# ABMA

## White Paper

### Boiler Horsepower:
### History of Definitions in the Firetube Boiler Industry

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# Table of Contents

## 1. Introduction

The purpose of this paper is to discuss developments over the past 50 years in the design of firetube boilers, as they relate to reductions in the boiler heating surface per Boiler Horsepower (Bhp). It is emphasized that only firetube boilers are discussed and that parallels should not automatically be drawn to transfer this logic to the design of other types of boilers which are not the topic of this paper.

## 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. It was not until the $17^{th}$ Century, however, that there is any recorded practical use of steam. At that time the events of the Industrial Revolution, primarily in England, promoted the more rapid development of the steam engine by such inventors as Thomas Newcomen and James Watt.

James 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 $18^{th}$ Century. In these early times the primary use of the boiler was to generate steam for steam engines.

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

Boiler design progressed from what was essentially a kettle to a relatively large-diameter flue pipe submerged in water – the first firetube 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 either an external or an internal furnace for the combustion of the fuel. The modern-day, modified Scotch Marine boiler 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 it was for pumping water out of mines, driving the machinery in mills, propelling steam locomotives or steam ships. It therefore followed that boiler ratings became based on the size of the steam engine that they were capable of driving. The quantity of steam required to operate a one horsepower steam engine became known as one Boiler Horsepower. (Note that the watertube boiler did not become a serious competitor to the firetube boiler until after the first watertube boiler patent of 1867; thus the term Boiler Horsepower has been tied to firetube boilers from the earliest days of boiler development.)

Variations in steam engine efficiency in those early days made it difficult to assign a single number (pounds per hour) to the amount of steam required to drive a one horsepower steam engine. Tests that were conducted in 1876 determined that at that time it took approximately 30 pounds of steam per hour 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 steam rate of 30 pounds of steam per hour (PPH) at 70 psig pressure and a feedwater temperature of 100 degrees 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 degrees F (33,475 Btu/hr.).

Also during this same time period, it was determined that for the steel firetube boilers of the day, which utilized brick set bases with large amounts of refractory and were coal fired, it was necessary to have 10 square feet of heating surface for the attached steam engine to generate one mechanical horsepower. As a result it became an industry practice to rate (firetube) boilers in Boiler Horsepower, and to base this rating on heating surface (1 Bhp per 10 square feet of heating surface).

As time passed, competition between (firetube) boiler manufacturers forced improvements in boiler design and fuel burning equipment; these factors, together with a swing to liquid and gaseous fuels, resulted in cleaner combustion and better heat transfer within the boiler. This resulted in a progressive reduction in the heating surface required per Boiler Horsepower. By the 1960's the 10 square foot per Boiler Horsepower criterion had become 5 square feet per Boiler Horsepower -- a standard which is still widely quoted in the United States today.

During the latter part of the $20^{th}$ Century many manufacturers of firetube boilers marketed these same 5 square feet per Bhp boilers with larger burners, steam nozzles and safety valves which allowed them to be operated at less than 5 square feet of heating surface per boiler horsepower with acceptable reliability and efficiency.

Also during this same time frame certain jurisdictional requirements were being enforced that demanded licensed boiler operators for boilers over a certain number of square feet of heating surface. This resulted in firetube boiler designs developed specifically for certain State or City requirements. Some of these units have been operated for many years with less than 5 square feet of heating surface per Boiler Horsepower with acceptable efficiency and reliability.

Manufacturers of other boiler types such as watertube and cast iron sectional boilers have used the Boiler Horsepower rating as a means of comparison in the size ranges that compete with firetube boilers. They have not typically, however, related the Boiler Horsepower to square feet of heating surface, only to the net output generated by the boiler, with steam boilers expressed in measurements of 34.5 pounds per Boiler Horsepower from and at 212° F, and with hot water boilers expressed in measurements of 33,475 Btu/hr per Boiler Horsepower.

## 3. Basic Design Requirements

Currently the major criteria governing the design and manufacture of firetube boilers are:

- The ability to meet the required level of pollutant emissions.
- The ability to meet the required efficiency and other performance standards.
- Compliance with the ASME Boiler and Pressure Vessel Code.
- Compliance with the requirements of the National Board of Boiler and Pressure Vessel Inspectors through the local jurisdictional authorities.
- Compliance with required safety and installation Codes.
- The ability to produce a competitively-priced product.
- The ability to meet the perceived needs of the customer in terms of operational performance, reliability and maintenance costs.

It has been proven over the years that these criteria can be met with variable amounts of fireside heating surface. Thus, the nominal five square feet of heating surface per boiler horsepower axiom has become less important as a critical design component.

## 4. Today's Environment

The heavy emphasis at the present time is in meeting national and local pollutant emission standards, particularly in the area of oxides of nitrogen (NOx). Several different technologies are being utilized depending upon the required level of NOx reduction. Combustion chamber heat release rates have become a factor in maintaining stable combustion over normally expected operating (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 flames and combustion chamber geometry, in the interest of reducing NOx emissions, and this, combined with the use of computers in other areas of boiler design, has produced a much more refined design environment than existed at the time the 5 square foot per boiler horsepower axiom was introduced.

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

Improvements in the area of materials and manufacturing have also provided firetube boiler manufacturers with the opportunity to improve efficiency, while at the same time reducing overall heat transfer surface area. As an example internally finned flue tubes and other heat transfer enhancing devices have become available in recent years.

Obviously the developments listed above have all contributed to the ability of manufacturers of firetube boilers to produce smaller, (i.e. lower heating surface) boilers while at the same time meeting acceptable levels of 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 boiler design, as well as that of the fuel burning equipment. This will inevitably result in smaller, higher efficiency boilers with lower pollutant emissions.

Combustion technology in terms of NOx reduction is rapidly approaching the point of diminishing returns. Should further emission reductions be required, one method of achieving compliance will be a significant increase in boiler efficiency (i.e. lowering overall fuel consumption). This, combined with the fact that there has always been a tendency to minimize the footprint of the boiler room on the part of architects and engineers, will result in more compact, higher efficiency boilers – lower heating surface per Boiler Horsepower.

Industry in cooperation with the Department of Energy has recognized this, and programs are being initiated along the lines outlined above to meet this goal.