Indirect fired, water bath heaters have been used in the oil and natural gas industry for decades. Initial designs were developed to support disposable, localized support at drill sites. As the convenience of local heat sources grew, their use became more widespread and used for dew point applications at local distribution system gate stations. Though convenient, the early design cared little about efficiency and emissions. Today's natural gas systems operate in an environment where more focus is placed on combustion emissions and operating efficiency.

Today we will review the importance of design points and design considerations. The emphasis will be on how these can improve combustion efficiency and emissions. The highlighted topics we will review include:

- Combustion
    - Primary Air Impact
    - Secondary Air Impact
- Combustion System design
    - Energy Transferred
    - Bath Media
    - Combustion System Losses
    - Burner Tuning

Combustion:

Natural gas combustion is influenced by fuel / air mixing, natural gas quality, and control of air flow through the combustion system. The key is a design that will ensure complete combustion under all operating conditions.

Fuel Gas and Dew Point heaters typically use natural draft combustion systems, with atmospheric, eductive air supply burners. Repeatable combustion performance of these burners hinges on when air is introduced into the combustion process, whether primary or secondary air.

Primary Air Impact

Primary air in the combustion process is the air supplied and mixed with the fuel prior to ignition and supports burner flame stability. Secondary air is free air that is available to the combustion process after the main flame is lit and aids in complete combustion of all fuel gas introduced in the combustion process.

Primary air is introduced through the burner's mixing chamber and is driven by the fuel gas supply pressure and the burner's venturi design. The burner assembly's mixer and venturi alignment and machining quality will impact the consistency of the primary air pulled into the fuel/air mixture. If the mixer's jet is misaligned with the throat of the venturi, the venturi interior machine quality is rough or the burner main nozzle is overly restrictive, the consistency of the primary air pulled into the burner's mixer will vary. This will create unstable burner performance and poor combustion emissions.

Fuel gas supply pressure to the burner's mixer creates a vacuum developed at the throat of the burner's venturi. The more stable this fuel gas supply pressure the more consistent the vacuum in the burner mixer. The amount of fuel supplied to the burner is relative to the required burner energy input, i.e., the gross energy input into the combustion system. As fuel gas supply pressure increases, the fuel flow to the burner and the amount of primary air will increase. To fine tune the primary air supply to the burner, the burner's primary air shutter can be adjusted to provide the best burner stability.

Secondary Air Impact

The secondary air supply available is relative to the combustion chamber heat density and remainder of the combustion system design. As noted above, any incomplete combustion not supported by the primary air supply needs to be consumed through secondary air supply from the combustion chamber. If the chamber's heat density is too high or the chamber too restrictive for adequate secondary air flow, complete combustion will not occur resulting in high combustion emissions, higher stack temperatures, and reduced combustion efficiency.

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Combustion System Design:

The combustion system design is influenced by the energy being transferred, the bath media, and combustion system losses.

Energy Transferred

The energy transferred is also known as the heat transfer duty for the heater. This drives the design of the combustion chamber diameter, and length. This chamber design will impact the performance of the burner, the combustion emissions, the combustion efficiency, and the size of the indirect heater.

In the previous section we discussed the combustion chamber heat density. This is the measure of the gross burner input / cross-sectional area of the inside of the fire tube. This design parameter is what sets the fire tube diameter for the combustion chamber. A typical fire tube internal design cross section heat density should not exceed 12,500Btu/sqin. This is a maximum design basis and limits combustion chamber efficiency options, which results in higher main flame temperatures, higher NOx production, and just enough secondary air supply to support complete combustion. As a result, main flame lengths become longer, stack temperatures will increase and the combustion efficiencies will be reduced.

Lower combustion chamber heat densities will improve secondary air flow around the main flame, shortening the main flame, and utilizing more of the combustion chamber for combustion flue gas temperature absorption. This will reduce the stack temperatures and improve combustion efficiency.

Bath Media

The fire tube diameter, and the length of the fire tube determines the amount of external surface area available to transfer the burner's main flame and combustion flue gas temperatures to the bath media. The fire tube flux rate is defined as the net energy transferred / fire tube external surface area, Btu/sqft. The design maximum flux rate varies depending on the bath media and its ability to absorb the energy being released by the fire tube. Below is a table of maximum recommended fire tube flux rates per bath media typically used for natural circulating bath heaters.

Bath Media	Flux rate (Btu/sqft.)
100% Water	12,000
50% Water / 50% Ethylene Glycol	10,500
50% Water / 50% Propylene Glycol	9,500

Table 1: Maximum recommended fire tube flux rates.

Note: The bath media selected is typically dictated by customer preference and environmental impact.

Corrosion inhibitor and pH balancing additives are required for each of these bath media to avoid heater shell, process coil, and fire tube corrosion. Glycol is added to the heater bath media to increase the boiling point and reduce the freezing point of the bath. If the fire tube flux rate is allowed to exceed the values listed above, the additives intended to maintain bath stability will degrade. In the case of the glycol medias, the glycol will be scorched and no longer effective. The result will be a highly acidic, highly corrosive bath media, emphasizing the need to ensure bath media. This leads to an emphasis on the importance of sampling and testing bath media concentrations annually as part of the heater preventative maintenance plan.

Designing a fire tube with a flux rate near these maximum values, though safe for the bath media, does not guarantee good combustion efficiency. This is because the higher flux rate will result in higher stack temperatures. As with any heat transfer application, a balance between effective heat transfer and combustion efficiency is required.

