MEASURE 1.2.1 Test boiler efficiency on a continuing basis.

RATINGS

New Facilities	Retrofit	O&M
		A

Periodic efficiency testing is an important part of the management of any boiler plant, for these reasons:

- a large fraction of a facility's total energy consumption flows through its boilers, so even a small drop in efficiency represents a large amount of energy and cost in absolute terms. In facilities where boilers have operated for long periods of time without being tested, it is not uncommon to find that efficiency has fallen by five or ten percent, which may represent a very large cost.
- efficiency testing is the most accurate indicator for adjusting the boiler and its auxiliary equipment, such as adjusting the air-fuel ratio (covered in Subsection 1.3). Efficiency testing tells you the "bottom line" economic performance of the boiler, unlike indirect clues, such as flame color.
- you can localize most boiler problems by knowing how to exploit the full range of efficiency test methods. Efficiency tests are to boilers what blood tests are to human beings.
- efficiency testing is the first step in estimating the benefit of potential boiler improvements, such as adding an economizer or an air-fuel control system.

Boilers are vulnerable to conditions, such as tube fouling, that may reduce their efficiency over relatively short periods of time. Therefore, you should test boiler efficiency on a regular basis. Fortunately, boiler testing is easy. It is practical for most facilities to have at least one person who is proficient in testing. This individual need not be a boiler operator, or even a member of the physical plant staff.

You may need several types of efficiency tests to get a complete picture of boiler performance. There is one main type of test, called a "combustion efficiency" test. You may have to supplement this with one or two specialized tests, such as a test for carbon monoxide, to get a complete picture of your boilers' performance. This Measure tells you how to select the appropriate tests for your boilers, how to do them, and the weaknesses of each method. In a short time, you can be testing your boiler efficiency with confidence.

What "Efficiency Testing" Means in Boilers

Efficiency is defined as the ratio of the useful output energy produced by a system to the raw energy input into the system. In principle, it is possible to test the overall efficiency of a boiler plant. You could do this by measuring the energy content of the steam or hot water that is exported by the boiler plant and the total quantity of energy that is input to the boiler plant, including fuel for the boilers and other energy for the auxiliary equipment.

SUMMARY

The basic step in maintaining boiler efficiency. Know the theory well enough so that you understand which tests to use, and what they are telling you.

SELECTION SCORECARD

Savings Potential	$ $ $
Rate of Return	% % % %
Reliability	✓ ✓
Ease of Initiation	☺ ☺ ☺

In actual boiler plants, such a comprehensive test is impractical. Measuring steam or hot water energy with reasonable accuracy, say within one percent, is possible only under laboratory conditions. Field measurements of flow are vulnerable to error, even if they are done by expensive consultants. Measuring input energy is also subject to error. You would have to analyze the energy content of your fuels, make corrections for ambient conditions, and create very stable test conditions. This is not possible under realistic conditions.

Fortunately, you don't need to measure the total efficiency of a boiler plant if your objective is to tune up the plant's efficiency, rather than running a testing laboratory. You can use an easy procedure, called a "combustion efficiency" test, to measure the aspects of boiler efficiency that cause most losses in normal operation. The "combustion efficiency" test determines how completely the fuel is burned, and how effectively the heat of the combustion products is transferred to the steam or water.

The efficiency of the other boiler plant components, such as pumps, fans, and motors, tends to remain constant, so you don't need to test their efficiency on a continuing basis.

