Steam End-User Training
Conclusion Module

Slide 1 - Conclusions

Let's briefly examine the major items we have covered in this training.

[Slide Visual – Conclusions]

Banner:
DOE's BestPractices
Steam End User Training

Conclusion

Slide 2 - Course Objectives

We had a long list of items to address in this training.

[Slide Visual – Steam End User Course Welcome]

- **Become familiar with U.S.DOE Tools Suite to assess steam systems**
- **Identify the measurements required to manage steam systems**
- **Measure boiler efficiency**
- **Estimate the magnitude of specific boiler losses**
- **Identify and prioritize areas of boiler efficiency improvement**
- **Recognize the impacts of fuel selection**
- **Characterize the impact of backpressure and condensing steam turbines**
- **Quantify the importance of managing steam consumption**
- **Identify the requirements of a steam trap management program**
- **Evaluate the effectiveness of thermal insulation**
- **Evaluate the impact of condensate recovery**
- **Recognize the economic impacts of steam system operations**

Slide 3 - Tools

You were introduced to the U.S.DOE Steam Tools, the Scoping Tool, the Assessment Tool, and the Insulation Tool.

[Slide Visual – Tools Visual Description]

- **In order to properly evaluate steam systems the physics of each process must be understood**
  - **Thermodynamics**
  - **Heat transfer**
  - **Fluid flow**
- **U.S.DOE Tools Suite**
  - **Steam System Survey Guide**
  - **Steam System Scoping Tool (SSST)**
  - **Steam System Assessment Tool (SSAT)**
  - **Insulation evaluation software – 3E-Plus**
- **Process measurements**

Slide 4 - Measure

We emphasized the importance of measurements and the management consequences developed from each measurement.

[Slide Visual – Measure]

You are not managing what you do not measure

Slide 5 – Primary Measurements

We pointed out many of the essential measurements required to manage the steam system.

[Slide Visual – Primary Measurements]

- **Boiler**
  - **Flue gas temperature**
  - **Flue gas oxygen content**
  - **Boiler fuel flow**
  - **Boiler steam flow**
  - **Water chemistry**

- Blowdown rate
- Boiler efficiency
- Combustibles
- System balancing
  - PRV steam flows
  - Turbine efficiencies
  - Electrical unit cost
- Steam consumers
  - Steam consumption
  - Control set points
- Condensate return
  - Makeup water flow
  - Condensate recovery
- Steam trap performance
- System
  - Fuel unit cost
  - Total fuel consumption
  - Steam production

Slide 6 - Boiler Efficiency

We explored the classic definition of boiler efficiency and the implications it holds.

[Slide Visual – Classic Boiler Efficiency]

$$n_{boiler} = \frac{\text{energy desired}}{\text{energy that costs}} (100)$$

The boiler efficiency is equal to the energy desired; divided by the energy that costs; all multiplied by 100.

$$n_{boiler} = \frac{\text{m-dot}_{steam} (h_{steam} - h_{feedwater}) (100)}{\text{m-dot}_{fuel} \; HHV_{fuel}}$$

Boiler efficiency is equal to the mass flow rate of the steam; multiplied by the difference in the enthalpy of the steam and the enthalpy of the feedwater; divided by the mass flow of the fuel; multiplied by the higher heating value of the fuel; all multiplied by 100.

Where:

n_{boiler} = Efficiency of the boiler, also called combustion efficiency, overall efficiency (dimensionless)
m-dot$_{steam}$ = Mass flow rate of steam generated in the boiler
m-dot$_{fuel}$ = Mass flow rate of fuel burned
h_{steam} = Enthalpy is energy content of steam
$h_{feedwater}$ = Enthalpy is energy content of feedwater
HHV_{fuel} = Higher Heating Value of fuel

Slide 7 – Indirect Efficiency

We examined the indirect boiler efficiency method.

[Slide Visual – Boiler Loss Indirect Efficiency]

- **Boiler efficiency can also be determined in an indirect manner by determining the magnitude of the losses**
  - **Primary losses are typically**
    - **Shell loss**
    - **Blowdown loss**
    - **Stack loss**

$n_{indirect}$ = 100 percent – E_{Losses}

Indirect Boiler Efficiency is equal to 100% minus the sum of all boiler losses.

