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ERRORS IN BOILER EFFICIENCY STANDARDS

by

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Topics to be Discussed

The Old:

- **Where do we go ?**
- **Why Absolute Standards ?**
- **Review of PTC and European**

The New:

- **Mechanics … Fuel Flow**
- **Criticism**
- **Applicability**
- **Examples**
- **Recommendations**

Where do we go …

… is Boiler Efficiency arbitrary ?

What one Vendor stated …

“I am well aware that the codes as they stand are <u>arbitrary and can be manipulated</u>, so it is certainly a case of Buyer Beware when it comes to bid evaluations by our Clients.”

Why Absolute Standards ?

- **To Prove we understand the system … or not !**
  Do we understand basic <u>conversion</u> and Q_{WF} ?
  Do we understand the <u>quantity</u> of fuel required ?

- **If standards only provide a "consistent basis for comparison" then now can we freeze the reference temperature at 77F, then determine HHV at 95F, use combustion air at -10F, blow for soot, use constant pressure conversion, and hope to understand.**

- **1% in boiler efficiency is worth » $20 million for a Steam Generator supplying a 400 MWe unit.**

ASME PTC 4 and EN 12952-15

- ASME PTC 4 has replaced PTC 4.1
- EN 12952-15 has replaced the British and the German DIN-1942 with -

  BSI EN 12952-15:2003

  DIN EN 12952-15:2004.

- Heat Loss = Indirect = Energy Balance
- Input-Output = Direct = Gross Method

ASME PTC 4 and EN 12952-15

- Reference temperature = 25C.
- Corrections can be made to HHVs (EN).
- Gross or net (PTC is weak, parallel in EN).
- APH is included within boundary.
- Heat Credits are set to zero (PTC), or in error (EN).
- PTC: Energy Bal. $\eta_{B-HHV} = 1.0 - \sum \text{Losses} / \text{HHVP}$
- EN EB: $\eta_{B-HHV} = 1.0 - \sum \text{Losses} / (m_{AF}\,\text{HHVP} + Q_{G-Z})$
- EN I-O: $\eta_{B-HHV} = Q_{WF} / (m_{AF}\,\text{HHVP} + Q_{G-Z})$
- Corrections allowed to guarantee conditions.
- Variance procedures.

Mechanics of the New

$$\oint \partial Q_{T\text{-}Cal} = -\ HHV$$

- **T_{Cal} serves as the reference for all thermodynamics**
  Gaseous Fuels: HHV are computed at T_{Cal}
  Solid & Liquid: HHV are measured at T_{Cal}

- **The Steam Generator boundary derives from the principle that thermal efficiency must only address how the as-fired fuel interacts with gas / air / working fluid.**

Mechanics of the New

$$\oint \partial Q_{T\text{-}Cal} = -\,HHV$$

$$HHV = -\,HPR_{Ideal\text{-}HHV} + HRX_{Cal\text{-}HHV} - \Delta H_{v/p}$$

$$HHVP = -\,HPR_{Ideal\text{-}HHV} + HRX_{Cal\text{-}HHV}$$

$$HHVP + HBC = -\,HPR_{Ideal\text{-}HHV} + HRX_{Cal\text{-}HHV} + HBC$$

$$HHVP + HBC = -\,HPR_{Ideal\text{-}HHV} + HRX_{Act\text{-}HHV}$$

$$\eta_B\,(HHVP + HBC) = -\,HPR_{Ideal\text{-}HHV} + HRX_{Act\text{-}HHV} - \sum Losses$$

$$\eta_B\,(HHVP + HBC) = -\,HPR_{Ideal\text{-}HHV} + HRX_{Act\text{-}HHV} - \sum Stack\ Losses - HNSL$$

$$\eta_B\,(HHVP + HBC) = -\,HPR_{Act\text{-}HHV} + HRX_{Act\text{-}HHV} - HNSL$$

$$\eta_B = (\,-\,HPR_{Act\text{-}HHV} + HRX_{Act\text{-}HHV} - HNSL\,)\,/\,(HHVP + HBC)$$

$$\eta_B = (\,-\,HPR_{Act\text{-}HHV} + HRX_{Act\text{-}HHV}\,)\,\eta_A\,/\,(HHVP + HBC)$$

$$\eta_B = \eta_C\,\eta_A$$

Firing Correction (HBC)

