REAL-TIME HEATRATE MONITORING OF COAL-FIRED UNITS

Sastry Munukutla, Director
Robert Craven, R&D Engineer

CENTER FOR ENERGY SYSTEMS RESEARCH
(formerly Center for Electric Power)
Tennessee Technological University

OVERVIEW

1. Boiler efficiency calculation – Anomaly
2. Consistent set of definitions
3. Output/loss method
4. Tennessee Technological University approach
5. Field results (heatrate, coal composition, coal flow rate)

ASME PTC4 – 1998
SECTION 3 – GUIDING PRINCIPLES (p 19)

$$\text{Steam Generator Efficiency} = \frac{\text{output}}{\text{input}} * 100$$

"This single definition yields many different values for efficiency depending upon the choice of items to be included as output, items to be included as input and higher or lower heating value of the fuel. Entwistle et. al. discuss this problem at length and demonstrate that at least 14 different values of efficiency can be computed from the same data."

[ASME 84-JPGC-PTC-6; ASME 88-JPGC-PTC-3]

PTC 4.1 - 1964

$$\text{input} - \text{output method}$$

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}$$

$$= \frac{\text{heat absorbed by working fluid}}{\text{heat in fuel} + \text{credits}}$$

$$= 1 - \frac{\text{heat losses}}{\text{heat in fuel} + \text{credits}}$$

Credits Heat in Entering Air, Heat in Atomizing Steam, Sensible Heat in Fuel, Pulverizer Power, Boiler Circulating Pump Power, PA Fan Power, Recirculating Gas Fan Power, Heat Supplied by Moisture in Entering Air, Heat in Cooling Water

Losses Unburned Carbon in Refuse, Heat in Dry Gas, Moisture in Fuel, Moisture from Burning Hydrogen, Moisture in Air, Heat in Atomizing Steam, Carbon Monoxide, Unburned Hydrogen, Unburned Hydrocarbons, Radiation and Convection, Radiation to Ash Pit, Sensible Heat in Slag & Latent Heat of Fusion of Slag, Sensible Heat in Flue Dust, Heat in Pulverizer Rejects, Heat in Cooling Water, Soot Blowing.

CONSISTENT SET OF DEFINITIONS

$$\eta_B = \text{Boiler Efficiency} = \frac{Q_S}{M_C * HHV}$$

$$HR_C = \text{Steam Cycle Heatrate} = \frac{Q_s}{Kwg}$$

$$HR_G = \text{Unit Gross Heatrate} = \frac{HR_C}{\eta_B} = \frac{M_C * HHV}{Kwg}$$

$$Q_s = \text{Heat transferred to steam (Btu/hr)}$$

$$M_C = \text{coal flow rate (lb/hr)}$$

$$HHV = \text{Btu/lb}$$

$$Kwg = \text{gross generation (kw)}$$

$$SS = \text{station service power}$$

$$\text{Net Unit Heatrate} = \frac{M_C * HHV}{(Kwg - SS)} = \frac{HR_C}{\eta_B} * \frac{Kwg}{(Kwg - SS)}$$

Dividing the steam cycle heatrate by boiler efficiency is permissible only when η_B is defined as above, (not by any of fourteen different ways)

When boiler efficiency and steam cycle were considered as independent parameters, we could have used any definition for boiler efficiency. However, in the last fifteen years, it was clearly established that the coupling between boiler efficiency and steam cycle heatrate is very important. The output-loss method evolved as the most viable method for heatrate.

OUTPUT/LOSS METHOD

output / loss method

input = output + losses

$$M_C * HHV = Q_S + L \qquad (1)$$

$$L = \ell * M_C$$

$\ell \rightarrow$ Losses per unit mass of coal

dividing Equation 1 throughout by $M_C * HHV$ (2)

$$1 = \frac{Q_S}{M_C * HHV} + \frac{L}{M_C HHV} = \eta_B + \frac{\ell}{HHV}$$

$$\eta_B = 1 - \frac{\ell}{HHV} \qquad (3)$$

In order to utilize this method, it is necessary to choose a control volume tightly around the boiler