Limitations of the Combustion Efficiency Test

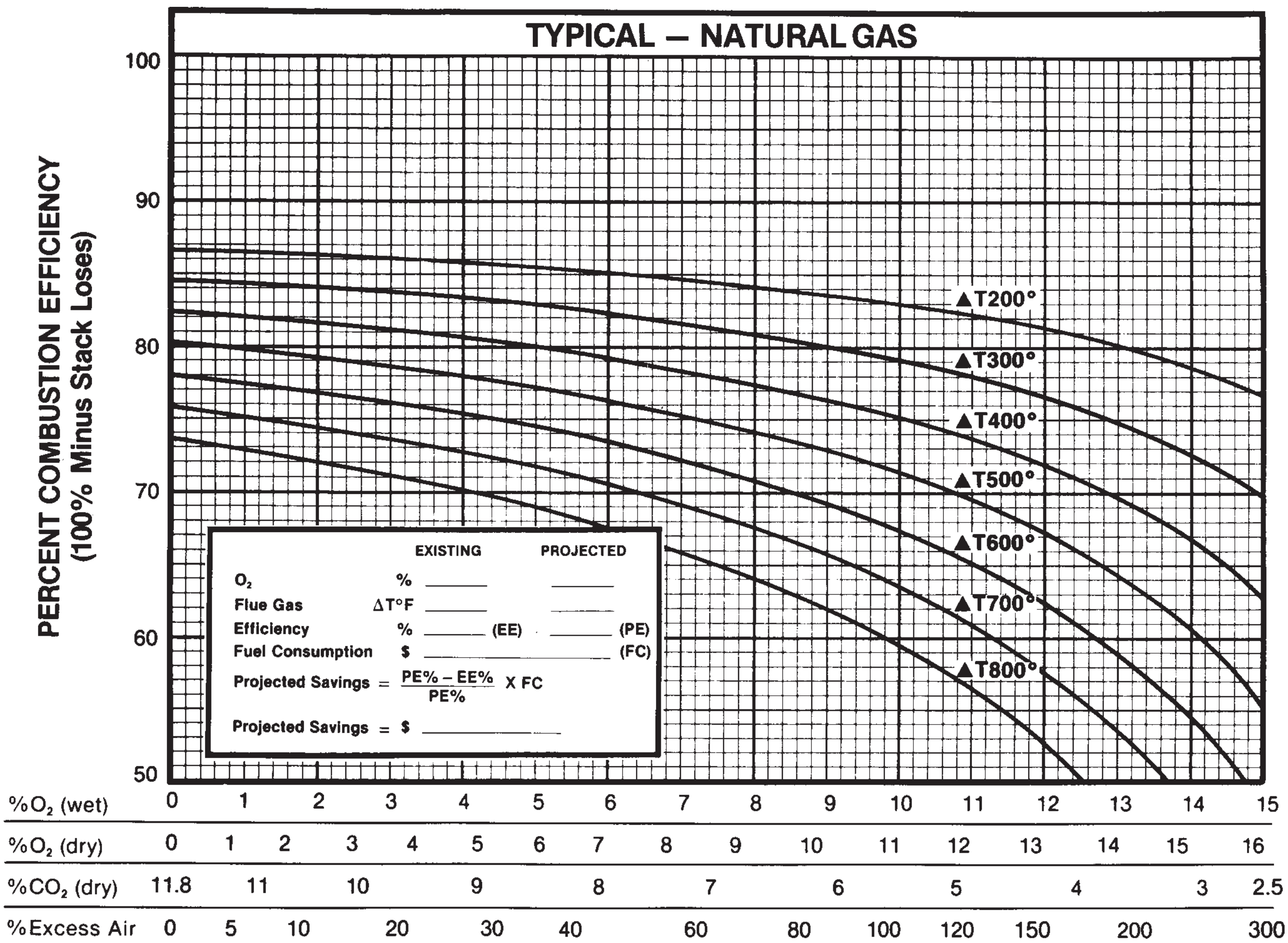
The combustion efficiency test is your primary tool for monitoring boiler efficiency. You can achieve accuracy in the range of one percent of efficiency if you do the testing carefully and use equipment of good quality. However, be sure that you understand what the test is telling you. The combustion efficiency test does not account for:

- ***standby losses.*** You perform a combustion efficiency test when the boiler is operating under a steady load. Therefore, the combustion efficiency test does not reveal standby losses, which occur between firing intervals. You cannot measure standby losses directly. You have to estimate them from the type of boiler and the firing schedule. See Measure 1.5.3 for an explanation of standby losses.
- ***heat loss from the surface of the boiler to the surrounding space.*** As a practical matter, you cannot measure this loss. Typical estimates state that the loss from surface radiation is about two percent of the boiler's full load energy consumption. (Subsection 1.11 shows you how to reduce surface heat loss and recover the heat.)
- ***blowdown loss.*** The amount of energy wasted by blowdown varies over a wide range. (Subsection 1.8 shows you how to minimize blowdown loss and how to recover heat from blowdown.)
- ***soot blower steam.*** The amount of steam used by soot blowers is a variable that depends on the type of fuel and the judgement of the staff. (Subsection 1.6 shows you how to minimize soot blower steam consumption.)
- ***auxiliary equipment energy consumption.*** The combustion efficiency test does not account for the energy use by auxiliary equipment, such as burners, fans, and fuel pumps. (To minimize this energy consumption, see the Subsections that cover the specific types of auxiliary equipment.)

