Steam End-User Training
Steam Generation Efficiency Module
Efficiency Definition Section

Slide 1 - Steam Generation Efficiency Module

This module will discuss steam generation efficiency and the primary factors that affect it. . The general concepts of boiler efficiency will be discussed.

[Slide Visual – Contents of Module Sections]

Banner:
DOE's BestPractices
Steam End User Training

Steam Generation Efficiency
Efficiency Definition
Radiation and Convection Losses –
Shell Losses
Blowdown Losses
Stack Losses

Slide 2 - Boiler Types

There are many types of boilers, but the primary boiler designations are *fire-tube boilers* and *water-tube boilers*. A fire-tube boiler is one in which the combustion gases are inside the tubes. This schematic depicts a 3-pass fire-tube boiler, in which we have a combustion zone, and smaller tubes that allow more heat transfer from the exhaust gases. Fire-tube boilers served as our first industrial steam generators. The large diameter pressure vessel holds all of the stress of the high-pressure steam. As industrial requirements necessitated higher pressure steam and greater steam flow rates, the vessel had to become larger and the wall of the vessel had to get thicker to accommodate the stress of greater pressures. These factors made boiler manufacturing difficult and expensive. As a result, water-tube boilers were developed. These boilers contain hundreds of tubes that hold the high-pressure steam and water. These relatively small diameter tubes can accommodate the stress of much higher pressures than the large diameter vessel.

Water-tube boilers allow the combustion gases to provide heat transfer to the water (and steam) that is contained in the tubes of the boiler. A common water-tube boiler arrangement will incorporate an upper steam-drum that allows the liquid water and steam to separate. A lower drum, often called a mud-drum, will serve as the lower collection header for the tubes. Hundreds of relatively small diameter tubes will connect the mud-drum to the steam-drum. As the water heats and boiling occurs the fluid rises in the tubes to the steam drum.

[Slide Visual - Boiler Types (Fire-Tube and Water-Tube)]

This schematic depicts a 3-pass fire-tube boiler, in which we have a combustion zone (at the bottom), and smaller tubes that allow more heat transfer from the exhaust gases. The pressure vessel holds all of the stress of the high-pressure steam.

Water-tube boilers allow the combustion gases to provide heat transfer to the water (and steam) that is contained in the tubes of the boiler. A typical water-tube boiler arrangement will incorporate an upper steam-drum that allows the liquid water and steam to separate. A lower drum, often called a mud-drum, will serve as the lower collection header for the tubes. Hundreds of relatively small diameter tubes will connect the mud-drum to the steam-drum. As the water heats and boiling occurs the fluid rises in the tubes to the steam drum.

Slide 3 - Fire-Tube Boiler

Generally, fire-tube boilers are designed for lower pressure and less capacity than water-tube boilers—but their operating ranges overlap. A typical fire-tube boiler might have a steam production rate of 5,000 pounds per hour, while a typical water-tube boiler might have a steam production rate of 200,000 pounds per hour. Fire-tube boilers produce saturated steam in most all cases.

[Slide Visual - Fire-Tube Boiler]

This schematic depicts a 3-pass fire-tube boiler, in which we have a combustion zone (at the bottom), and smaller tubes that allow more heat transfer from the exhaust gases. The pressure vessel holds all of the stress of the high-pressure steam.

- **Steam pressure limited**
  - **Typical 300 psig maximum**
- **Steam flow rate limited**
  - **Typical 1,200 BHp maximum**
    - **40,000 lbm/hr**
- **Saturated steam output**
- **One inherent efficiency advantage over water tube type – shell loss is minimal**
- **Generally manufactured offsite**
- **Many different styles**

Slide 4 - Water-Tube Boiler

Water-tube boilers can produce saturated steam or they can be equipped with a superheater internal to the boiler. From the standpoints of management, investigation, and improvement, knowing the differences between the two boiler types is not essential—because they generally work the same. There are no significant efficiency related reasons to choose one type of boiler or the other. The reasons for choosing one or the other are usually related to the relative cost for the given pressure and steam production requirements.

