PETRO-CANADA OIL AND GAS

FIRE-TUBE IMMERSION HEATER OPTIMIZATION PROGRAM & Field Heater Audit Program


by Phil Croteau P. Eng.
Energy Efficiency Engineer

January 15-17, 2007
Outline (25 min session)

- Overview – Top 5 Priorities (PTAC – TEREE)
- PTAC – TEREE: the Origin of the “Fire-tube Heater Study”
- Combustion Efficiency – Excess Air
- Heat Transfer – Fire-tube Design
- Combustion Efficiency – Fire-tube Selection
- Combustion Efficiency – Heat Flux Rate
- Burner Selection
- Burner Duty Cycle
- Combustion Efficiency – Reliability Guidelines
- Heater Tune-up – Inspection Procedure
- Insulation
- PCOG Fire-tube Immersion Heater Optimization Program
- Field Audit Program (NRCAN Energy Audit Incentive Program)
- Conclusion, Q&A
Overview: Top 5 Priorities, ER & EE

PTAC - TEREE Study 2004-2005: Top 5 Priorities for ER and EE

Petroleum Technology Alliance Canada

– Technology for Emission Reduction and Eco-Efficiency

1. Venting of Methane Emissions
2. Fuel Consumption in Reciprocating Engines
3. *Fuel Consumption in Fired Heaters*
4. Flaring and Incineration
5. Fugitive Emissions
Common concern for many upstream operating companies is the energy consumption associated with **immersion heaters**. Energy often used to fire these heaters is high quality refined sales gas. Common problem with the immersion heaters is that they may have low fuel efficiencies between 30% and 60%. Compared to common boiler technology these heaters should be able to run at 70 to 80% efficiency. Recent estimates suggest that heaters currently waste in excess of 2 to 3 billion BTU/hr of fuel (1360 to 2040 e3m3/d gas) that could be conserved to generate added sales. At an average cost of $5/GJ this represents $100 to $150 million of lost revenues due to inefficient use of fuel gas. Also represents an associated 1.5 million additional tonnes of carbon dioxide being discharged into the atmosphere per year.
Project Sponsors

The following sponsors collaborated with PTAC to provide financial and technical support:

- Petro-Canada
- EnCana Corporation
- Husky Energy
- Nexen
- Shell Canada
- CETAC-West
- CAPP
- BP Canada

The report has now been publicly released, and is available to view on the PTAC website at

www.ptac.org/techeetteree.html
- We built a heater, fired it with several different burners!

Stack Temp Monitoring – ECG!
PTAC Lineheater Study

Fired as 2-3-4 passes

Primary Air Measurement
Burner Vendors Participating

- A-Fire
- ACL
- Bekaert (MCI) (3)
  7 combinations
- Eclipse
- Hauck
- Kenilworth (4)
- Maxon (3)
- North American
- Pro-Fire (2)
- Pyronics (4)

10 burner vendors = 25 burners tested
TESTS – OPEN FLAME TESTS
HEATER TEST STAND - INSTRUMENTATION

DCS control and data recording
Heat Transfer

PTAC Test – Glycol, 2-3-4 passes

- Fire-tube Design
Combustion Efficiency – Excess Air
The GOOD, the BAD & the UGLY!
Combustion Air Control

As found: fouled flame cell!
Excess air 0.0%
Stack CO >110,000 ppm!

Flame cells are not filters!

Excess air baffles!
Excess Air/O2 Control
COMBUSTION EFFICIENCY
- IMPACTED BY FIRE-TUBE SELECTION
(SENSIBLE HEAT RECOVERY!)
COMBUSTION EFFICIENCY
- IMPACTED BY FIRE-TUBE HEAT FLUX RATE

- ~ 76%
- ~ 69%

Average Surface Heat Flux Charts for 4" to 36" 2 Pass Fire Tubes

- High Target Efficiency = 82%
- Low Target Efficiency = 72%

Surface Heat Flux Rate (BTU/hr/ft²)

- 6,000 btu/hr/ft²
- 10,000 btu/hr/ft²

Energy transferred into the liquid: "Total immersed tube-surface area"
# Burner Selection

