CONDENSING BOILER TECHNOLOGY

Presented by:

Jim Cooke
Mechanical Solutions NW
1125 Andover Park W. Bldg. D
Seattle, WA  98188
Email:  jim@msinw.com
What is condensing boiler technology?
CONVENTIONAL BOILER TECHNOLOGY
Non-condensing construction

Fin tube boiler

Cast-iron sectional boiler
ENERGY CONTENT OF NATURAL GAS

SENSIBLE HEAT
89.8%

Heat that can be measured or felt by a change in temperature

LATENT HEAT
10.2%

Latent – Definition: Latin for “hidden”

Heat that can be measured or felt by a change in temperature
NATURAL GAS COMBUSTION

- Natural gas \( \text{CH}_4 \)

- Oxygen

- Nitrogen

- Air

- Combustion

- Light

- Heat

- Carbon Dioxide \(-\text{CO}_2\)

- Water vapor

- Nitrogen

- Nitrogen Oxides

Ashrae Presentation
CONVENTIONAL BOILER HEAT FLOW

Fuel input = 100%

- Sensible heat = 89.8%
- Latent Heat = 10.2%
- Flue gas loss = 3 to 5%
- Boiler stand-by and jacket loss = 3 to 5%

Into mechanical room

Up chimney

Useful heat

Seasonal efficiency of conventional Boilers = 80%+
Latent heat + Flue gas losses = 15%

CONVENTIONAL BOILER HEAT FLOW

Fuel input = 100%

Boiler standby and jacket loss = 5%

Useful heat = 80%
HEAT RECOVERY FROM FLUE GASES

- Simplified Chemical Combustion Formula:
  \[ CH_4 + 2 \ O_2 \rightarrow CO_2 + 2 \ H_2O \]

How do we capture the latent heat?

Water vapor (steam) containing latent heat
LATENT HEAT RECOVERY

- Water vapor turns to liquid when it is reduced in temperature.
- Energy is released when vapor turns to liquid
LATENT HEAT RECOVERY

1 pound of water

- Ice melting (Latent heat of fusion) requires 144 Btus.
- Water vaporizing (Latent heat of condensation) requires 970 Btus.

Diagram: Graph showing the temperature and total heat in Btus for ice melting and water vaporizing.
• Water vapor condenses below the dew point temperature

• CO₂ % of flue gas influences dew point temperature
Latent Heat

Heat Loss < 2 %

Fuel input = 100 %

Sensible heat = 89.8 %

Seasonal efficiency of conventional boilers = 82 %+

Seasonal efficiency condensing boilers = 96 %+

Flue gas loss < 1 %

Boiler stand-by and jacket loss < 1 %
Latent heat + Flue gas losses = 3%

CONDENSING BOILER HEAT FLOW

Fuel input = 100%

Useful heat = 96%

Boiler standby and jacket loss = 1%
EFFICIENCY INCREASES DUE TO FLUE GAS CONDENSATION

Combines the following:

1. Additional latent heat gain from condensate

2. Lower flue gas loss:
   - The flue gas temperature is lower because the sensible and latent heat is almost completely transferred to the boiler water

3. Lower radiant standby losses:
   - Due to lower boiler water temperatures
Why use condensing boiler technology?
MORE USABLE HEAT THROUGH CONDENSATION

What influences the rate of condensation?
FACTORS INFLUENCING EFFECTIVENESS OF CONDENSING TECHNOLOGY

- Fuel
- Burner type
- Heating system
- Piping layout
- Govt regulation
- Return water temp

Effective use of condensing technology
FACTORS INFLUENCING EFFECTIVENESS OF CONDENSING TECHNOLOGY

Heating system

Effective use of condensing technology

Return water temp
SIMPLIFIED CONDENSING BOILER OPERATION

Steady state boiler efficiency %

Dew Point of Natural Gas

Condensing mode

Non-Condensing mode

Boiler return water temp °F

80 82 84 86 88 90 92 94 96 98

60 80 100 120 140 160 180 200
RETURN WATER TEMPERATURE

Boiler return water temperature determines condensing operation
TYPICAL HYDRONIC WATER TEMPERATURE REQUIREMENTS:

High temperature:
- Finned tube baseboard: 140 - 190 °F
- Air heat fancoils: 140 - 180 °F
- Pool/spa heat exchangers: 160 - 180 °F
- DHW production: 150 - 190 °F

Medium temperature:
- Cast iron radiators: 100 - 140 °F
- Low mass radiant floor: 100 - 150 °F
  ie: wood joist floors

Low temperature:
- High mass radiant floor: 80 - 120 °F
  ie: concrete floors
- Snowmelting systems: 80 - 120 °F
Traditional boilers must be kept hot above 140°F.

Boiler water temperature maintained above 133°C (273°F) for on/off control.

Dew point for natural gas is approximately 133°C (273°F).

Boiler water temperature modulated for outdoor reset control.