$n_{indirect}$ = 100 percent – $Loss_{shell}$ – $Loss_{blowdown}$ – $Loss_{stack}$ – $Loss_{misc}$

Indirect Boiler Efficiency is equal to 100% minus the shell losses, minus the blowdown losses, minus the stack losses, minus the miscellaneous losses.

Where:

$n_{indirect}$ = Indirect efficiency
E_{Losses} = Sum of all Losses
$Loss_{shell}$ = Shell Losses
$Loss_{blowdown}$ = Blowdown Losses
$Loss_{stack}$ = Stack Losses
$Loss_{misc}$ = Miscellaneous Losses

Slide 8 – Stack Loss (Natural Gas)

We identified the techniques available to allow the individual boiler losses to be quantified.

[Slide Visual – Stack Loss Table for Natural Gas]

- **To determine the order-of-magnitude importance of tuning a conservative evaluation will be made assuming 5% oxygen can be attained.**
  - **Efficiency could improve from 78.8% to 80.1%**

Flue Gas Oxygen Content Wet Basis [%]	Stack Loss [% of fuel higher heating value input] Net Stack Temperature [Δ°F] {Difference between flue gas exhaust temperature and ambient temperature}											
	155	180	205	230	255	280	305	330	355	380	405	430
1.0	13.1	13.6	14.1	14.7	15.2	15.8	16.3	16.9	17.4	18.0	18.5	19.1
2.0	13.2	13.8	14.3	14.9	15.5	16.1	16.6	17.2	17.8	18.4	18.9	19.5
3.0	13.4	14.0	14.6	15.2	15.8	16.4	17.0	17.6	18.2	18.8	19.4	20.0
4.0	13.6	14.2	14.8	15.5	16.1	16.7	17.4	18.0	18.7	19.3	20.0	20.6
5.0	13.8	14.5	15.1	15.8	16.5	17.2	17.8	18.5	19.2	19.9	20.5	21.2
6.0	14.1	14.8	15.5	16.2	16.9	17.6	18.3	19.1	19.8	20.5	21.2	22.0
7.0	14.4	15.1	15.9	16.6	17.4	18.1	18.9	19.7	20.5	21.2	22.0	22.8
8.0	14.7	15.5	16.3	17.1	17.9	18.8	19.6	20.4	21.2	22.1	22.9	23.7
9.0	15.1	16.0	16.8	17.7	18.6	19.5	20.4	21.2	22.1	23.0	23.9	24.8
10.0	15.5	16.5	17.4	18.4	19.4	20.3	21.3	22.2	23.2	24.2	25.2	26.1
Actual Exhaust T [°F]	225	250	275	300	325	350	375	400	425	450	475	500
Ambient T [°F]	70	70	70	70	70	70	70	70	70	70	70	70

At 380 degrees Fahrenheit net stack temperature at 5% oxygen content, the stack loss is 19.9%
At 380 degrees Fahrenheit net stack temperature at 7% oxygen content, the stack loss is 21.2%

<u>Slide 9 - Fuel Selection</u>

We addressed some of the main fuel selection issues.

[Slide Visual - Three Boilers]

Fuel: Green Wood
Fuel cost: $2.00/10^6Btu
Steam production: 80,000 lbm/hr
Efficiency: ~71.3%

Fuel: Natural gas
Fuel cost: $10.00/10^6Btu
Steam production: 100,000 lbm/hr
Efficiency: ~84.2%

Fuel: Number 6 oil *HS*
Fuel cost: $5.00/10^6Btu
Steam production: 80,000 lbm/hr
Efficiency: ~87.4%

<u>Slide 10 – Backpressure</u>

The fundamentals of backpressure steam turbines were presented.