POWER PLANT MODEL

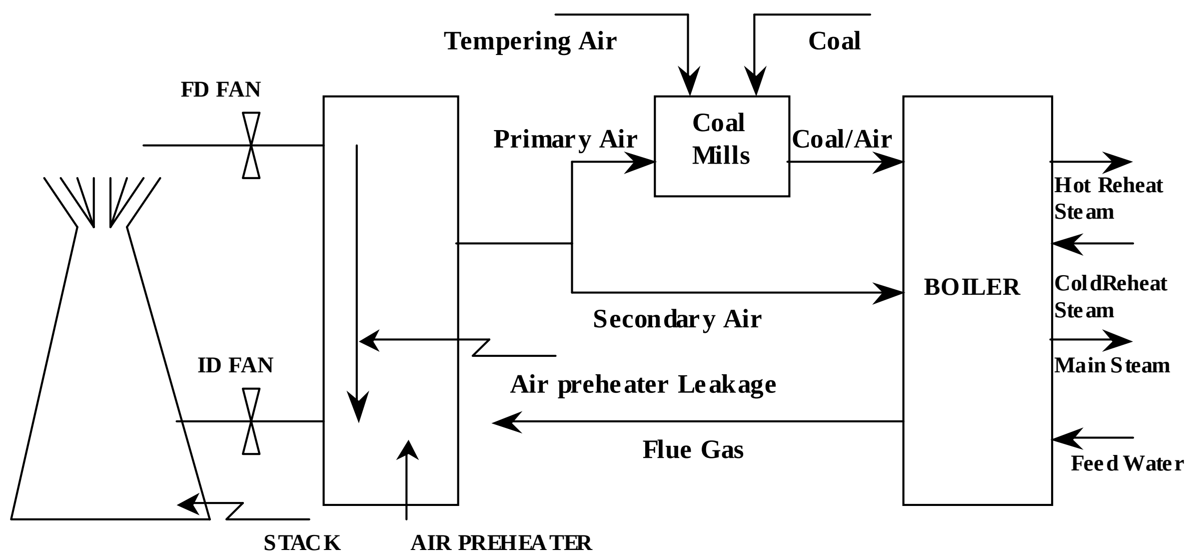


Figure 1. Schematic of the System Modeled by the Output/Loss Method

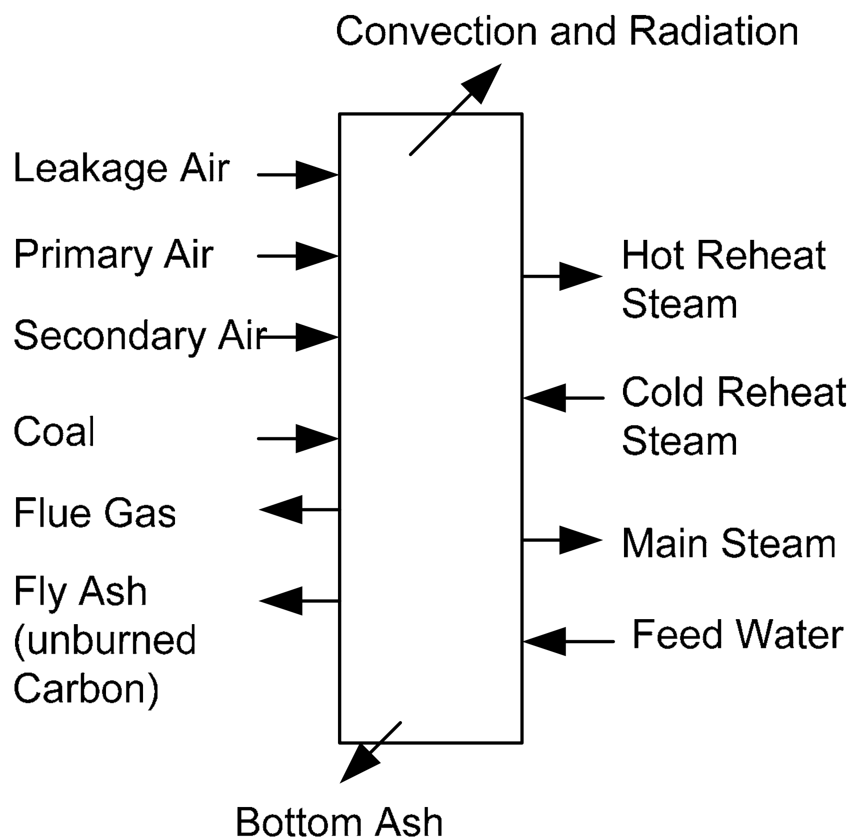


Figure 2: Energy analysis for the boiler

T.T.U. APPROACH

1. Determine Coal Composition from Flue Gas Analysis

   (Addition of Moisture Measurement, Real-Time BTU and Ash Measurement and Nitrogen in Flue Gas Measurement will enhance the accuracy)
2. Start with combustion equation and determine mass of CO_2, CO, SO_2, H_2O, O_2 & N_2 per unit mass of coal.
3. Calculate Q_s
4. Perform energy balance around boiler and determine heat transfer to steam per unit mass of coal. (Verify by loss calculation)
5. Calculate M_C, η_b, HR_c, HR_G, and HR_N

(A Chemical Company was mandated to monitor coal flow and report to EPA. The Boiler was very old and it would not have been possible to add Belt Scales or Feeders. TTU calculation was approved by EPA for reporting the coal flow.)