While the combustion efficiency test does not give the overall efficiency of the boiler plant, it is by far the easiest method of tracking moment-to-moment, day-to-day, and season-to-season variations of boiler efficiency. Combustion efficiency testing tells you how far boiler efficiency drifts away from the best efficiency that you can achieve when the boiler is fully tuned up.

How to Do a Combustion Efficiency Test

You test combustion efficiency by measuring either the oxygen content or the carbon dioxide content in the flue gases. The oxygen test can provide much better accuracy in the range of air-fuel ratio where the boiler is supposed to operate. In recent years, oxygen testers



Preferred Utilities Manufacturing Corp.

Fig. 1 Form for calculating combustion efficiency This form works with either oxygen or carbon dioxide measurements. You don't need this if you have an electronic efficiency tester that calculates efficiency automatically. The graph nicely illustrates the fixed relationships between the amounts of oxygen, carbon dioxide, and excess air in the flue gas, for a particular type of fuel.

of good quality have become available at modest prices. Therefore, use the oxygen test as your fundamental test for combustion efficiency.

Testing for combustion efficiency using the oxygen method consists of three easy measurements:

- the percentage of oxygen in the flue gases
- the temperature of the flue gases
- the temperature of the air going into the boiler

Make the oxygen measurement with a specialized tester that is described below. Make the two temperature measurements with ordinary thermometers. To make the flue gas measurement, you may have to drill a small hole in the flue or breeching, as close to the outlet of the boiler as possible. (Check first. Unless the facility is brand new, somebody probably made a hole already.)

Some combustion efficiency testers have an internal computer that calculates the efficiency directly from these measurements. If you don't have such a unit, use the three measurements with an efficiency table or graph for the specific type of fuel. These are provided with the test equipment, or you can find them in reference books. A typical graph for calculating combustion efficiency is reproduced in Figure 1.

For example, using the graph in Figure 1, say that the oxygen tester gives a reading of 5% oxygen in the flue gases. (This is the "wet" value, which means that the water vapor has not been removed from the flue gas sample.) If the flue thermometer reads 480°F and the air going into the boiler has a temperature of 80°F, the flue-to-inlet temperature difference is 400°F. Entering the table with these numbers gives a combustion efficiency of 80%.

It's that easy. The carbon dioxide test is done in the same way, except that a different tester is used to measure carbon dioxide instead of oxygen, and the efficiency table or graph is based on carbon dioxide percentage.

You may do other tests, explained below, to supplement the combustion efficiency test or to measure pollutants. These tests are even simpler.

The Logic of Combustion Efficiency Tests

Your boiler burns fuel efficiently if it satisfies these conditions:

- it burns the fuel completely
- it uses as little excess air as possible to do it
- it extracts as much heat as possible from the combustion gases.

The combustion efficiency test analyzes the flue gases to tell how well the boiler meets these conditions. The test is essentially a test for excess air, combined with a flue gas temperature measurement. The only purpose of bringing air into the boiler is to provide oxygen for combustion. Bringing in too much air reduces efficiency because the excess air absorbs some of the heat of combustion, and because it reduces the temperature of the combustion gases, which reduces heat transfer. The temperature of the flue gas indicates how much energy is being thrown away to the atmosphere.

All the calculations needed to perform the efficiency test are contained in the efficiency table, so no mathematics is needed. The efficiency table uses this logic:

- The amount of oxygen in the flue gas indicates directly the amount of excess air that is flowing through the boiler. The atmosphere contains about 21% oxygen. All this oxygen would be consumed if combustion were perfect. Therefore, the presence of oxygen in the flue gas indicates that more air is being used than is necessary for perfect combustion.
- The efficiency table is based on a certain heat content for the fuel. This is why there are different tables for different fuels. The tables also assume that the fuel is burned completely. These assumptions provide the amount of heat released in combustion.
- The volume of flue gas is known from the assumed chemical composition of the fuel and the amount of excess air. Knowing the volume of the flue gas and its temperature indicates how much energy is contained in the flue gas. This energy is wasted.
- Knowing how much energy is being produced and how much is being lost gives the combustion efficiency.

If your efficiency tester has a built-in efficiency computer, it follows the same logic, and you don't even have to look up numbers in the table.

You can also test combustion efficiency by measuring the carbon dioxide content of the flue gases instead of measuring the oxygen content. Although the test procedure is the same as for oxygen testing, the principles of the carbon dioxide test are different. Carbon dioxide content indicates both the amount of fuel burned and the amount of energy released because it is a principal residue of fuel combustion. (The other major residue is water vapor.) If there were no excess air, the amount of carbon dioxide in the flue gases would be a certain amount, determined by the chemical composition of the fuel. A lower concentration of carbon dioxide therefore indicates excess air.