[Slide Visual – Combined Heat and Power - Cogeneration]

A red arrow depicts the fuel input to the High-Pressure and High-Temperature Boiler. Steam produced from the boiler is delivered to a steam turbine/generator, with the steam section depicted as a cone-shape figure. Steam schematically leaves the steam section of the turbine at the bottom. A thick white line to the right of the steam turbine leading to the rectangle shape of the generator, is the shaft. A red arrow leaves the generator section, indicating Electrical Power Export.
The steam schematically leaving the bottom of the steam turbine enters a heat exchanger depicted as a circle with a red zigzag arrow through it.

Condensate leaves the heat exchanger at the bottom and a pump, depicted as a circle/square combination, returns the condensate to the top of the boiler.

Turbine is 70% isentropic.
Generator is 95% efficient.
Boiler is 85% efficient.

What would be the component efficiencies of a typical industrial facility?

What would be the overall "energy" conversion efficiency?

Slide 11 – Condensing Turbines

The operating characteristics of condensing steam turbines were identified.

[Slide Visual – Condensing Turbine Performance]

Condensing Turbine Impact Power Cost			
	Impact Condensing Power Cost [$/MWh]		
Fuel Cost	Turbine Isentropic Efficiency [%]		
[$/10^{6}Btu]	40	60	80
2.00	56	39	30
4.00	111	78	60
6.00	167	116	89
8.00	223	155	119
10.00	278	194	149
12.00	334	233	179
Steam inlet	400	psig	
Steam inlet	700	°F	
Steam exit	1.4	psia	
Boiler Efficiency	84	%	

Slide 12 – Steam Demand Costs

We discussed steam end-use components.

[Slide Visual – Steam Demand]

A fan represented by a circle/square combination supplies airflow at 10,000 standard cubic feet per min air at 65 degrees Fahrenheit (noted as T_i) and three green arrows leading from a cone-shaped duct transition to a length of horizontal rectangular duct. Inside the rectangular duct section, three vertical white lines with a circle at the top and bottom of each line represent a steam coil which is joined at a header at the top of the steam coil, outside the rectangular duct. A white arrow leads to the header indicating 20 psig saturated steam supply at the steam coil inlet. The bottom of the steam coil has a steam trap (represented as a rectangle with a "T" and circle inside) for each of the three coil passes.

The steam traps schematically deliver condensate from the bottom to a header leading away from the ductwork with a white arrow. It is noted that 20 psig saturated liquid condensate enters the steam traps.

The airflow that is heated from the steam coil is represented by three red horizontal arrows and is at 120 degrees Fahrenheit (noted as T_c).

[Slide Visual – Boiler Equations]

$Q_{air} = \text{m-dot}_{air}(C_p)_{air}(T_e - T_i)_{air}$

Energy is equal the to the mass flow rate of the air; multiplied by the specific heat capacity of air, multiplied by the difference in the Temperature existing the heat exchanger minus the Temperature entering the heat exchanger.

$Q_{air} = 10{,}000(\text{std ft}^3/\text{min})(0.074(\text{lbm/std ft}^3)(0.24(\text{Btu/lbmR})(120°\text{F} – 65°\text{F})(60 \text{ min/1 hour})$

Energy is equal the to the100,000 standard cubic feet per minute ; multiplied by the0.074 pounds per standard cubic feet; multiplied by 0.24 BTU per pound-Rankine; multiplied by the difference 120 degrees Fahrenheit minus 65 degrees Fahrenheit; multiplied by 60 minutes per hour)

$Q_{air} = 587{,}300 \text{ Btu/hr}$

Energy is equal the to 587,300 Btu per hour.

- **Steam demand reduces to 70% of original value.**
  - **Steam saving is 250 lbm/hr.**
    - **$34,000/yr.**

Where:

Q_{air} = **Quantity of energy**
m-dot$_{air}$ = **Mass flow of the substance**
C_p = **Specific heat capacity of the substance**
T_i = **Temperature of air entering heat exchanger**
T_e = **Temperature of air exiting heat exchanger**

Slide 13 – Maintenance Program

The foundational components for a world-class steam trap management program were discussed.