- **HIGH PRIMARY AIR INSPIRATION, TURNDOWN, FUNCTIONALITY**
- **MAXON VENTITE**

## Burner Characteristics

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Maxon Large</th>
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<tbody>
<tr>
<td>Description</td>
<td>2&quot; Venturi</td>
</tr>
<tr>
<td>Address</td>
<td>8375 Dixie Road, Unit 3</td>
</tr>
<tr>
<td>City, Province, Code</td>
<td>Mississauga, ON, L5T 2E1</td>
</tr>
<tr>
<td>Dimensions</td>
<td>14&quot;</td>
</tr>
<tr>
<td>Overall Length</td>
<td>31&quot;</td>
</tr>
<tr>
<td>Web Site</td>
<td><a href="http://www.maxonventite.com">http://www.maxonventite.com</a></td>
</tr>
</tbody>
</table>

**Compact burner assembly features gas nozzle, venturi, mixer, and primary air shutter combination. Heavy duty cast iron components.**

**Gas Nozzles**

Heavy duty cast iron nozzles include integral flame retention device with large main gas orifice and 8 smaller holes located around its perimeter. Available with integral pilot and flame rod mount (Pilot Pilot).

**Gas Mixer & Primary Air Adjustment**

Gas mixer features a low end loss ball shaped inlet. Heavy duty cast iron "recessed" type shutter includes a locating screw. Gas connection through the back of the mixer. Simple rear access to the orifices by removing the back plate of the register.

**Secondary Air Adjustment**

- No secondary air adjustment incorporated

## Burner Test Results

<table>
<thead>
<tr>
<th>BTU/hr</th>
<th>%</th>
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<tbody>
<tr>
<td>524,000</td>
<td>100%</td>
</tr>
<tr>
<td>304,000</td>
<td>100%</td>
</tr>
<tr>
<td>148,000</td>
<td>100%</td>
</tr>
<tr>
<td>531,000</td>
<td>50%</td>
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<tr>
<td>290,000</td>
<td>50%</td>
</tr>
<tr>
<td>118,000</td>
<td>50%</td>
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<tr>
<td>530,000</td>
<td>28%</td>
</tr>
<tr>
<td>290,000</td>
<td>28%</td>
</tr>
<tr>
<td>117,000</td>
<td>28%</td>
</tr>
<tr>
<td>531,000</td>
<td>10%</td>
</tr>
<tr>
<td>290,000</td>
<td>10%</td>
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</tbody>
</table>
BURNER SELECTION
- ECLIPSE
BURNER SELECTION

- HIGH PRIMARY AIR INSPIRATION,
  TURNDOWN,
  FUNCTIONALITY
Burner Duty Cycle Management
- short duty cycle at high firing rate vs. the longer duty cycle firing at a lower rate
Duty Cycle to the Extreme - This is the consequence of an extremely low main burner duty cycle, only the pilot ran, condensing moisture in “Products of Combustion”. Water accumulates and freezes at the flame cell as it tries to drain out. Level rises until even the pilot is extinguished! This is a concern for oversized heaters, more common a problem than we accept.
Combustion Efficiency, Emission and Reliability Guidelines 4 Pages

<table>
<thead>
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<th>Page 1 of 4</th>
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</table>

**Efficiency Definition**: Efficiency is defined as the percentage of gross BTU input that is realized as useful BTU output of a heater. There are two ways of calculating this efficiency: the HHV efficiency uses the higher heating value of fuel input, and the LHV efficiency uses lower heating value of fuel input.

**LHV and HHV Based Efficiency Calculations**: For example, pure methane HHV = 1012 BTU/scf and LHV = 911 BTU/scf, and the difference is the amount of energy used to evaporate water produced during the combustion process from the hydrogen contained in the fuel. Hence for the same combustion process using methane as a fuel, the LHV efficiency value is about 10% higher than the HHV efficiency value. Where the LHV efficiency is easier to use for evaluation of traditional style heaters which do not condense water out of the products of combustion, it cannot be meaningfully used for newer condensing type heaters. In addition, since fuel is measured and sold based on its HHV value, only the HHV based efficiency should be used for the economic evaluation of the heater performance. LHV based efficiency is typically used in the US while the HHV efficiency is more commonly used in Canada. All regulatory requirements in Canada related to burner and fuel control rating are based on HHV of fuel. Error many heater specifications and many combustion analyzers do not clearly state the basis for efficiency calculations, caution should be exercised when using these efficiency values.

