The KN-10 a “White Paper”

By Ken Cohen

I had a number of goals in mind when I designed the KN-10. One was to design a product that reflected modern requirements such as high efficiency, modulation, small footprint, etc. Another was to accomplish this in a manner that reduced the common problems associated with installation and the variability of the environment to which a boiler is subject over its lifetime.

Gas Pressure

It is not uncommon in many parts of the country to have gas pressure that varies considerably over the year. In some areas, pressures less then 3" H_2O can occur. *The KN-10 can tolerate variations of pressure to the gas valve from 2" H_2O to 14" H_2O without any effect on combustion quality (CO_2) at full boiler input.* Actually, the boiler will operate, albeit with decreasing but still acceptable CO_2, with as little as 1" H_2O pressure. (The low gas pressure switch is factory set to ~ 1.8" H_2O, so would need readjustment if the boiler were to be operated with lower pressures). We worked closely with the gas valve manufacturer to supply a valve that would accomplish this wide supply pressure range with very low-pressure drop.

Air/ Fuel Coupling TRUE-FLOW

Typical of many boilers, the airflow and gas flow to the burner/s are independent of each other. Since CO_2 is a function of air/fuel ratio, changes in flow of air or fuel from any cause will cause shifts in CO_2. Excessive flue or air inlet length, flue or air inlet blockage, or pressure variations due to wind or changes in boiler room pressure can affect the airflow while fluctuations in gas pressure regulation can affect the gas flow. These changes will cause undesirable effects such as reduced efficiency, bad emissions, and nuisance failures. Accumulation of these affects can shorten the effective life of a boiler. While calibration during boiler start up can minimize air/fuel errors, they cannot compensate for the random changes that occur due to weather, gas availability or other unpredictable changes that occur during the year. In all boilers, the air and gas flows are represented by a flow equation of the form:

[1] $q = CA\sqrt{\Delta P / \rho}$

$Where:$

$q = flow$

$C = constant$

$A = flow\ area$

$\Delta P = pressure\ drop$

$\rho = density$

The air/ fuel ratio is: [2] $q(air)/q(gas) = A(air)/\ A(gas) \times \sqrt{\Delta P(air)/\Delta P(gas)} \times \sqrt{\rho(gas)/\ \rho(air)}$

This ratio (~10:1 for natural gas) is established by adjusting the A and ΔP for the air and fuel to achieve a given air/fuel ratio (producing a given CO_2) for a given input.

If a boiler is to modulate (change its input (q)), a means must be provided to minimally ensure the air/fuel ratio stays within a range that does not adversely effect emissions or affect reliability. The CSA approval process, a requirement for all manufacturers, tests for these limits.

However, these limits are very broad and are no insurance, as stated previously, about performance in the field. Dependent on design, modulation can exacerbate these effects.

The KN-10 design uses a gas following method such that a change in airflow causes an instantaneous change in gas flow that maintains the air/fuel ratio precisely. A change in airflow can be purposeful, such as changing the boiler input, or a random fluctuation. *In either case, the boiler input will change, not the CO_2.*

In any given installation the density of the gas and air are relatively constant (Temperature differences may affect the ratio. However, this effect is usually minor. The density change of gas and air with altitude are similar. Since the BTU of the gas is linear with density, the boiler automatically de-rates).
Thus: $\sqrt{\rho(gas)/\rho(air)} \cong (K\rho)$

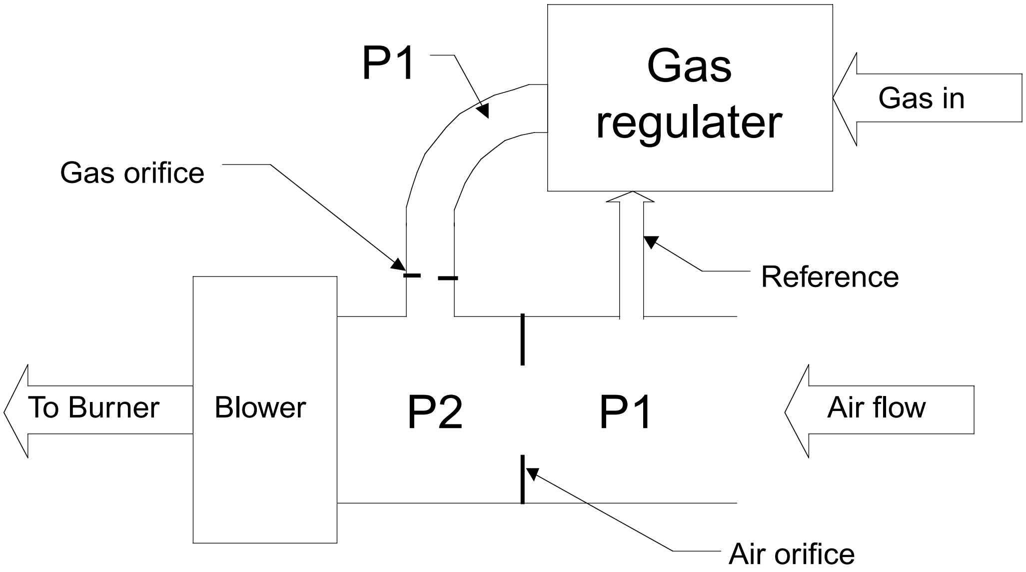
The Area ratio of the air and gas orifices ($A(air)/A(gas)$) is a constant (K) since the air and gas orifices are factory fixed diameters (to produce a given CO_2).