[Slide Visual – Steam Demand]

- **Training is essential**
- **Investigate each trap at least one time each year (problem areas and high pressure should be more frequent)**
  - **Performance**
    - **Testing equipment is required**
    - **An order of magnitude leak rate should be determined for failed traps**
      - **Orifice calculations set the maximum steam flow**
  - **Trap type**
    - **Trap selection should match the application**
    - **Universal mounts can be a good option**
  - **Installation**
  - **Establish an investigation route**
  - **Condensate return**
  - **Outsourcing can be a good option**
- **Maintain a steam trap database**
- **Prioritize repairs based on loss estimates**
- **Daily monitor receiver vents**

Slide 14 - Insulation Savings

Insulation issues and evaluations were addressed.

[Slide Visual – 3EPlus – Cost of Energy]

Cost of Energy –
Bare and Insulated Surfaces

Energy Tab
Item Description = Missing Insulation
System Units = ASTM C585
Geometry Description = Steel Pipe - Horizontal
Bare Surface Emittance = 0.8
Nominal Pipe Size = 10 in.
Process Temperature = 550 °F
Ave. Ambient Temperature = 70 °F
Ave. Wind Speed = 3 mph

Fuel Type: Natural Gas
Heat Content: 1000 BTU/cubic foot
Fuel Cost: 10.00 $/Mcf
Efficiency: 80 percent
Hours Per Year = 8760
Outer Jacket Material = Aluminum, oxidized, in service
Outer Surface Emittance = 0.1
Insulation Layer 1 = Calcium Silicate BLK+PIPE, Type I
Thickness: 3.08 in.

Append to Audit - Browse

Variable Insulation Thickness	Cost ($/ft/yr)	Heat Loss (Btu/ft/yr)	Savings ($/ft/yr)
Bare	636.90	50950000	
Layer 1	28.74	2300000	608.200

Table reads: Layer 1 Savings are 608.200 $/ft/yr

Savings = 608 $/ft-yr (20 ft) – 12,000 $/hr

Slide 15 – Condensate Return Example

The important aspects of condensate recovery were identified.

[Slide Visual - Condensate Return Example]

The schematic depicts condensate return in a heat exchanger. Heated material and high pressure steam enter into the heat exchanger through several passes. Steam exits the heat exchanger through a steam trap and then routed to a vented condensate receiver. The condensate temperature is 212 degrees Fahrenheit. It is transferred to an insulated condensate return pipe and ultimately pumped to the boiler. A Level Controller senses the liquid level in the receiver.

- **Condensate temperature entering boiler water system is 180°F**
- **Makeup water temperature is 70°F**

Slide 16 – Driving Force

In all of these areas we connected the real-world equipment to the energy analysis and we translated our findings into the language of business—economics.

[Slide Visual – Driving Force]

What is the main driving force for change??

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- **Energy**
- **Reliability**

- **Maintenance**
- **Productivity**
- **Quality**
- **Cost avoidance**
- **Emissions reductions**

Slide 17 – Contact Information

Here is some contact information for this training, including websites, e-mail addresses, and phone numbers.

[Slide Visual – Contact Information]

- **BestPractices Steam**
  - **http://www1.eere.energy.gov/industry/bestpractices/**
    - **Tools**
    - **Books**
    - **Fact-sheets**
    - **Tip-sheets**
- **Save Energy Now Assessments**
- **Industrial Assessment Centers**
- **EERE Information Center**
  - **(800) 862-2086**
  - **eereic@ee.doe.gov**

- **Tony Wright**
  - **US DOE BestPractices Technical Manager**
  - **(865) 574-6878**
  - **wrightal@ornl.gov**

- **Bill Orthwein**
  - **US DOE BestPractices Program Manager**
  - **(202) 586-3807**
  - **william.orthwein@ee.doe.gov**

Slide 18 – U.S. DOE Tip Sheets

The Department of Energy has developed reference materials to help identify steam system improvement opportunities. This is a list of tip sheets that can help you effectively manage your steam system. They can all be found at the web address at the bottom of the screen.

