ERC AND PEPCO COMMERCIALIZING SOFTWARE FOR OPTIMIZING BOILER OPERATIONS

The increase in competitive pressures in the utility industry, along with more stringent restrictions on NO$_x$ emissions, has led many utilities to look for ways of optimizing the operation of their coal-fired boilers. Lehigh University’s Energy Research Center and the Potomac Electric Power Company (PEPCO) have developed an intelligent software package, referred to as Boiler OP, which can help utility and industrial boiler operators achieve their NO$_x$ and boiler performance goals.

A utility might wish to optimize combustion for any of several reasons. Numerous studies performed over the last several years show NO$_x$ emissions levels can usually be reduced substantially through adjustments to boiler operating conditions. At the same time, because of changes in parameters such as steam temperatures, flue gas flow rates and combustible losses, boiler efficiency and unit heat rate are affected by changes in boiler control settings. The utility might thus wish to adjust the control settings of the boiler to minimize NO$_x$ or heat rate, or perhaps find the operating conditions which give the best heat rate subject to meeting a target level of NO$_x$.

Some coal-fired boilers have chronic problems with high levels of unburned carbon. This causes reduced boiler efficiency and it makes it difficult to sell the ash. In a case such as this, the objective of the optimization might be to reduce the level of unburned carbon. Some boilers are subject to frequent opacity excursions and in cases such as these, the opacity violations can often be eliminated or made less severe through combustion optimization.

Typical controllable parameters include mill or burner loading patterns, air register settings, and furnace O$_2$ levels. Because of the large number of parameters which can be varied, it is often difficult to determine the “best” combinations of control settings based on traditional test and analysis methods. A systematic approach is needed in identifying the optimal boiler operating conditions and tuning the boiler. The software can be used to determine the boiler settings which produce minimum NO$_x$ emissions or to determine those settings which produce a minimum heat rate subject to target NO$_x$. 

Dave Cramer from PEPCO is entering a set of test data into Boiler OP for performing boiler optimization calculations.
GATHERING AND ANALYZING DATA WITH BOILER OP

Any method for combustion optimization requires access to boiler operating data. It also requires analysis and manipulation of the data to extract information on how to set the boiler controls to achieve the desired results. Boiler OP was developed to simplify the process and assist the plant engineer and boiler operators in determining what control settings to use.

Expert System

Boiler OP combines an expert system, neural networks and an optimization algorithm into a single program which runs on an IBM compatible PC. The software package is designed to guide a plant engineer safely through a series of parametric boiler tests to gather the comprehensive database needed to perform the optimization.

The plant engineer first configures the software according to the specific plant hardware and testing objectives. The expert system then recommends a test program and control settings for the test points. The test engineer adjusts the boiler controls accordingly, and the test data are collected by the plant’s data acquisition system. The data are stored in a database for later use and are utilized by the expert system to determine each test point in the testing sequence. After the testing is complete, data from the database are exported to the neural network for modeling. The optimization algorithm then uses the relationships developed by the neural networks to determine the best combination of control settings which meet the testing objectives.

The expert system contained in Boiler OP relies on CLIPS 6.0, a commercially available package which has been configured to this application. The expert system uses general deduction methods, knowledge specific to the combustion process, and general rules of thumb developed through experience to guide Boiler OP in designing a test program for the user and in collecting data.

Neural Networks

Data collected under the guidance of the expert system are stored in a database and are used to train the neural networks imbedded in Boiler OP. A neural network works much the same way as the human brain in processing information. It does not require a physical model of the problem—it learns from observations made through the data.

The neural network used in this model is a backpropagation model, which accounts for the way it deals with the errors in predicted values. The architecture consists of three fundamental layers called nodes. These three layers, referred to as the input, output and the hidden layers, comprise the neural network and give it the ability to analyze non-linear relationships. A neural network learns the correlations between the inputs and the outputs through the hidden layers. If all correlations were linear, then the inputs and outputs would be connected together directly, but in the combustion process, many relationships are interdependent and non-linear, thus requiring hidden nodes.
Boiler OP utilizes a commercially available neural network software package. To reduce the cost and time of testing, the configuration of the network was optimized for the application to combustion tuning to assure that the program runs efficiently and learns with a minimum amount of data.

