

ABMA

White Paper

Historical Advancement
of Fire-Side Heating Surface
in Firetube Boilers

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1. Introduction

The purpose of this presentation is to discuss design development, over the past 50 years, of horizontal steel fire-tube boilers, specifically relating to reduction in boiler fire-side heating surface per Boiler Horsepower. It is emphasized that only horizontal steel fire-tube boilers are discussed herein and that parallel logic to the design of other types of boilers should not be drawn.

2. Historical Background

The concept of generating steam has been known since the first century A.D., when Hero, of Alexandria, described a boiler and reaction turbine. Not until the 17th Century, however, was there any recorded practical use of steam. The events of the Industrial Revolution, primarily in England, promoted the rapid development of the steam engine by such inventors as Thomas Newcomen and James Watt.

Watt is credited with being the first inventor to separate the steam engine, and the boiler, into two separate units in the latter part of the 18th Century. In these early times, the primary use of the boiler was to generate steam for steam driven engines.

As steam driven engines replaced the horse, as a means of motive power, it followed that steam driven engines were rated in 'Horsepower'.

Boiler design progressed from what was essentially a kettle to a relatively large-diameter flue pipe submerged in water – thus the first fire-tube boiler.

As power and pressure requirements increased, boilers became larger and the single-flue pipe became a larger number of smaller diameter flue tubes combined with an external, or internal, furnace for the combustion of the fuel. The modern-day 'modified Scotch Marine' boiler, generally comprising horizontal steel furnace combustion chamber(s) and/or fire-tube convective pass(es), in 'dry-back' or 'water-back' configurations, owes its heritage to these early multi-tube boilers and their application in ships constructed on Scotland's River Clyde.

The primary application of the boiler was still motive power; whether for pumping water from mines, driving machinery in mills, propelling steam locomotives or ships. Therefore, boiler ratings were based on the size of the steam engine that they were capable of driving. The quantity of steam required to operate a 1 horsepower steam engine became known as 1 Boiler Horsepower. (Note that the water-tube boiler was not prevalent until after the first water-tube boiler design patent of 1867; thus, the term Boiler Horsepower (Bhp) has been associated with fire-tube boilers from the earliest days of boiler development).

During this period, variations in steam engine efficiency made it difficult to assign a qualified rating (i.e. Pounds per Hour (PPH)) to the amount of steam required to drive a 1 horsepower steam engine. Tests, conducted in 1876, determined approximately 30 pounds of steam per hour was required to produce 1 horsepower of mechanical work. In 1889, the American Society of Mechanical Engineers (ASME) standardized the term "Boiler Horsepower" as being based on a conventional steam engine evaporation rate of 30 pounds of steam per hour (PPH), at 70 PSIG pressure, and a feedwater temperature of 100° F. This definition was subsequently modified to: Boiler Horsepower – the unit of capacity expressed as the equivalent evaporation of 34.5 pounds of water per hour, from and at 212° F (33,475 Btu/hr.).

Also, it was determined that for the steel fire-tube boilers of the day, which utilized brick set bases incorporating large amounts of refractory, and generally coal fired, 10 square feet of fire-side heating surface was necessary for a steam engine to generate 1 mechanical horsepower. As a result it became an industry standard practice to rate fire-tube boilers in Boiler Horsepower, and to base this

rating on fire-side heating surface (1 Bhp per 10 square feet of fire-side heating surface).

Competition between fire-tube boiler manufacturers eventually forced improvements in boiler design and fuel burning equipment. This, together with a broad shift towards liquid and gaseous fuel utilization, resulted in cleaner and more reliable combustion and improved heat transfer within the boiler. Progressive reduction in the fire-side heating surface required, per Boiler Horsepower, was therefore consistent with these advancements. By the 1960's, the 10 square feet of fire-side heating surface per Boiler Horsepower criterion decreased to 5 square feet of fire-side heating surface per Boiler Horsepower - an axiom which is commonly cited today, particularly in the United States.

During the latter part of the 20th Century, many manufacturers of fire-tube boilers designed and marketed boilers with greater input capacity burners with requisite steam nozzle and safety valve(s) characteristics which therefore permitted operation at less than 5 square feet of fire-side heating surface per boiler horsepower with acceptable reliability and efficiency.

