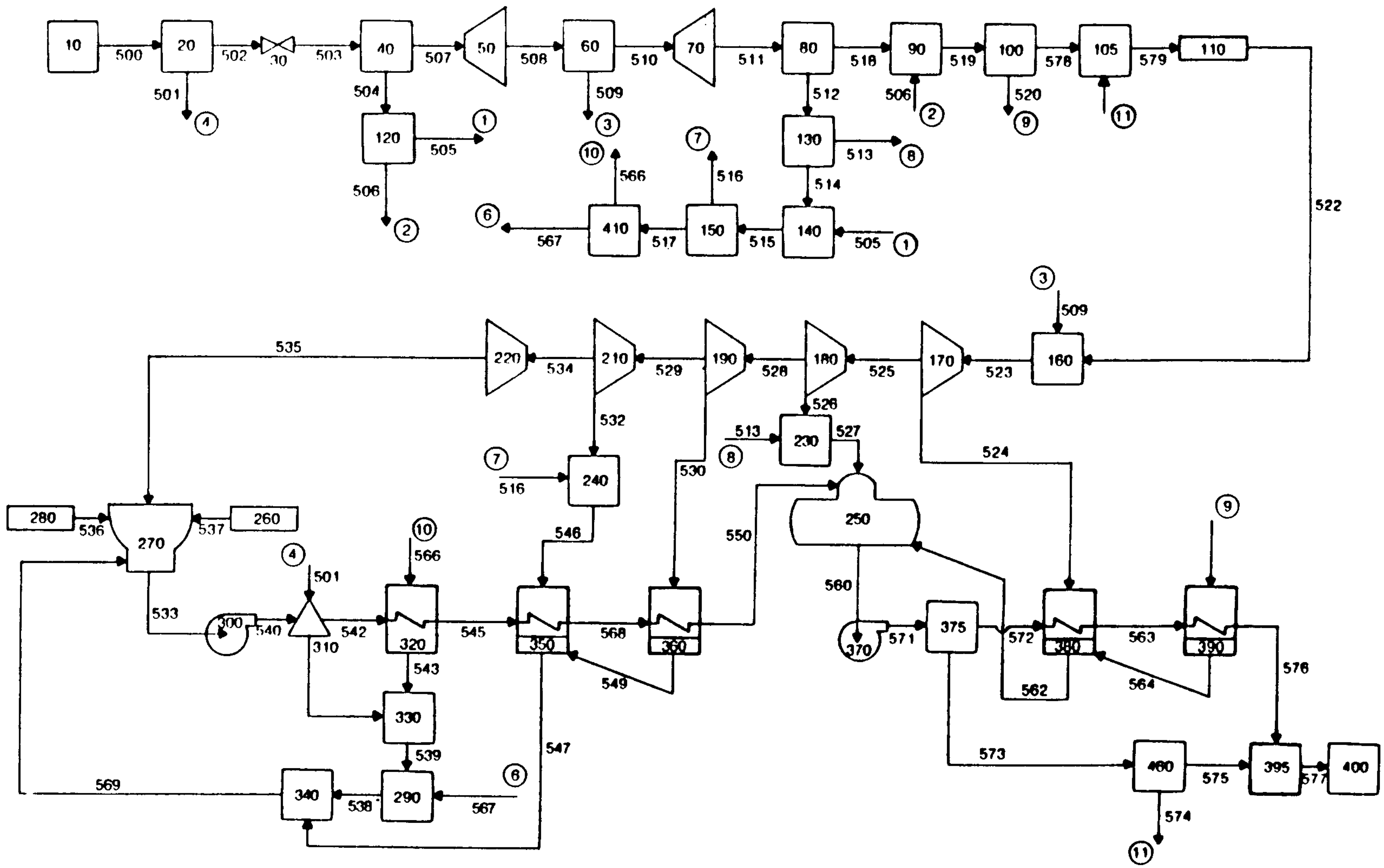

Figure 3A - Paint Creek Unit 4 PEPSE Turbine Cycle Model

