# *Crompton – Gallagher: Boiler Efficiency Calculator (1919)*

JOS Plus

*Stephan Weiss*[1]

From the beginning of industrial revolution up to now, steam is one of the primary sources for mechanical energy. Some issues of JOS ago, I introduced a slide rule for calculations during the design of steam piston engines.[2] I will now go back a step within a steam power plant to the place where the steam comes from, the boiler system, and will describe a really unusual slide rule combination to calculate the efficiency of a steam boiler.

### The Basics of Water and Steam

In order for some readers to understand the kinds of calculations that this slide rule facilitates, I should first explain some basic thermodynamics of water. This is an extensive subject, and I will limit myself to the essentials.

A boiler produces steam at an operating point with predefined high temperature and pressure. The stages that liquid water passes through until becoming steam are commonly demonstrated with help of a Temperature-Entropy-Diagram, called T-S-Diagram, and the distinctive points within (See Figure 1).When steam is extracted from the boiler to drive an engine this flow must be compensated by a continuous input stream of feed water at either ambient temperature or heated. That feed water is pumped under pressure into the boiler (See Figure 1, points 1-2).

Within the boiler the feed water is heated until reaching a temperature where the water starts to vaporize (points 2-3). The mixture of water and steam is called wet steam (points 3-4). During this stage the steam is heated further until all water has gradually vaporized at constant temperature. This stage should not be confused with evaporation, which only occurs below the boiling temperature and on the surface.

In the following process the dry saturated steam is overheated until the steam reaches the appropriate temperature in the boiler (points 4-5). Points 2 to 5 lie on an isobar with constant pressure p. All three processes, heat water, vaporize water, and overheat steam, need thermal energy, transferred from burning coal or other fuels, to the boiler system. The yellow areas below the different processes indicate the amount of thermal energy.

### The Thermal Efficiency

Efficiency is defined by output divided by input, here more precisely thermal efficiency by the ratio of useful output energy to heat-energy as input, expressed in energy terms.

In accordance with the first law of thermodynamics this ratio has a value between 0 and 1, in percentage between 0% and 100%. In reality thermal efficiency is significantly smaller than 1 because of heat loss or alternate forms of energy generated unintentionally. The thermal efficiency of a power plant influences the costs of steam production and has therefore always been a feature the designers drew attention to.[3]

The efficiency of power plant steam boilers cannot be easily quantified or compared with other systems because thermal input and output depend on different variables. The named slide rule allows five of them as input:

* boiler pressure,
* temperature of superheated steam,
* temperature of feed water,
* water evaporated per lb. of fuel,
* calorific value of fuel.[4]

These variables are measured during a test for thermal efficiency. To compare the results they must be reduced to a common basis. This is done with standard conditions. They are defined thus:

Definition 1:

> These standard conditions presuppose a feed water temperature of 212 degrees Fahrenheit and a steam pressure equal to the normal atmospheric pressure at sea level, 14.7 pounds absolute. Under such conditions steam would be generated at a temperature of 212 degrees, the temperature corresponding to atmospheric pressure at sea level, from water at 212 degrees. The weight of water which would be evaporated under the assumed standard conditions by exactly the amount of heat absorbed by the boiler under actual conditions existing in the trial, is, therefore, called the equivalent evaporation **from and at 212 degrees.**

Definition 2:

```
The factor for reducing the weight of
water actually converted into steam
from the temperature of the feed, at
the steam pressure existing in the
trial, to the equivalent evaporation
under standard conditions is called
the factor of evaporation. This factor
is the ratio of the total heat added
to one pound of steam under the
standard conditions to the heat added
to each pound of steam in heating the
water from the temperature of the feed
in the trial to the temperature
corresponding to the pressure existing
in the trial. This heat added is
obviously the difference between the
total heat of evaporation of the steam
at the pressure existing in the trial
and the heat of the liquid in the water
at the temperature at which it was fed
in the trial.[5]
```

The expressions in bold are used on the instrument.

## The Instrument

The Boiler Efficiency Calculator was designed to calculate the thermal efficiency of a boiler system with the above named five variables and based on standard conditions. The US patent reads:

```
This invention relates to an apparatus
for calculating the thermal efficiency
of a steam generating plant and other
data incidental to and involved in the
process of determining the said
thermal efficiency from the
observations and readings commonly
taken for that purpose.
```

The instrument is shown in Figure 2. The calculator is 25 cm long and consists of two parallel joined simple slide rules and a wooden chart that can be moved vertically between them. The nomograph on the chart holds two scales and a two-dimensional diagram. The instrument is marked with *Boiler Efficiency Calculator* on the chart and *Crompton - Gallagher Patent, No. 128,878. 1919.* on the body.

