The Boiler is a Calorimeter

Philip D. French, P.E.

French & Associates Consulting Engineers, P.C.

THE BOILER IS A CALORIMETER

Presented at the 1998 User's Group Meeting
Scientech, Inc., Performance Systems Department
Idaho Falls, Idaho, June 20-25, 1998
by:
Philip D. French, P.E., President
French & Associates Consulting Engineers, P.C.
6 N.E. 180th Street
Smithville, Missouri 64089

ABSTRACT

This paper demonstrates how heat rate calculations can be validated on a daily basis in order to ensure the accuracy and the reliability of the results. Two (2) different methods are used to calculate Net Unit Heat Rate. By comparing these two values and reconciling the differences, errors in the data can be quickly identifying and corrected. Thus, the accuracy and the reliability of both methods are maintained.

Reports are generated automatically by PMAX® to facilitate the comparison of the two Net Unit Heat Rates. The procedure is simple, but the resulting data is surprising. In comparing the results of the two methods, it quickly becomes obvious that the fuel quality can change dramatically from day to day.

The boiler is, in fact, a calorimeter. By measuring the heat that is transferred to the steam we can calculate an "implied heating value of the coal". Trends are used to dramatize how much the heating value of the coal can vary from day to day. The need for frequent coal samples is evident from the examples that are included.

The main benefit of this automated comparison of heat rates is that operations personnel have a better indication of unit performance by ensuring that both methods of calculating heat rate are accurate and reliable. Also, the credibility of the PMAX® system is reinforced and, therefore, it is better utilized. Coal quality changes are quickly identified and their impact on the boiler is better understood. Another benefit of this procedure is that coal scale measurement problems are quickly identified. This minimizes errors in fuel inventory accounting and reduces the impact of fuel inventory adjustments.

THE BOILER IS A CALORIMETER

Presented at the 1998 User's Group Meeting
Scientech, Inc., Performance Systems Department
Idaho Falls, Idaho, June 20-25, 1998
by:
Philip D. French, P.E., President
French & Associates Consulting Engineers, P.C.
6 N.E. 180th Street
Smithville, Missouri 64089

SECTION 1 - INTRODUCTION

We automate processes in order to reduce manpower, eliminate drudgery, increase the speed (or frequency) and eliminate human error. Computers do a great job of collecting data, performing calculations and producing reports. But, our ability to automate plant performance reporting exceeds our ability to scrutinize the raw data. The result is that reports contain erroneous data. Monitoring the raw data can be time consuming. At least part of the solution is to automate some of the work involved in identifying bad raw data.

In this paper, two (2) different methods are used to calculate Net Unit Heat Rate. Errors in the data can be quickly identifying and corrected by comparing these two values and reconciling the differences. Thus, the accuracy and the reliability of both methods are maintained.

It is not difficult to calculate a value for Net Unit Heat Rate. However, it can be difficult to calculate an accurate value consistently. This is especially true if we are using realtime data. Once the calculations are programmed correctly, they are always correct until they receive some bad inputs. Bad inputs cause the calculations to be in error and cause the realtime system to loose credibility. Unfortunately, bad inputs occur more often than most people realize.

The biggest obstacles to correctly calculating Net Unit Heat Rate are knowing the heating value of the fuel and being able to identify when a field instrument is providing erroneous data. Monitoring the data and identifying bad inputs can be time consuming. If the errors are allowed to accumulate over time, then we lose our ability to properly monitor unit performance and it can impact our ability to manage the fuel inventory. This paper presents a method for identifying errors in calculating Net Unit Heat Rate quickly and easily.

By using two methods to calculate Net Unit Heat Rate and reconciling the differences between them, we build the confidence of the operating personnel that the realtime values are reliable. With this confidence, they are able to use realtime data to improve unit performance. The additional information that is gained concerning coal quality is also valuable. Part of the process of reconciling the two Net Unit Heat Rates involves calculating an "implied heating value" for the coal. In order to do this, we use the boiler as a calorimeter.

The famous Chinese philosopher, Confucius, allegedly said that, "A man with one watch always knows what time it is, but a man with two watches is never sure." This paper shows that by comparing two values we can identify when there is a problem with either of them.

SECTION 2 – THE BOILER IS A CALORIMETER

In the laboratory, an adiabatic bomb calorimeter is used to determine the heating value of a coal sample. A few ounces of coal are burned in the calorimeter and the heat is absorbed by a surrounding water jacket. The rise in the temperature of the known quantity of water allows the analyst to determine the heating value of the fuel.