Outside temperature affects boiler water temperature.
IMPACT OF SYSTEM TEMPERATURES ON CONDENSATION

Example 1: Supply/return temperature:

90/70°C, 194/158°F

Dewpoint temp

57°C/135°F

Condensation range

System water temperature

Outside temperature

-2.5°C 25.5°F

Fin tube
IMPACT OF SYSTEM TEMPERATURES ON CONDENSATION

Example 2: Supply/return temperature:

75/60°C, 167/140°F

Condensation range

Dewpoint temp 57°C/135°F

System water temperature

Outside temperature

-11.5°C  11.3°F

Hydro-Air

Radiators

Ashrae Presentation

Foil 25
Nov 2005
IMPACT OF SYSTEM TEMPERATURES ON CONDENSATION

Example 3: Supply/return temperature: 40/30°C, 104/86°F

Dewpoint temperature (natural gas 57°C/135°F)

Condensation range

System water temperature

Outside temperature

Radiant floor
CONDENSING / NON CONDENSING RATIO
ASHRAE weather data for Boston, MA

Design temperature
Boston: +7°F

System water temperature
Supply 160°F
Return 140°F
Dewpoint temp

Condensation range
72 - 176 °F

97% Condensing
3% Non-condensing

Ashrae weather data, hours of occurrence:
Sept - May
ASHRAE weather data for Boston, MA

**Condiensing / Non Condensing Ratio**

- Condensation
- Rangerange

<table>
<thead>
<tr>
<th>°F</th>
<th>176</th>
<th>172</th>
<th>168</th>
<th>164</th>
<th>160</th>
<th>156</th>
<th>152</th>
<th>148</th>
<th>144</th>
<th>140</th>
<th>136</th>
<th>132</th>
<th>128</th>
<th>124</th>
<th>120</th>
<th>116</th>
<th>112</th>
<th>108</th>
<th>104</th>
<th>100</th>
<th>96</th>
<th>92</th>
<th>88</th>
<th>84</th>
<th>80</th>
<th>76</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Design temperature
  - Boston: +7°F
- Supply 180°F
- Return 160°F
- Dewpoint temp

- Ashrae weather data, hours of occurrence: Sept - May
  - 1497 hr 24.3%
  - 1675 hr 27%
  - 2258 hr 36.5%
  - 627 hr 10%
  - 124 hrs 2%
  - 11 hrs 0.2%

**System water temperature**

- 75% Condensing
- 25% Non-condensing

**Notes:**
- Ashrae Presentation
- Nov 2005
SYSTEM WATER TEMPERATURE DROP

180°F

What about a higher temperature drop?
30°F……40°F?

150°F
TRUE SYSTEM EFFICIENCY
System Components

Fan coil sizing

Air flow

180°F

160°F

140°F

120°F

Same BTU’s delivered

TRUE SYSTEM EFFICIENCY
System Components

Fan coil sizing

Air flow

180°F

160°F

140°F

120°F

Same BTU’s delivered
ANNUAL FUEL UTILIZATION EFFICIENCY
For residential boilers < 300 MBH

Heated, humidified space, max 90°F, 80% RH

---

Fuel Input
Air Input
Vent Damper
Jacket losses considered to be zero

Air Input
Fuel Input

O₂ %, CO ppm
T_{flue gas}

T_{air}

140°F
120°F

Cold Water in
Heat exchanger
Hot Water out

Boiler
Constant load

Condensate measured for condensing boilers test

Box: Condensed water measured for condensing boilers test

---

Ashrae Presentation
Foil 31
Nov 2005
COMBUSTION EFFICIENCY
Testing for non-condensing gas commercial boilers


COMBUSTION EFFICIENCY
Testing for non-condensing gas commercial boilers

FACTORS INFLUENCING EFFECTIVENESS OF CONDENSING TECHNOLOGY

Effective use of condensing technology

Burner type
CO₂% of flue gas influences dew point temperature

Higher CO₂
= Higher Dew point
= More Condensation

Lower CO₂
= Lower Dew point
= Less Condensation
What influences the CO$_2$%?

THE BURNER!
NATURAL GAS COMBUSTION

1 part gas

10 parts air

Excess air
NATURAL GAS COMBUSTION
Atmospheric Burner technology

- 60% Excess Air
- 6% CO₂
- 8% O₂
NATURAL GAS COMBUSTION

Power-fired burner technology

25% Excess Air
9.5% CO₂
4% O₂
BURNER REQUIREMENTS FOR CONDENSING BOILERS

- Combustion with minimal excess air
  - CO$_2$: 9.5 to 10%
  - Excess air: 20 – 25%

- Fully modulating input
- Precise calibration thru entire firing range
- Low NO$_x$ and CO emissions
DEW POINT AND ALTITUDE

Dew Point of Natural Gas
Based on 1000 btu/ft³, 50% RH and 60°F Room Air

- 10.3% CO₂
- 8% CO₂

Altitude – Feet above sea level
FACTORS INFLUENCING EFFECTIVENESS OF CONDENSING TECHNOLOGY