In other words, the oxygen test indicates the amount of excess air directly, whereas the carbon dioxide test indicates excess air indirectly, based on an assumption about the chemical composition of the fuel.

■ Assumptions of Combustion Efficiency Testing

Be aware that the efficiency tables used in combustion efficiency testing make some assumptions. Most importantly, they assume a certain average chemical composition of the fuel. This makes it important to use the specific table for the fuel being burned. If you use a tester that calculates the efficiency, you have to set the type of fuel in the tester.

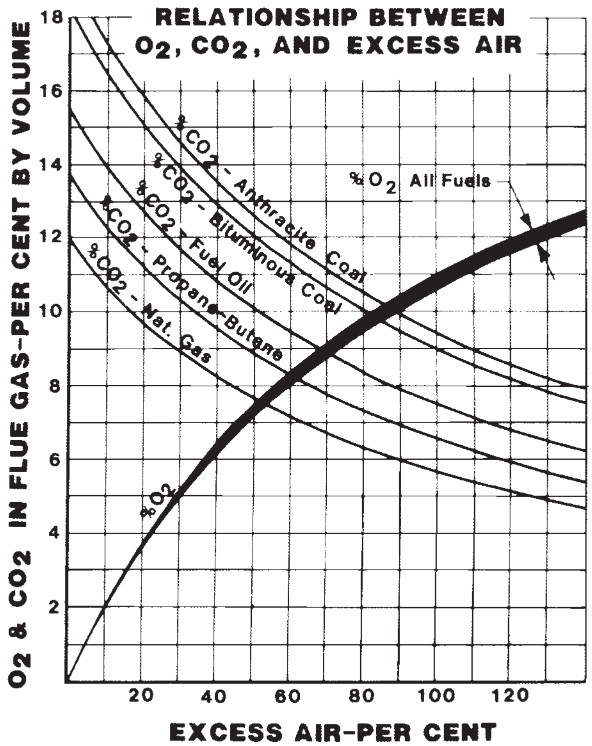


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Fig. 2 Why flue gas oxygen indicates combustion efficiency more accurately than carbon dioxide First, the oxygen content changes radically with excess air. Second, the relationship between oxygen and excess air is almost independent of the fuel type.

The chemical composition of a fuel varies considerably even within a given type (such as “No. 2 oil”). However, the effect of such differences is small enough to ignore for most practical purposes.

Another assumption of the tables is that the fuel is burned completely. As long as the burners are operating properly and the air-fuel ratio is not grossly out of range, this is a reasonable assumption. However, burner malfunctions and insufficient air cause incomplete combustion. These conditions cause fuel to be thrown into the boiler without producing heat. The unburned fuel is not detected by the oxygen or carbon dioxide tests, so these tests yield artificially high efficiency figures if combustion is incomplete. This is one reason why you need an additional test to check for incomplete combustion.

To be extremely accurate, you would have to measure the temperature of the fuel, to take into account the sensible heat carried by the fuel. As a practical matter, this energy is minor in comparison with the chemical energy of the fuel. Furthermore, the temperature of the fuel that is delivered to the boiler usually varies little from one time to another. So, you can forget about fuel temperature in most cases. (The temperature of heavy fuel oil is important for viscosity control. That aspect is covered in Subsection 1.9.)

Why the Oxygen Test is Better than the Carbon Dioxide Test

For any given fuel, there is a fixed relationship between the amounts of oxygen and carbon dioxide in the flue gas. This is why you can measure either one to determine combustion efficiency. The fixed relationship between oxygen, carbon dioxide, and excess air is shown in Figure 1.

The oxygen test is more accurate than the carbon dioxide test. The reason is apparent from the graph in Figure 2. When you approach the optimum excess air setting, the relative change in oxygen is much greater than the relative change in carbon dioxide for a given change in excess air. For example, with No. 2 oil, an increase in excess air from 2% to 10% causes oxygen in the flue gas to increase by a factor of five, a change that you can measure easily. On the other hand, the same increase in excess air causes carbon dioxide to drop by only 10%, a difference that is more difficult to measure accurately.