We do essentially the same thing with the utility boiler. We burn a known quantity of fuel (coal, oil or gas) and measure the amount of heat that is given off to the water and steam. By measuring the pressure, temperature and flow rate of the water and steam, we can calculate the net heat that is input to the water by the burning of the fuel. Given this information we can calculate the heating value of the fuel. In the case of the bomb calorimeter, the results from a small sample are extrapolated to represent the heating value of many tons of coal. In the case of the utility boiler, the "sample" size is equal to the tons of coal that are burned.

SECTION 3 – TWO METHODS OF CALCULATION

The first method used to calculate Net Unit Heat Rate is a time-honored approach. This paper will refer to this as the Coal Flow Method. The amount of coal that is burned is weighed and the fuel's heating value is determined by laboratory analysis. The product of these two values is the heat input to the boiler. Dividing this numerator by the net unit output results in the Net Unit Heat Rate.

Definition – Heating Value

In this paper, the term "heating value" is defined as the amount of heat recovered from the burning of the coal when the water remains in the vapor state. Its units are Btu/lb. This value is often referred to as "low heat of combustion", "net heating value" or "low heating value".

Definition - Method 1- Coal Flow Method:

The first method that is used to calculate Net Unit Heat Rate shall be called the "Coal Flow Method" for the purposes of this paper. The result is called "Coal Heat Rate" and is defined as follows:

$$\text{NET UNIT HEAT RATE} = \text{Coal Heat Rate (in Btu / kWh)}$$

$$= \frac{\text{(Tons of fuel) x (2000 Lb./Ton) x (Heating Value, Btu/Lb.)}}{\text{(Net Generation, kWh)}}$$

The first method is adequate for many purposes. To use it you need an accurate fuel flow measurement, representative fuel samples and you must wait several days for the laboratory analysis of the fuel samples. The accuracy and frequency of the coal analyses are critical when using this method of calculating Net Unit Heat Rate.

If we want to use performance data to evaluate current operation, then we must be able to calculate Net Unit Heat Rate in realtime (or in near realtime). We cannot afford to wait several days before we can calculate Net Unit Heat Rate (NUHR). We need to use a second method to calculate NUHR that is less dependent on an accurate fuel analysis.

The second method utilizes PMAX® to calculate a realtime turbine cycle heat rate and a boiler efficiency to determine the NUHR.

Definition - Method 2- Steam Flow Method:

The second method that is used to calculate Net Unit Heat Rate shall be called the "Steam Flow Method" for the purposes of this paper. The result is called "Steam Heat Rate" and is defined as follows:

$$\text{NET UNIT HEAT RATE} = \text{Steam Heat Rate (in Btu / kWh)}$$

$$= \frac{\text{(Net Turbine Cycle Heat Rate)}}{\text{(Boiler Efficiency,\%)/100}}$$

$$= \frac{\text{(Sum of the Heat Input to the Steam)}}{\text{(Net Generation, kWh) x (Boiler Efficiency, \%)/100}}$$

(Where the "Heat Input to the Steam" equals the mass flow rate of the steam multiplied by the change in enthalpy. In practice, the numerator contains several terms that account for different turbine sections and cycle losses, such as boiler blowdown.)

The numerator in the second method does not require that we know the fuel analysis. In the denominator, however, we do need a good estimate of the fuel analysis in order to calculate boiler efficiency. For this purpose we use an assumed or historical fuel analysis that is typical of recent analyses. The errors that are introduced by using an assumed fuel analysis on the boiler efficiency calculation are relatively small when we use the Heat Loss Method. The largest influence on boiler efficiency using the Heat Loss Method comes from the stack losses. These losses are primarily driven by excess oxygen, flue gas temperature and moisture. Both excess oxygen and flue gas temperatures can be measured accurately in realtime. The lack of realtime moisture data will have the biggest impact on the accuracy of the boiler efficiency calculation. However, this will introduce only an insignificant error. So, in general, the Heat Loss Method of calculating boiler efficiency is not significantly affected by day-to-day changes in the fuel analysis, and therefore, the Steam Flow Method for calculating NUHR is not greatly affected.

SECTION 4 – AUTOMATED REPORTING – RECONCILE HEAT RATES

It was necessary to determine a time interval that was appropriate for comparing the two methods. PMAX® is capable of calculating a fairly accurate realtime NUHR (Steam Flow Method) every few minutes. However, the Coal Flow Method cannot accurately yield a NUHR for such a short time interval because we cannot accurately measure small coal flows for short periods of time. Net Unit Heat Rates were calculated using both methods for time periods of varying lengths. After studying the results, it was concluded that a reporting interval of once per day resulted in a fairly accurate Coal Flow Heat Rate. In other words, for a 24-hour period, there was good agreement between the two methods of calculating NUHR. This also conveniently coincided with several reports that were already being created on a daily basis (midnight to midnight).

