



# Industrial Steam Systems: Opportunities for Energy and Productivity Savings

An Online Continuing Education Course for Engineers

**Course Number: M-6003**

**Credit: 6 Hours / 6 PDH / 6 CPD**

# Industrial Steam Systems: Opportunities for Energy and Productivity Savings

## 1. INTRODUCTION

This course provides technical information on some of the major opportunities available to improve the energy efficiency and productivity of industrial steam systems. The course covers five main areas of investigation: (1) profiling a steam system, (2) identifying steam properties for the steam system, (3) improving boiler operations, (4) improving resource utilization in the steam system, and (5) investigating energy losses in the steam distribution system. The course discusses major areas where steam systems can be improved and outlines calculations that can be performed to quantify steam system improvement opportunities.

---

This course is intended for steam system operational personnel and plant energy managers. Often operations personnel and energy managers are unaware of the opportunities available for energy and productivity savings in their steam systems, or they are unsure of the calculation procedures required to determine the savings opportunities. The purpose of this course is to assist operations personnel and energy managers in identifying significant opportunities to improve their steam systems.

The course does not attempt to guide steam system users in the implementation phase of improvement projects. In some cases, improvements may be simple to make, but others will require the assistance of qualified steam system experts. However, if the guidance of this document is followed, many possible opportunities for improving the steam system should be identified.

These guidelines are organized to assist steam users to take the following steps in identifying opportunities to improve their steam systems:

- First, the analysis basis must be determined; guidelines are provided for profiling individual steam systems. Methods are presented to estimate the fuel costs and operating characteristics of the facility and to identify improvements in energy efficiency that translate to operational cost savings.
- Second, the steam properties of the facility are identified to allow calculations to be performed in latter sections of the analysis.
- Third, the boiler operation is investigated. This analysis centers on evaluating the fuel-to-steam conversion efficiency of the boiler.
- The fourth analysis area is concerned with resource utilization throughout the facility. The main concerns in this area are to use the most appropriate fuel, to maintain the proper steam balance throughout the system, and to integrate process energy.

## 2. PROFILING THE STEAM SYSTEM

### 2.1 OVERVIEW AND GENERAL PRINCIPLES

In general, operational changes are based on economic factors. Thus, the economics of the steam system should be determined. The main factors in this evaluation are associated with the fuel supplied to the boilers. The total cost of fuel supplied to the boilers will provide an order of magnitude of the economic potential associated with a proposed operational change. The unit cost of fuel is also important in the evaluation of system performance and operational changes. From the standpoint of managing the steam system, more measurements will allow more informed management. The energy management principle “You cannot manage what you do not measure” holds true.

### 2.2 UTILITY COSTS

The total cost of fuel supplied to the facility should be determined. Typically, this value is known from fuel invoices. This is a very important value from an operations and analysis standpoint. As boiler and steam system efficiency improves, the amount of fuel purchased decreases for a given steam production. This becomes the justification for any economic investment. Caution should be exercised to include only fuel supplied to the boilers. Many facilities have only one fuel metering device, and fuel may be used in process equipment or in heating and air conditioning equipment. If the amount of fuel supplied to the boilers is not metered, the fuel consumption can be estimated. The methods used in the estimation process will be discussed in Sect. 4.4, “Boiler Fuel Flow Estimate.”

The time that the boilers operate also needs to be determined to allow savings and cost evaluations to be based on the appropriate operating hours. Many facilities operate 24 h/d and 365 d/year. The operating hours,  $T$ , for this facility would be calculated as follows.

$$T = 24 \text{ h/d} (365 \text{ d/year}) = 8760 \text{ h/year} \quad . \quad (1)$$

A determination of fuel cost is essential for the efficient management of a steam system. Gaseous fuels are typically sold in units of 1000 standard cubic feet (i.e.,  $10^3$  std ft<sup>3</sup>,  $10^3$  ft<sup>3</sup>, 1000 scf, and Mcf). Gaseous fuel pricing is also provided based on 100 standard cubic feet (Ccf). Fuel oils are typically sold in terms of gallons, while coal is sold primarily based on tons. A steam system survey investigates the use of energy throughout the steam system. Therefore, it is beneficial to determine the fuel cost on an energy basis. To accomplish this, some properties of the fuel must be known. The main property required is the fuel energy content that is termed the “fuel heating value.” In the United States, the higher heating value (HHV) is commonly used; in Europe and many other parts of the world, the lower heating value is used. The difference in the values is in the fuel analysis and, in particular, the state of the water involved in the combustion process. This course will use the fuel HHV for all calculations. Fuel heating value and the fuel sales price are used to determine the fuel unit cost. Three examples of this calculation are provided below.