$$
\begin{aligned}
HBC = \; & C_P \, (T_{AF} - T_{Cal})_{Fuel} && \textbf{Fuel} \\
& + Q_{SAH} / m_{AF} && \textbf{SAH} \\
& + W_{FD} / m_{AF} && \textbf{FD Fan} \\
& + [\, (h_{Amb} - h_{Cal})_{Air} && \\
& \qquad a\,(1.0 + ß)(1.0 + \psi_{Ref})\, N_{Air} && \textbf{Comb. Air} \\
& + (h_{g\text{-}Amb} - h_{g\text{-}Cal})_{H2O}\, b_A\, (1.0 + ß)\, N_{H2O} && \textbf{Moisture} \\
& + (h_{Steam} - h_{f\text{-}Cal})_{H2O}\, b_Z\, N_{H2O} && \textbf{In-Leakage} \\
& + C_P \, (T_{Amb} - T_{Cal})_{PLS}\, b_{PLS} && \\
& \qquad (1.0 + \gamma)\, N_{CaCO3}\,] / (xN_{AF}) && \textbf{Limestone}
\end{aligned}
$$

Energy of Reactants (HRX)

Start with an ultimate analysis and a calorimetric determination of the fuel (HHV), record T_{Cal}

$HPR_{Ideal\text{-}HHV}$ = Ideal Products at T_{Cal}

$$HRX_{Cal\text{-}HHV} = (HHV + \Delta H_{V/P}) + HPR_{Ideal\text{-}HHV}$$

Firing Correction (HBC) converts from T_{Cal} to the actual As-Fired:

$$HRX_{Act\text{-}HHV} = HRX_{Cal\text{-}HHV} + HBC$$

Energy of Products (HPR)

$HPR_{Act\text{-}HHV\text{-}k}$ = [Heat of Formation at T_{Cal} plus sensible heat (T_{Stack} - T_{Cal})] $_k$

Water is the key:

Can not form water from combustion, referenced to ΔH^f_{Cal} , mix it with fuel water at T_{Cal} and then think its OK to apply HHV at any other temperature. Water's energy and MAF's energy levels must be the same. The key is the $HRX_{Cal\text{-}HHV}$ term.

$HPR_{Act\text{-}HHV\text{-}H2O}$ = [Heat of Formation at T_{Cal} plus sensible heat (h_{Stack} - h_{Cal}); Fuel Water; Air Moisture; Leakage] $_{H2O}$

Non-Chemistry & Non-Stack Losses

HNSL losses are only included if they affect computed fuel flow (i.e., affect the combustion process)

+ Radiation & Convention
+ Ash Pit and Fly and Bottom Ash terms
+ Miscellaneous sensible heats
- ID Fan

$$\eta_A = 1.0 - HNSL / [- HPR_{Act\text{-}HHV} + HRX_{Act\text{-}HHV}]$$

$$\eta_B = \eta_C \, \eta_A$$

$$m_{AF} = Q_{WF} / [\eta_B (HHVP + HBC)]$$

Criticism

$$\Delta H^0_{f-T} = \Delta H^0_{f-25} + \int_{25}^{T} dh_{\text{Compounds}} - \sum \int_{25}^{T} dh_{\text{Elements}}$$

Contribution to HHV from Ash and MAF:

$$\Delta HHV = \gamma_{Fuel\text{-}Ash}\, h_{T\text{-}Ash} + \gamma_{Fuel\text{-}MAF}\,(- HPR_{Ideal} + HRX_{Cal})_{MAF}$$

Contribution to HHV from Water:

$$\Delta HHV = \gamma_{Fuel\text{-}H2}\,(\Delta H^o_{Vap\text{-}T} - \Delta h_{fg\text{-}T})_{H2O} + \gamma_{Fuel\text{-}H2O}\, h_{T\text{-}H2O}$$

EN 12952-15 (DIN 1942):

$$HHV_T = HHV_{25} + [\, (\mu C_P)_{MAF\text{-}Fuel} + (\gamma C_P)_{Fuel\text{-}H2O} + (\mu C_P)_{dry\text{-}Air} - (\mu C_P)_{Stack\text{-}Gas} - (\mu C_P)_{Stack\text{-}H2O}\,]\,(T - 25)$$