PMAX® collects the necessary data from midnight to midnight, creates a Daily Report and prints it automatically. A typical Daily Report would contain the following items:

1. The tons of coal weighed through each feeder plus the total tons of coal burned for the 24-hour period. (Gas and oil consumed would also be included as applicable.)
2. The assumed heating value of the fuel. (This is a constant value that can be manually changed if desired.)
3. Net megawatt hours produced during the period.
4. With the above data, a Coal Heat Rate is calculated and displayed on the Daily Report. (For this report the Coal Flow Method uses an assumed heating value.)
5. During the reporting period (midnight to midnight) PMAX® calculates several hundred values for the realtime NUHR using the Steam Flow Method and this data is archived. After midnight, the archived data is automatically searched by PMAX® and an average for the period is calculated. This value is shown on the Daily Report as the average Steam Heat Rate for the previous day.
6. PMAX® calculates an "Implied Heating Value" and displays it on the Daily Report.

<u>Definition - Implied Heating Value:</u>

The Implied Heating Value is defined as "the heating value of the fuel that would be required in order for the Coal Heat Rate to equal the Steam Heat Rate". In other words, we use the boiler as a calorimeter to determine the amount of heat that is absorbed by the water (the numerator) and we use the fuel quantity that was used in the Coal Heat Rate (the denominator) to determine BTUs per pound of fuel. If all of the raw data inputs are correct and if the samples are accurate, then the Implied Heating Value will equal the "low heat of combustion" (as determined by the laboratory analysis of the samples) for the given time period.

PMAX® calculates an Implied Heating Value and it is displayed on the Daily Report to help plant personnel in reconciling the differences in the two NUHRs. On most days, the day-to-day change in the coal's heating value will be the main reason for any discrepancy between the two NUHRs.

Close agreement between the Coal Heat Rate and the Steam Heat Rate indicates that:

1) The assumed heating value is reasonably close to the actual heating value.
2) All inputs to both methods of calculating NUHR are reasonably correct.
3) The actual daily average NUHR is close to the two calculated values.
4) The PMAX® realtime heat rates (several hundred values) were accurate for the 24-hour period.

When the Daily Report is first reviewed, the Implied Heating Value may seem grossly different from the assumed value. However, it still may be correct. As seen in the examples that follow, the heating value can vary significantly from one day to the next.

If the implied heating value is unreasonable and cannot be reconciled, then the task becomes that of finding the cause for the deviation, such as an erroneous instrument. Either value of NUHR could contain the error. One of the examples that are discussed later shows how an instrument error is identified by an unreasonable implied heating value.

The implied heating value is a valuable tool in reconciling the two values for NUHR that are shown on the Daily Report. Often, the reconciliation process is simply a matter of agreeing with the change in implied heating value from the previous day. A knowledge of the fuel yard conditions and the fuel source are helpful in this process.

SECTION 5 – EXAMPLES

In this paper, examples from three different generating units are used. Each example shows some anomalies in the data and how the differences are reconciled. The primary fuel is coal, but the calculations are also designed to include any supplemental firing of oil or gas. For simplicity, this paper generally refers to the fuel as coal.

Example No. 1

Example No. 1 is shown in Figures No. 1A and 1B. Both figures apply to the same generating unit and are for the same 31-day period.

Refer to Figure No. 1A. This trend shows the calculated values that are printed on the Daily Reports. Supervisory personnel would notice on each of the first nine days that there is close agreement between the Coal Heat Rate and the Steam Heat Rate. This would generally indicate that there are no instrumentation problems. In order to reconcile the two NUHR values we need only compare the implied heating value of the coal to the assumed value. The difference between the two values of NUHR is attributed to changes in the actual heating value of the fuel.

Refer to Figure No. 1B. Notice that the implied heating value changed from about 8450 Btu/lb. to about 8750 Btu/lb. during the nine day period. The laboratory analysis heating values are also shown on Figure No. 1B. The laboratory analyses for the first 9 days confirm the increase in the implied heating value. However, this could not be confirmed until the laboratory analyses were received (often several days (or weeks) after the fuel is already burned). Plant personnel must use their knowledge of the fuel yard conditions and the fuel supply source to help in reconciling the two values of NUHR. So, hopefully, they would be able to rationalize why the heating value was increasing during these nine days.

On Day 10 (Fig. 1A) the Coal Heat Rate jumps from its typical 10,300 Btu/kWh to over 11,000 Btu/kWh. The reason for this is that rainy weather has caused the heating value to drop from about 8750 to about 8250 Btu/lb. The laboratory analyses heating values (Fig. 1B) confirm that the heating value dropped significantly during this period.

