ASME POWER2009-81221

ERRORS IN BOILER EFFICIENCY STANDARDS

by

Fred D. Lang, P.E.
Exergetic Systems, Inc
Lang@ExergeticSystems.com

For delivered paper (Rev. 27) visit:
www.ExergeticSystems.com

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 conversion and Q_{WF} ?

  Do we understand the quantity 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. $\eta_{B\text{-}HHV} = 1.0 - \sum Losses / HHVP$
- EN EB: $\eta_{B\text{-}HHV} = 1.0 - \sum Losses / (m_{AF}\, HHVP + Q_{G\text{-}Z})$
- EN I-O: $\eta_{B\text{-}HHV} = Q_{WF} / (m_{AF}\, HHVP + Q_{G\text{-}Z})$
- 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

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

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

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

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

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

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

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

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

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

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

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

Exergetic Systems

Firing Correction (HBC)

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

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

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

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 …

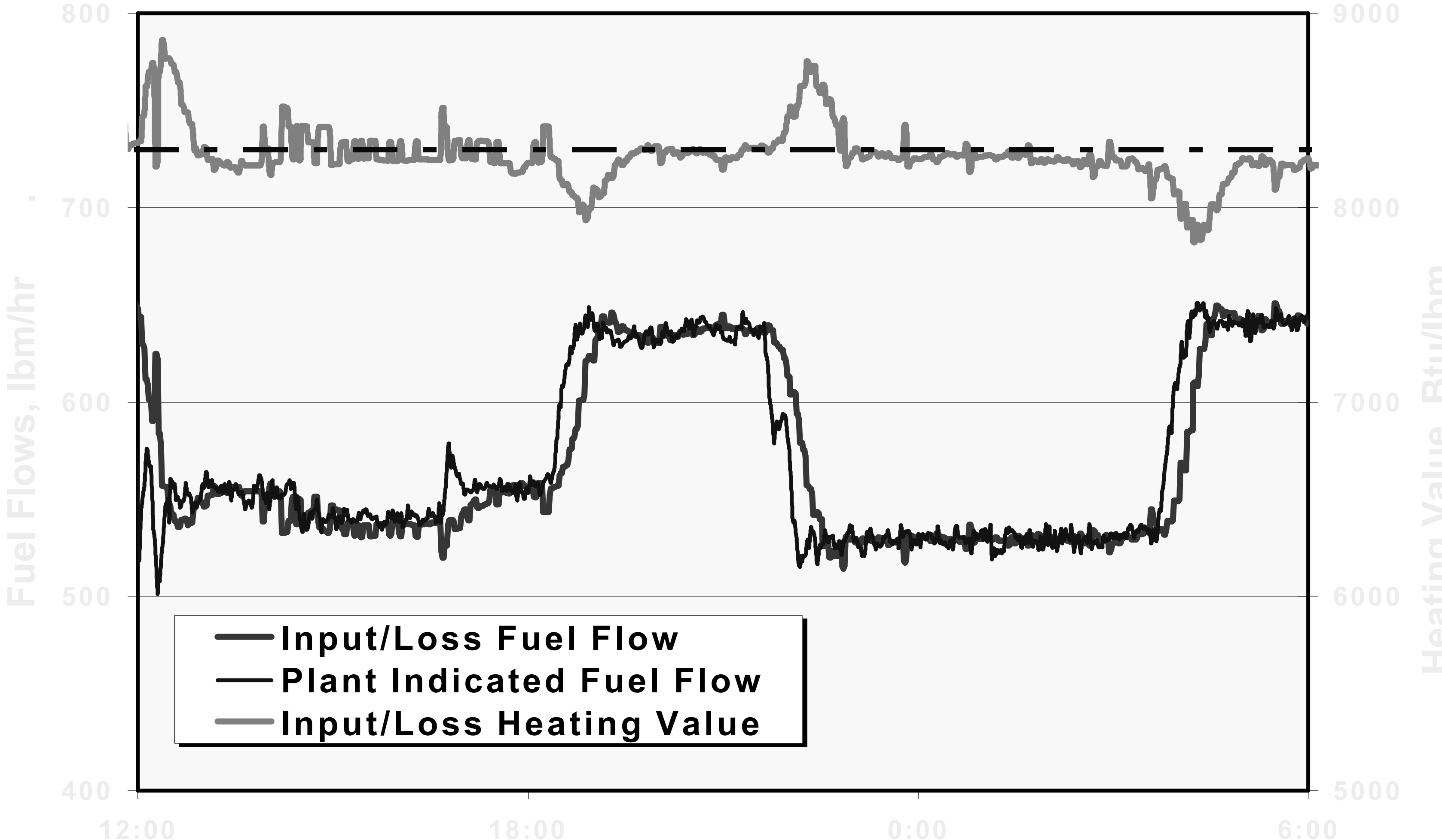
  PTC 4 agrees & EN 12953-15 disagrees.