Applicability of the New

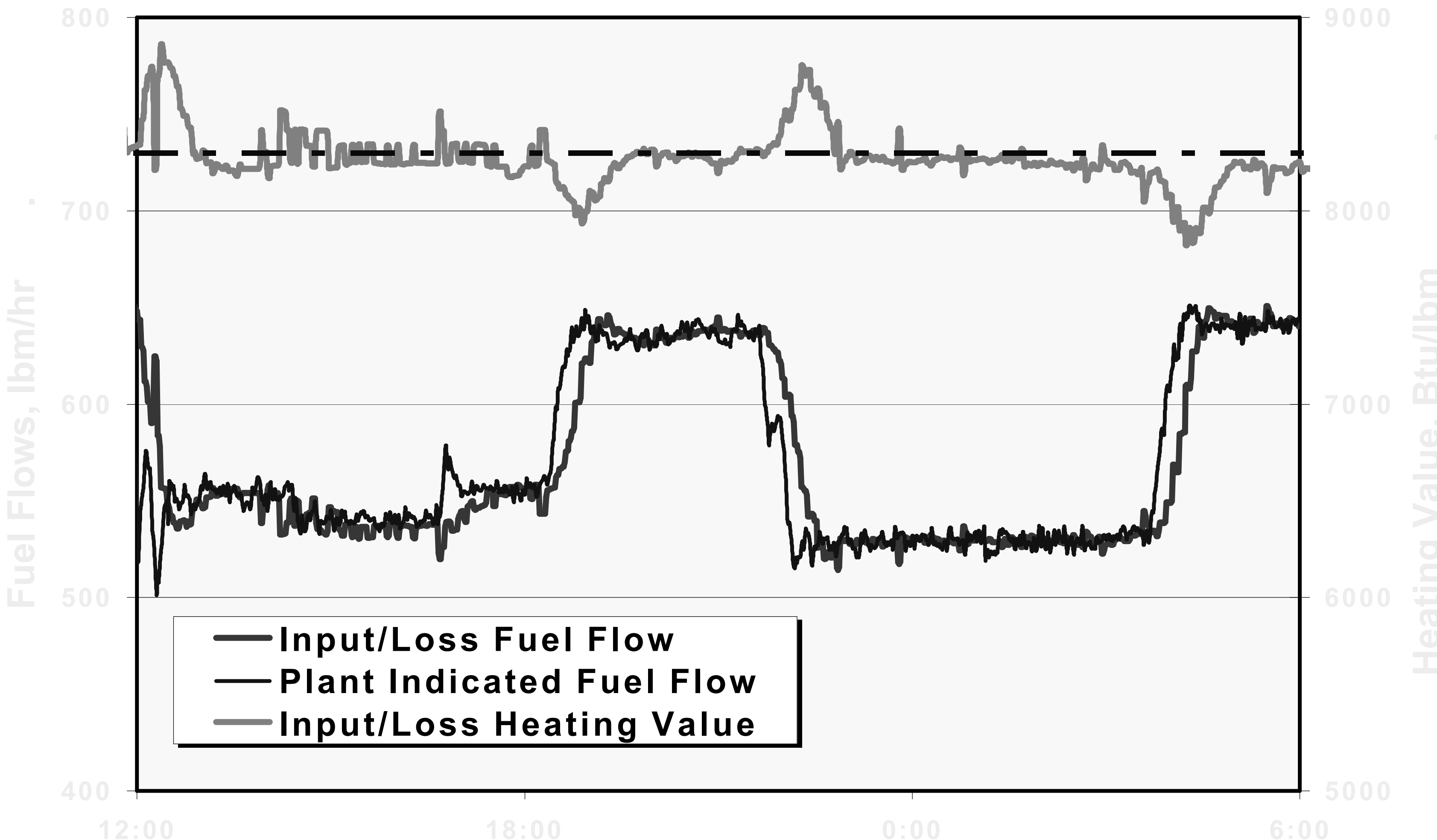
- **Energy Balance is only allowed if:**
  Fuel Water + Hydrogen > 10%.
- **If Energy Balance, base tolerance on:**
  Fuel sampling of ultimate analyses and HHVs
  Useful Energy Flow (Q_{WF})
- **If Energy Balance, calculation of fuel flow is required.**
- **If Input-Output, base tolerance on:**
  Fuel sampling of ultimate analyses and HHVs
  Useful Energy Flow (Q_{WF})
  Use an agreed T_{Ref} with an assigned range,
  leading to a Firing Correction tolerance.

Example …

- **Say we are firing PRB in identical units in the Sahara and in the Antarctic:**
  both HHVs were determined at 77F, adjustments made to produce the same losses, with different Firing Corrections, units will have the same efficiencies …
  PTC 4 agrees & EN 12953-15 disagrees.