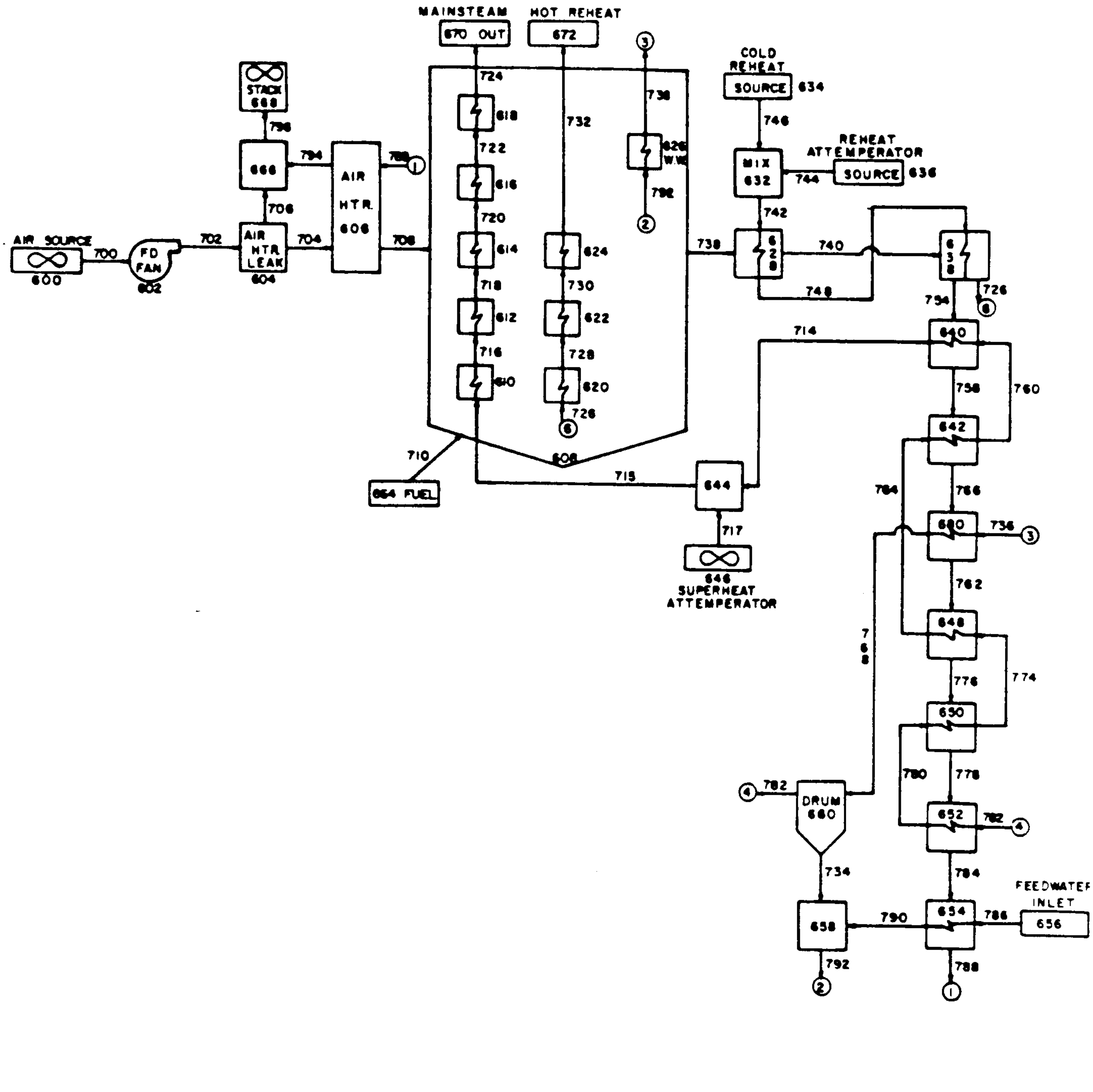

Figure 3B - Paint Creek Unit 4 PEPSE Boiler Model