The lower slide rule helps to calculate the degree of evaporation, the upper one finally leads to the thermal efficiency.

The movable chart is used as replacement for a printed steam table. The chart contains a curve for saturated steam and 20 curves for overheated steam, marked with temperatures from 40 to 400 °F over the temperature of saturated steam. The curves give their heat in B.T.U. (British Thermal Units)[6] on top edge depending on the boiler pressure written on the right side of the diagram. On the left side the temperature of saturated steam is given in relation to the scale on the right.

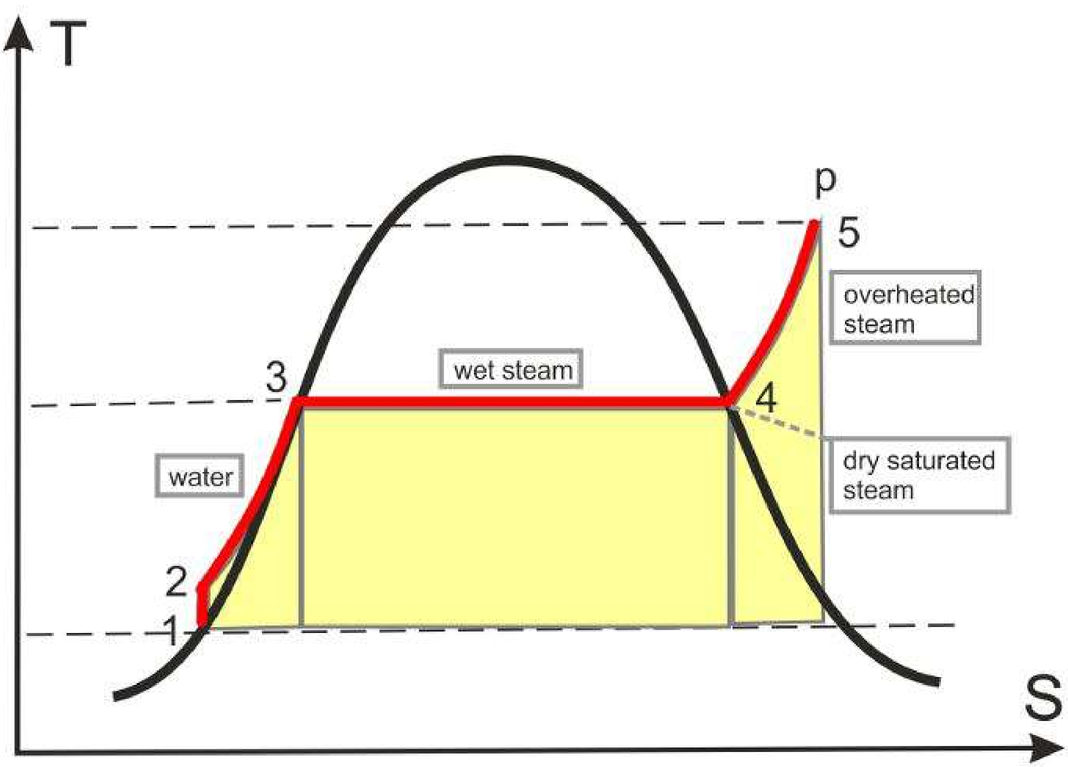


**FIGURE 1. Schematic T-S-Diagram for Water**
(T for temperature, S for entropy)

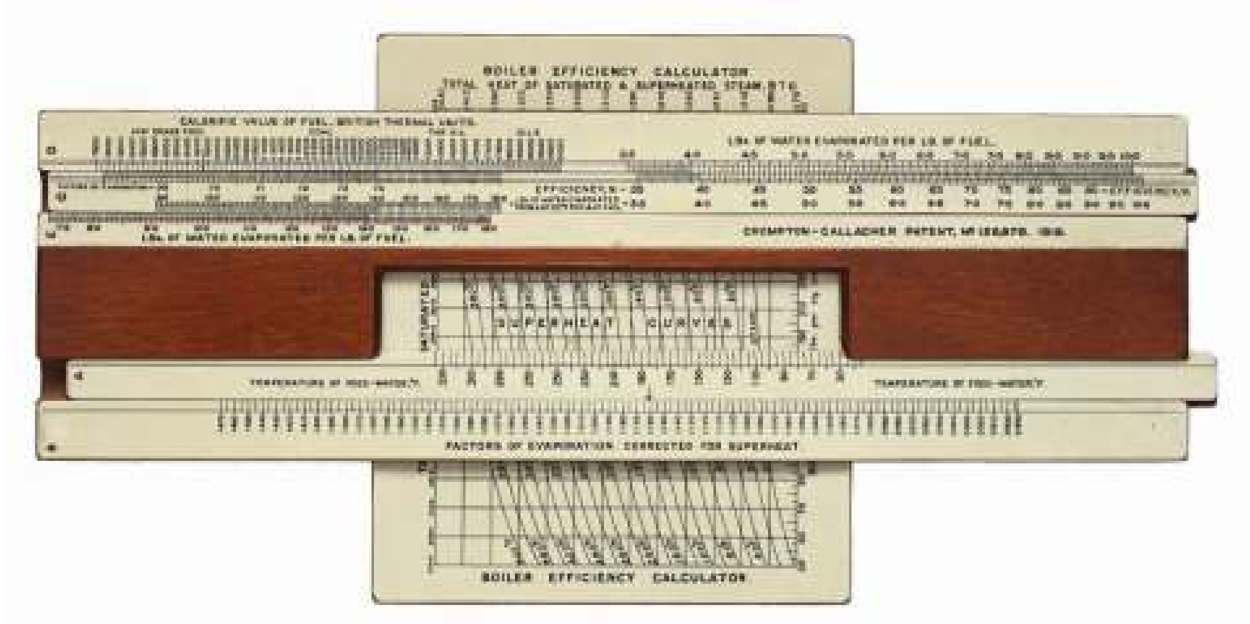


**FIGURE 2. The Boiler Efficiency Calculator**

The named patent on the stock is not the only one that has been granted. There is also an US patent from 1922 and a French patent from 1921[7] The latter uses metric instead of British Standard units, but up to now I have never seen an instrument with such markings.

Shortly after application for GB patent the instrument has been improved, because French and US patent specifications include a third scale on the upper slide rule.

The instrument must have had a forerunner. In 1909 *The Electrician* reports about a Boiler Efficiency Calculator, a "novel type of slide rule", with four scales and "corrections" – whatever that may be.[8] The instruction for use given there is almost in line with the later instrument. Crompton or Gallagher as inventors are not named.