- **Now, same fuel, but HHV determined at 34F & 120F:**

  with no further adjustments, different HHVs will again produce the same efficiencies …

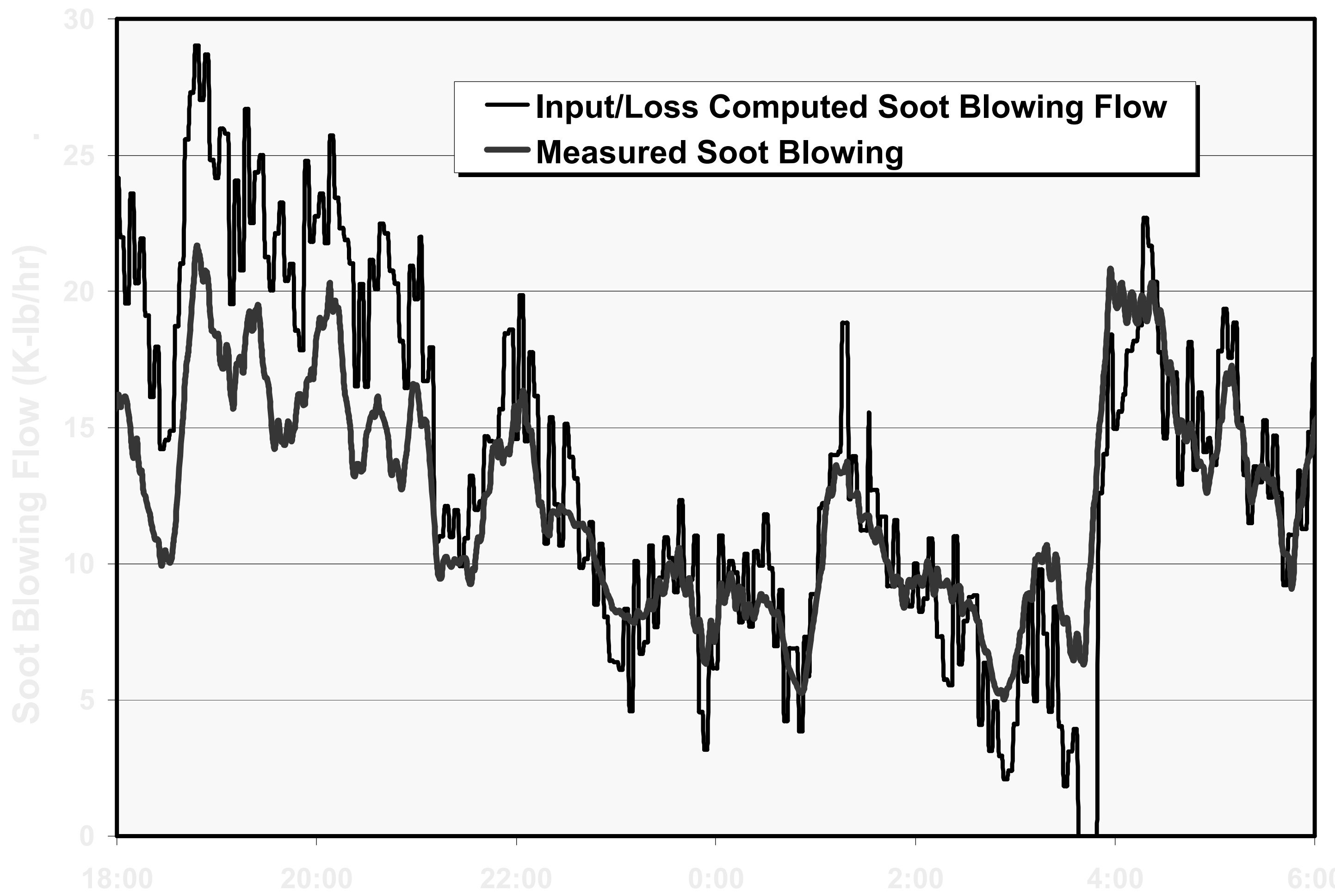
  PTC 4 disagrees & EN 12953-15 disagrees.