The first example is for natural gas with a purchase price of \$7.00/10<sup>3</sup> ft<sup>3</sup>. The example natural gas has an HHV of 987,124 Btu/10<sup>3</sup> ft<sup>3</sup> (23,000 Btu/lb<sub>m</sub>). This results in a fuel cost,  $\kappa_{\text{natural gas}}$ , of \$7.09/10<sup>6</sup> Btu.

$$\kappa_{\text{natural gas}} = \$7.00/10^3 \text{ ft}^3 \left( \frac{10^3 \text{ ft}^3}{987,124 \text{ Btu}} \right) \frac{1,000,000 \text{ Btu}}{10^6 \text{ Btu}} = \$7.09/10^6 \text{ Btu} \quad . \quad (2)$$

The next example determines the fuel cost,  $\kappa_{\text{No. 2}}$ , for No. 2 fuel oil with a purchase price of \$1.00/gal. The example No. 2 fuel oil has an HHV of 139,874 Btu/gal.

$$\kappa_{\text{No. 2}} = \$1.00/\text{gal} \left( \frac{1 \text{ gal}}{139,874 \text{ Btu}} \right) \frac{1,000,000 \text{ Btu}}{10^6 \text{ Btu}} = \$7.15/10^6 \text{ Btu} . \quad (3)$$

The final example is for coal that is purchased with a price of \$50.00/ton and an HHV of 13,500 Btu/lb<sub>m</sub>.

$$\kappa_{\text{coal}} = \$50.00/\text{ton} \left( \frac{1 \text{ ton}}{2,000 \text{ lb}_m} \right) \frac{1 \text{ lb}_m}{13,500 \text{ Btu}} \left( \frac{1,000,000 \text{ Btu}}{10^6 \text{ Btu}} \right) = \$1.85/10^6 \text{ Btu} . \quad (4)$$

The energy-based cost of coal,  $\kappa_{\text{coal}}$ , is typically much lower than the common liquid and gaseous fuels. These examples and several other common fuels are summarized in the Table 1.

**Table 1. Typical fuel properties**

Fuel	Typical sales unit	Example price (\$/sales unit)	Energy content (Btu/sales unit)	Energy content (Btu/lb <sub>m</sub> )	Unit price (\$/10 <sup>6</sup> Btu)	Fuel “density” (lb <sub>m</sub> /sales unit)
Natural gas	10 <sup>3</sup> standard ft <sup>3</sup>	7.00	987,124	23,000	7.09	42.92
No. 1 fuel oil	Gallon	1.18	134,510	19,810	8.77	6.79
No. 2 fuel oil	Gallon	1.00	139,874	19,400	7.15	7.21
No. 4 fuel oil	Gallon	0.76	146,731	18,860	5.18	7.78
No. 5 fuel oil	Gallon	0.60	146,891	18,760	4.08	7.83
No. 6 fuel oil	Gallon	0.51	145,485	18,300	3.51	7.95
Coal	Ton	50.00	27,000,000	13,500	1.85	2,000.00

The information contained in Table 1 is not representative of fuel prices and properties universally. The table demonstrates typical data for the purpose of providing examples. Each fuel has a wide range of properties and costs. These properties are provided as examples, and each facility should use data for that particular site.

Most fuels maintain consistent properties and are supplied based on certain specifications. In general, coal can have the widest range in properties because most other fuels are produced with certain tolerances. Coal storage and handling typically provides the opportunity for the fuel to contact water. Generally, coal is specified on a “dry” basis. However, the coal is not supplied to the burner on a dry basis. Therefore, to determine the actual performance of the boiler, periodic “as-fired” coal samples should be analyzed to determine the qualities of the coal supplied to the boiler. Periodic “as-received” coal samples should also be analyzed to determine what is actually being purchased. In these analyses, care must be given to the surface or extrinsic water. The surface water is part of the commodity purchased and supplied to the boiler. It does affect the boiler performance; therefore, surface water should not be lost in the analysis. Coal analysis typically grinds the coal prior to analysis. This grinding evaporates the surface water, which can provide test results with erroneously low moisture values.

Care should also be exercised in understanding the fuel pricing structure. When determining the economic benefit of an efficiency improvement, only the incremental cost of fuel is affected. For example, the first 500 10<sup>3</sup> ft<sup>3</sup> of natural gas purchased each month may carry a price of \$7.50/10<sup>3</sup> ft<sup>3</sup>; the remaining natural gas purchased may carry a lower price of \$6.75/10<sup>3</sup> ft<sup>3</sup>. If the

facility always consumes much more than  $500 \times 10^3 \text{ ft}^3$  of natural gas each month, an increase in boiler efficiency will impact the system according to a fuel cost of  $\$6.75/10^3 \text{ ft}^3$ .