- **Now, same fuel, but HHV determined at 34F & 120F:**
  with no further adjustments, different HHVs will again produce the same efficiencies …
  PTC 4 disagrees & EN 12953-15 disagrees.

Fuel Flow, 640 MWe Coal-Fired



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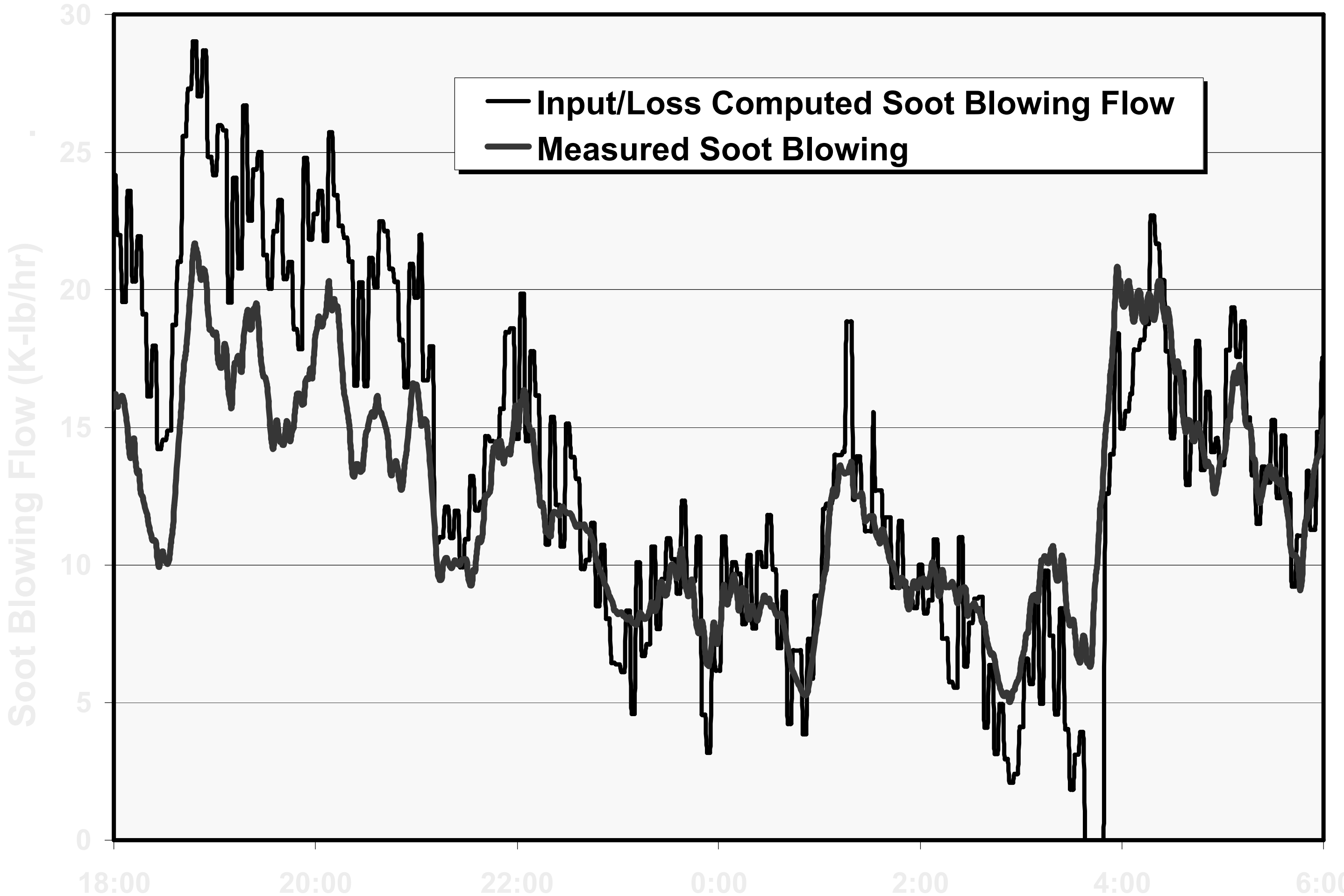
Soot Blowing Flow Emulating a Tube Leak



