CALCULATING COMBUSTION EFFICIENCY

For years there have been different views as to the proper way to adjust an oil burner. The two most popular views concern low stack temperature and a high CO_2.

The majority of the technicians feel that keeping the stack temperature as low as possible is best, claiming most of the wasted heat goes up the stack. On the other hand there are technicians who claim a high CO_2 is the first priority. Keeping the stack temperature as low as possible without sacrificing CO_2. They contest that a low CO_2 means that we are not totally burning our oil during the process of combustion.

Usually we have a problem trying to maintain our CO_2 when lowering the stack temperature. This occurs because we end up underfiring the burner to achieve the low stack temperature.

Example: We have a boiler rated at 30 gph oil and the manufacturer has recommended a 450° stack temperature. This means that under tests made by the manufacturer the stack temperature was 450° when the boiler was fired to capacity.

The size of the gas passes through the boiler, combustion chamber, as well as the original burner are all designed around the boiler capacity. If we try to cut our capacity to say 20 gph we are firing the burner at less than it was designed for into a boiler with too much area for our 20 gph. We probably will not be able to provide adequate heat for combustion so our CO_2 will crop. Our excess air will rise due to having a small fire and not adequately filling the combustion zone. Not to mention trying to cut the air supply down below the burner rating while trying to maintain air velocity needed to properly shape the flame.

Carbon monoxide will most likely become evident as a result of a cool combustion zone not evaporating the oil at the rate necessary for adequate fuel/air mixing.

We will use as an example #2 fuel oil analyzed at .05% sulphur (S), 12% hydrogen (H2), and 87.95% carbon (C). This fuel oil remains the same in both examples.

In the October 1979 FOOH ("Take a Close Look at Combustion"), we examined the chemical process of combustion in detail. We also examined the chemical products contained in oil and how to figure the Btu content of oil, as well as how to figure the quantity of air necessary for good combustion. In the present article, however, we are concerned only with stack temperature so we will not go through the lengthy process of analyzing the oil, etc.

Before we can determine the quantity of heat we are wasting up the stack, we must first know the exact quantity we are supplying to the boiler. This is determined by analyzing the oil we are burning. When this is done we find the oil contains 19,728 Btu's per pound of fuel. The API gravity of the sample is 7.13 pounds per gallon, so our Btu content per gallon is 7.13 x 19.728 or 140,660 Btu's per gallon.

The theoretical air required for combustion is 14.47 pounds per pound of fuel. There are 13.6 cubic feet of air in one pound at 80°F so we will need 197 cubic feet of air per pound of fuel. If this is multiplied by 7.13 we will have 1,403 cubic feet of air per gallon of oil.

We need both weight and volume measurements. Most of our calculations will be done using weight as the unit of measurement, however, because volume is the most common measurement we will eventually need to convert back.

In calculating the quantity of heat wasted up the stack, we are only going to concern ourselves with two types of losses--heat carried away in the dry chimney gases and the evaporation of moisture formed by the burning hydrogen. There are other minimal losses, but for the purpose of this examination, the two mentioned above will be sufficient.

Example #1: An oil burner firing 30 gph. Our combustion test shows 12½% CO_2 with a 480°F stack temperature. Our ambient boiler room temperature is 80°F. According to our Bacharach Efficiency Chart, we have 84% combustion efficiency with a 16% net stack loss.

We will first calculate the heat carried away by the dry chimney gas using the following formula:

$H = 0.24W\ (tg-ta)$

H = Btu lost per pound of fuel

W = Weight of dry chimney gas per pound of fuel in pounds

tg = Temperature of flue gas °F

ta = Ambient temperature °F

0.24 = constant for mean specific heat of dry flue gas.

In order to obtain the approximate weight of the dry chimney gas, we must first determine the amount of excess air present at 12½% CO_2. By examining a CO_2--excess air chart we find our excess air is approximately 25%. Checking back in our calculations, we had determined the theoretical quantity of air needed to burn our sample was 14.47 pounds per pound of fuel. We now must add 25% to this figure giving us 18.09 pounds of air per pound of fuel. Due to one of the fundamental laws of physics (the Law of Conservation of Matter--stating there must be a balance between the sum of elements entering and leaving a process), we must now add the 1 pound of fuel to the 18.09 pounds of air. This is because the air and oil will combine in combustion and will exist together. Our stack temperature in this is 480°F with an ambient temperature of 80°F.

$H = 0.24W\ (tg-ta)$

$H = .24 \times 19.09 \times (480^\circ - 80^\circ)$

$H = .24 \times 19.09 \times 400^\circ$

H = 1832.6 Btu's per lb. of fuel

Next we will calculate the quantity of heat loss due to the evaporation of moisture formed by the burning hydrogen using the formula:

$H = 9H\ (1089.0 + 0.46\ tg-tf)$

H = weight of hydrogen per pound of fuel in pounds

tg = temperature of flue gas

tf = fuel temperature

Going back to our fuel analysis, we find the weight of hydrogen is .12 pounds per pound of fuel. The flue gas temperature is again 480°F and we will consider the fuel temperature to be 80°F, the same as ambient.