Fuel Flow, 640 MWe Coal-Fired



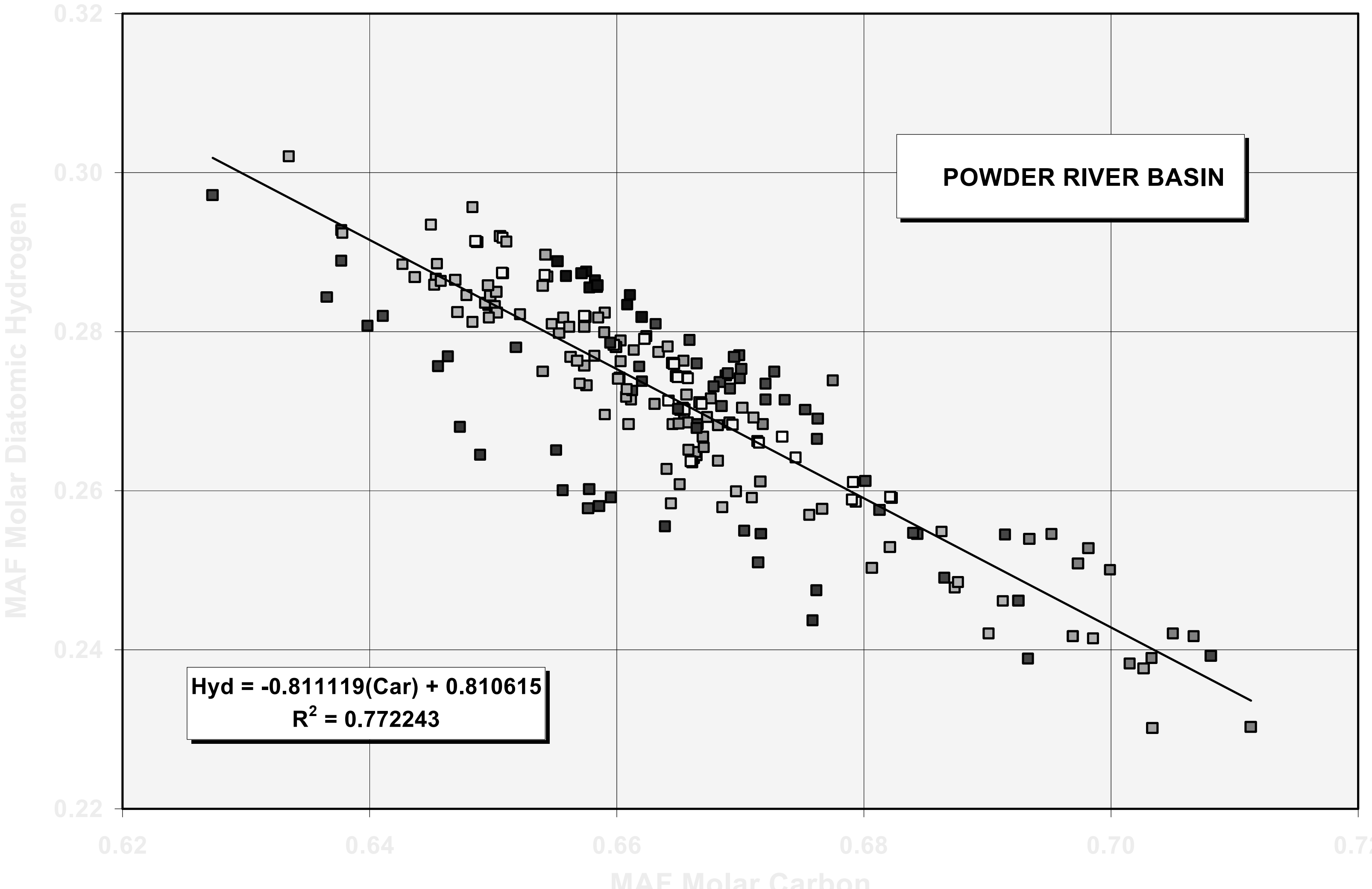
Exergetic Systems

Soot Blowing Flow Emulating a Tube Leak



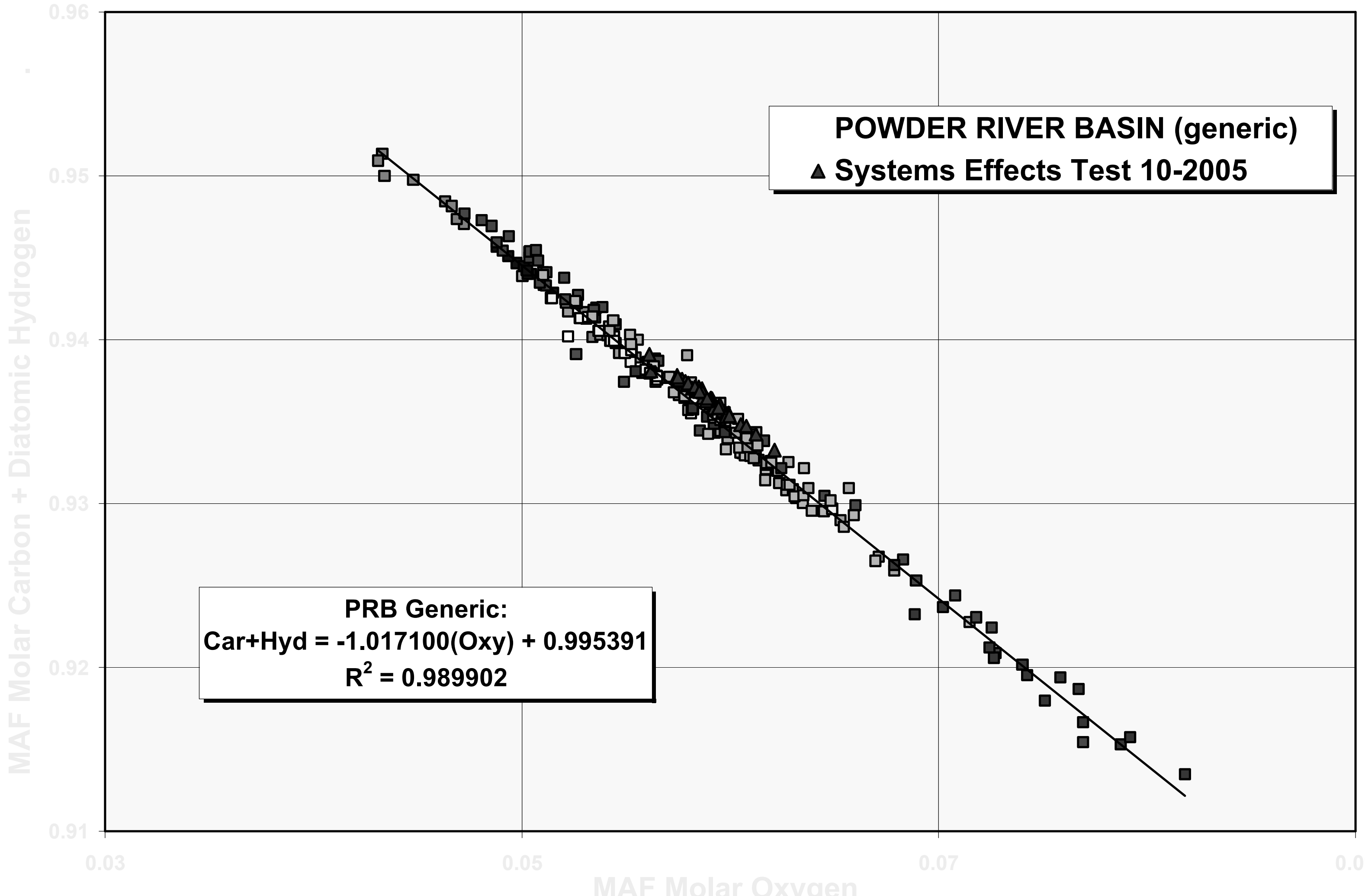
Exergetic Systems

H = f (C) for Powder River Basin



Exergetic Systems

OHC Approach for Interrogating Data



Exergetic Systems

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 not
mere starters and stoppers,
Thank You.