Another advantage of the oxygen test is that the results are much less sensitive to variations in the chemical composition of the fuel. Figure 2 shows this dramatically. The amount of carbon dioxide in the flue gas depends on the amount of carbon in the fuel, and the amount of excess air is calculated from this carbon dioxide value. There are large differences in the chemical composition of some fuels, such as industrial by-product gases. All liquid and gas fuels have some variation.

In contrast, the oxygen test provides a direct indication of excess air. Variations in carbon content do not affect the results of the oxygen test at all, and variations in the total energy content of the fuel affect the oxygen content much less than they affect the carbon dioxide content.

Unlike the carbon dioxide test, the oxygen test works only in the region of excess air. There is no oxygen to measure when there is no excess air. This is not a problem in normal testing, because you should always operate boilers with a small amount of excess air.

Check the Oxygen Test with the Carbon Dioxide Test

Boiler efficiency testing is so important that it is worth a small additional effort to check the oxygen test with a carbon dioxide test. Test equipment for both tests is readily available. The cost in time and money for the additional test is minor. If continuous-reading oxygen test equipment is installed in your boiler plant, check this equipment occasionally with portable test equipment that checks for both oxygen and carbon dioxide.

If the carbon dioxide test does not give the same results as the oxygen test, something is wrong. One (or both) of the tests could be erroneous, perhaps because of stale chemicals or drifting instrument calibration.

Another possibility is that outside air is being picked up along with the flue gas. This occurs if the combustion gas area operates under negative pressure and there are leaks in the boiler casing. Watch out for this problem in boilers with induced draft fans and in boilers that have atmospheric burners.

A discrepancy between the two tests could also be caused by a defect in the burner assembly, such as a clogged nozzle. Remember that *combustion efficiency testers assume complete combustion of the fuel*. Any condition that interferes with complete combustion renders the tests invalid, and also breaks the correlation between oxygen content and carbon dioxide content.

Beware of electronic efficiency testers that claim to "measure" both oxygen and carbon dioxide. Many such units really measure only the oxygen percentage. They calculate the carbon dioxide percentage from the oxygen percentage, using assumptions about the fuel composition. *The carbon dioxide indications of such units are meaningless, and you cannot use them for cross checking purposes*.

Tests for Incomplete Combustion

No boiler is capable of burning fuel without some amount of excess air, although the percentage of excess air may be small. As the excess air is reduced toward zero, there is some fuel that is not burned completely. This partially burned fuel creates smoke, leaves deposits on firesides, and creates environmental problems.

Unburned fuel may also represent a significant waste of energy. The amount of waste depends on the energy content of the unburned fuel components. For example, the unburned components of heavy oil are mostly organic compounds that have a high energy content. On the other hand, the unburned components of coal may consist largely of foreign matter that has much lower energy content than coal itself. One source estimates that each 0.1 percent of unburned combustibles in flue gas typically represents between 0.3 and 0.6 percent of the energy content of the fuel. *This waste of energy is not measured by the combustion efficiency test.*

Therefore, optimum efficiency requires some positive amount of excess air, even though the combustion efficiency test indicates maximum efficiency with no excess air. If the boiler is working properly, the optimum amount of excess air is small.

To fine-tune the excess air, you may need an additional test that detects small amounts of incompletely burned combustion products. Two common tests for this purpose are smoke density and carbon monoxide in the flue gas.

■ Smoke Opacity Test

Before combustion efficiency test equipment became available, the amount of air was adjusted by observing the smoke emerging from the stack. For example, boilers burning heavy oil used the rule that the flue gases should be a "light brown haze." This is no longer satisfactory as a primary test, but it continues to be a useful check. If there is too much smoke when the excess air is set to a reasonably low figure, something is wrong. Therefore, measuring smoke density ("opacity," to be precise) continues to be a valuable diagnostic test.

You can use the smoke density test with heavier grades of oil and with solid fuels. Smoke density is not a reliable indicator with gaseous fuels and with light oils. The unburned residue of these fuels is not visible unless air is very deficient.

■ Carbon Monoxide Test

The carbon monoxide content of flue gas is a good indicator of incomplete combustion with all types of fuels, as long as they contain carbon. Carbon monoxide in the flue is minimal with ordinary amounts of excess air, but it rises abruptly as soon as fuel combustion starts to be incomplete. This makes it an excellent indicator when making your final adjustments of the air-fuel ratio.