[Slide Visual - Water-Tube Boiler]

Water-tube boilers allow the combustion gases to provide heat transfer to the water (and steam) that is contained in the tubes of the boiler. A typical water-tube boiler arrangement will incorporate an upper steam-drum that allows the liquid water and steam to separate. A lower drum, often called a mud-drum, will serve as the lower collection header for the tubes. Hundreds of relatively small diameter tubes will connect the mud-drum to the steam-drum. As the water heats and boiling occurs the fluid rises in the tubes to the steam drum.

- **Operating pressures range from atmospheric to in excess of 4,000 psig**
- **Steam production ranges from 5,000 lbm/hr to 10,000,000 lbm/hr**
- **Saturated or superheated steam output**
- **Constructed onsite or offsite**
- **Many different styles**

Slide 5 - Common Fuels

This table contains information concerning the most common fuels used in the United States—and throughout the word. Natural gas is widely distributed through a national pipeline system. This fuel is primarily methane gas. Number 2 fuel oil is also known as *heating oil* and *home heating oil*. Number 2 fuel oil is distributed as a liquid that is very similar in composition to diesel fuel. During the distillation process, number 6 fuel oil is the material remaining after gasoline, kerosene, diesel, and other lighter materials have been boiled from the crude oil mixture. Number 6 fuel oil is also known as *heavy fuel oil*, *bunker C fuel oil*, and *residual fuel oil*. Number 6 fuel oil most often contains sulfur and is designated as High Sulfur content or Low Sulfur content. This is noted as HS and LS respectively in the information provided in this course. Number 6 fuel oil generally will not flow as a liquid until it has been heated to well above room temperature.

Coal properties vary significantly from region to region and from mine to mine. The characteristics of coals are not at all standard; but, some general characteristics can be used as a basic guide to coal properties. In the united states, the most common coals are the Eastern Bituminous Coals and the Western Sub-Bituminous Coals. A characteristic difference in these coals is moisture content. Eastern coal typically has less intrinsic moisture than western coal.

Natural gas and number 2 fuel oil are generally considered very easy fuels to utilize. The heavier fuel oils, like number 6 fuel oil are very common; but, are more difficult to handle. Number 6 fuel oil is generally a solid at room temperature and is heated to more than 200 degrees Fahrenheit to be pumped to the boiler burner. Solid fuels like coal and green-wood are much more difficult to handle and store. Solid fuels generally contain a portion of noncombustible material called ash that must be disposed of after the combustion process.

Green-wood is a dominant fuel in the pulp-and-paper industry because they generate a significant amount of waste-wood materials. It should be noted that green-wood is typically bark and tree components that were recently a part of a live tree. This fact is important because live trees are essentially half liquid water—green-wood as a fuel is nominally 50 percent liquid water. Green-wood is commonly known as *hog fuel*, *wood chips*, and simply *wood*.

The unit costs identified in this table are reflective of the average U.S. fuel costs for 2005. This information is understandably not current; but, it is reflective of the common differences in fuel prices. It is common for the energy based cost of natural gas to be four times greater than the energy based cost of coal—or even more. Fuel oil prices can be even higher. This is a dominant reason why we use coal.

It should be noted that there is significant volatility in the fuel market.

[Slide Visual - Common Fuel Table]

Typical Fuel Properties				
	Sales	Example Price	HHV	Unit Price
Fuel	Unit	[$/sales unit]	[Btu/lbm]	[$/10-Btu]
Natural Gas	10^3std ft^3	7.00	23,311	7.00
Number 2 Fuel Oil	gallon	1.80	19,400	12.92
Number 6 Oil (LS)	gallon	1.20	18,742	7.82
Number 6 Oil (HS)	gallon	1.00	18,815	6.62
Eastern Coal	ton	45.00	13,710	1.64
Western Coal	ton	30.00	10,088	1.49
Green Wood	ton	11.00	5,250	1.05

Slide 6 - Boiler Example

Throughout this training we will use an example steam system that reflects a steam system with real-world characteristics. This example system will help us illustrate the importance and usefulness of tools and investigations presented in this training. Throughout this course we will discuss all the aspects of this steam system; but, we will start by looking at one of the boilers serving this example site.