H = 9H (1089 + .46 tg-tf)

H = 9 x .12 (1089.0 + (.46 x 480) - 80

H = 1.08 x (1089.0 + 220.8 - 80)

H = 1.08 x 1229.8

H = 1328.18 Btu's per pound of fuel

Our approximate total Btu loss for Example #1 is 1328.18 + 1832.6 or 3160.8 Btu's per pound of fuel. This may now be converted to Btu's per gallon by multiplying 3160.8 x 7.13 or 22,536 Btu's per gallon of fuel.

If our fuel has been analyzed at containing 140,660 Btu's per gallon, our percentage heat wasted up the stack would be calculated as:

$\frac{22,536}{140,660}$ or 16%

This percentage is the same as the net stack loss from our Bacharach Efficiency Chart.

Example #2: The same equipment firing 20 gph with combustion test results showing 10% CO_2 with a 330° stack temperature.

Our ambient temperature will remain the same at 80°F. According to our Bacharach Efficiency Chart we have 86½% efficiency with a 13½% net stack loss. We are firing the same oil sample. We will calculate the stack loss the same as Example #1. Our figures will all remain the same with the exception of stack temperature and excess air. The formula will remain: heat carried away by dry chimney gases = .24W (tg-ta).

When we figure our weight of dry chimney gas per pound of fuel (W) we will still use the same theoretical quantity of air, 14.47 per pound of fuel. The difference here is that we have approximately 58% excess air due to the drop in CO_2. 58% in excess of 14.47 will give us 22.86 pounds of air per pound of fuel, to which we must add the 1 pound due to the oil and air combining in the boiler giving us 23.86 as the weight of dry flue gas per pound of fuel. The stack temperature dropping to 330°F, keeping the ambient temperature at 80°F, we will solve the problem in the following manner:

H = .24W (tg-ta)

H = .24 x 23.86 x (330 - 80)

H = 5.73 x 250

H = 1432.5 Btu's per pound

We will solve for the evaporation of moisture formed by burning hydrogen in the same manner as Example #1. H = 9h (1089.0 + .46 tg-tf). Everything will stay the same except the stack temperature which is now 330°F.

H = 9h (1089.0 .46 tg-tf)
H = 9 x .12 x (1089 (.46 x 330) - 80)
H = 1.08 x (1089 151.8 - 80)
H = 1.08 x 1160.8
H = 1253.664 Btu's per pound of fuel

Our approximate total Btu loss in Example #2 is 1432.5, 1253.6 or 2686.1 Btu's per pound of fuel. This may also be converted to Btu's per gallon of fuel by multiplying 2686.1 x 7.13 or 19,152 Btu's per gallon of fuel.

Our percentage of being wasted up the stack is calculated as follows:

$\frac{19,152}{140,660}$ or 13.6%

We can see by the above examples that our percentage of waste will be 2.4% lower by firing the boiler at 20 gph as compared to 30 gph. However, there are still some unanswered questions.

Q: What about cycle time?

Regardless of what we do with the burner our load is going to be the same. If our load requires 20 gph this means our burner is going to operate continuously with the 330° stack. Our other example would be cycling and only operating approximately two thirds of the time with the higher stack.

If our oil contains 140,660 Btu's per gallon and we burn 20 gallons per hour we are burning 20 x 140,660 or 2,813,200 Btu's per hour. If we waste 19,152 Btu's per gallon, we are wasting 20 x 19,152 or 383,040 Btu's in one hour of continuous running time.

Conversely, in the first example we are burning 30 gph. If we ran continuously we would waste 30 x 22,536 or 676,080. However, we are only operating two thirds of the time so to obtain the actual Btu's lost we multiply 2/3 x 676,080 450,720 Btu's per hour.

In the instance cited above, the boiler with the lower stack temperature and the longer running time is more efficient. We stated before that our percentage of waste was 2.4% lower. Although this is true, our actual percentage of wasted fuel saved by using the lower stack temperature is:

$$100 - \frac{383,040}{450,720} \text{ or } 15\%$$

This is a savings of 3 gallons of oil per hour of running time at 20 gph firing rate. A considerable savings.

Q. How low can we go on CO_2 with the same type of results?

As our CO_2 drops our excess air will rise. This will considerably change the results of the formula H = .24 w (tg-ta). As our excess air increases, so will our weight of dry flue gas (w). Around 7.9% CO_2, 100% excess air, keeping the same stack temperature, we will have equal waste. As our CO_2 drops below this point we will increase our waste above that of the higher stack temperature. As an example, 7% CO_2 with a 330°F stack temperature and 125% excess air will give us 23,287 Btu's lost up the stack per gallon. This is 751 Btu's per gallon higher loss than with the 480°F stack temperature.

We must also remember that by lowering stack temperature we may lower the temperature in the combustion zone to the point where our oil is not evaporating properly. This may cause CO as droplets of oil burn off the refractory. When Carbon burns to CO, we lose 72% of the available heat for each pound of CO in the gas.

We must remember that obtaining maximum combustion efficiency is more than simply dropping the stack temperature. It is the proper combination of stack temperature, CO_2, and cycle time which gives us maximum fuel efficiency. There is no doubting that our greatest fuel waste is up the stack but it may be excess air and not overfiring.