It was during this same period that certain jurisdictional mandates were promulgated that required licensed boiler operators for boilers in excess of a certain defined fire-side heating surface criterion. These limitations generally afforded opportunity to employ less than 5 square feet of fire-side heating surface per Bhp. This furthered development of fire-tube boiler designs specifically for particular jurisdictional requirements, again with acceptable reliability and efficiency.

Manufacturers of other boiler types, such as vertical, water-tube and cast iron sectional boilers, have used the Bhp output rating as a means of comparison with fire-tube boilers. They have not, typically, related Bhp output to a certain square feet of fire-side heating surface criterion, opting generally to rate by net output generated by the boiler; steam boilers expressed in measurements of PPH, 34.5 pounds per Boiler Horsepower from and at 212° F, or millions of Btu/Hr (MBH), and hot water boilers expressed in measurements of 33,475 Btu/hr per Boiler Horsepower, or millions of Btu/Hr (MBH).

3. Basic Design Requirements

Criteria which govern the design and manufacture of fire-tube boilers include:

- Compliance with the ASME Boiler and Pressure Vessel Code.
- Compliance with required safety and installation Codes.
- The ability to meet the required efficiency and other performance standards.
- The ability to meet the required level of pollutant emissions.

- Compliance with the requirements of the National Board of Boiler and Pressure Vessel Inspectors through local jurisdictions having authority (JHA).
- The ability to meet the perceived needs of the customer in terms of operational performance, reliability and maintenance costs.
- The ability to produce a competitively priced product.

Fire-tube boiler manufacturers have established over the years that these criteria can be satisfied with varying fire-side heating surface specifications. Thus, the nominal 5 square feet of fire-side heating surface per boiler horsepower axiom is less important as a critical design consideration.

4. Today's Environment

Presently, considerable design emphasis is devoted towards pollutant emission standards compliance, particularly in the area of oxides of nitrogen (NO_x). Several technologies exist which are being utilized depending upon the required level of NO_x emissions reduction. Combustion chamber heat release rates have increasingly become a factor in maintaining stable combustion over normally expected operating input turndown ranges with some of these technologies. This may impact on the distribution of boiler heat transfer surface within the boiler.

Computational fluid dynamic (CFD) modeling techniques are being utilized in some areas to model flame pattern and combustion chamber geometry, in the interest of reducing NO_x emissions, and this, combined with the use of similar design analysis of fire-tube boiler design, has produced a much more refined design environment than existed before the 5 square feet of fire-side heating surface per boiler horsepower axiom was introduced.

Research and development, over the past thirty years, has given fire-tube boiler manufacturers a better understanding of boiler design requirements over a wide range of applications.

In addition to advances in combustion technology, improvements of materials and manufacturing capabilities have provided fire-tube boiler manufacturers with the opportunity to improve efficiency, while reducing overall heat transfer surface area. As an example, internally augmented flue tubes, and other heat transfer extraction and enhancement methods and devices, have become prevalent in the past decade.

The developments indicated above have all contributed to the ability of manufacturers of fire-tube boilers to produce reduced footprint boilers, with subsequent lower heating surface requirements, while maintaining acceptable levels of performance, efficiency and emissions.

5. Considerations for the Future

It is apparent that the powerful analytical tools available today will continue to be applied to improve fire-tube boiler design, as well as that of the fuel burning equipment. This will inevitably result in smaller, higher efficiency fire-tube boilers with lower pollutant emissions.

Combustion technology, with specific regard to NO_x reduction, is rapidly approaching the point of diminishing returns. Should further emission reductions develop, one method of achieving compliance will be a significant increase in boiler efficiency, thus reducing fuel input consumption. Combined with an obvious general tendency by end users, architects and engineers, to minimize the boiler room footprint in building construction, the resultant more compact and higher efficiency boilers, requiring lower heating surface per Boiler Horsepower, will be furthered. Albeit, the resulting improvements will remain predicated upon the particular fire-tube boiler system application requirements, materials and manufacturing limitations.

Manufacturers of fire-tube boilers, recognizing the benefit of enhanced design and materials technology, currently apply these resources to advance product design, performance and manufacturing competitiveness. Individually, and together with the US Department of Energy, programs have been initiated to further development of these, and other technologies, to meet with the ever increasing expectation of fire-tube boiler capabilities.