For this example the boiler is producing 100,000 pounds per hour, of 400 PSIG, 700 degree Fahrenheit steam from the combustion of natural gas.

This boiler is equipped with a fuel flow meter and the cost of the fuel is taken as 10 dollars per million BTU.

[Slide Visual - Water-Tube Boiler]

Water-tube boilers allow the combustion gases to provide heat transfer to the water (and steam) that is contained in the tubes of the boiler. A typical water-tube boiler arrangement will incorporate an upper steam-drum that allows the liquid water and steam to separate. A lower drum, often called a mud-drum, will serve as the lower collection header for the tubes. Hundreds of relatively small diameter tubes will connect the mud-drum to the steam-drum. As the water heats and boiling occurs the fluid rises in the tubes to the steam drum.

- **Natural gas fired boiler ($10.0/106Btu)**
  - **Steam pressure is 400 psig**
  - **Steam temperature is 700°F (superheated)**
  - **Boiler capacity is 120,000 lbm/hr**
  - **Current operating load is 100,000 lbm/hr**
  - **Natural Gas Supply is 2,480 sft/m**

Slide 7 - Case Study

This data will provide enough information to calculate the fuel related operating cost of the boiler.

[Slide Visual – Operating Cost]

Boiler fired with natural gas which has a higher heating value of 23,311 Btu/lbm
HHV is 1,000 Btu/sft^3
Steam conditions: 400 psig, 700°F
Output: 100,000 lbm/hr (steady)
Rating: 120,000 lbm/hr (maximum continuous)
Feedwater: 600 psig, 242°F
Fuel supply: 149,000 sft^3/hr (2,480 sft^3/min)
Fuel cost: $10.00/10 Btu ($10.0/10^{3}sft^3)

Determine the operating cost of the boiler

Slide 8 - Boiler Operating Cost

The fuel related operating cost of this example boiler is $13,000,000 per year. It should be noted that this example boiler can be considered a typical industrial boiler. The fuel is natural gas, which is one of the simplest fuels to burn. It is interesting to note that the characteristics of this boiler are not extreme; in other words, the boiler is producing a moderate amount of steam under typical conditions. Additionally, while the fuel cost may not be exactly representative of the fuel costs at a given facility this example cost is not extraordinary. The characteristics of this boiler are easily scalable to most boilers. It should also be noted that the investigation and improvement techniques required to manage this example boiler are the same techniques available to all boilers. Along with this is the fact that this example boiler is a real boiler that appropriately represents the types of opportunities potentially available to many boilers. Boilers are extremely expensive components—this is the reason we are interested in them.

[Slide Visual –Boiler Operating Cost Calculation]

K_{boiler} = V-dot$_{fuel}$ x k-dot$_{fuel}$ x $t_{operation}$

Boiler operating costs equals the cost of fuel in units per hour ; multiplied by the cost of the fuel per unit; multiplied by the hours of operation

Where:
K_{boiler} = Boiler Operating Costs
V-dot$_{fuel}$ = Volume Flow of Fuel Units per Hour (fuel supply)
k-dot$_{fuel}$ = Cost of Fuel per Unit (fuel costs)
$t_{operation}$ = Operating Period

K_{boiler} =149,000 sft^3/hr x (10.0 \$/10^3-sft^3) x (8,760 hrs/yr).

Boiler operating costs equals 149,000 standard cubic feet per hour; multiplied by 10 dollars per standard cubic feet; multiplied by 8,760 hours per year.

K_{boiler} = 13,000,000 \$/yr

Boiler operating costs equals $13,000,000 per year.