Electricity is a significant utility supply to most industrial facilities. A good point of comparison is between the unit cost of fuel and electricity. Electrical rate structures are generally complicated, but the main components are usually electrical demand and energy. Electrical energy charges are determined from the total amount of energy consumed at the site—the total kilowatt-hour (kWh) value of energy consumed. Electrical demand charge is based on the maximum rate of electrical energy consumption for the site during the billing period. Electrical energy charges are provided on a dollar per kilowatt-hour ( $\$/\text{kWh}$ ) basis, while demand charges are based on a monthly dollar-per-kilowatt basis. These two factors combine to determine the total electrical cost at the facility. To compare electrical costs to fuel costs, they must be examined on an equal energy basis. Electrical costs can be converted to a British-thermal-unit (Btu) basis fairly simply. The following conversion can be used to determine the electrical energy unit cost. An electrical cost of  $\$0.040/\text{kWh}$  for energy ( $\kappa_{\text{electrical energy}}$ ) and  $\$14.60/\text{kW}$  each month for demand ( $\kappa_{\text{electrical demand}}$ ) will be used in the example.

$$\kappa_{\text{electrical energy}} = \$0.04/\text{kWh} \left( \frac{1 \text{ kWh}}{3,413 \text{ Btu}} \right) \frac{1,000,000 \text{ Btu}}{10^6 \text{ Btu}} = \$11.72/10^6 \text{ Btu} . \quad (5)$$

$$\kappa_{\text{electrical demand}} = \$14.60/\text{kW month} \left( \frac{1 \text{ kWh}}{3,413 \text{ Btu}} \right) \frac{1,000,000 \text{ Btu}}{10^6 \text{ Btu}} \left( \frac{1 \text{ month}}{730 \text{ h}} \right) = \$5.86/10^6 \text{ Btu} . \quad (6)$$

These two charges would be added for a combined demand and energy charge of  $\$17.58/10^6 \text{ Btu}$  ( $\$0.060/\text{kWh}$ ). This can be compared to the fuel cost to determine the most appropriate energy source for various applications. This would not be the final analysis because many factors must be integrated into the analysis (such as boiler efficiency and steam system losses), but this would provide an indication of the relative cost of energy sources.

### 2.3 BENCHMARKS

Benchmarking is the practice of determining key operating parameters of a system to provide points of comparison. Benchmarking is a valuable tool to track system performance, to identify problems, and to determine the effectiveness of system alterations. Some practical benchmarks are boiler efficiency, steam unit cost, and finished product energy requirement. The variation in steam flow with plant production and with the seasons can also provide valuable input for system improvement analysis.

One universal or common benchmark is annual fuel expenditure. Annual fuel expense is not a classic benchmark because benchmarks are references to a unit of production or consumption. However, annual fuel expense is a key indicator of steam system activities, and it is a common tracking indicator.

Benchmarks can be used to compare a facility with a theoretical system to determine the maximum attainable performance (classic efficiency). Benchmarks are also used to compare the current operation to past operation. This can identify potential failures within the system as well as highlight efficiency and production improvements. Another common use of benchmarks is to compare similar facilities.

A direct example of a benchmark is steam production unit cost. Some facilities are equipped with steam flowmeters, which can be used in conjunction with the total fuel cost to determine the steam cost. As an example, a steam generation facility produces 2,400,000 lb of steam in a 24-h period. During the same period 27,780 gal of No. 2 fuel oil is consumed. The following

calculation demonstrates the method used to calculate the relative steam cost for the facility, the benchmark. The fuel cost is \$1.00/gal, and conversion factors must be introduced into the calculations to maintain appropriate units.

$$\kappa_{\text{steam}} = \frac{\text{fuel consumed}}{\text{steam produced}} (\text{fuel price}) . \tag{7}$$

$$\kappa_{\text{steam}} = \frac{27,780 \text{ gal/d}}{2,400,000 \text{ lb/d}} (\$1.00/\text{gal}) \frac{1,000 \text{ lb}_m}{10^3 \dots} = \$11.56 / \text{lb}_m .$$

The unit cost of steam is the “price” or the cost of steam distributed to the facility. The unit cost must be used internally for the facility, such as heating, possibly sootblowers, etc. The benchmark is a concrete marker that represents the unit cost.

The information in this document. Additional information is provided throughout this document with the major sections. The boiler operating cost. Boiler operation is a major cost throughout this document. As indicated previously, a cost of steam is a major cost of the boiler.

$$\dot{K}_{\text{boiler}} = 1 \tag{8}$$

$$\dot{K}_{\text{boiler}} = 2$$

## 2.4 CALL TO ACTION:

1. Determine the total cost of the facility (per year, \$/month, and \$/season).
2. Calculate the unit cost of steam energy (\$/10<sup>6</sup> Btu).
3. Compare the unit cost of fuel to other available fuel supplies.
4. Determine the unit cost of electricity supplied to the facility (\$/10<sup>6</sup> Btu).
5. Compare the unit cost of fuel to the cost of electricity supplied to the facility.
6. Determine the typical steam production for the facility (lb<sub>m</sub>/h and lb<sub>m</sub>/d).
7. Determine the production cost of steam for the facility (\$/10<sup>3</sup> lb<sub>m</sub>).
8. Determine the amount of steam required to produce a product (lb<sub>m</sub> steam/lb<sub>m</sub> product).