guest column

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CATCHING UP TO *Better boilers*

Does the design guideline of '5 sq ft/bhp' truly apply to boiler technology of today?

Over the past few decades, forced-draft boiler design has undergone many advances in technology. Improvements have been made in firetube design, going from the conventional two-pass type of arrangement to boilers such as the three-pass wetback designs.

Similarly, in the cast iron market, section design has been transformed both in extended surface configurations, as well as in materials engineering.

Likewise with steel bent watertube boiler design, changes have been made, taking the original design from a loose gas side flow pattern boiler to one which has a forced, five-pass gas side flow pattern. To varying extents, all of these technologically advanced products have seen years of field application to support research and tests performed during their developmental stages.

With these advances come improved heat transfer characteristics of the boiler, increased efficiencies, and reliable operation while not compromising equipment life or material integrity. And, while design engineers have, for the most part, kept pace with these advances in their engineering specifications, there still exists certain "minimum design standards" that have been in place since the technology of the 1950s. The most prevalent of these is the requirement that a boiler be designed with "a minimum of 5 sq ft of heat transfer surface area per boiler horsepower." When studying this requirement, the question begs to be asked: why?

> A boiler with five passes on the gas side will have a higher overall heat transfer coefficient than its predecessor, and thus will not require the same amount of surface area to achieve the same rate of heat transfer.

$$Q = U \times A \times \Delta Tm$$

In this equation:

- Q = the rate of heat transfer
- U = the overall heat transfer coefficent
- A = the total heat transfer surface area
- ΔTm = the logarithmic temperature differential

FIGURE 1. Equation used for heat exchanger design from first principles.

MINIMUMS TO BE MET

The most common answer to this question is that a boiler must be designed with a certain minimum amount of surface area so as to protect the materials of its construction against damage due to "overworking" of the boiler.

What is really meant by overworking is that, if a boiler, or any heat exchanger, is designed with a very low surface area for a given amount of heat input, it will transfer as much heat as its design allows, but due to the low amount of surface, the material wall temperatures on the hot side will be elevated to a point that approaches the critical temperature of the material being used.

This, in turn, will result in material degradation and fatigue, causing premature failure of the material and subsequently failure of the boiler. Another consideration that plays into allowing a certain minimum amount of surface area relates to the fact that all heat exchangers, boilers included, will foul. This fouling creates an additional boundary layer to heat transfer, which in turn can elevate material wall temperatures.

While these are valid considerations, it does not mean that certain boiler, or heat exchanger, designs are unable to safely transfer a given amount of heat with lower amounts of heat transfer surface area. The amount of surface area required for a given heat exchanger depends primarily on the actual design of the heat exchanger itself. In addition, heat exchanger design may be related directly and mathematically by the overall heat transfer coefficient (U) of the particular unit (Figure 1).

To use the equation in Figure 1, the value for "U" must first be determined. To calculate this value, many variables and factors are considered, but suffice it to say that this coefficient represents the so-called "heart" of the heat exchanger design.

A high value for "U" represents a heat exchanger with excellent heat transfer characteristics, such as high velocities, turbulence, good contact, low fouling factors, and extended residence time. Certain design strategies may be employed to increase the value of this coefficient, such as designing the heat exchanger with a multiple pass arrangement for the fluids, either on one or on both sides (hot and/or cold side), the incorporation of baffles or the use of extended surfaces.

LESS AS MORE

By using these heat exchanger design methods, a unit may be

GIVEN INFORMATION: $Qa = Qb$ and $\Delta Tma = \Delta Tmb$

AND: $Qa = Ua \times Aa \times \Delta Tma$
$Qb = Ub \times Ab \times \Delta Tmb$

THEN: $Ua \times Aa \times DTma = Ub \times Ab \times DTmb$

SINCE: $\Delta Tma = \Delta Tmb$, then it is known that

$Ua \times Aa = Ub \times Ab$ and, since $Ua > Ub$, it is given that

$\underline{Aa < Ab}$

FIGURE 2. Equation comparing two shell-and-tube heat exchangers, one with shell side baffles that transfers the same amount of heat with less surface area

designed with less heat transfer surface area while still transferring the same amount of heat as a unit of a more basic design. Consider the simple example of two single-pass, straight tube, shell-and-tube heat exchangers with water as the fluid on both sides. Both units are identical in design (i.e., tube diameter, shell diameter, nozzle sizes and so forth), with the same materials of construction.

However, the first heat exchanger (HE-a) is designed with shell side baffles while the second unit (HE-b) has no baffles. In this scenario, it is known that "Ua" will be greater than "Ub," simply by using shell side baffles. Given that the heat transfer rates are identical, the flow rates through each unit are the same and that the entering and leaving temperatures are equal, then the equation in Figure 2 may be derived.

This means that the heat exchanger that incorporates the use of shell side baffles may be designed to transfer the same amount of heat as the unit without baffles, but it does so with less heat transfer surface area. This does not mean, however, that the unit with less surface area is being overworked, it is simply an indication that this heat exchanger design has an improved mechanism for transferring the heat from one fluid to the other. In short, material integrity is maintained while the heat transfer characteristics are improved.

SYSTEM DESIGN IMPLICATIONS

This example, while simple in application, may be used analogously to applications involving boilers of differing design. Again to cite the difference in design in steel bent watertube boilers available today vs. the original design from the 1950s, today's design provides for a true, forced, five-pass gas side flow pattern with gas side baffles for increased turbulence and contact, while the original design incorporates a loose gas side flow pattern which allows the products of combustion to exit the boiler through the path of least resistance.

And, while a minimum design standard, which limits the amount of surface area to no less than 5 sq ft/bhp, may be applicable to the 1950 design model, it is quite evident that the boiler with five passes on the gas side will have a higher overall heat transfer coefficient than its predecessor, and thus will not require the same amount of surface area to achieve the same rate of heat transfer.

And furthermore, the five-pass boiler design will be capable of transferring this heat without over-working the materials of which it is constructed. It has simply been designed with an improved heat transfer mechanism.

This same discussion may be related not only to the bent watertube design, but also to the firetube and the cast iron designs. The required heat transfer surface area for any given boiler, or heat exchanger, is primarily a function of the design of that particular boiler.

Without doubt, a new boiler design must be researched, tested, and then operated in field application over a period of time to verify that performance in practice does in fact approximate closely design calculations made during development of the product.

Design calculations must also take into account all variables that may affect equipment integrity and material life. However, once this has been done, which is the case with today's bent watertube, firetube, and cast iron boiler technology, then minimum design standards which have been in place for half a century should be reviewed and amended, thus allowing for the use of improved boiler design and technological advancement. **ES**

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