FIELD RESULTS

1. HEATRATE
2. COAL COMPOSITION
3. COAL FLOW RATE

UNITS MODELED

1. Plant Scherer, Four 880 MW units
   Georgia Power, Georgia

2. J. M. Stuart Station Unit 4, 600 MW
   O. M. Hutchings Station, 65 MW
   Dayton Power, Ohio

3. Plant Miller Unit 4, 680 MW
   Alabama Power, Alabama

4. Greenriver Unit 2, 60 MW
   Kentucky utilities, Kentucky

5. Kingston Unit 9, 200 MW
   TVA, Tennessee

6. JPM Unit 300 MW, Genoa Unit 300 MW, Five Alma Units 300 MW
   Dairyland Power Cooperative, Wisconsin

7. Monticello Station, Two 500 MW Units
   Texas Utilities, Texas

8. Plant Hammond, 500 MW
   Georgia Power, Georgia

9. Brandon Shores Unit 700MW
   Baltimore Gas & Electric, Maryland

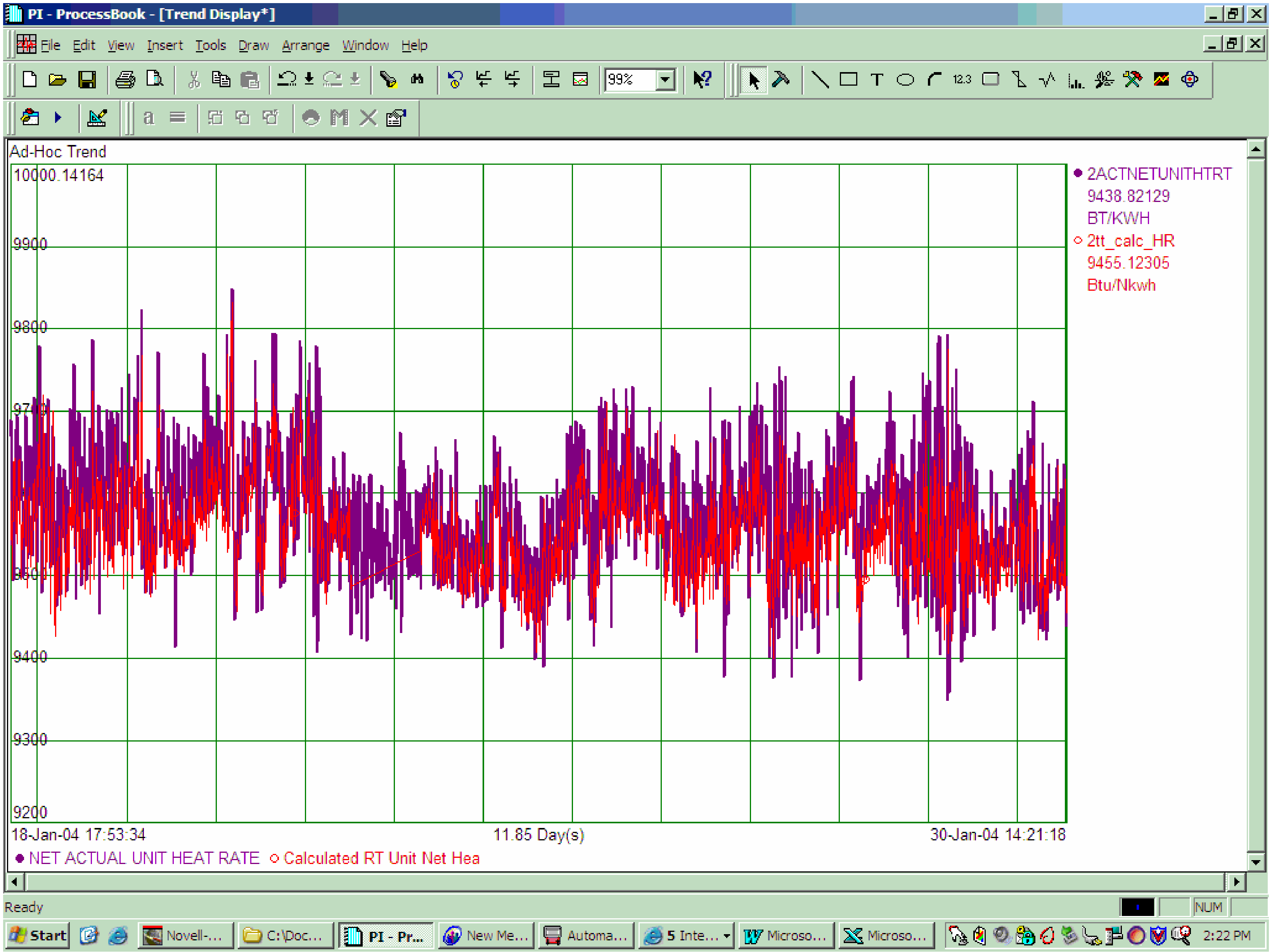
