LIVE STEAM FEED WATER HEATING.

A PAPER READ BY

AUGUSTUS W. HAMILTON

BEFORE

The Belfast Mechanical and Engineering Association,

25TH MARCH, 1902.

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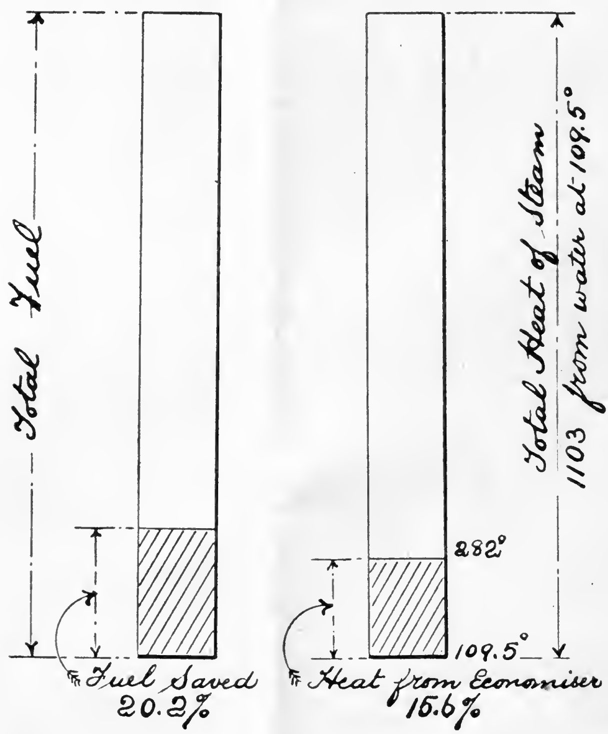
Diagram of Green's Economiser test showing difference between the per centages of Heat returned in the feed and Fuel saved. Steam press. 80 lbs.
Temp. of feed without Economiser 109.5°
" " " with " 282°



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Live steam feed water heating has always been a subject of controversy; those who have made careful and accurate tests are convinced of its efficiency, while others will not admit a saving that has not been satisfactorily explained by theory.

Some practical men smile at theories, and yet I have always found that the most practical men wish to be satisfied as to how the saving is made theoretically before testing the matter practically.

The first thing that called my attention to the matter was the fact that exhaust steam heaters always saved more fuel than could be accounted for by the heat units which they returned to the boiler in the feed water.

The number of heat units required to convert a pound of water into steam is accurately known. It has always been taken for granted that if a certain proportion of these heat units is supplied to the water from some exterior source, such as a feed water heater or economiser, the saving of fuel would be in the same proportion.

Careful tests have shown in every instance that there is a greater saving than can be calculated in this way. For example, where careful tests were made with Green's economisers :—

1st. Where the feed was receiving 17% of the total heat of the steam from the economiser, the saving of fuel was 21%.

2nd. Where the feed was receiving 20·4%, the saving in fuel was 24·7%.

3rd. Where the feed was receiving 20·3, the saving in fuel was 26%.

4th. Where the feed was receiving 15·6, the saving in fuel was 20·2%.

So that in four very carefully made tests the differences between the actual saving and the calculated saving were 4, 4·3, 5·7, and 4·6, all in excess of the theoretical saving.

My partner, Mr. M'Master, has always been a very strong advocate of a hot feed. Wherever he finds a boiler feeding at less than 200 degrees he recommends an exhaust steam heater, so that we have made and fitted quite a number of them. They have all been very satisfactory; like Green's economisers, they always saved more than the calculated amount. This was satisfactory enough from a commercial point of view, but from a scientific point of view it was not satisfactory to find practice continually varying from theory, and always in the same direction.

When theory and practice disagree, theory must either be wrong, or it may explain only part of the result, which may be the effect of two separate factors, only one of which has been considered in the theory.

This, I think, is what occurs in these feed heaters; the theory accounts quite correctly for the quantity of heat returned to the boiler in the feed water, but it entirely fails to consider another result of feed heating, which is, that the heating surfaces of the boiler are used in a different way, less surface being used to raise the temperature of the feed, and more surface being used to evaporate it.

This is the point that all feed heaters have in common. Live steam heaters do not bring any heat into the boiler from an exterior source, but they do alter the working conditions of the boiler by greatly increasing the heating surface used for evaporation.

It is in this fact that we must look for the cause of the extra saving made by economisers and exhaust heaters, and the whole saving made by live steam heaters.