A typical maximum design defined by many LDC requests that the fire tube flux rate not exceed 8,000Btu/sqft. This helps in two ways:

1. Increases the longevity of the bath media due to lower flux rates.
2. Reduces the stack temperatures, improving combustion efficiency.

With the fire tube design that considers both the fire tube heat density and flux rate the fire tube will support good heat transfer and complete combustion if the remainder of the combustion system supports the air flow necessary for complete combustion.

Combustion System Losses

From the flame arrestor-to-the fire tube-to-the stack design, are all impactful to the combustion chamber air flow. Of these three, the stack design is essential to providing the appropriate amount of air needed for combustion.

The stack design for natural draft combustion systems takes advantage of a draft effect caused by the flue gas rising in the stack. The actual draft effect is created by the relative difference in density between the flue gas and the ambient air temperature along with the difference in elevation between stack discharge and the combustion chamber air supply.

Stack Draft must efficiently overcome the losses in the combustion system to effectively sustain complete combustion through varying ambient conditions. The volume of fresh air drawn into the combustion chamber is relative to the cross-sectional area of the stack riser. The larger the stack riser diameter, the more stack volume is displaced, the higher the air flow supply for combustion.

What impacts the stack effect?

1. Changes in differential temperature between the average stack temperature and the ambient temperature; caused by:
    a. Burner Input adjustment / fluctuation
    b. Fluctuation in ambient temperature
2. Additional Resistance in the Combustion Chamber; caused by:
    a. Secondary Air Control position
    b. Stack dampers position
    c. Turbulators

Most of these points will remain constant during heater operation. Ambient temperature fluctuation can result in stack performance changes where the amount of excess air volume will nearly double during cooler ambient operations versus warmer ambient periods.

The best stack design must consider both operating extremes to result in a stack and combustion system that performs at its optimum capability. The following factors must be considered when developing a stack design:

1. Burner Gross heat input
2. Combustion Chamber pressure losses
3. Fire Tube flux rate
4. Ambient Temperature (Minimum and Maximum)
5. Site Elevation (feet Above Sea Level)
6. Typical combustion performance

If the above design points are incorporated in a heater design, tuning the burner for the specific application will be easier and more adaptable to changes in environmental conditions.

Burner Tuning:

Combustion emissions for natural draft combustion systems vary throughout the US. Some areas allow maximum carbon monoxide (CO) emissions to be as high as 200ppm, while others have stricter guidelines, only allowing a maximum emission of 50ppm. Under most cases the natural draft emissions can be maintained at less than 50ppm if adequate air is available. It is important to note that the highest emissions values typically occur at the higher operating temperatures when the draft effect is at its lowest.

Carbon monoxide production is directly tied to excess air during combustion and requires that excess air, or excess Oxygen% (O2%), be available to ensure complete combustion occurs in the combustion chamber. For natural draft combustion 3% excess O2% is typically required to ensure the CO levels remain below 50ppm. This is dependent on fuel gas quality and if additional resistances exist in the combustion chamber, air supply, or stack. Additional resistances require a higher excess O2% to ensure adequate draft is developed during pilot and main burner light-off and transition.

Consideration must be given to the ambient temperature range the burner will be operated on and the ambient temperature the day the burner is being tuned. As we learned during the stack discussion, ambient temperature has a major influence on stack draft. Therefore, during warm ambient temperatures, the stack draft will be at its lowest resulting in lower excess O2% and the highest possibility of CO emissions. The inverse is true with colder ambient temperatures, the draft is higher, creating higher excess O2%.

A technician experienced in burner tuning is recommended for any adjustments to the burner. The main objective when tuning the burner is to create the best combustion efficiency under all conditions. The best way to accomplish this is creating the least amount of excess O2%. However, with a natural draft burner, technicians can only tune the burner to support the best combustion performance for the day the burner is tuned. The technician must account for the ambient temperature range that will occur after leaving the site. For example, a heater installed where the ambient temperature range is expected to be between 0°F and 100°F having a combustion emission of less than 50ppm CO and an excess O2% from 3%O2 to 6.7%O2. On a day with an ambient temperature of 70°F, the technician would need to tune the burner that results in combustion emissions with little to no ppm CO emissions at ~4.2% excess O2.

Once the burner is tuned for the ambient temperature and expected combustion requirements, operating tests are required to ensure startup is without disruption or instability.

Closing thoughts:

Improving combustion performance and efficiency has long been attempted using different solutions. Based on practical application and the design principles shared above, we understand the following:

1. Different burners in the same combustion chamber will produce consistency in combustion efficiency.
   a. While several types of natural draft burners are more effective at entraining primary air prior to combustion, the effects of ambient temperature changes will continue to be an overwhelming influence on stack draft performance resulting in reduced efficiency during colder burner operation.
2. Fixed Secondary air control will produce consistent combustion efficiency.
   a. Fixed secondary air control and stack dampers are good for the ambient conditions on the day they are adjusted but will require seasonal adjustment to maintain reliable performance through varying ambient operating temperatures.
3. Modulation of an atmospheric injection type burner versus 100% ON/OFF control produces better efficiency throughout the operating range.
   a. Though modulation provides variable heat (fuel gas) input to the combustion chamber, the burner performs best at the 100% design point of the burner required capacity. Additionally, reduced fuel gas flow operation will cause the stack and combustion system to overdraft losing much of the heat energy up the stack.

A heater's combustion system design must ensure the combustion performance is sustainable through all operating conditions. This design is not reliant on a single element, but all the parts designed in conjunction with each other to support complete combustion, good emissions, and the best combustion efficiency available.