Slide 9 - Operating Cost

The cost of fuel for a typical boiler is so large that even very small changes in efficiency can represent significant cost impact. A 1 percent improvement in efficiency for the example boiler represents approximately $130,000 per year of fuel savings.

[Slide Visual – Savings Calculation 1]

0.01 x $13,000,000/yr - $130,000 savings!

There are other cost factors associated with boiler operations—water treatment costs, auxiliary equipment costs, maintenance costs, and operations costs; however, these costs typically combine to be significantly less than the cost of fuel for the boiler. Each cost factor should be investigated; but, fuel cost typically dominates.

In this example boiler investigation we will identify real-world methods that will reduce the fuel consumption of this boiler more than 7 percent, which represents more than $1,000,000 per year.

Calculations are often thought of as academic exercises; however, in the case of managing boiler performance and cost, evaluating boiler efficiency is one of the most important and practical tools available to us. To illustrate the importance and usefulness of boiler efficiency, we will examine the efficiency of an example boiler. We will also explore the major factors that impact the efficiency and operating cost of a boiler.

[Slide Visual – Operating Cost]

Boiler fired with natural gas which has a higher heating value of 23,311 Btu/lbm
HHV is 1,000 Btu/sft^3
Steam conditions: 400 psig, 700°F
Output: 100,000 lbm/hr (steady)
Rating: 120,000 lbm/hr (maximum continuous)
Feedwater: 600 psig, 242°F
Fuel supply: 149,000 sft^3/hr (2,480 sft^3/min)
Fuel cost: $10.00/10 Btu ($10.0/10^{3}sft^3)
Operating cost: 13,000,000$/yr

- **A small change in boiler efficiency (even 1%) can represent a significant economic impact**

Other operating costs include:

- **Water treatment**
- **Boiler feed pumps**
- **Flue gas conditioning**
- **Maintenance (personnel, services, equipment)**
- **Typically these costs combine to be much less than fuel costs**

Slide 10 - Efficiency Definition

Calculations are often thought of as academic exercises; however, in the case of managing boiler performance and cost, evaluating boiler efficiency is one of the most important and practical tools available to us. To illustrate the importance and usefulness of boiler efficiency, we will examine the efficiency of an example boiler. We will also explore the major factors that impact the efficiency and operating cost of a boiler.

[Slide Visual – Efficiency Sub-Section: Efficiency Definition]

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Radiation and Convection Losses –
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Slide 11 - Classic Boiler Efficiency

Boiler efficiency is a way to determine how much fuel energy a boiler converts into steam energy. Steam energy is the desired commodity and fuel energy is the purchased commodity. The equation shown here is a simplified description of the energy efficiency of a boiler—expressed in terms of fuel energy into the boiler and steam energy out of the boiler.

[Slide Visual – Classic Boiler (Direct) Efficiency Equation]

n_{boiler} = **energy desired /**
energy that costs

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

The fuel energy supplied to the boiler is determined by multiplying the fuel flow rate by the fuel energy content. Fuel energy content is described in terms of the heating value of the fuel, which is an expression of the thermal energy that is released when the fuel is burned. The maximum thermal energy that can be released when a fuel is burned is identified as the fuel Higher Heating Value or HHV of the fuel. The fuel heating value is determined by laboratory analysis.

[Slide Visual – Classic Boiler (Direct) Efficiency Equation 2]

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

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.

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**

The energy desired is the energy added to the steam as it passes through the boiler. Steam energy is determined by multiplying the steam production (or mass flow rate) by the specific energy added to the steam as it passes through the boiler. We describe the energy content of the steam as the *enthalpy* of the steam (*h* in the equation)—*enthalpy* is the thermodynamic property describing the amount of energy residing in the material. The energy added to the steam in the boiler is the difference in enthalpy of the steam leaving the boiler versus the feedwater entering the boiler. Enthalpy values are obtained from thermo-physical property data sets and field measurements like steam temperature and pressure.

[Slide Visual – Enthalpy Definition]

Enthalpy –energy of a substance that can be converted into heat, work, and other forms of energy.