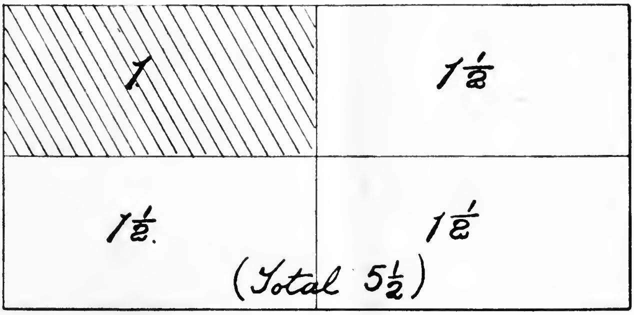
In the case of a boiler working with a feed below the temperature of evaporation, the heating surface has two functions to perform—first, it has to raise the temperature of the feed to the temperature of evaporation, then it has to add the latent heat necessary for evaporation; therefore, the heating surface may be regarded as being divided into two parts—one part raising the temperature of the feed, the other evaporating the feed. These are two distinctly different physical operations, and we have no right to assume that a square foot of heating surface transmits the same quantity of heat in each case.

I am not aware of any experiment that proves it; on the contrary I think I can show you reasons, resting on experimental proofs, for believing that heat is absorbed much more rapidly when water is evaporating. If this is so, and more heat is absorbed from a square foot of heating surface in contact with evaporating water than would be absorbed from the same square foot in contact with water rising in temperature, there is manifestly an advantage in using all the heating surface for evaporation, for in this way more heat will be absorbed from the flue gases and less heat wasted up the chimney.

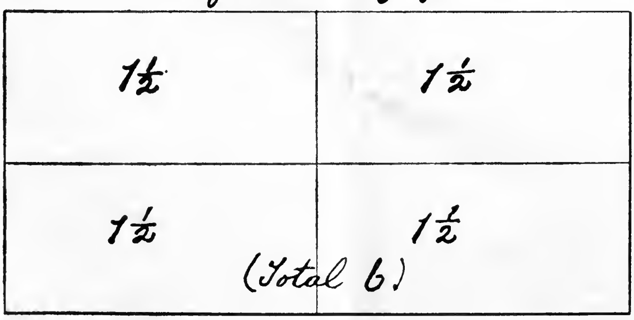
A perfect live steam heater is a means of gaining the whole of this

Live Steam Feed water Heating.

Diagram showing one fourth of Boiler Heating surface being used for heating feed water at the low efficiency.



Effect of Live Steam Heating, all the Heating Surface is used at the high rate of efficiency.



See page 6.

advantage, for it delivers the feed water at the temperature of evaporation, and all the heating surface is used for evaporating water.

Economisers rarely, and exhaust heaters never, make the feed hot enough to gain as much in this way as a live steam heater does; they, however, gain part of this advantage. This is the reason that they show a greater saving than can be accounted for by the heat they utilise from waste sources.

As an example of the gain that can be made in this way by live steam heating, take the case of a boiler with feed water at such a temperature that a quarter of the heating surface of the boiler is required to raise the feed to the temperature of evaporation, the remaining three quarters being used for evaporation. If the efficiencies of these two parts of the heating surface are in the proportion of 1 to $1\frac{1}{2}$, then the relative quantities of heat absorbed on the two parts will be 1 on the part used for heating, and $1\frac{1}{2}$ on each of the quarters used for evaporating, or $4\frac{1}{2}$ for the three quarters. Adding these gives $5\frac{1}{2}$ as the relative quantity of heat transmitted by the whole heating surface of the boiler.

The effect of the live steam heater is to make the whole heating surface into evaporating surface. In this example one quarter of the heating surface would have its efficiency raised from 1 to $1\frac{1}{2}$, and the relative quantity of heat transmitted from the whole surface would be 4 times $1\frac{1}{2}$, or 6, instead of $5\frac{1}{2}$ without the heater, a gain of $\frac{1}{2}$ on $5\frac{1}{2}$, or 9%. This is quite a common case in practice. (See diagram p. 5.)

I have pointed out that the only action of a live steam heater on the working condition of a boiler is to cause all the heat from the fuel to be delivered to evaporating water, whereas, without the heater, part of this heat is delivered to water only heating. As this is the only direct action of the heater, the economy made by it must be due to the increased efficiency of the heating surface when used for evaporation.