In Figure No. 1B notice that the implied heating value "lags" the sampled (laboratory analysis) heating value. This is due to the residence time of the coal as it travels from the sample point (often in the fuel yard) to the bunkers and then to the furnace.

Again, referring to Figure No. 1A, we see that the fuel supply returned to normal on about Day 12 and there were no major deviations between the Steam Heat Rate and the Coal Heat Rate until about Day 22. On Days 22, 23 and 24, there is a significant drop in heating value. This is due to an equipment outage in the fuel yard that made it necessary to reclaim fuel from an emergency reclaim area that contained poor quality coal. Again, subsequent laboratory analyses agreed with the implied heating value that was calculated by PMAX®.

Figure No. 1B shows three constant lines. These are the 31-day averages for the three heating values (Assumed, Implied and Laboratory Analysis). The average implied heating value for the month is 8610 Btu/lb. This is about 1% lower than the assumed heating value (8700 Btu/lb.) and about 0.24% lower than the average of the 31 laboratory analyses (8631 Btu/lb.). The assumed heating value was too high, but there was close agreement between the implied heating value and the average of the laboratory analyses. This gives credibility to the calculated results for the time period.

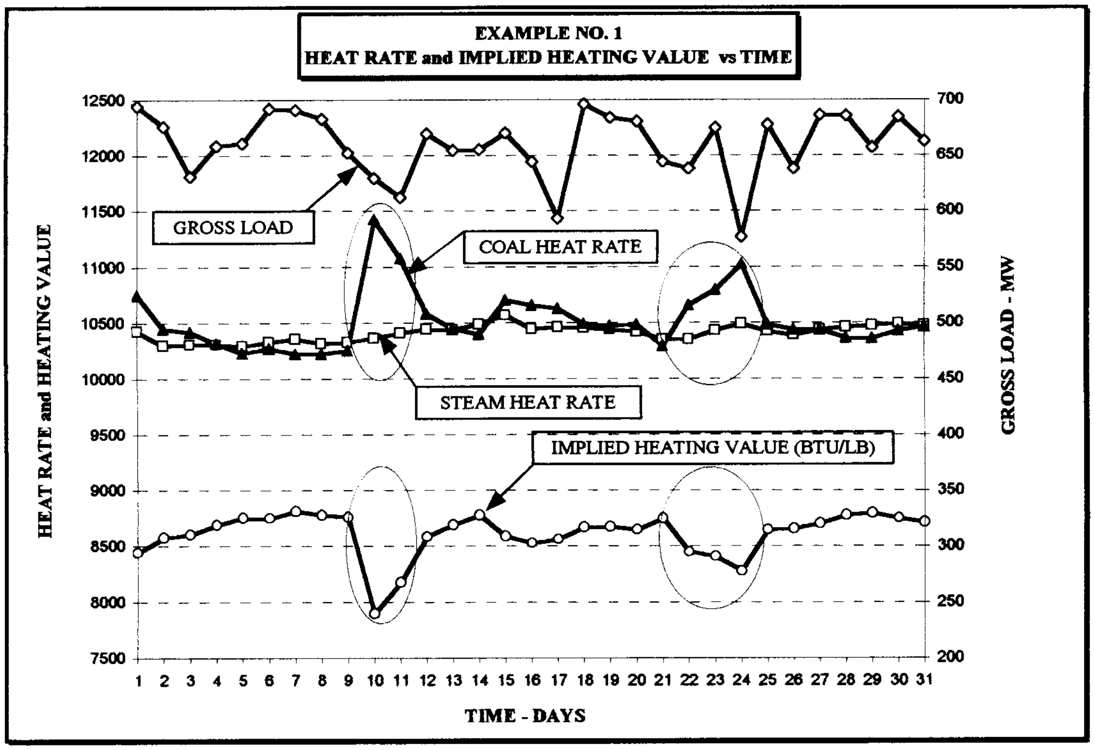

FIGURE NO. 1A

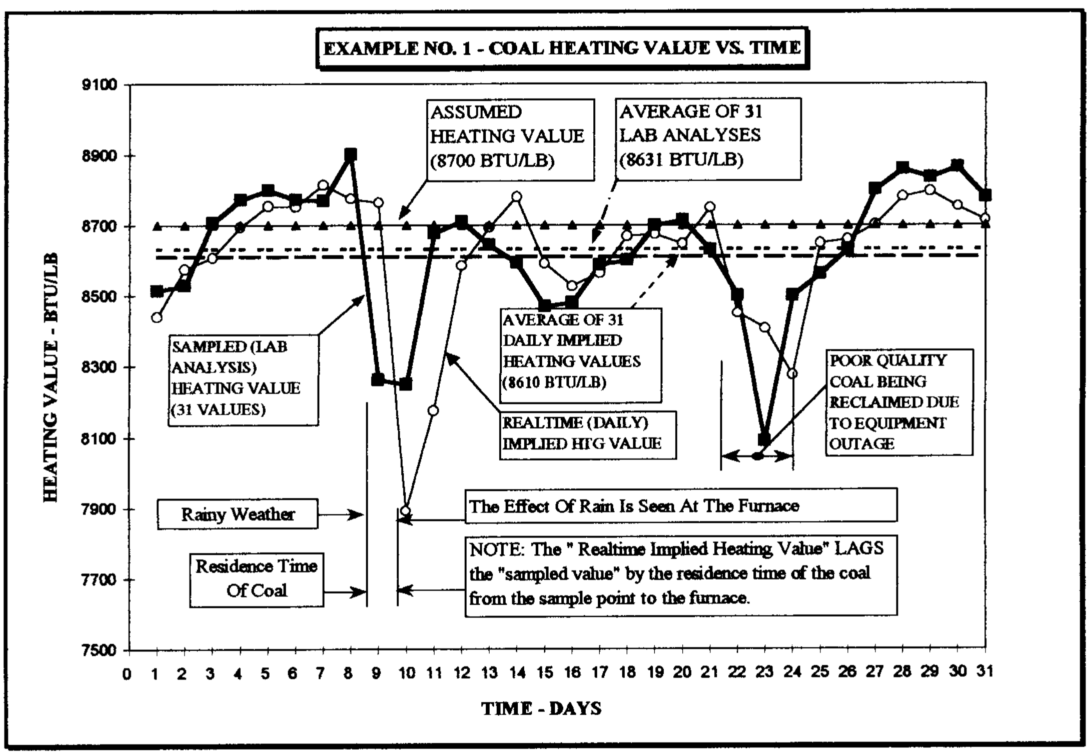

FIGURE NO. 1B

Example No. 2

Example No. 2 is shown in Figures No. 2A and 2B. Both figures apply to the same 31-day period. This is the same 31-day period that was used in Example No. 1, but Example 2 is for a different generating unit located at a different plant site. The same 31-day period was chosen in order to show the similar affect due to the rain on the same days. The rainy period is indicated by ellipses at Days 9 and 10. The affect of the rain on the implied heating value gives credibility to the calculated data. The lack of adequate samples makes further verification of the calculated results difficult.