### An Example of Usage

All three patent specifications from 1919 to 1922 give examples of usage, the English patent in a general way, the others with numbers. The example from US patent is copied hereafter. In contrast to the patent text the letters C and D on the real instrument I worked with are exchanged. Figure 3 follows this calculating example and shows the sequence of entries and readings on a real instrument. The readings and settings start with the yellow dot and end at the red en-framed efficiency. Movements of sliders cannot be emulated in a single static figure; therefore, the positions of numbers match with their scales, but not with their exact positions there.

The readings during a test of a power plant are:

- ✓ boiler pressure... 180 lbs. per sq.in.
- ✓ temperature of feed water economizers... 100° F.
- ✓ temperature of superheated steam... 480° F.
- ✓ water evaporated per lb. of fuel... 7.5 lbs.
- ✓ calorific value of fuel... 12800 B.T.U.

The original instruction for use reads:

> Move the chart F until the 180 lbs. pressure line lies along the inside edge of the scale A. At the left hand end of the 180 lbs. pressure line is found the temperature in F. of saturated steam at the pressure, viz 379.8° F. Deduct this figure from the observed temperature of superheated steam thus, 480 - 379.8 = 100.2. Therefore the degrees of superheat are 100.2.
>
> Neglecting the decimal figure, find the 100° F. superheat curve and move slide A until the mark indicating the temperature of the feed water i. e. 100° F. is over this curve. The arrow-head on slide A will now be pointing to 1.223 on the scale B which is the factor of evaporation.
>
> Move slide D to the left until the factor 1.223 is under the arrow-head at left hand end of scale C.
>
> The water evaporated from and at 212° F. can now be read off on scale D, opposite the mark on scale C indicating 7.5 lbs. of water evaporated per lb. of fuel. It will be 9.17 lbs.

