Boiler Efficiency Software Demo

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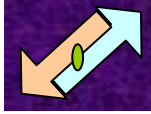
DOE Steam BP Mtg, Houston (5-20-08)

Presentation Outline

- Background
- Prototype demo
- Software development issues
- Q & A



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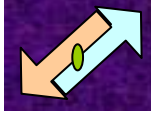


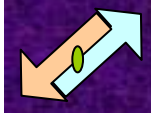
Methodology Issues . . .

- ASME (Boiler only)
  - Heat balance
  - Heat Loss
- Boiler only vs Steam Gen System
- HHV vs LHV
- Point efficiency vs Full range curve
- What about multiple pr. levels ?

Definition of Efficiency

$$\eta = \frac{\text{TOTAL USEFUL OUTPUTS}}{\text{TOTAL ENERGY INPUTS}}$$

- In numerator, the term USEFUL is critical
- In denominator, the term TOTAL is critical
- Units of measure must be CONSISTENT



ASME Efficiency, heat loss method

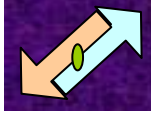
$$\eta = \frac{\text{Fuel (HHV) - Losses}}{\text{Fuel (HHV)}}$$

- Losses = stack gas, unburned, radiant, convective
- Boiler BD and leaks are not included in losses; therefore effectively treated as a Useful Outputs

ASME heat loss method, HHV, point η

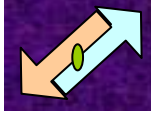
Energy outputs from Boiler	Considered	Incl as Useful
Steam (assume single pr level)	✔	✔
Stack gas - sensible heat	✔	x
Stack gas - latent heat	✔	x
Stack gas – unburned fuel loss	✔	x
Boiler blowdown	x	✔
Convective heat loss to atmos	✔	x
Radiant heat loss to atmos	✔	x
Leaks	x	✔

Do you agree that Boiler BD and Leaks are USEFUL OUPUTS ?