Refer to Figure No. 2A. This trend shows the calculated values that are printed on the Daily Reports. There are two areas where the Steam Heat Rate and the Coal Heat Rate differed significantly. They are indicated by the ellipses.

Example No. 2 is included to illustrate the importance of regular and frequent coal samples. Figure No. 2B shows average values for the three heating values (Assumed, Implied and Laboratory Analysis). Note that in Example No. 1 we had 31 coal samples (one laboratory analysis for each of the 31 days). In Example No. 2, however, there were only 15 samples taken during the 31-day period. The 15 values for the laboratory analyses are shown by square symbols. The solid line connects only the contiguous values. Samples were not taken on a number of days when the implied heating value was low. The average for 31 implied heating values was only 8554 Btu/lb., while the average value for the 15 samples was 8720 Btu/lb. That is nearly a 20 percent difference. This shows the importance of regular and frequent samples.

There is a second area on Figure No. 2B where the Steam Heat Rate and the Coal Heat Rate deviated significantly. That occurred between Days 18 and 20. Unfortunately, there is not enough information available during this time to identify the cause for that difference.

We cannot draw solid conclusions about the NUHR because of the lack of samples. However, visual inspection suggests that the implied heating values are consistently lower than the laboratory analyses. If this is true, then an instrument that is out of calibration could be causing either the Steam Heat Rate to be too low or the Coal Heat Rate to be too high.