10. Dadri Unit, 500 MW
    NTPC, India

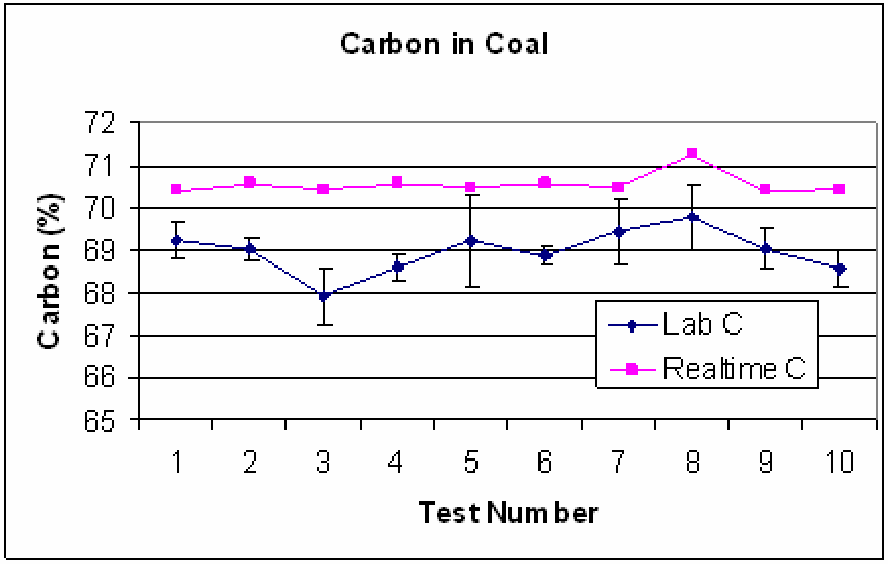
11. Clover Station, Two 600 MW Units
    Dominion Generation, Virginia

12. Huntly Station, 250 MW Units
    Genesis Power New Zealand

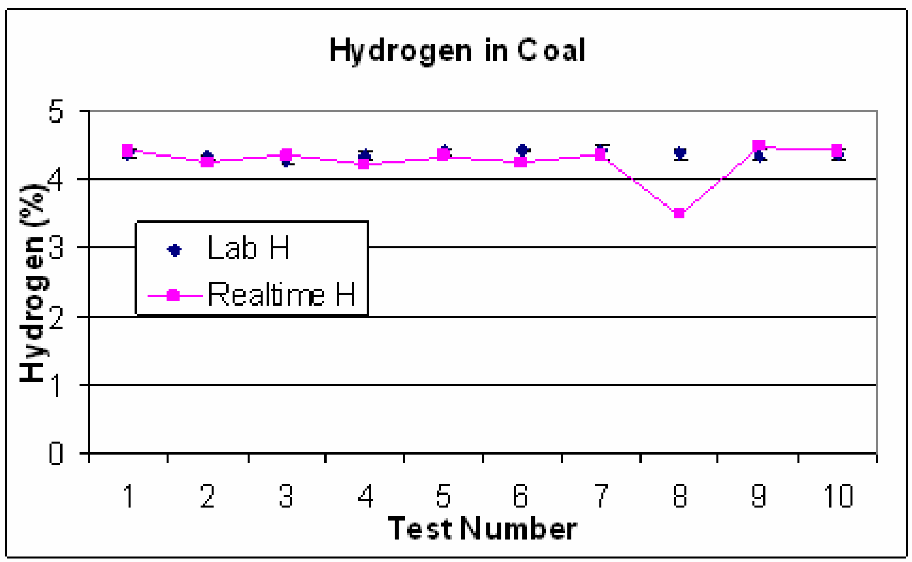
COMPARISON OF TTU REAL-TIME HEATRATE MONITOR WITH HEATRATE FROM PERFORMANCE TEST

	Performance Test Btu/kWh	TTU Real-Time Btu/kWh	% Difference	Unit Load MW
1.	11705	11876	+1.46	125
2.	11185	10831	-3.16	150
3.	10869	10831	-.35	175
4.	10842	10586	-2.46	200
5.	10460	10370	-.86	250
6.	10418	10348	-.67	215
7.	10378	10345	-.31	325
8.	10355	10360	+.05	350
9.	10901	10781	-1.1	170
10.	10326	10211	-1.11	298
11.	10418	10287	-1.26	345
12.	10409	10255	-1.48	350