**Combustion Efficiency - Overall Combustion Efficiency**

Combustion efficiency can be expressed as the ratio of the amount of heat produced to the amount of heat that could be produced under ideal conditions. Combustion efficiency can be measured in various ways, including:

- **Heat loss from the heater**: These losses include:
  - Heat loss to the structure on the surface of the heater
  - Heat loss to the structure of the surrounding equipment
  - Heat loss to the structure of the surrounding space
  - Heat loss to the structure of the surrounding environment
  - Heat loss to the structure of the surrounding atmosphere

**Heater Design Specific Losses**

- **Stack Oxygen**: Stack oxygen level should be maintained between 2% and 4%, which corresponds to between 9.5% and 21.5% excess air. Below 2% oxygen, sharp increase in CO emissions is expected; above 4% oxygen additional excess air “burning a free fire” through the heater decreases the combustion efficiency.

**Stack CO**: Stack CO levels should be maintained below 400 ppm to maintain safe conditions. Typically, depending on the burner design, CO readings increase as low (below 2%) or high (above 1%) oxygen levels. High CO readings indicate incomplete combustion due to insufficient air flow or due to flame quenching with too much air.

**Stack NOx**: Stack NOx levels are a function of burner design and specifically flame shape and temperature. Smaller and hotter flames tend to produce higher NOx levels. Also burners with a single fuel injection point tend to produce higher NOx levels than those with multiple smaller and spread out points (fuel staging effect). Typically, properly designed natural draft burners produce between 60 ppm and 80 ppm converted to 3% oxygen (V/V dry basis) in the stack. Within a given burner design NOx formation is pretty well fixed and cannot be changed by regular tune-up techniques.

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**IMMERSION HEATER FIELD INSPECTION AND EFFICIENCY EVALUATION REPORT**

**COMBUSTION EFFICIENCY, EMISSIONS AND RELIABILITY GUIDELINES**

**PETROLEUM TECHNOLOGY ALLIANCE CANADA**

**Design by: PSII Energy Efficiency Engineering Ltd.**
**Heater Tune-up / Inspection Procedure**

1. **Gas Leak Test:** Check area around the heater and inside the fuel train or control enclosure (if present) for safe H2S, O2 and LEL levels.

2. **Visual Inspection:** Inspect heater for obvious signs of deterioration, corrosion, damage to instrumentation or fuel train components.

3. **Pilot Observation:** Check if heater main burner is lit. If not, check if the pilot is on. If pilot is not on check if the fuel to the pilot is turned on and if so turn the pilot fuel off and wait a few minutes for the fire tube to ventilate. Check with the control room if there is any reason why the heater is turned off. Once safe to do so, turn the main burner manual fuel valve off, reignite the pilot and observe. The pilot should be at least 4" to 8" in length, if smaller, try to increase fuel flow to pilot until "solid" pilot is established.

4. **Record Heater Data:** Record heater data such as make, model, year built, serial number, design process duty, burner type and size, burner orifice size, fire tube OD and length, stack OD and height, etc. as per enclosed inspection and evaluation report sheet.

5. **Main Flame Observation:** Check all heater permissible such as liquid level, temperature, HI shutdown, bath temperature setpoints. If everything is OK, open the main burner manual valve. Observe main flame shape, color, stability, anchoring, noise, and species on the tube surface.

6. **Fuel Pressure Measurement:** Measure and record fuel gas supply pressure, and main burner pressure (after regulation) while it is lit.

7. **Fuel Flow Measurement:** If available measure fuel gas flow to the main burner by timing the gas meter or measuring pressure drop across the fuel metering orifice. Another simple method is the measurement of the burner gas orifice size and calculation of the gas flow using orifice pressure drop charts. Since the mixture pressure inside the burner Venturi is typically negligible compared to the burner inlet pressure the burner inlet pressure can be used as an approximation of the pressure drop in the charts. Note, that this method cannot be utilized if the fuel gas orifice is used in conjunction with an adjusting needle valve as it is often the case with Eclipse burners.

8. **Heater bath temperature check:** Locate bath temperature gauge and record bath temperature. Record also the temperature control setpoint of the temperature controller.

9. **Stack Measurement:** Locate sampling port in the straight length of stack above the fire tube exit from the heater. If no port is available, drill and tap 3/8 UNC hole in the stack. Using combustion analyzer take reading of Flue Temperature, O2, CO, NOx and efficiency. Record also the ambient air temperature. After taking the sample install a 3/8" bolt using high temperature anti-seize compound or a brass bolt.