But, even if the results of feed water heating did not lead to this conclusion, many experiments, carefully conducted with a view to discovering the rate of heat transmission through plates, prove that the rate of transmission always increases rapidly when evaporation begins.

So long ago as 1872, Mr. William Anderson read a paper before the Institute of Civil Engineers, in which he gave the results of experiments made with steam jacketed pans heating water. He found that the quantity of heat passed through the metal per square foot per degree per hour was 260 units when heating water, and that the number of units was 606 after the water began to evaporate, showing a greatly accelerated passage of heat when evaporating, $2\frac{1}{3}$ times as much as when only heating. (See diagram p. 8.)

In another experiment, while heating the water to the boiling point, the heat transmitted per square foot per degree per hour was 368 units, but after evaporation began the heat transmitted was 660 units. Here the passage of heat for evaporating water was 1·8 times as much as in heating without evaporation.

Sir Frederick Bramwell, in discussing Mr. Anderson's paper, gave particulars of similar experiments made by him with a jacketed copper pan. He experimented with steam successively of 5, 10, 15, and 20 pounds pressure, raising the water in temperature from 58 to 212 degrees, and evaporating it.

In the first experiment, with 5 lbs. steam pressure, he found that the average rate of transmission of heat per square foot per degree per hour was 162 units, while the water was being heated up to 200 degrees, whilst in heating from 200 to 212 the rate advanced to 327 units, and, when ebullition commenced, to 427 units.

The results of his numerous experiments with different pressures all proved that the rate of transmission was more than doubled when ebullition commenced.

These experimental results prove that the efficiency of the heating surface is largely increased when the water in contact with it is in a state of ebullition.

Once this fact is known, the results obtained by live steam heating are easily explained.

Without a heater, part of the heating surface of the boiler must be used to heat the feed, thus it is used at the low efficiency. If the feed is heated with live steam, this part of the heating surface is no longer required to heat the feed, but is covered with water in a state of ebullition, the efficiency is greatly increased, more heat is passed from the flue gases into the steam, and less heat is lost up the chimney.

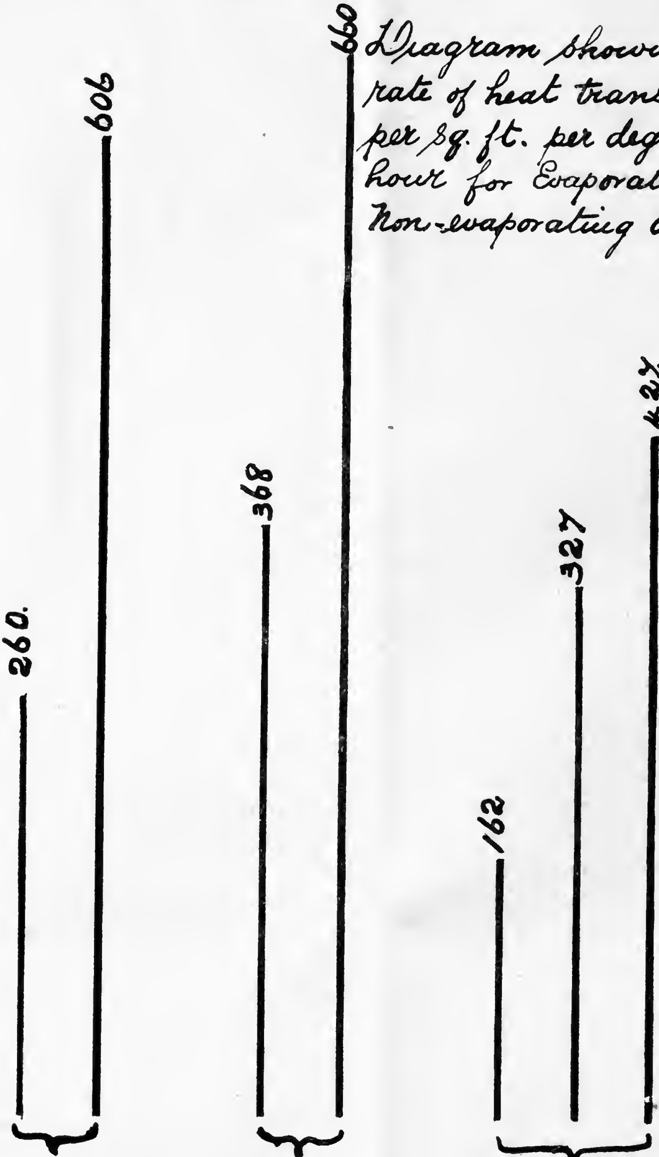
A live steam heater alters the working of the boiler, the heating surface is made more efficient, and less heat is lost. A Green's economiser increases the area of the heating surface, and less heat is lost. The action of the one is just as simple as the action of the other. There are only *two* ways by which the loss of heat up the chimney *can* be reduced : one way is to increase the *efficiency* of the heating surface, the other is to ncrease the *area* of the heating surface. The live steam heater does the first, the economiser does the second.