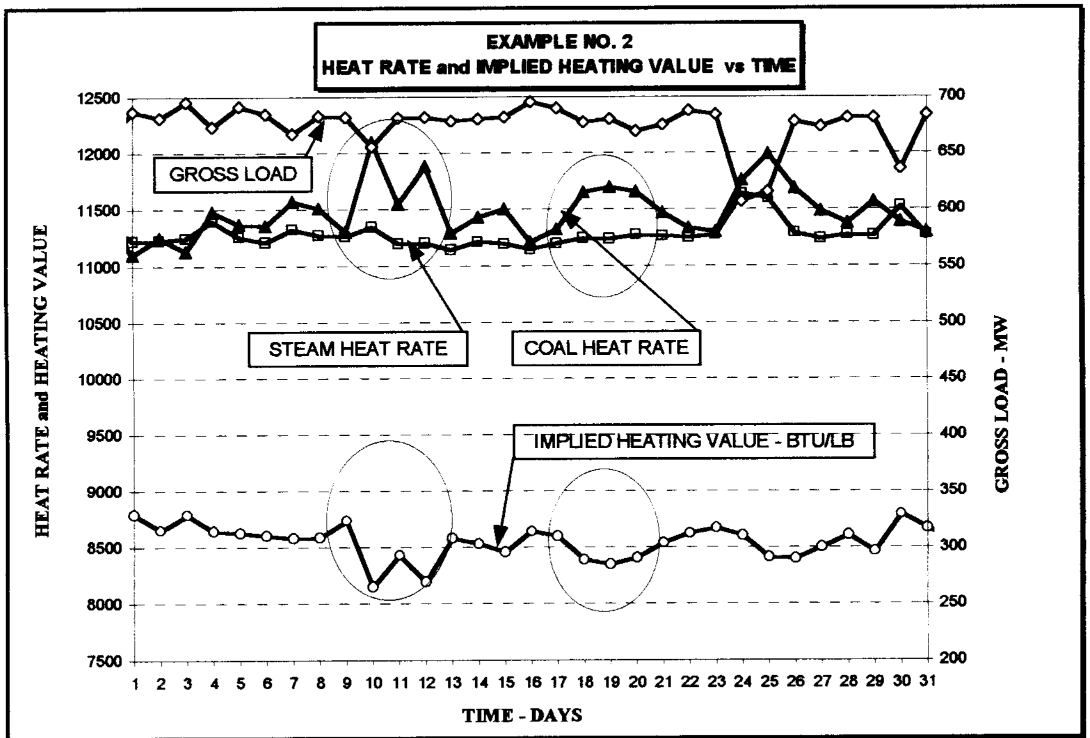

FIGURE NO. 2A

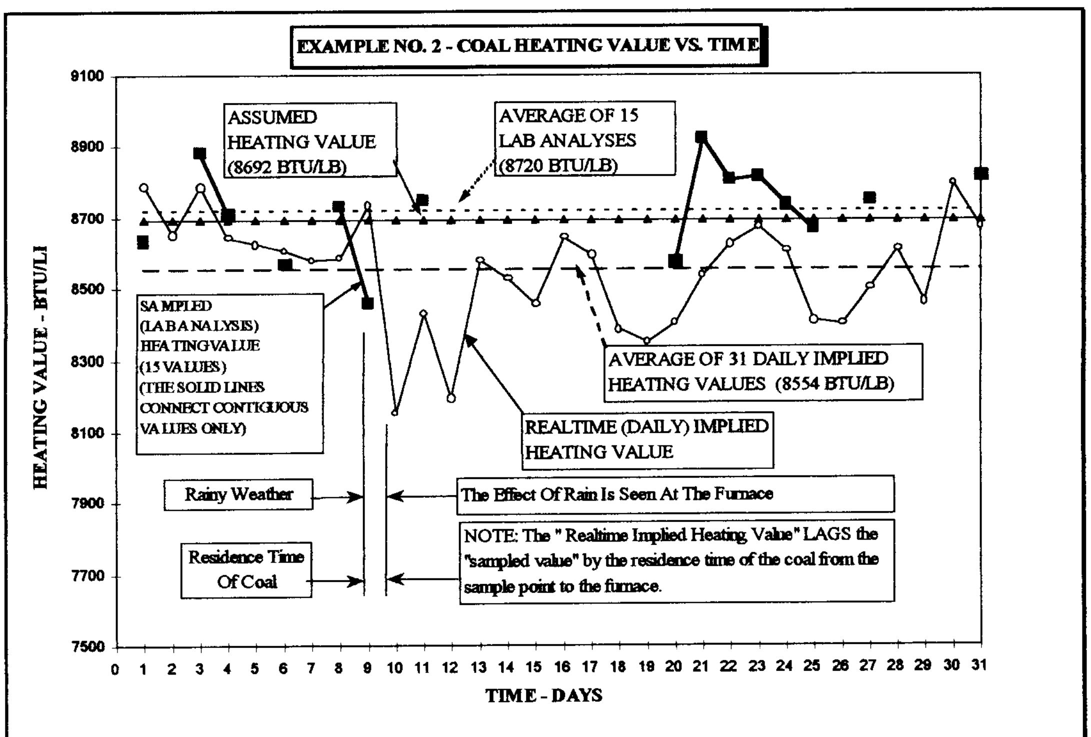

FIGURE NO. 2B

Example No. 3

Example No. 3 is shown in Figures No. 3A and 3B. Both figures apply to the same generating unit and are for the same 31-day period.