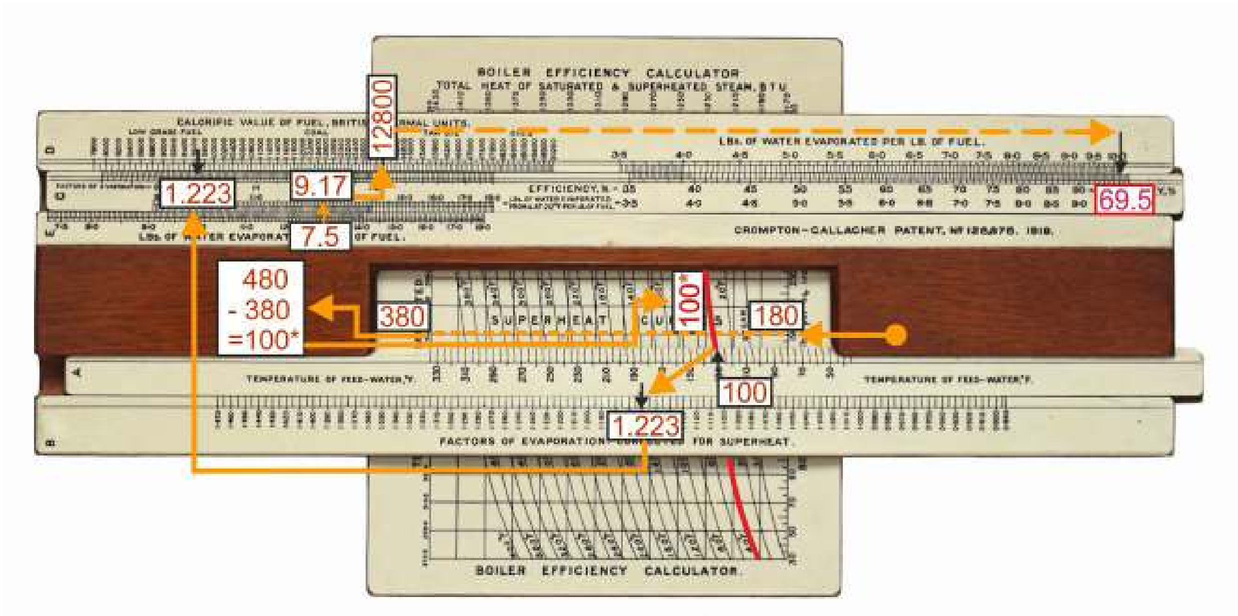


**FIGURE 3. Schematic Entries and Readings for a Given Calculating Example**[12]

> Now look for the 12800 British thermal units mark on the left hand of scale C and move slide D further to the left until the 9.17 mark just obtained is opposite this B.T.U. line. The arrow head on left of scale C[9] will then be opposite 69.5 on slide D, which is the required thermal efficiency.

The instrument does not seem to have had a long career. About 1920, Pickworth and scientific and technical journals mentioned the calculator only with a few words.[10,11] Shortly afterwards we lose track of this exceptional instrument. The Powerhouse Museum shows an item online named "'Boiler efficiency calculator 1919" (Registration number 2010/1/511).

## Notes

1. JOS Plus indicates that supplemental material for this article is available at www.oughtred.org. The supplemental material contains the PDF files of the three patents.
2. Weiss, Stephan: *Golding's Horse Power Computer (1908),* Journal of the Oughtred Society, 23:2, Fall 2014.
3. Cooley, M.E.: *Factors in the Cost of Steam Making*, The Technic – The Annual of the Engineering Society of the University of Michigan, 1896, pages 82-87.
4. Calorific value is the amount of heat produced by the complete combustion of a material or fuel, measured in units of energy per amount of material (cited from en.wiktionary.org).
5. Both definitions are cited from Babcock & Wilcox Company: *Steam, Its Generation and Use,* Sep. 2007, page 116 URL http://www.gutenberg.org/ebooks/22657?msg=welcome_stranger
   This book gives a good presentation of the underlying relations with formulas included.
6. One B.T.U. is the amount of energy needed to cool or heat one pound of water by one degree Fahrenheit.
7. Crompton, James and Gallagher, William: *Apparatus for the Calculation of the Thermal Efficiency, and other Data Involved Therein, of Steam Generating Plant,* British Patent 128,878 (1919).
   --: *Appareil pour le calcul du rendement thermique et d'autres données connexes, des installations génératrices de vapeur,* French Patent 514,896 (1921).
   --: *Calculating Device*, US Patent 1,424,344 (1922).
8. The Electrician, Vol. LXIII, Apr.-Oct. 1909, page 285.
9. This section should read the arrow head on right of scale C.
10. Pickworth, C.N.: *The Slide Rule: A Practical Manual*, London, 1920, page 121.
11. The Electrical Review, Vol. LXXXVII, Jul.-Dec. 1920, page 121.
12. All figures from the author and from the author's collection.