The experiments from which I have quoted prove the fact that the rate at which heat passes through the plates is greatly increased when evaporation begins. The fact is in itself sufficient to explain the action of the heater, but it is interesting to go a step further, and endeavour to see why the evaporating water does increase the rate.

For small differences of temperature it is found experimentally that the rate of transmission of heat through a metal plate is nearly proportional to the difference of temperature on the two sides of the plate; but

Live Steam Feed water Heating.

Diagram showing rate of heat transmission per sq. ft. per degree per hour for Evaporating & Non-evaporating water.



See page 7.

for great differences, such as occur in steam boiler furnaces, the transmission increases at a faster rate than the difference of temperature, so that it is nearly proportional to the square of the difference.

This is the law that governs the rate at which heat is transmitted, so that when our experiments prove that the rate is increased by evaporation, it follows that evaporation must, in some way, have increased the difference of temperature on the two sides of the plate. We may fairly assume that the temperature on the fire side has not been raised, therefore the temperature on the water side must have been reduced when evaporation began.

This is exactly what might have been expected from what is known of evaporation: it always cools the surface upon which it takes place, so that water evaporating on a surface will cool that surface far below the temperature which would be obtained by merely circulating the water over it without evaporation.

This peculiar power of evaporation has been made use of for many purposes, and can be demonstrated by very simple experiments: perhaps the most simple is to wet your finger and blow upon it; you at once feel the cold produced by the evaporation, and the more rapid the evaporation the greater the cold. If the hand is wet with some very volatile liquid, such as spirits, the cold is greater, owing to the more rapid evaporation; or if the air is drier, the rate of evaporation is increased and a greater degree of cold is produced. This is the principle of the Hygrometer, an instrument used to measure the quantity of moisture in the atmosphere. It consists of two ordinary thermometers placed side by side, the bulb of one being covered with cambric, which is kept continually moist by means of a wick that dips into water. If the air is saturated with moisture so that no evaporation is taking place, the two thermometers register exactly alike; but if the air is not fully saturated, evaporation takes place at the wet bulb and reduces its temperature, which is shown by that thermometer registering some degrees less than the dry bulb thermometer. The temperature registered by the wet bulb thermometer depends upon the rate of evaporation, and the rate of evaporation depends upon the relative quantity of moisture in the air; so that by observing the different temperatures registered by the two thermometers, the relative quantity of moisture in the air can be calculated. This is usually ascertained from a table which has been prepared for the purpose.

If water is evaporated rapidly without the addition of heat, its temperature is reduced to the freezing point, and it becomes ice. This is an old and well-known experiment, but it illustrates the cooling power of evaporation so well that I wish to call your attention to it.

The means employed to produce the rapid evaporation is to place the water in an open dish under the receiver of an air pump; the pump is set to work and a vacuum formed; the water evaporates rapidly when relieved of the atmospheric pressure, and is soon converted into ice. To assist the pump in maintaining a vacuum, some sulphuric acid or other absorbent of aqueous vapour is generally used. But the only essential point for the success of the experiment is that the evaporation is rapid.

Man cannot live if his temperature rises much over a hundred, but he can live in an atmosphere much hotter than a hundred, for his skin becomes moist, and evaporation keeps him comparatively cool.

Another example is the use of ammonia for refrigeratory purposes. The liquid ammonia is passed over a coil through which brine is circulating; the ammonia evaporates on the coil and thus absorbs the heat from the brine. The cooling effect is entirely due to the evaporation, for if ammoniacal gas at the same temperature as the liquid ammonia is passed over the coil no heat is absorbed, there is no cooling effect. Or if the liquid ammonia is passed over the coil without evaporating, there is no cooling effect.

This makes it manifest that it is evaporation alone which produces the difference of temperature on the two sides of the coil which causes the heat to flow from the brine to the ammonia.