An excessive level of carbon monoxide that occurs in the normal region of the air-fuel ratio indicates trouble within the boiler. Carbon monoxide rises excessively if any defect in the boiler causes incomplete combustion, even with excess air. This makes carbon monoxide testing an excellent tool for discovering combustion problems, especially if it is used in combination with oxygen testing. For example, the carbon monoxide test might reveal a fouled burner. It might also point toward a more subtle problem, such as a poor match of the burner assembly to the firebox, causing a portion of the flame to strike a surrounding surface. (Cooling the flame interrupts the combustion process, leaving carbon monoxide and other intermediate products of combustion in the flue gases.)

Carbon monoxide also forms if there is a great excess of air. This is not a matter of practical significance. Once you set the air-fuel ratio properly, the carbon monoxide content falls into the proper range if there are no other problems.

Flame Appearance

The practice of adjusting burners on the basis of the color and shape of the flame is no longer acceptable, now that more accurate tests are readily available. However, you should still check the color and shape of the flame periodically to verify that there are no combustion problems, such as a clogged burner or water in the fuel.

Tests for Specific Environmental Pollutants

Environmental regulations may require you to test flue gases to ensure that emission of certain pollutants, such as nitrogen oxides, sulfur oxides, hydrogen sulfide, and chlorine, does not exceed specified limits. These tests are usually simple, requiring nothing more than sucking a flue gas sample into a specialized chemical or electronic tester.

Controlling pollutants requires specialized procedures, such as recirculating the flue gases, increasing air flow, or adjusting the burner flame. These procedures are likely to affect efficiency. Do efficiency testing as part of any change you make to control pollutants. Keep your pollutants within limits by using methods that reduce efficiency the least.

How to Select Test Equipment

Efficiency test equipment must be accurate. The objective is to measure efficiency within a fraction of a percent, because a difference this small can correspond to a large amount of energy. The entire range of possible boiler efficiencies corresponds to a range of flue gas oxygen content from zero to twenty percent. At the high end of the efficiency range, an error of two percent in flue gas oxygen results in a half percent error in combustion efficiency.

You don't need the skill of a surgeon to do combustion efficiency testing, but you do have to be careful. Some types of test equipment require more finesse than others. Let's look at what is available.

■ Oxygen and Carbon Dioxide Testers

The pioneer of combustion efficiency testers is the Orsat analyzer, a chemical testing apparatus in which flue gases are mixed with a liquid reagent that changes volume as a result of the reaction. The apparatus displays the volume change accurately, providing an accurate indication of combustion efficiency. Oxygen, carbon dioxide, carbon monoxide, and other gases can be analyzed.

The Orsat analyzer is simple and accurate. A portable version is available at moderate price. However, the apparatus is built of delicate glass tubing and requires a fine touch. Modern testers are much more rugged and much easier to use, so the Orsat analyzer is now a museum piece.

A similar chemical approach is used by the vintage Bacharach "Fyrite" tester, which is compact and made of plastic. One version of this unit tests for oxygen, and a different version tests for carbon dioxide. They are shown in Figure 3. The "Fyrite" is less accurate than the Orsat, but it is rugged and fairly easy to operate. It is the least inexpensive of all combustion gas analyzers. You need to read a table to use this device.

These testers require replacing their chemicals after a certain number of tests, and the chemicals have a limited storage life.

In recent years, electronic testers have become available for analyzing flue gases. Some typical units are shown in Figure 4. Most electronic testers use an electro-chemical cell as the gas sensing element. A different cell is required for each gas being measured.

The most common sensor used in oxygen testers is a zirconium oxide element that develops a voltage difference across two sides if there is a difference in oxygen concentration. The zirconium oxide element has the advantage that it can be exposed to flue gases for thousands of hours.

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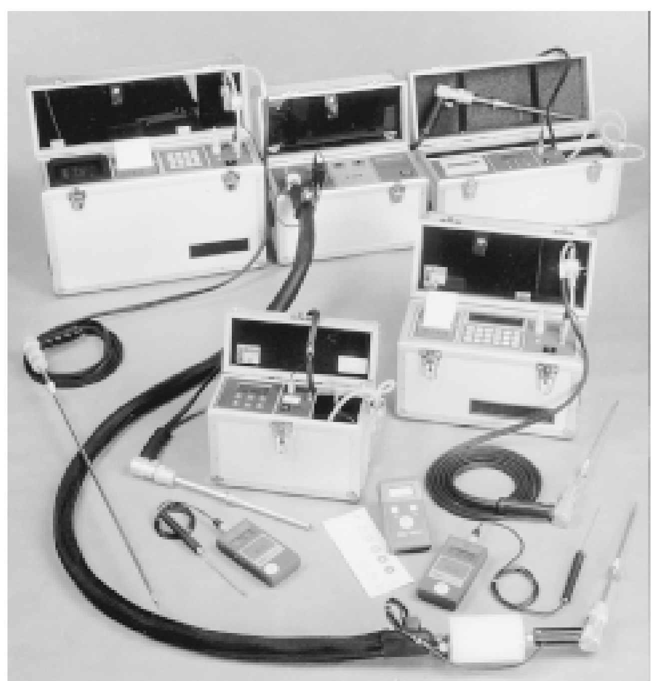
Fig. 3 Chemical combustion efficiency testers One tests for flue gas oxygen, the other for carbon dioxide. The rubber hose draws a flue gas sample through a liquid in the tester. A chemical reaction changes the liquid volume, revealing the amount of gas.