Effective use of condensing technology

Piping layout
USE OF MIXING VALVES WITH
CONDENSING BOILERS

INCORRECT

CORRECT

Foil 42
Nov 2005
CONDENSING BOILERS IN TWO TEMPERATURE SYSTEMS
CONDENSING BOILERS IN HIGH FLOW SYSTEMS

Hydraulic system decoupling

High temp system

Low temp system
INJECTION PUMPING WITH CONDENSING BOILERS

INCORRECT
COMBINATION OF BOILERS

System Supply

Non-Condensing boiler
LAG BOILER

Boiler

Condensing boiler
LEAD BOILER

System Return
MULTIPLE FUNCTION, MULTIPLE TEMPERATURE SYSTEM

Indirect DHW tank

High Temp Heating - Fan coil

3 way mixing valve

Low Temp Heating - RFH
Construction requirements of condensing boiler technology
PHYSICAL REQUIREMENTS OF THE HEAT EXCHANGER SURFACES

Best material for condensing boilers:
- Single wall
- Highly conductive
- Smooth surface

Flue Gas

Boiler Water

122°F

Heat Flow

Condensate formation

Dew Point
Natural gas

194°F

158°F

131°F

122°F
Flue gas and condensate must flow in the same direction (parallel flow).
CONDENSING BOILER CONSTRUCTION

Condensing boiler requirements:

- Counterflow principle for flue gas and boiler water – optimal heat transfer
- Parallel flow direction for flue gas and condensate – uniform flow with self-cleaning effect of heat transfer surfaces
Why is material construction of the boiler heat exchanger so important?
pH VALUES OF VARIOUS FLUIDS

Acidic

- Battery acid
- Gastric acid
- Lemon juice

Basic

- Ammonia
- Distilled water (neutral)
- Lake water

pH-Value

0 1 2 3 4 5 6 7 8 9 10 11 12

Flue gas condensate
Oil
Gas
Typical household sewage
MATERIAL REQUIREMENTS FOR CONDENSING BOILERS

- Highly corrosion resistant
- High strength with thin wall thickness
- Formable
- Long term reliability
FINNED TUBE HEAT EXCHANGERS

New aluminum fin heat exchanger surface

Same heat exchanger surface after short term use
CONDENSATE DISPOSAL

How much condensate will be produced?

What do we do with it?
<table>
<thead>
<tr>
<th>Components Tested</th>
<th>Drinking Water Limits</th>
<th>Wine</th>
<th>Vertomat 05 - 89 DIN-DVGW Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg/ltr.</td>
<td>mg/ltr.</td>
<td>mg/ltr.</td>
</tr>
<tr>
<td>Lead</td>
<td>0.04</td>
<td>0.1 - 0.3</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.005</td>
<td>0.001</td>
<td>&lt; 0.005</td>
</tr>
<tr>
<td>Chrome</td>
<td>0.05</td>
<td>0.06 - 0.03</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Copper</td>
<td>3.0*</td>
<td>0.5</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.05</td>
<td>0.05 - 0.03</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Mercury</td>
<td>0.001</td>
<td>0.00005</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Vanadium</td>
<td>-</td>
<td>0.26 - 0.06</td>
<td>not determined</td>
</tr>
<tr>
<td>Zinc</td>
<td>5.0*</td>
<td>3.5 - 0.5</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Tin</td>
<td>-</td>
<td>0.7 - 0.01</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Sulphate</td>
<td>240</td>
<td>5 - 10</td>
<td>4.6</td>
</tr>
<tr>
<td>pH Value</td>
<td>6.5 - 9.5</td>
<td>3 - 4</td>
<td>3.5 - 5</td>
</tr>
</tbody>
</table>
CONDENSATE FLOW RATE

Amount of condensate vs. Flue gas temperature

- Boiler return water temperature
- Flue gas temp. at full input
- Flue gas temp. at partial load

- Condensate flow rate
- g/kWh

- Temperature scales: °C and °F

- Values at 100 g/kWh and 68, 30, 86 °C
CONDENSATE FLOW RATE

124,000 btuh boiler (at full firing rate)

104°F supply

22 USG/day

86°F return
CONDENSATE DISPOSAL

- Plastic pipe (CPVC, ABS, PEX) sloped towards drain
- NO Copper!
- P trap required

To floor drain, or condensate pump

pH 3-4
CONDENSATE NEUTRALIZATION

- Neutralization unit
- Filled with granular neutralizing material

To floor drain, or condensate pump

pH 7-8
CONSTRUCTIVE AND PHYSICAL REQUIREMENTS FOR CONDENSING BOILERS

- Combustion with minimal excess air (high CO$_2$)
- Fully modulating burner
- Low heat exchanger surface temperatures
- Parallel flow of flue gas and condensate
- Counter-flow of flue gas and heating water
- Highly corrosion resistant material
SYSTEM DESIGN REQUIREMENTS FOR CONDENSING BOILERS

- Low temperature heat release surfaces
- Modulate water temperatures with outdoor reset controls
- Higher system water temperature drops
- Piping layouts to reduce boiler return water temperatures
CONDENSING BOILER TECHNOLOGY

THANK-YOU

Jim Cooke
Mechanical Solutions NW
1125 Andover Park W. Bldg. D
Seattle, WA  98188
E-mail: jim@msinw.com