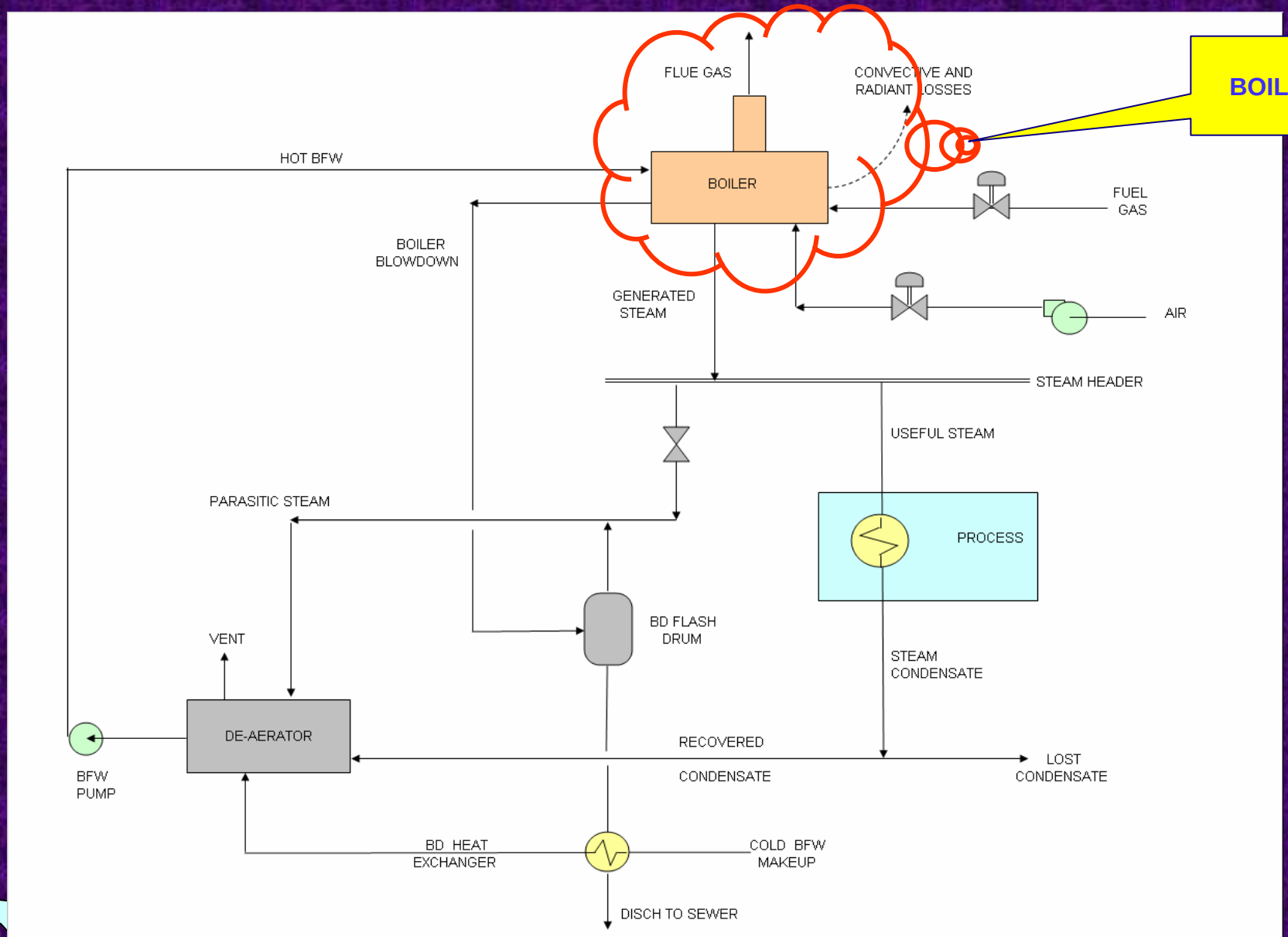


ASME heat loss method, HHV, point η

Energy Inputs to Boiler	Considered	Should Incl ?
Heat of combustion (HHV)	✔	✔
Parasitic steam use in De-aerator	x	✔
Sensible heat of fuel	x	✔
Sensible heat of combustion air	x	✔
Sensible heat of BFW (to econ)	x	✔
BFW treatment + pumping power	x	✔
Air supply fan power	x	✔
Boiler control system power	x	✔
Boiler building HVAC + lights	x	✔



System vs Boiler



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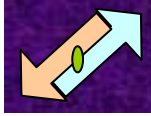
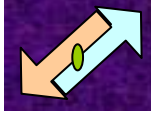


Screen shots – 1 (Fuel, eg. gas)

Fuel =	mixed hydrocarbon gases with composition as below											Stoich
		atoms per mole							HHV	LHV	oxygen
	MW	C	H	lb/scf	scf/lb	Vol %	lb/h	mol/h	Btu/scf	Btu/scf	mol/h
Inerts	36	0	0	0.0950	10.5	4.3	1470	40.8	0	0	0
CO	28.01	1	0	0.0739	13.5	0.2	53	1.9	321	321	2
H_2	2.016	0	2	0.0053	188.0	0.5	10	4.7	324	274	2
CH_4	16.04	1	4	0.0423	23.6	84.5	12874	802.6	1010	911	1605
C_2H_6	30.07	2	6	0.0793	12.6	8.0	2285	76.0	1769	1622	266
C_3H_8	44.1	3	8	0.1164	8.6	2.0	838	19.0	2516	2318	95
C_4H_{10}	58.12	4	10	0.1534	6.5	0.5	276	4.7	3255	3015	31
C_5H_{12}	72.15	5	12	0.190	5.3	0.0	0	0.0	3978	3682	0
					20.2	100.0	17806	949.9	1064	963	2001
HHV reported by Lab Analysis				1060	Btu/scf		37432	Btu/nm3 (HHV)			
Deviation from calculated value =				-0.4	%	OK					

COLOR CODES:	123	measured value (input)
	321	iteration parameter
	456	design paramter (input)



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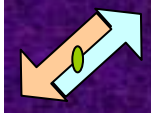
Screen shots – 2 (mat bal calcs)