10. **Hi CO / LOW O2 with air passages closed:** If CO reading is high (in thousands of ppm) and O2 reading very low (close to zero), the heater is being fired substoichiometrically without sufficient oxygen. Remove sample probe from the stack immediately to prevent damaging the CO analyzer cell. Let analyzer purge the cell until CO reading drops to zero. Open access port in the flame arrester to allow more air flow. Insert analyzer probe back into the stack and observe CO readings. If readings have improved, with the access port open, there is a good possibility that the flame cell is plugged up and needs cleaning. Check also position of any secondary air control devices to make sure that they are blocking the air flow into the burner.

11. **Hi CO / LOW O2 with air passages open:** Bumer primary air is unadjustable and must be opened. Open slowly watching the analyzer CO readings until CO levels are low. If there is no or slow reaction, reduce fuel gas pressure to main burner gradually also watching for changes in CO. On some burner models (Eclipse) there could be also a fuel needle valve present which could be adjusted. Note that overfiring of the heater without sufficient combustion air does not increase the heat transfer and it may even decrease it through tube sooting or decrease in the flame temperature. It is also unsafe and may lead to a premature heater failure.

12. **Hi CO / HIGH O2:** The indication is that there is too much combustion air. Reduce the primary and secondary air down to 2 to 4% oxygen at the stack.
Insulation Heat Loss from Vessel Shell

- reduction in lost heat (demand) is a 100% saving, adjustments to appliance efficiency, etc. is only partial.
PCOG Fire-tube Immersion Heater Optimization Program

“You cannot manage what you do not measure.”

Philip J. Croteau - P.Eng.
Gerald Hewitt - Operations
Harley Siebold - Operations
Rev. Mar 27, 2006
DRAFT
Essential Elements of a Heater Optimization Program

Executive Summary

• quantify your number of heaters
• identify/understand their service
• quantify how much fuel they are thought to consume
• make assumptions of their current efficiency
• identify the potential efficiency target and savings
• identify how to get there

Statement of Commitment

• Body of the Program Document

Conclusions

TRAINING, AUDITING, MAINTENANCE & TAKING ACTION TO IMPROVE!
Overview: Fire-tube Heater Survey

Just how many fire-tube heaters do we/you fire!

- Following is an ~ count of both PCOG and third party. If we don’t steward the third party heaters, who will.

- Do we/you have heaters operated by third party?

<table>
<thead>
<tr>
<th></th>
<th>FR – Reboilers: Amine, Glycol …</th>
<th>FL – Lineheaters: Glycol, Salt Bath …</th>
<th>FT - Treaters</th>
</tr>
</thead>
<tbody>
<tr>
<td>195</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>510</td>
<td></td>
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<td></td>
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<tr>
<td>11</td>
<td></td>
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<td></td>
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<tr>
<td>716</td>
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Target is to audit 1/3 of heaters per year on 3 yr rotation.
Statement of Commitment:

Through our TLM program, Petro-Canada focuses on improvements in the elements of safety, environment, reliability, economics and the general management of our facilities.

As one of the areas of focus, Petro-Canada had recently committed resources and funding to participate in a study to review and improve our understanding in the design and operation of fire-tube immersion heaters and follow-up with implementation to optimize that equipment. Management is committed to improving the performance of these heaters through expectations of support from Operations, Maintenance and Engineering (OME).
Heat Transfer
- Fire-tube Design

Duty Cycle

Burner Selection

FIRE-TUBE IMMERSION HEATER DESIGN & OPERATION

Combustion Analysis
- 3 T’s plus Excess O2
  
  Time – Temperature - Turbulence
  
  + Excess O2: approx. 3%

  Time at Temperature

  “NEW” addition of the 4th T – Training!
Long and Skinny Fire-tube to Improve Heat Transfer

Sept 2006 test heater built, Wildcat Hills Choke Heater 6’ was added to standard fire-tube Flux = 7,000 Btu/hrft²

1 mm Btu/hr process duty

- Longer, more slender fire-tube is not new, many older heaters were built this way and exhibited better efficiency!

Vendor made the fire-tube, shell and process coils longer (with fewer return bends, lowering coil press drop!), shell dia. finished smaller. Fabricated cost of steel ended up similar to standard design.
- Petro-Canada is actively participating in 10 applications pursuing fire-tube heater efficiency improvements.

- Assisted by the NRCAN audit process we are attempting to assess 1/3 of our heater fleet/yr. on an ongoing cycle.

**NRCAN Industrial Energy Audit Incentive Program**

This incentive is designed to help defray the cost of hiring a professional energy auditor to conduct an on-site audit at an industrial facility.
- Stack temp and fuel gas pressure to burner orifice are key variables!
Combustion Analysis – O2, Excess Air, CO, NOx, comb. efficiency, ambient, bath and stack temp,
Heater Utilization – **New Equip Performance Validation**, in this case heater was only firing 31% duty at < 1/3 design firing rate. Only 10% design utilization, not ideal for a new heater!