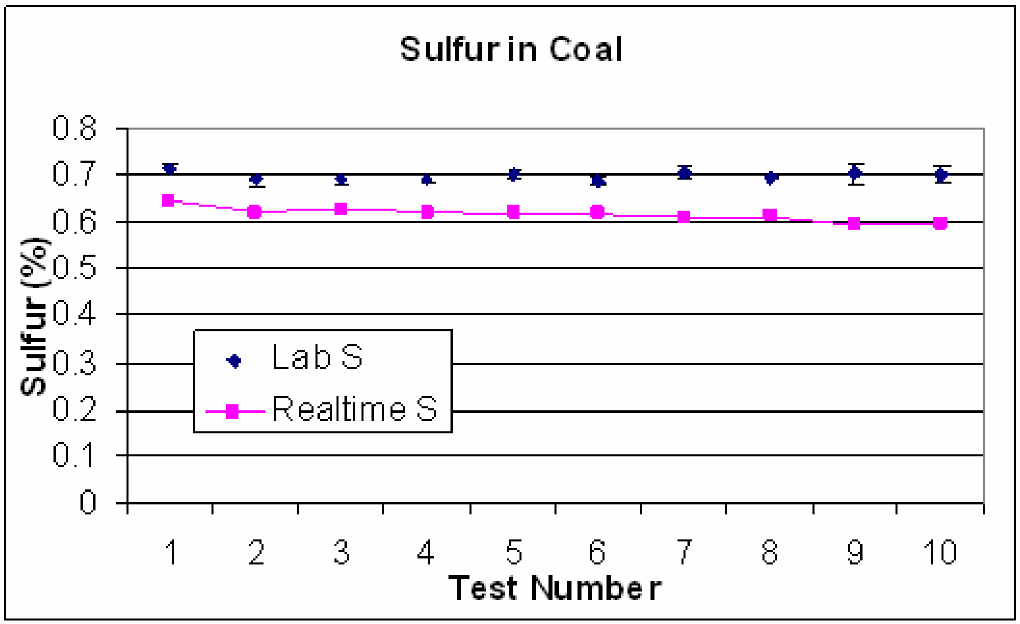

PI - ProcessBook - [Trend Display*]
File Edit View Insert Tools Draw Arrange Window Help
Ad-Hoc Trend
10000.14164
9900
9800
9400
9300
9200
2ACTNETUNITHTRT
9438.82129
BT/KWH
2tt_calc_HR
9455.12305
Btu/Nkwh
18-Jan-04 17:53:34
11.85 Day(s)
30-Jan-04 14:21:18
NET ACTUAL UNIT HEAT RATE
Calculated RT Unit Net Hea
Ready
NUM
2:22 PM



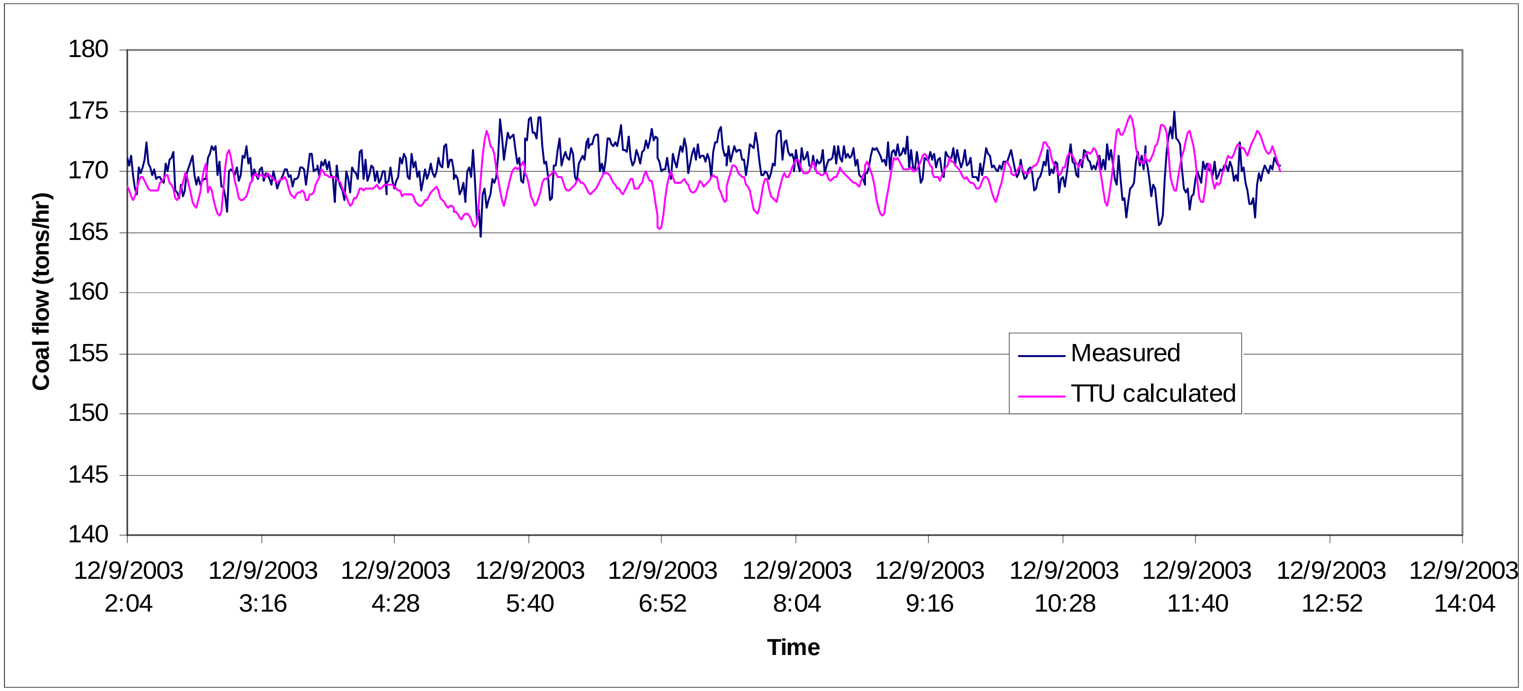
Percent carbon comparison between laboratory results and real-time prediction