Fuel energy is determined by multiplying the fuel consumption rate by the fuel energy content, also known as the heating value.

An alternate expression for the energy content of the fuel is identified as the Lower Heating Value (LHV). Most common fuels are composed primarily of carbon and hydrogen. These elements react with oxygen in the combustion process and primarily form carbon dioxide and water. The water formed in the combustion process is initially vapor (steam). If this water-vapor is allowed to cool below its condensation temperature the vapor will condense liberating heat. This energy release from the water-vapor represents additional energy available from the combustion of the fuel. The difference between the Higher Heating Value and the Lower Heating Value is the Higher Heating Value accounts for this additional energy liberation when the water-vapor condenses. The Lower Heating Value measures the fuel energy release with all the combustion products remaining in the vapor phase.

[Slide Visual – Lower Heating Value]

LHV – fuel energy released with all the combustion products remaining in the vapor phase.

Slide 12 - Boiler Efficiency 1

It is interesting to identify typical boiler efficiency. This will allow us to compare our boiler to typical operation. If we can identify best-practice boiler efficiency then we can characterize the operation of our boiler—possibly identifying the improvement potential.

[Slide Visual – Typical Boiler Efficiencies]

A typical boiler will have an efficiency of ----?

Slide 13 - Boiler Efficiency 2

If we were to examine many boilers we would probably find that the typical boiler efficiency is in the mid-80 percent range. We would also see that many of the boilers would have higher efficiency than this and many would have lower efficiency than this. But, we would see very few boilers with efficiencies much greater than 90 percent and very few boilers with efficiencies much lower than 70 percent.

Green-wood is a common fuel in many industries most prominently in the pulp and paper industry. The term green-wood refers to wood products that have not been dried. Pulp and paper plants harvest trees to process them into pulp and paper products. Paper is not made from the bark and limbs of the trees. As the trees are harvested the limbs, bark, and poor quality materials are removed along with other parts of the tree that cannot be converted into paper. This "green-wood" is fresh from the forest and typically contains about 50 percent cellulose and 50 percent liquid water. Green-wood is used as a major fuel source because it is readily available and is low-cost. However, a fuel that is composed of 50 percent liquid water will burn inefficiently—the liquid water will boil and carry a large amount of energy out of the boiler. As a result, green-wood-fired boilers will operate with low efficiency.

It is interesting to note that a typical industrial coal-fired boiler will operate with relatively high efficiency. This results from the fact that hydro-carbon fuels are composed primarily of hydrogen and carbon. Carbon combusts and forms carbon dioxide. Hydrogen combusts and forms H_2O—water. Water is God's greatest chemical for absorbing and transporting energy. Most of our boilers burning hydrocarbon fuels release water-vapor (steam) as a product of combustion. As a result, a significant portion of the energy available in the fuel is carried out of the boiler in the water-vapor that is formed in the combustion process. Fuels containing less hydrogen exhaust less water-vapor in the flue gases and generally have higher efficiency. Coals generally contain some amount of liquid water, some amount of ash (rocks), but mostly carbon.

Fuel oils usually contain more hydrogen than coals but they typically contain very little ash and almost no liquid water. As a result, fuel oil-fired boilers will operate with relatively high efficiency.

Natural gas contains a relatively large amount of hydrogen. Therefore, natural gas-fired boilers will operate with efficiencies lower than comparable coal and oil-fired boilers.

There are many factors that impact boiler efficiency—fuel type is one of them, the way we control the combustion process is another, and energy recovery equipment installed on the boiler is one more major factor effecting efficiency.

[Slide Visual – Typical Boiler Efficiencies]

A typical boiler will have an efficiency of ----?

70% Green Wood
82% Natural Gas
90% Oil and Coal

Efficiency is primarily dependent on the type of fuel, the combustion control effectiveness, and the energy recovery equipment.