Opportunity to save capital building heaters smarter, smaller!
### Summary Sheet of Expected Savings

<table>
<thead>
<tr>
<th>UPGRADE RECOMMENDATIONS</th>
<th>Urgency of Upgrades: 1 = high, 2 = medium, 3 = low</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Add PLC/CCP control</td>
<td></td>
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<tr>
<td>2. Add modulating control</td>
<td></td>
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<tr>
<td>3. Improve burner settings</td>
<td></td>
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<tr>
<td>4. Change pressure regulation</td>
<td></td>
</tr>
<tr>
<td>5. Modify instrument gas system</td>
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<tr>
<td>6. Replace burner housing</td>
<td></td>
</tr>
<tr>
<td>7. Install flue pipe</td>
<td></td>
</tr>
<tr>
<td>8. Install stack</td>
<td></td>
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<tr>
<td>9. Add stack support</td>
<td></td>
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<tr>
<td>10. Add steam thermometer</td>
<td></td>
</tr>
<tr>
<td>11. Replace flame tube</td>
<td></td>
</tr>
<tr>
<td>12. Changes in design (not to be listed)</td>
<td></td>
</tr>
<tr>
<td>13. Other major modification</td>
<td></td>
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</tbody>
</table>

### ESTIMATE OF SAVINGS

<table>
<thead>
<tr>
<th>Estimated Total Fuel Flow</th>
<th>Expected Fuel Flow Correction</th>
<th>To compensate for other demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,500 MMBTU/hr</td>
<td>10,000 MMBTU/hr</td>
<td>100 MMBTU/hr</td>
</tr>
<tr>
<td>5,250 MMBTU/hr</td>
<td>5,000 MMBTU/hr</td>
<td>0 MMBTU/hr</td>
</tr>
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### Annual Fuel Consumption

<table>
<thead>
<tr>
<th>Estimated Annual Fuel Consumption</th>
<th>12,600 MMBTU/hr</th>
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<tr>
<td>12,600 MMBTU/hr</td>
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### Effective Efficiency

<table>
<thead>
<tr>
<th>Effective Efficiency</th>
<th>52.16%</th>
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<tbody>
<tr>
<td>Annualized Efficiency</td>
<td>52.16%</td>
</tr>
<tr>
<td>Improvement in efficiency</td>
<td>1.12%</td>
</tr>
</tbody>
</table>

### Annual Fuel Savings Due to Efficiency Improvement

<table>
<thead>
<tr>
<th>Annual Fuel Savings Due to Efficiency Improvement</th>
<th>12,600 MMBTU/hr</th>
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</thead>
<tbody>
<tr>
<td>12,600 MMBTU/hr</td>
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### Annual Fuel Savings Due to Elimination of Fuel Pressures below 5.0T

<table>
<thead>
<tr>
<th>Annual Fuel Savings Due to Elimination of Fuel Pressures below 5.0T</th>
<th>1,755 MMBTU/hr</th>
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<td>1,755 MMBTU/hr</td>
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### Total Annual Fuel Savings

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<th>Total Annual Fuel Savings</th>
<th>1,755 MMBTU/hr</th>
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<td>1,755 MMBTU/hr</td>
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### Annual CO2 Emission Reduction

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<tr>
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<th>1,755 MMBTU/hr</th>
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<tr>
<td>1,755 MMBTU/hr</td>
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</table>
The means to achieve improved efficiency is as simple as:

• **training** – theory, operations, combustion testing with analyzer, CMMS (EMPAC)
• manage **excess air** in combustion
• manage the burner **duty cycle**
• strive for 82% **combustion efficiency** (depends on service, i.e. bath approach temp)
• provide adequate **insulation** to reduce energy demand (reduction is a 100% improvement)
• steward regular **combustion analysis and inspection** of heaters spring and fall, focusing on duty cycles, CO in combustion, excess air and stack temperature (fire-tube exit temp)
• **integrate** burner duty with **process demand** where possible
• **design** new equipment to address the items above (burners and fire-tubes)
• maintain **CMMS records** of fired equipment
• **DESIGN YOUR HEATER TO MEET THE SERVICE – DUTY, FIRING MODE, ENGAGE (OME), PRODUCTION AND PROJECT GROUPS!**