Refer to Figure No. 3A. This trend shows the calculated values that are printed on the Daily Reports. On Day 5 the Coal Heat Rate was about 500 Btu/kWh higher than the Steam Heat Rate. This was because of incorrect coal flow reading(s). This area is indicated by ellipses. By Day 8 the instrumentation problem was corrected and the two heat rates were again in close agreement. These incorrect coal flow readings can affect our fuel inventory accounting.

Figure No. 3B shows average values for the three heating values (Assumed, Implied and Laboratory Analysis). If we throw out the 3 implied heating values for Days 5, 6 and 7, then the average implied heating value for the month (28 values) is 8625 Btu/lb. This is about 0.6% lower than the assumed heating value (8680 Btu/lb.) and about 0.3% lower than the average of the 25 laboratory analyses (8652 Btu/lb.). The close agreement of these three numbers gives credibility to the results for the time period. Compare this to the 20% difference in the heating values shown in Example No. 2.

SECTION 6 – FUEL INVENTORY ACCOUNTING

Fuel inventory management is becoming more critical as deregulation comes about. Optimizing fuel inventory and timing fuel deliveries properly can result in significant savings. It is, therefore, important to recognize coal scale problems quickly and correct them quickly.

In order to know the quantity of coal on hand, we typically use aerial photography to calculate the volume of the pile. We then measure densities and calculate the number of tons. From that time on, we subtract the tons of coal burned and add the tons that are received. However, in practice, coal scales are not always as accurate or as reliable as we would like for them to be.

Errors in weighing coal can accumulate over long periods of time and cause our fuel inventory calculation to be incorrect. When this occurs, it is necessary to make large corrections to the inventory accounting. Typically, this is done annually. However, with the information that is included in the Daily Report it is possible to recognize incorrect coal flows and calculate an estimated coal flow. Therefore, corrections to the coal inventory accounting data are small.