Thus [2] becomes:
[3] $q(air)/q(gas) = (K)\times(K\rho)x\sqrt{\Delta P(air)/\Delta P(gas)}$

To vary the input to the KN-10, we change the airflow via a variable speed blower. From equation [1], this causes the ΔP across the air orifice A to change.

In a simple, but elegant way, we make $\Delta P(gas) = \Delta P(air)$ under all conditions.

Equation [3] thus becomes:
[4] $q(air)/q(gas) = (K)\times(K\rho)$ The air/fuel ratio is a constant!



Referring to the sketch above, the Gas regulator is a precision device that detects the pressure, P1 that exists at the air inlet orifice via a reference connection and creates the same pressure ahead of the gas orifice. The pressure P2 is the same for both orifices. Thus: $\Delta P(gas) = \Delta P(air)$

As you can see, changing P2 by varying blower speed or blocking the flue, or changing P1 by blocking the air inlet, will cause a change in flow thru the boiler, thus changing its input. However, since $\Delta P(gas) = \Delta P(air)$, and referring to equation [4], the air fuel ratio remains a constant. Thus, the CO_2 does not change. Due to the precision of the gas regulator, the CO_2 will remain constant for flow blockage exceeding the 3:1 turn down of the boiler. This is true for blockage in either direction,

The symmetric air fuel coupling of the KN-10 design eliminates a number of failure modes while maintaining high combustion efficiency over time. The importance of this feature cannot be overstated. The boiler automatically adapts itself to its environment. We have given this system the trade name **TRUE-FLOW** because it adapts to all conditions.

Ignition System

By far, the most common failures in a boiler are related to the ignition system. It's a difficult environment. Heat, radiation and moisture contribute to degradation of components. We paid a great deal of attention to the pilot and ignition components to minimize this failure mode.

The burner on the KN-10 is a flat rectangular shape (for even heat distribution). The pilot, actually, a "mini burner", (~8000 BTU/HR) is created by isolating a small portion of the entire burner. This is accomplished with a tubular structure and gas injector located on the back of the burner. A spark and ground rod located immediately below it lights the pilot. A significant advantage of this technique is that the pilot is part of the main burner as opposed to a separate device. Thus, the potential for delayed ignition is essentially eliminated.

The compact design of the KN-10 results in a very high energy density in the combustion chamber. To ensure long igniter life, materials compatible with this environment were chosen. The insulators are made from Alumina, a material that can operate at very high temperatures. The igniter wires are made from the well-proven high temperature material, Kanthal™. The wire is heavy gauge extending a minimum distance from the insulator to prevent thermal warping.

To minimize components in the hot zone, a UV detector is used to detect the pilot and main flame. To prevent condensation from forming in the detector tube and cool the UV detector, cooling air is injected into the detector tube. This air is supplied from a small air pump. The performance of the air injector system is monitored with a pressure switch.The igniters and UV detector tube are contained in a single component, ensuring alignment and simplifying replacement.

The UV detector "looks" directly at the pilot flame. To ensure that the detector only responds to pilot flame and not spark, a type of ignition transformer was chosen that sparks in opposite phase to the phase when the detector is active.

The ignition transformer is a high-energy component, capable of sparking over wide electrode gaps. This ensures pilot ignition as the electrode wires erode over time.

Following proof of pilot, the main gas valve is opened and the pilot and spark are shut off. The fuel mixture is introduced across the burner, including the pilot area. What was the pilot area is now included in the entire burner, leaving no "cold spot" to raise stress.

As described, careful attention was paid to the development of the ignition system in recognition of its importance to reliability.

Condensing

The goal is to design a product that can survive the ravages of acidic condensate in a way that strikes a balance between life and first cost.

There have been four approaches used in designing a boiler to achieve this goal.

1. Make the heat exchanger entirely out of a material that resists the effects of the corrosive condensate.
2. Make the portion of the heat exchanger that is subject to condensation out of corrosion resistant material.
3. Coat the heat exchanger with a material that can withstand both the temperature and corrosive environment.
4. Make the heat exchanger out of a material that does corrode, but is designed to provide long life in a condensing environment.