**Optimization Calculations**

The optimization algorithm is used to determine optimal solutions based on user defined objectives. The software queries the user to determine if he/she is looking for the lowest possible NOx or if he/she would like to achieve a given NOx level with optimal unit performance. Once these limits are established, along with other operating constraints, the optimization algorithm mathematically finds the best solution using the information generated by the neural network software.

Several methods were explored and the Nelder and Meade Simplex Method was found to work best in this application. This method uses a direct search approach called the simplex method for finding the optimal solution.

**BOILER OP AND PLANT OPERATORS**

In addition to the testing and optimization capabilities Boiler OP provides the plant engineer, it also has a group of features called Operator Tools which were developed specifically for plant operators. These are intended to allow the operators to review the status of boiler operations as they affect NOx and unit performance, examine the consequences of improper control settings, explore alternative control settings, and reoptimize boiler settings with new constraints.

For example, Boiler OP can be used to determine new optimized boiler control settings. This capability becomes useful in cases where plant management asks the operators to lower daily average NOx levels to meet an end of year emissions limit or perhaps raise NOx levels with accompanying reductions in heat rate. If equipment limitations arise which necessitate a change in control settings, BoilerOP can be used to determine the combination of new settings which meets emissions and performance goals subject to the equipment constraint. Boiler OP can also be used by plant operators to compare actual boiler settings to the recommended settings and determine the impacts on NOx, heat rate and unburned carbon.

Once the initial parametric boiler testing is complete, no additional testing is needed to use these Operator Tools. The database created during the initial testing is used by the Operator Tools for predictions and reoptimizations. The user decides on the tool to be used and inputs the necessary information. The software then recalls the neural networks and optimization algorithm to give the desired answer.

**TYPICAL COST SAVINGS**

By using the combination of boiler control settings which minimize LOI or heat rate or provide the best boiler efficiency, substantial savings can often be realized due to reduced fuel consumption. If the goal of the optimization is to reduce heat rate, reductions of up to 50 to 100 Btu/kWh are typical of those which can be achieved by using Boiler OP. For a 600 MW coal-fired unit with a net unit heat rate of 9,000 Btu/kWh and firing $2/10^6$ Btu fuel, the annual cost savings is in the range of $700,000/year for a 90 Btu/kWh reduction in heat rate. Additional savings will occur if the optimization makes it possible to avoid installation of expensive low NOx burners, sell fly ash due to reduced LOI levels or eliminate unit derates due to opacity excursions. By using the methods contained in Boiler OP, PEPCO was able to save approximately $40 million at Potomac River Station. In this case, the plant was successful in reducing NOx to below the regulatory limit without installing low NOx burners.

**SOFTWARE DESCRIPTION**

Boiler OP is designed for users with no background in expert systems and neural networks. All of the calculations and analyses performed by the program are invisible to the user. The software is written in Visual Basic and C++ and runs on an IBM personal computer under Microsoft Windows. The data can be collected manually or through an interface with an existing plant data acquisition system. The user interface is configured to ensure the user provides all the information needed to optimize the unit being tested.

The current versions of Boiler OP can be used with tangentially-fired pulverized coal boilers with either conventional burners or low NOx burners and overfire air. A
wall-fired version of Boiler OP is under development and will be complete by June 1997. With minor modifications to the software, the approach can also be used for boilers fired with oil or natural gas and boilers in which NO\textsubscript{x} is controlled by other means such as selective non-catalytic reduction.

### BOILER OP NOW AVAILABLE FOR LICENSING

Companies interested in using Boiler OP at their facilities can obtain licenses through the Energy Research Center. The cost of a Boiler OP software site license depends on the application and any special user requirements. For more information on licensing or on how Boiler OP can help you achieve your optimization goals, please contact:

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