Ambient (basis) temp	80	F	**Stm gen rate (trial)**	**283.9**	Klb/h	
Fuel Gas firing rate	6000	scfm (plant data)	Calculated Stm Gen	284.3	Klb/h	
	17806	lb/h	Boiler steam gen capacity	375	Klb/h	
Gas molecular weight	18.7	lb/mole		188	TPH	
Stoichiometric air (dry)	9.96	scf/scf gas	Full-load heat input (fuel)	506	MMBtu/h	
	15.41	lb/lb gas	Boiler operating load	76	%	
Relative Humidity of air	54	%		142	TPH	OK
Water vapor partial press	0.51	psia	Steam pressure	625	psig	
Moisture content	1.92	lb H2O/100 lb dry air		640	psia	
Measured oxygen in FG	3.03	%	Steam sat temp	493	F	
Calc Oxygen in fluegas	3.03	%	Steam superheat	235	F	
Measured CO in flue gas	400	ppm	Steam temp (actual)	728	F	
Excess air	16.0%		Sat steam enthalpy	1201	Btu/lb	
Actual air flow	318.3	Klb/h (dry basis)	Cp of superheated steam	0.6944	Btu/lb-F	
Water vapor in supply air	6.1	Klb/h	Superheated stm enthalpy	1364	Btu/lb	
Air preheating	0	F	BFW flow	285.9	Klb/h	
Air supply temp	80	F	BFW temp	308	F	OK
Flue gas flow (dry)	336.1	Klb/h	BFW enthalpy	278	Btu/lb	
Water of combustion	34.8	Klb/h	Blowdown, % of steam	0.7	%	
Flue gas temp, F	400	F	Blowdown enthalpy	480	Btu/lb	
water vapor enthalpy	1241	Btu/lb				
Combustibles in Flue Gas	600	ppm				
Unburned fuel	0.21	%				



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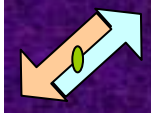
Screen shots – 3 (heat loss calcs)

				Boiler dimensions, ft			
				Height	60		
Wall surface material	1	Use 1 for metal, and 2 for brick		Length	40		
Wind velocity	3	ft/sec		Width	25		
Boiler surface area	7800	ft2 (vertical faces only)					F
Convective Coeff (still air)	0.98	Btu/ft2-h-F		Boiler wall temp		140	F
Convective losses	0.5	MMBtu/h		Amb temp in boilerhouse		97	F
				Temp diff vs ambient		43	
Estimation of Radiative losses:							
Emissivity of boiler walls:	0.9		Number of Openings in boiler wall			6	
Radiant heat flux	52	Btu/ft2-h	Diameter, or width (if rectangular)			8	inches
Radiant heat loss (walls)	0.40	MMBtu/h	Approx area of opening/peephole			60	sq in
Radiant heat loss (holes)	0.61	MMBtu/h	Boiler wall thickness (incl insul)			4	inches
Radiant heat loss (total)	1.01	MMBtu/h	Radiant loss factor (average)			0.722	
			Temp in combustion space			3271	F
(a) Stefan-Boltzmann law:	0.26	% of fuel heat input	Blackbody radiant flux			335204	Btu/ft2-h
(b) empirical correlation:	0.47	%					
(c) ASME correlation	0.34	% (without ΔT or air velocity corrections)					
	↓						
Radiant heat losses	0.40	% (choose value based on three alternative estimates above)					



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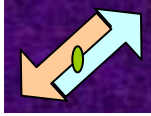
Screen shots – 4 (heat bal + eff calcs)

HEAT BALANCE							
Heat in fuel (HHV)	383.0		Unburned fuel	0.8			
Heat in combustion air	3.7		Radiant loss	1.5			
Heat in air moisture	0.1		Convective loss	0.5			
Heat in BFW	79.4		Flue gas	75.1	(including water vapor)		
Total heat inputs	466.2	MMBtu/h	Blowdown	1.0			
			Total heat losses	79.0	MMBtu/h		
Heat in steam	387.3	MMBtu/h					

EFFICIENCY CALCULATION (modified ASME method)

		MMBtu/h	JDK Note		
Primary Input (Fuel, HHV)		383.0	ASME method takes credit for heat		
			content of condensed moisture in flue		
Losses:	Flue gas (sensible)	27.8	gas as if it were a useful output.		
	Flue gas (moisture of combustion)	41.5	Same for boiler blowdown.		
	Radiation	1.5	These are not realistic assumptions.		
	Convection	0.5			
	Unburned fuel	0.8	Boiler Efficiency =	**81.2%**	by ASME method
	Total	72.2		**80.4%**	by heat balance
Useful Output (net steam vs BFW)		308.7	Optimum air flow =	316	Klb/h
				4124	Kscfh



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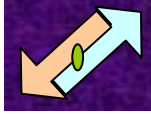
Let’s give it a spin …

Live Software Demo



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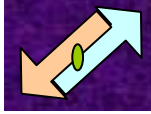

Software Development Issues

- Which efficiency to use?
- Multiple fuels capability
- Point vs range η (will need more data)
- Design vs Rating algorithm
- Default values database
- GUI and Report formats
- Diagnostic/advisory capability
- Economics of η improvement
- GHG emission estimates
- User manual
- Maintenance, Updates, & Hotline support

Questions?