Method 1 (exchanger entirely out of corrosion resistant material) ensures a long life for the heat exchanger, but is the most costly approach. The high cost cannot usually be justified in applications where condensing conditions are not continuous. Assuming heat exchanger life is not an issue, the life and reliability of everything else in the boiler design need be considered.

Method 2 ("mixed" exchanger design) has two significant design limitations.

1. Joining and sealing fundamentally different materials can be problematic.
2. It is difficult to ensure that condensing will not occur on that portion of the heat exchanger not designed for condensing service. The application environment is not always predictable.

Method 3 (coatings) has been historically difficult to implement. While organic and inorganic materials exist, toxicity, adhesion, and life have been barriers to wide scale adoption of this method.

Method 4 (materials that corrode) has the potential for the lowest cost, but requires careful design if acceptable life is to be achieved. It is the method I choose for the KN-10.For a boiler made from a material that exhibits corrosion, to have reasonable life, there are two prime considerations.

1. **Prevention of acidic concentration.**

   Condensate should not re-evaporate as fresh liquid is fed to the same area. This would cause the acid to concentrate and thus corrode that area at a much higher rate than would be expected from "fresh" condensate. An example of this would be condensation forming on the surface of a conventional boiler with the burner on the bottom. The condensate would move toward the burner due to gravity and at some point would evaporate. This pattern would lead to acid concentration. For the same reasons, pooling should be prevented. Formed condensate should be immediately removed to prevent evaporation.

   To prevent acidic concentration, the KN-10 boiler is down fired and counter flow. The burner, located at the top of the heat exchanger, fires downward. The return or inlet water enters the bottom of the exchanger and exits at the top. The hot combustion gases are cooled as they move toward the bottom of the exchanger and out the bottom located flue while the inlet water increases in temperature as it moves up the heat exchanger toward the outlet. Thus, condensate that forms on the exchanger surfaces moves downward toward cooler metal surfaces and lower gas temperatures preventing re-evaporation. The boiler, being a compact design, generates relatively high gas velocities across the heat exchanger. Thus, liquid condensate is "blown" off the heat exchanger pins due to the high gas velocities. The resultant thinning of the liquid surface also aids in reducing acid concentration.

   The heat exchanger was carefully designed to prevent any "pockets" or other shapes that could collect or pool the condensate. The condensate forms a "rain" which falls on a collection surface that is tapered toward a condensate drain at the center of the boiler. All the condensate is collected on this surface. Thus, it is coated with a material that can resist the corrosive and thermal environment existing at the boiler outlet. The condensate drain and "U" trap are made of Stainless steel and thermoplastic materials.

2. **Sufficient material for a reasonable life expectancy**

   It is important that the corrosion process be distributed across the heat exchanger surface. This will ensure that metal loss occurs evenly, resulting in the smallest reduction in thickness for a given weight of material lost. For this to occur, the energy distribution across the heat exchanger must be the same at any given height. The KN-10 is designed to ensure that this condition is met.

   The burner and heat exchanger design are such that the combustion gases are evenly distributed across the entire heat exchanger surface. The water distribution within the castings is accomplished in such manner that the temperatures at any position are the same across all iron sections. (The technique to accomplish this is the subject of a patent application).

   The highly balanced energy distribution coupled with the relatively short castings minimizes intersection stress. These design features make the KN-10 highly immune to thermal shock. Thus, the inlet water can be any temperature, as long as it's liquid.

Examination of castings subject to condensing conditions in our laboratory confirmed that condensing occurs across the entire exchanger surface. A computer model of the boiler was developed. The model was compared to actual performance data and found to be sufficiently predictive to justify its use. From this model, the amount of condensate and involved heat exchanger surface for any boiler condensing conditions could be established.

We based the useful life of the boiler on the criteria that the ASME safety factor used to establish the heat exchanger operating pressure could be reduced from ~ 6 to 3 (1/2 its value). The initial iron thickness is 1/4 ". Thus, the amount of material that could be removed due to condensate corrosion was determined. Heat transfer considerations show that reductions in the exchanger wall thickness do not substantially affect the rate of corrosion.

We submitted condensate samples to an independent laboratory to determine the quantity of iron in the condensate. Thus, we can determine the amount of exchanger thickness reduction from the iron lost per pound of condensate produced. The data suggests that heat exchanger life for worst case condensing conditions is:

- 32 years continuous operation (24 x7)
- 163 years at 40% load, 6 months operation

The analysis was done in a very conservative manner. Even if the analysis is flawed, there is an expectation of long heat exchanger life.