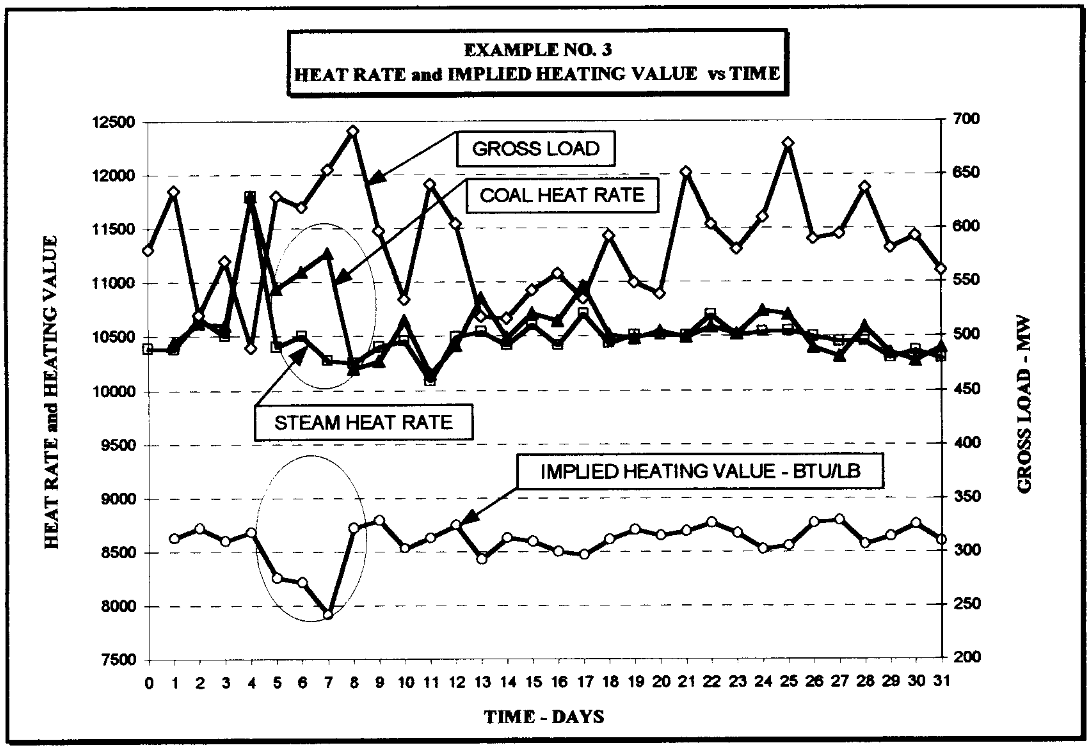

FIGURE NO. 3A

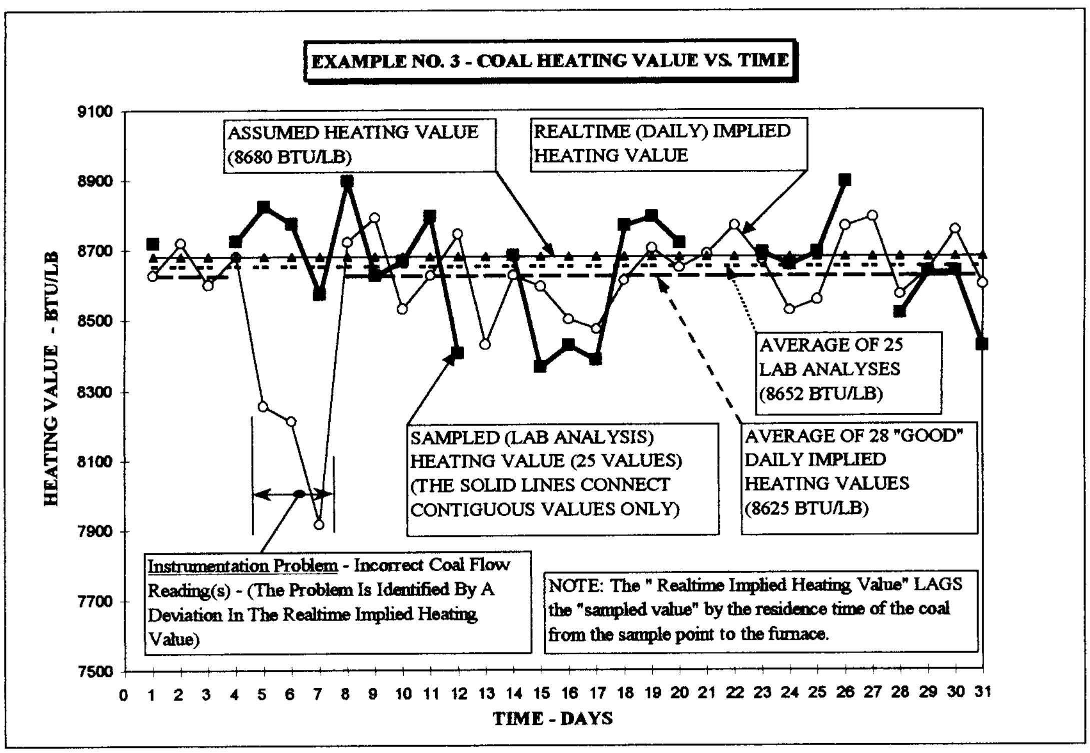

FIGURE NO. 3B

SECTION 7 – CONCLUSIONS

We rely heavily on automated reporting systems, but field instruments can give us bad data at any time. We need to automate ways to quickly and easily identify erroneous raw data. Two different methods of calculating Net Unit Heat Rate serve as a way to check both methods for accuracy. By reconciling the two values of Net Unit Heat Rate on a regular (daily) basis, we not only identify bad instruments, but we can also gain valuable information about the quality of the coal that is being burned.

Often, the only difference between the Steam Heat Rate and the Coal Heat Rate is the difference between the implied heating value and the assumed heating value. Knowledge of the fuel supply will help in reconciling the difference between the implied heating value and the assumed heating value. The heating value of the coal can change dramatically from day to day. Some conditions that will affect the heating value are the delivery source (or reclaim location), spot market variations, rainy weather and on-site blending. Unfortunately, it may be necessary to wait several days until the laboratory analysis of a coal sample is received before a final reconciliation of the heat rates can be made.

By using the boiler as a calorimeter, we can estimate the heating value of the fuel several days (or weeks) in advance of receiving laboratory analyses for the coal samples. An increased awareness of coal quality by operations personnel allows them to scrutinize coal quality affects in the fuel yard and in the boiler. The examples show the need for frequent and regular samples.

The close agreement between the implied heating value and the laboratory analyses gives credibility to the realtime performance monitoring system (PMAX®). Verifying the results of the 24-hour averages gives confidence that the minute-by-minute (or realtime) calculations are also correct. Operations personnel, therefore, have more confidence in the realtime system and are able to use the realtime information to reduce the heat rate.

Fuel inventory management is also improved by being able to quickly identify when the coal scales are reading incorrectly. When the scales are incorrect, the Daily Report gives a good set of data with which one can estimate the correct number of tons that were burned.

By reporting better information on a daily basis, our realtime systems gain credibility, we are able to reduce heat rate in realtime, we more closely scrutinize the affects of coal quality changes and can better manage the fuel inventory. All of these items will help to make the utility more competitive.