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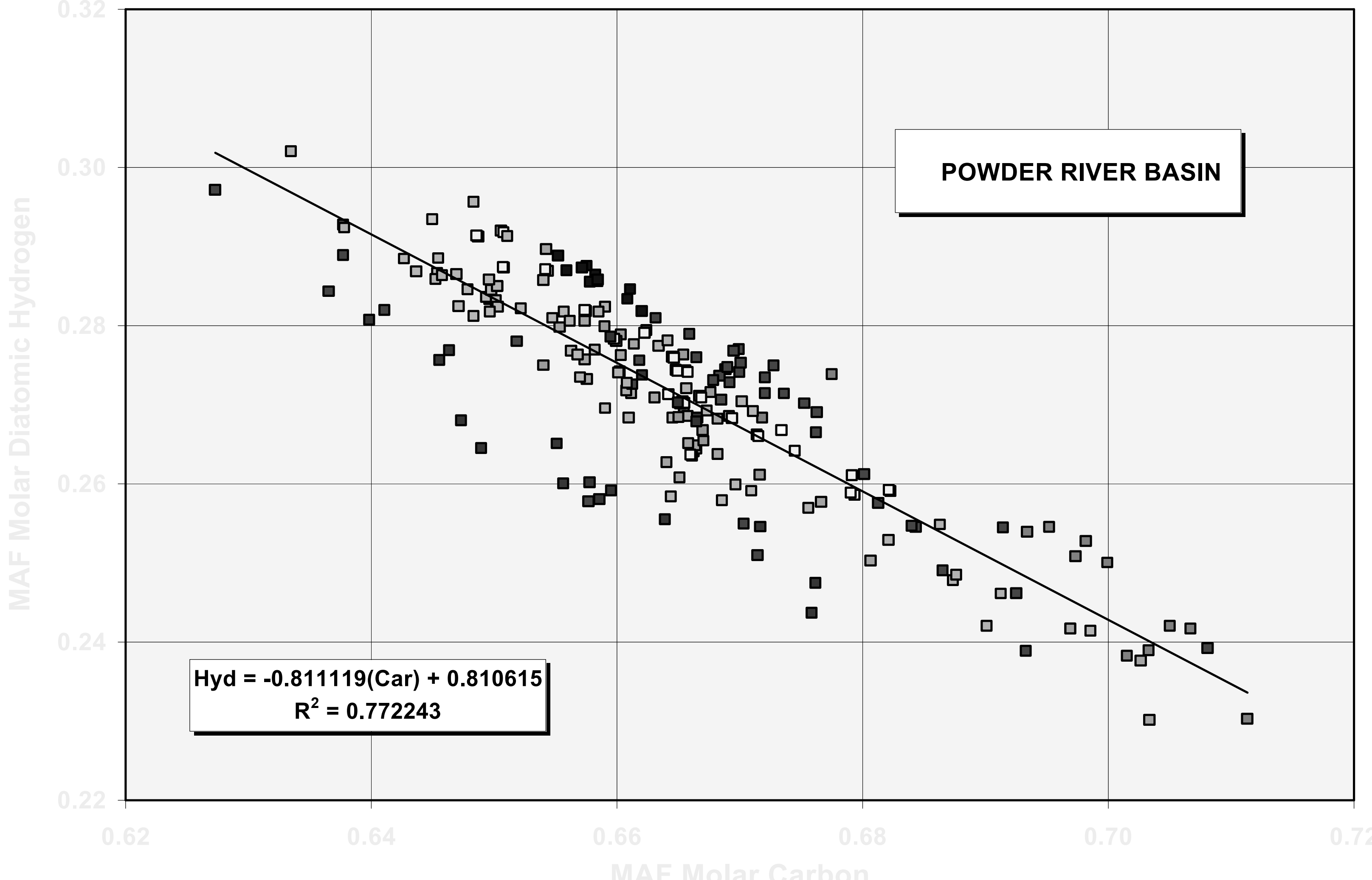
H = f (C) for Powder River Basin