IMR Environmental Equipment, Inc.

Fig. 4 Electronic flue gas analyzers These test for a variety of gases. Oxygen and carbon dioxide testers can calculate combustion efficiency directly.

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Fig. 5 Chemical carbon monoxide tester The simple device on the right draws a flue gas sample through a glass tube containing a chemical that reacts with carbon monoxide to change color. Each tube is used one time. By using different chemicals, the device can test for other flue gases.

The overwhelming advantage of electronic testers is that they provide an immediate and continuous readout simply by inserting a probe into the flue gases. This allows you to see the effect your of boiler adjustments immediately.

Some combustion efficiency testers avoid the need to use a table to calculate efficiency. They perform the efficiency calculation with a microcomputer and read out combustion efficiency directly. There is a potential for error with such testers because efficiency depends on the temperature of the inlet air as well as the temperature of the flue gas. Some testers use the temperature of the air surrounding the tester as the inlet air temperature. This introduces error because the air near the flue may be much warmer than the air entering the boiler. Better testers provide a separate remote thermometer for measuring the air inlet temperature while you take the flue gas sample.

Electronic testers of good quality are substantially more expensive than chemical testers. Still, the price is small compared to the benefit of keeping boiler efficiency optimized (unless your boilers are very small).

As with most electronic equipment, the quality of electronic flue gas analyzers varies widely. The best of the lot may be capable of better accuracy than the inexpensive chemical testers. The worst of the lot are incapable of providing useful accuracy.

A weakness of all electronic gas analyzers is that they must be re-calibrated frequently because the sensor output drifts. Fortunately, oxygen testers may be self-calibrating by using the oxygen content of the atmosphere as a calibration point. Testers for other gases require calibration using pre-mixed gases. Since the inner workings of these instruments are invisible, calibration is an act of faith in the calibration gases.

Most inexpensive electronic combustion analyzers do not measure carbon dioxide directly. Some units provide a carbon dioxide reading, but this is derived by internal calculation from the oxygen measurement. If you want to use a carbon dioxide test to check the oxygen test, a value that is calculated from the oxygen measurement is useless. Measure carbon dioxide with a separate instrument designed for that purpose.

■ Testers for Carbon Monoxide and Specialized Gases

You can find electronic testers for gases other than oxygen or carbon dioxide, but these tend to be expensive and specialized. The most economical testers for carbon monoxide and specific pollutant gases use disposable chemical capsules for each type of gas. These units are reliable and easy to use. See Figure 5.

For example, one type of tester uses disposable chemical capsules in the form of slender tubes. The tester consists of a holder for the capsule that is equipped with a pump that draws the gas sample through the capsule. The gas concentration is indicated by the length of a color change inside the capsule.

■ Smoke Testers

You can measure smoke density cheaply and reliably with a tester that is constructed like a bicycle pump. It pulls a measured amount of flue gas through a piece of filter paper. You compare the blackness of the smoke spot on the filter paper to a chart that comes with the tester. See Figure 6.

Another method of testing smoke density is to install an optical densitometer in the flue. This is a simple device that shines a light beam across the flue. The amount of light that is absorbed by the smoke is

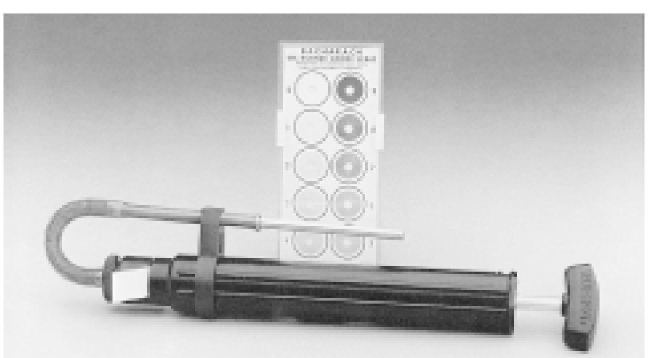

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Fig. 6 Smoke density tester This device, similar to a bicycle tire pump, sucks a flue gas sample through a piece of filter paper. The resulting smoke spot is compared with the chart behind the pump.