[Slide Visual – U.S. DOE Tip Sheets]

- **Benchmark the Fuel Cost of Steam Generation**
- **Clean Boiler Water-side Heat Transfer Surfaces**
- **Consider Installing a Condensing Economizer**
- **Consider Installing High-Pressure Boilers with Backpressure Turbine-Generators**
- **Consider Installing Turbulators on Two- and Three-Pass Firetube Boilers**
- **Consider Steam Turbine Drives for Rotating Equipment**
- **Considerations When Selecting a Condensing Economizer**
- **Cover Heated, Open Vessels**
- **Deaerators in Industrial Steam Systems**
- **Flash High-Pressure Condensate to Regenerate Low-Pressure Steam**
- **Inspect and Repair Steam Traps**
- **Install an Automatic Blowdown Control System**
- **Install Removable Insulation on Valves and Fittings**
- **Insulate Steam Distribution and Condensate Return Lines**
- **Improve Your Boiler's Combustion Efficiency**
- **Minimize Boiler Blowdown**
- **Minimize Boiler Short Cycling Losses**
- **Recover Heat from Boiler Blowdown**
- **Replace Pressure-Reducing Valves with Backpressure Turbogenerators**
- **Return Condensate to the Boiler**
- **Upgrade Boilers with Energy-Efficient Burners**
- **Use Feedwater Economizers for Waste Heat Recovery**
- **Use Low Grade Waste Steam to Power Absorption Chillers**
- **Use Steam Jet Ejectors or Thermocompressors to Reduce Venting of Low-Pressure Steam**
- **Use Vapor Recompression to Recover Low-Pressure Waste Steam**
- **Use a Vent Condenser to Recover Flash Steam Energy**

http://www1.eere.energy.gov/industry/bestpractices/tip_sheets_steam.htm

Slide 19 – U.S. DOE Technical Documents

For more detailed and in-depth information the Department of Energy has developed Technical Documents. Here is a list of technical documents that can help you effectively manage your steam system. They can all be found at the web address at the bottom of the screen.

[Slide Visual – U.S. DOE Technical Documents]

- **Improving Steam System Performance: A Sourcebook for Industry**
- **Achieve Steam System Excellence: Industrial Technologies Program BestPractices Steam Overview Fact Sheet**
- **BestPractices Steam Technical Brief: Steam Pressure Reduction-Opportunities and Issues**
- **BestPractices Steam Technical Brief: How to Calculate the True Cost of Steam**
- **BestPractices Steam Technical Brief: Industrial Heat Pumps for Steam and Fuel Savings**
- **BestPractices Steam Technical Brief: Industrial Steam System Heat-Transfer Solutions**
- **BestPractices Steam Technical Brief: Industrial Steam System Process-Control Schemes**
- **Guide to Combined Heat and Power Systems for Boiler Owners and Operators**
- **Guide to Low-Emission Boiler and Combustion Equipment Selection**
- **Review of Orifice Plate Steam Traps**
- **Save Energy Now in Your Steam Systems**
- **Steam Digest: Volume IV (2003)**
- **Steam Digest 2002**
- **Steam Digest 2001**
- **Steam Systems Energy Efficiency Handbook**
- **Steam Systems Survey Guide**

http://www1.eere.energy.gov/industry/bestpractices/techpubs_steam.html

Slide 20 - Homework

For your homework, take the Steam System Tool Suite Introduction web-based training, if you have not already. Then, try to apply it to your own steam system to identify at least one energy efficient improvement.

<u>Slide 21 – Thank You!</u>

You have completed the technical component of the Steam System End-User Training. In order to complete the training, test your knowledge with the End of Course Quiz. You can also re-visit the training course in its entirety or review a particular individual module of interest. Thank you for your time and effort!

[Slide Visual – Thank you!]

- **Technical component of the training is finished**
- **Test your knowledge with the End of Course Quiz**
    - **Your Steam End User Web-based Training will be Complete!**
- **You can revisit the training course anytime**
    - **Entire course**
    - **Individual Modules/Topics**
- **Visit ITP's Steam Resources for additional information**
- **Feedback is welcome!**