Slide 14 - Example Steam Properties

Let's return to our example boiler because we have enough information to evaluate boiler efficiency. In order to determine the energy added to the steam passing through the boiler, we must use steam property data often known as "steam tables". From the temperature and pressure measurements of the steam and feedwater we can identify their enthalpies—again, enthalpy is an indication of energy content. Here you can see for 700 degrees Fahrenheit and 400 pounds per square inch gage, the enthalpy of the steam is 1,362 BTU per pound of steam. The feedwater is at 242 degrees Fahrenheit and 600 pounds per square inch gage—the enthalpy of the feedwater is 210 BTU per pound as shown in the table.

[Slide Visual – Efficiency Example Steam Properties]

Properties							
Location	Temp	P	Specific Volume	Enthalpy	Entropy	Quality	P
	[°F]	[psia]	[ft³/lbm]	[Btu/lbm]	[Btu/lbm°R]	[%]	[psig]
Boiler outlet	700	414.7	1.58946	1,361.88	1.63527	****	400
Saturated vapor	448	414.7	1.12025	1,204.62	1.46906	100.0	400
Saturated liquid	448	414.7	0.01939	428.04	0.62561	0.0	400
Deaerator storage	239	24.7	0.01692	207.74	0.35233	0.0	10
Feed pump exit	242	614.7	0.01694	210.42	0.35615	0.0	600
Condensate	180	14.7	0.01650	147.91	0.26289	0.0	0
Makeup water	75	14.7	0.01605	43.04	0.08397	0.0	0

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

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.

Slide 15 - Direct Efficiency

The steam property data along with the fuel consumption data gives us enough information to calculate boiler efficiency. This boiler is operating with an efficiency of about 77 percent. We are expecting a typical natural gas fired boiler to operate with an efficiency in the low 80 percent range. This boiler is operating with an efficiency that is below the expected value—we anticipate that there may be opportunities to improve the performance of this boiler.

Direct Efficiency Calculation 1- Entering data into the direct efficiency equation, we get 77 percent boiler efficiency.

[Slide Visual - Direct (Classic) Efficiency Equations]

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

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.

$$n_{boiler} = \frac{(100{,}000\ lbm/hr) \times (1{,}361.88\ Btu/lbm - 210.42\ Btu/lbm) \times (100)}{(149{,}000\ sft^3/hr) \times (1{,}000\ Btu/sft^3)}$$

The boiler efficiency is equal to 100,000 pounds per hour, multiplied by 1,361.88 BTU per pound; minus 210.42 Btu per pound; divided by the 149,000 standard cubic feet per hour; multiplied by 1,000 Btu per standard cubic feet.

based on volumetric flow rate (HHV units are Btu/sft^3)

Or using fuel mass flow data ($p = 0.043\ lbm/sft^3$)

$$\text{m-dot}_{fuel} = (149{,}000\ sft^3/hr) \times (0.043\ lbm/sft^3) = 6{,}407\ lbm/hr$$

$$n_{boiler} = \frac{(100{,}000\ lbm/hr) \times (1{,}361.88\ Btu/lbm - 210.42\ Btu/lbm) \times (100)}{(6{,}407\ lbm/hr) \times (23{,}311\ Btu/lbm)}$$

The boiler efficiency is equal to 100,000 pounds per hour; multiplied by 1,361.88 BTU per pound; minus 210.42 Btu per pound; divided by the 6,407 pounds per hour; multiplied by 23,311 Btu per pound.

based on mass flow rate (HHV units are Btu/lbm)

$n_{boiler} = 77.1\%$

The boiler efficiency is equal 77.1%.

Slide 16 - Efficiency Calculation

In order to identify the improvement opportunities associated with this boiler, we ask "why is the efficiency not 100 percent?" In other words, if boiler efficiency indicates that 77 percent of the fuel energy went into the steam, where did the other 23 percent of the fuel energy go? It went to supply the losses of the boiler.