In the refrigerator the liquid ammonia is supplied to the brine coil at 60 or 70 degrees, and as it cools the brine to 24 degrees, or colder if wanted, the evaporation must cool the ammonia itself as well as the brine; so. a liquid which is comparatively warm can, by evaporation, carry off heat from a body colder than itself. Nothing colder than the brine is introduced into the apparatus; the transfer of heat is entirely due to the difference of temperature caused by evaporation.

It is plain that the evaporation of a liquid not only absorbs a large quantity of heat, but absorbs it so rapidly that it actually cools the surface on which the evaporation takes place considerably below the temperature of the liquid.

In this way the water side of the heating surface in a boiler may, when evaporation is taking place, be cooled below the temperature of the water, and by thus making a greater difference of temperature than non-evaporating water would make, the flow of heat is increased.

To conclude, I will sum up the facts :—

First. Live steam heaters do save fuel, and economisers show a greater saving than has been accounted for.

Second. Evaporating water absorbs heat more rapidly than water which is being only heated.

Third. The rate at which heat passes through a plate depends upon the difference of temperature on the two sides of the plate.

Fourth. Evaporation always cools the surface upon which it takes place.

If these four facts are examined, it will be seen that the first is a result of the second, and that the second is a result of the third and fourth.

Thus, a live steam heater saves fuel because evaporating water absorbs heat more rapidly than non-evaporating water; and the reason that evaporating water absorbs heat more rapidly than non-evaporating water is, that the rate of flow of heat through the plates depends upon the difference of the temperature on the two sides of the plate, and evaporation increases this difference by cooling the side upon which it takes place.

Professor John Perry, D.Sc., F.R.S., Professor of Mechanics and Mathematics in the Royal College of Science, has been kind enough to send me the following criticism:—

"*Dear Sir,*

"*I quite agree with what you say in your paper. You put the matter very clearly in a way that any Engineer can follow.*

"*But I wish you had gone further and considered—Why is it that heating surface is more efficient when there is ebullition?*

"*If you will refer to my book on 'Steam' (Macmillan & Co.), chap. xxxiii., you will find an account of what Professor O. Reynolds said in 1874.*

"*The more rapid the* SCRUBBING *of metal plate, by water on one side, by flame gases on the other, the more rapid is the flow of heat. There are simple experiments to illustrate this. Even a pot with a stirrer for making cocoa shows that water stirred (care being taken that there is no air above its surface which might be carried down by the stirring) heats very much more rapidly.*

"*Ebullition produces more rapid convective scrubbing. I should say, too, that ebullition under low pressure induces more heat to come through the metal than ebullition at high pressure; because low pressure steam is of greater volume, and produces more convective disturbance.*

"*I have recommended artificial stirrers in boilers worked by little electromotors.*

"*I again congratulate you on having written so clearly on a subject that is so little known.*

"*Yours truly,*

"*JOHN PERRY.*

"*A. W. Hamilton, Esq.*"

In his valuable work on "Steam," Professor Perry shows very plainly that the principal resistance to heat passing from the fire to the water does not occur in the metal of the plates but at the two surfaces, the total resistance being 1,000 times that of the metal itself. Apparently a layer of gas adheres to one side and a layer of water to the other side of the plate. Gases and water are notoriously bad conductors of heat, consequently these layers, of what I may call stagnant water and gases, offer an enormous resistance to the passage of heat.

Anything that tends to reduce the thickness of the stagnant layer or to remove it, will increase the efficiency of the heating surface.

Evaporation on the heating surface produces ebullition, and ebullition produces convective currents, which currents will, by their scrubbing action, tend to reduce the thickness of the stagnant layer of water adhering to the plate.

But this is not the only result of evaporation. When evaporation occurs, portions of the stagnant layer of water are converted into steam, and are thus entirely removed from the heating surface.

Evaporation thus has a double effect on the stagnant layer—it entirely removes such part of it as is converted into steam, and it creates convective currents, the scrubbing action of which reduces its thickness. These effects both tend to increase the efficiency of the heating surface.

The production of cold by means of evaporation has never been very clearly explained, although the fact has been established for a long time. I have considered it sufficient for my purpose in this paper that the fact is established: the explanation would require another paper fully as long as the above.

I greatly regret that, owing to no shorthand notes having been taken, I am unable to give the valuable and interesting discussion that followed.

I wish to take this opportunity of thanking the members who were present for the exceedingly kind way in which they received my paper.