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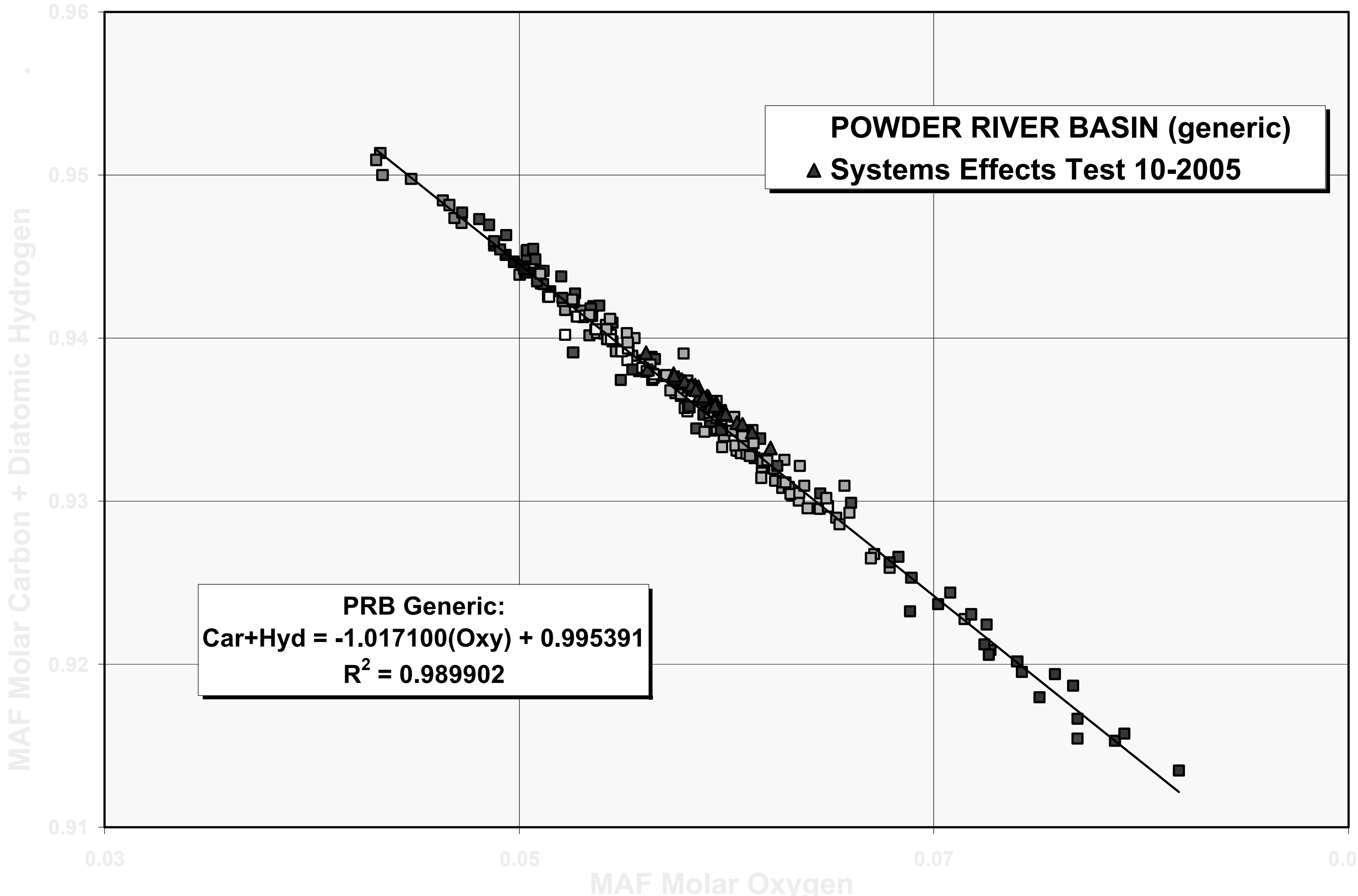
OHC Approach for Interrogating Data



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Recommendations for the New

- **Proposal are 16 recommendations (review paper).**
- **Reference temperature = Calorimetric temperature.**
- **No corrections allowed to measured HHVs.**
- **Gross or net efficiencies produce identical fuel flows.**
- **APH is included within boundary.**
- **Firing Corrections only affect Reactant streams.**
- **Energy Balance allowed: fuel water + hydrogen > 10%**

$$\eta_{B\text{-}HHV} = (HPR_{Act} - HRX_{Act})\ \eta_A / (HHVP + HBC)$$

$$m_{AF} = Q_{WF} / [\eta_{B\text{-}HHV}\ (HHVP + HBC)]$$

- **Input-Output required: fuel water + hydrogen < 10%**

$$\eta_{B\text{-}HHV} = Q_{WF} / [m_{AF}\ (HHVP + HBC)]$$

- **Simple treatment of variances.**

From the 1890 Edition of Steam:

"**Most of the abuses connected with steam engineering have arisen from two causes – avarice and ignorance:**

avarice on the part of men who are imbued with the idea that cheap boilers and engines are economical, … and

ignorance on the part of those who claim to be engineers, but who at the best are mere starters and stoppers."

To those who are <u>not</u>
mere starters and stoppers,
Thank You.