[Slide Visual - Equations]

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

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.

$$n_{boiler} = \frac{(100{,}000 \text{ lbm/hr}) \times (1{,}361.88 \text{ Btu/lbm} - 210.42 \text{ Btu/lbm}) \times (100)}{(6{,}407 \text{ lbm/hr}) \times (23{,}311 \text{ Btu/lbm})}$$

The boiler efficiency is equal to 100,000 pounds per hour; multiplied by 1,361.88 BTU per pound; minus 210.42 Btu per pound; divided by the 6,407 pounds per hour; multiplied by 23,311 Btu per pound.

$n_{boiler} = 77.1\%$

The boiler efficiency is equal 77.1%.

Why is the efficiency not 100%?

Slide 17 - Boiler Losses 1

What are the typical boiler losses? Where can fuel go other than into the steam?

[Slide Visual – Boiler Losses 1]

- **Identify the Boiler Losses**

This schematic depicts a water-tube boiler. Fuel and air enters at the lower left of the combustion zone, feedwater enters at the top into the steam drum which connects to the mud drum through many tubes. The mud drum is at the bottom of the boiler. Steam exits the boiler from the steam drum into the superheater section, which is shown at the top of the boiler. The combustion gases leaving the boiler through the ducting at the upper right.

Slide 18 - Boiler Losses 2

Even though boilers are insulated, their outer surfaces are hot, indicating they are not perfectly insulated and fuel energy is being lost. This is identified as the *shell loss* also known as *radiation and convection loss*.

Another loss associated with operating a boiler is identified as the *blowdown loss*. In order to maintain proper boiler water chemistry some of the boiler water must be removed. This is an energy loss because the water that is discharged has been heated with fuel energy.

The exhaust gases from the combustion process exit the boiler with fuel energy. This energy can be identified by the elevated temperature of the gases. But there also can be un-reacted fuel or extra air in the exhaust gases. These exhaust gas related losses are identified as the *stack loss*.

Many other losses can be identified for boilers; such as, the energy carried from the boiler with ash in a coal-fired boiler. However, the three losses identified—shell, blowdown, and stack—are present on all fired boilers and they represent the fundamental points of concern for managing boiler efficiency.

[Slide Visual – Boiler Losses 2]

- **Identify the Boiler Losses**

This schematic depicts a water-tube boiler. Fuel and air enters at the lower left of the combustion zone, feedwater enters at the top into the steam drum which connects to the mud drum through many tubes. The mud drum is at the bottom of the boiler. Steam exits the boiler from the steam drum into the superheater section, which is shown at the top of the boiler. The combustion gases leaving the boiler through the ducting at the upper right.

- **Arrows show losses leaving the boiler:**
  - **Outer surface as Radiation and Convection (Shell Losses)**
  - **Blowdown (Blowdown Losses)**
  - **Exhaust Stack (as Gases) as Combustion and Temperature (Stack Losses)**
  - **Fly Ash and Bottom Ash (Other Miscellaneous Losses)**

Slide 19 - Indirect Efficiency

Generally managing boiler performance focuses on identifying and managing the losses. In fact, one of our most important tools is to identify, quantify, and reduce the boiler losses. This is accomplished through an indirect efficiency evaluation technique, which is the tool most often used in the field. Boiler efficiency is determined in an indirect manner by assuming the boiler efficiency is 100 percent minus all of the losses. Each loss is identified and quantified in this analysis.

In the next sections of our training, we will focus on each of these losses. We will explore each loss in detail identifying how to evaluate each one for our boilers. Additionally we will identify the fuel impact associated with each loss and the real-world improvement opportunities that can be targeted in each area. The real benefit associated with evaluating boiler performance with the indirect efficiency tool is that as boiler efficiency is determined, the roadmap for improvement is established. Evaluating the individual losses not only characterizes each loss but it also affords us the opportunity to identify the improvement potential associated with each.

[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**

$$n_{indirect} = 100 \text{ percent} - E_{Losses}$$

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

$$n_{indirect} = 100 \text{ percent} - Loss_{shell} - Loss_{blowdown} - Loss_{stack} - Loss_{misc}$$

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