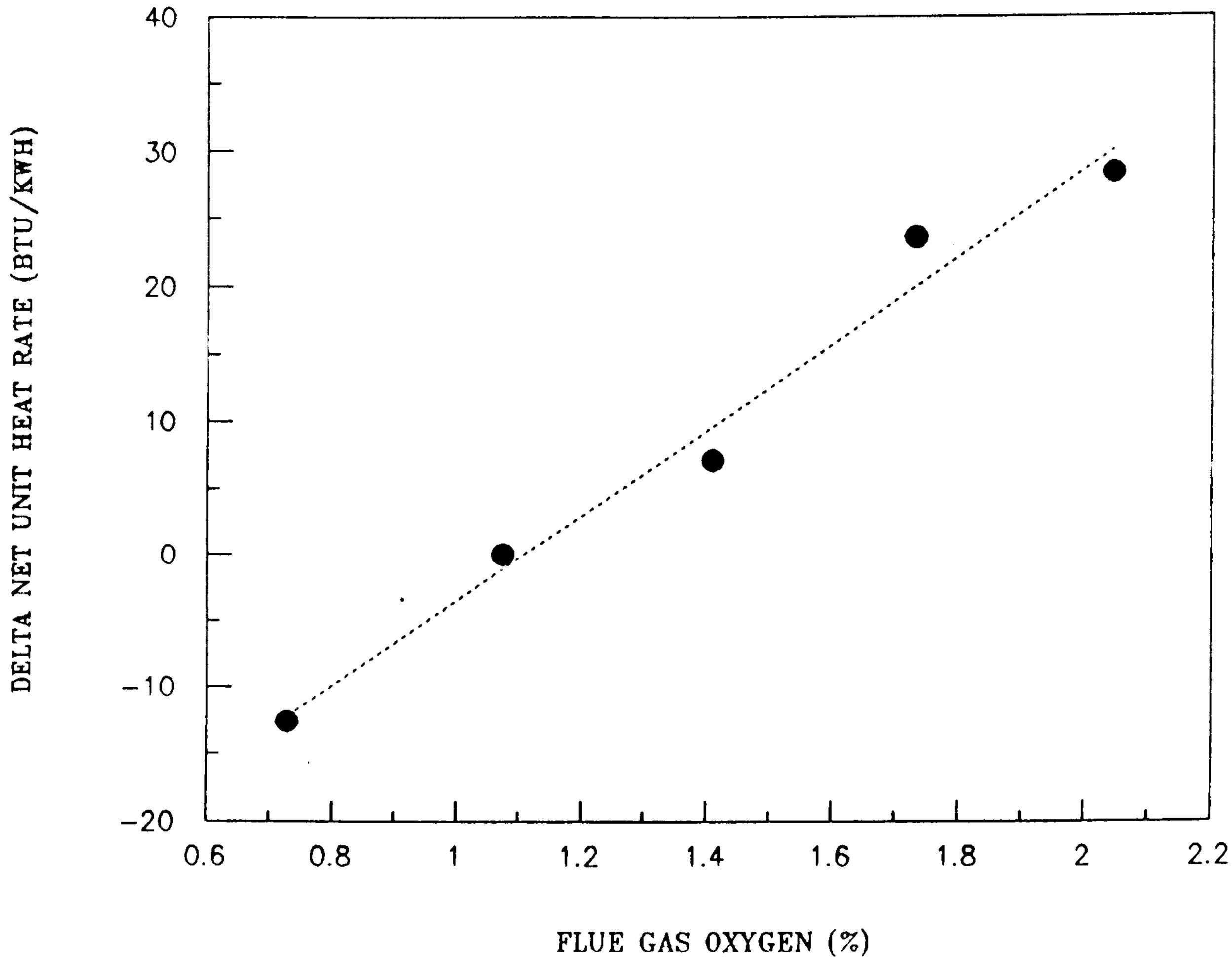

Figure 4 - Paint Creek Unit 4 PEPSE Results - Flue Gas Oxygen Effect