Percent hydrogen comparison between laboratory results and real-time prediction

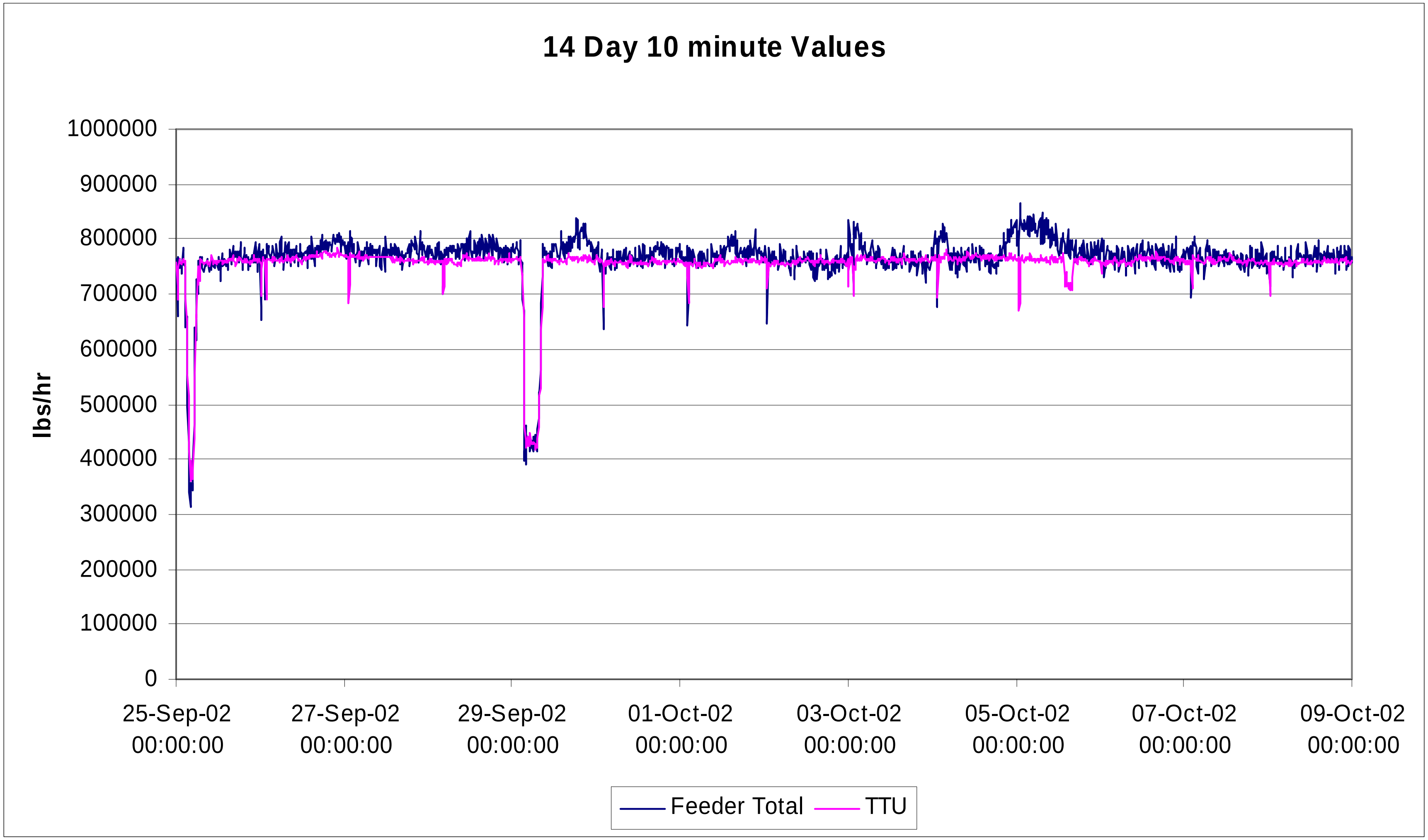


Percent sulfur comparison between laboratory results and real-time prediction

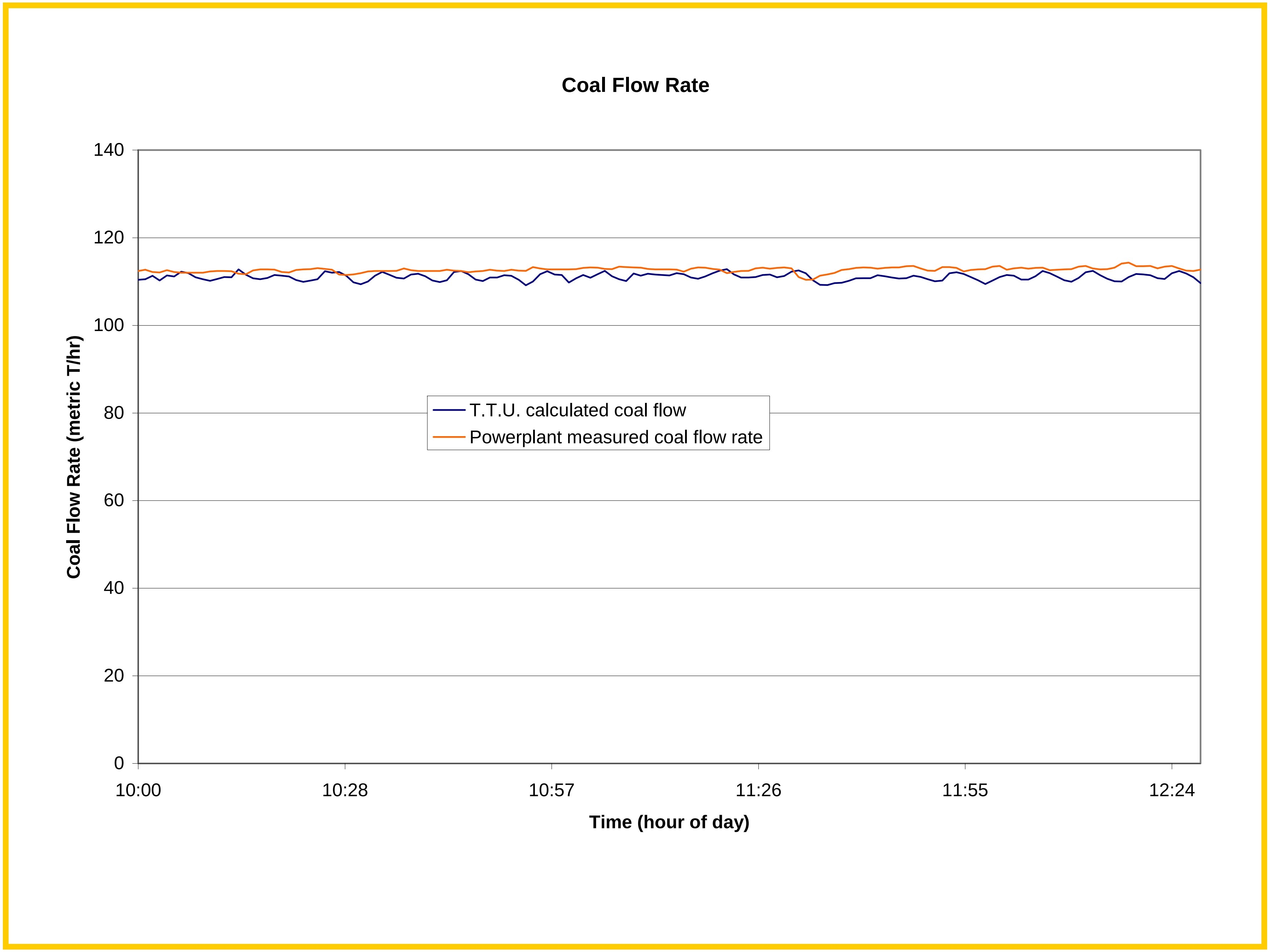


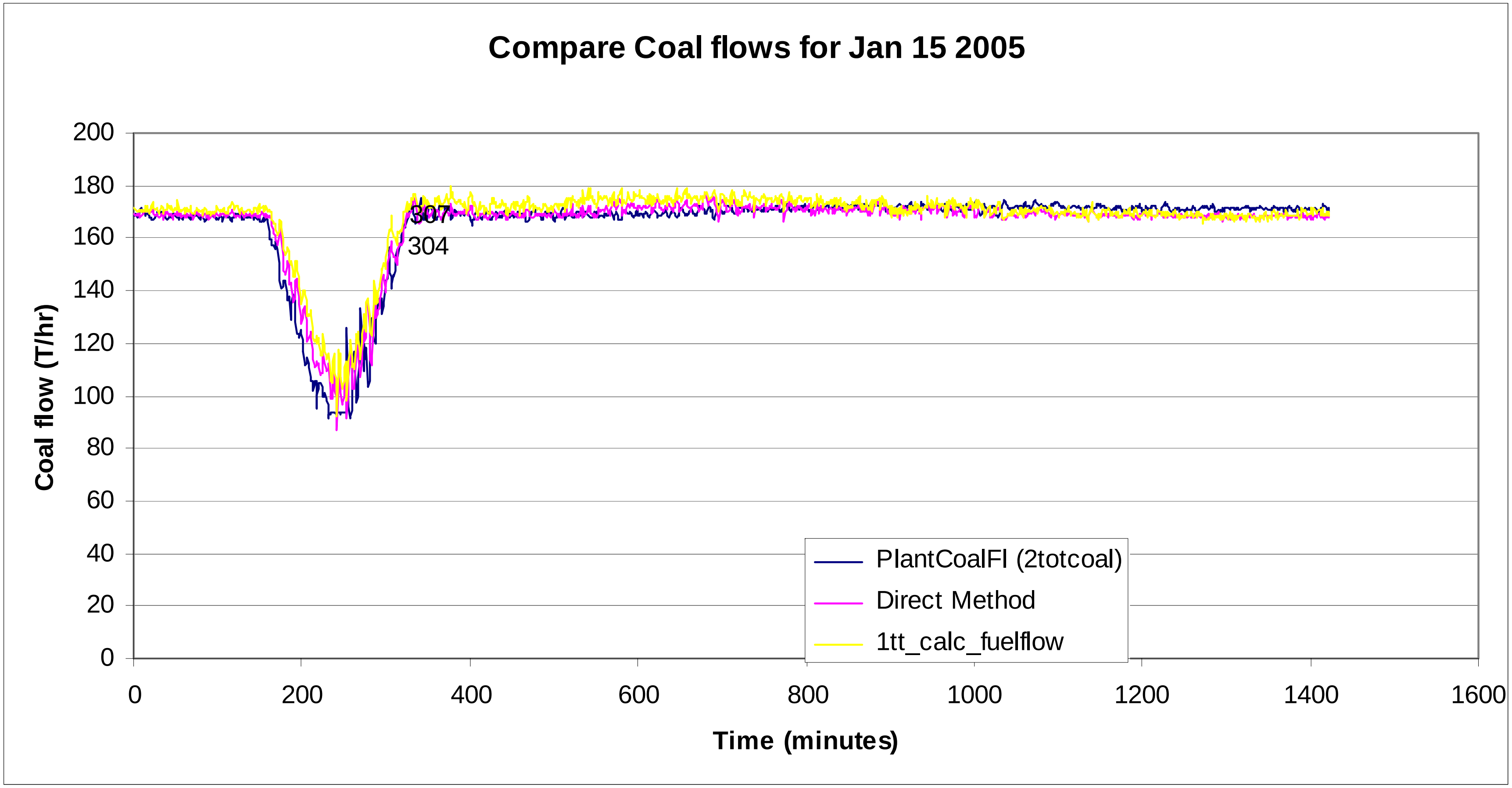
Measured versus Calculated Coal Flow

PLANT "A"



14 Day 10 minute Values
1000000
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
lbs/hr
25-Sep-02 00:00:00
27-Sep-02 00:00:00
29-Sep-02 00:00:00
01-Oct-02 00:00:00
03-Oct-02 00:00:00
05-Oct-02 00:00:00
07-Oct-02 00:00:00
09-Oct-02 00:00:00
Feeder Total
TTU


Coal Flow Rate
140
120
100
80
60
40
20
0
Coal Flow Rate (metric T/hr)
T.T.U. calculated coal flow
Powerplant measured coal flow rate
10:00
10:28
10:57
11:26
11:55
12:24
Time (hour of day)



Compare Coal flows for Jan 15 2005
Coal flow (T/hr)
200
180
160
140
120
100
80
60
40
20
0
0
200
400
600
800
1000
1200
1400
1600
Time (minutes)
307
304
PlantCoalFl (2totcoal)
Direct Method
1tt_calc_fuelflow

CONCLUSIONS

- It is not permissible to divide turbine cycle heatrate by a boiler efficiency (calculated in an arbitrary manner) to obtain unit heatrate.
- Consistent set of definitions have to be used for boiler efficiency, steam cycle heatrate and unit heatrate.
- Thermodynamic analysis based on a control volume tightly around the boiler would yield a consistent set of definitions.
- Field results from the T.T.U. Software indicate that the T.T.U. Software is giving fairly accurate results.