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Fig. 7 Small furnace, small tester Combustion efficiency testing is easy. It requires only a small hole in the flue. However, it is critical to keep air from leaking through the hole into the probe.

measured by a photocell. This device provides a continuous reading. In fact, some older oil-fired boilers use this device as the primary means of adjusting air-fuel ratio.

■ Thermometers

The thermometer that you use for flue temperature measurements must be accurate. An error of 40°F in the flue temperature measurement can result in a one percent error in boiler efficiency. Combustion efficiency testing is no place for a shirt pocket thermometer. Use a laboratory grade liquid-in-glass thermometer. Mercury-in-glass thermometers are available with maximum temperatures up to 1,200°F. To read the thermometer most accurately, get one that has a maximum temperature close to the maximum temperature of the flue gases. A 500°F (or 300°C) thermometer is appropriate for efficient boilers. A 750°F (or 400°C) thermometer is adequate for most others.

Good mercury thermometers are inexpensive, but they are fragile and difficult to read. Buy a couple of spares, along with a protective storage case.

Dial thermometers use a bimetallic sensing element that may drift with time. The only merit of dial thermometers is that they are easy to read. In a pinch, you can calibrate or check the low temperature end of a bimetallic thermometer by placing it in boiling water, which provides a reliable standard of 212°F (100°C) at sea level. If you use this method, correct for your altitude, because water boils at lower temperature at higher altitudes.

Electronic thermometers have high-tech appeal, but they may be inaccurate, just a toy dressed up with a digital output. Electronic temperature sensing elements are inherently non-linear. Most of the cost of the electronic thermometer goes to compensating for the weaknesses of the sensing element. Some electronic thermometers are accurate, but you typically have no way of distinguishing these units from the toys. Even with an electronic unit of high quality, be aware of the guaranteed accuracy range. For example, a one percent error in absolute temperature corresponds to an error of about 10°F at typical flue temperatures.

Avoid Error Due to Extraneous Air

The combustion efficiency test involves measuring a small quantity of residual oxygen in the combustion gases. In a well tuned boiler, the gases contain less than one percent of free oxygen. Therefore, the test is seriously falsified by any outside air that enters the test probe.

Be careful to avoid getting outside air into the probe at the probe hole. Sloppy technique may allow outside air to travel along the shaft of the probe and enter the tip. To avoid this, aim the probe toward the boiler, preferably by bending the probe to that it faces into the flue gas stream well inside the flue. Wrap a piece of cloth around the probe to act as a gasket between the probe and the edge of the hole. It's the same general idea as safe sex. See Figures 7 and 8.

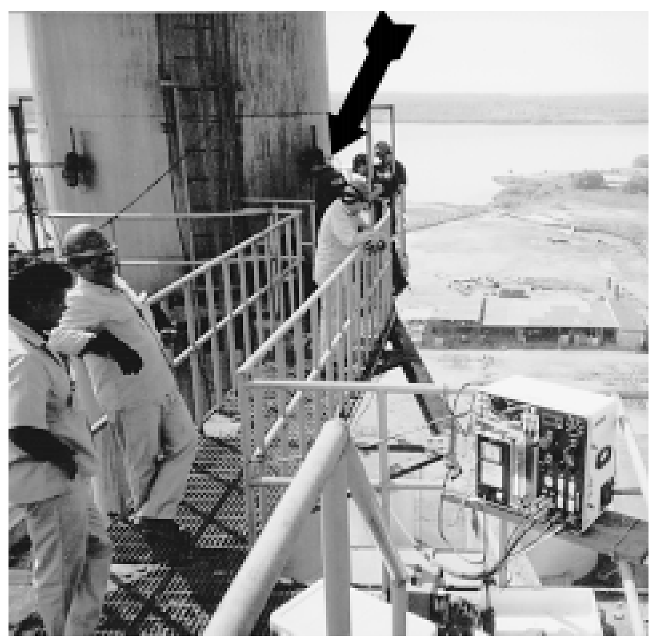

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Fig. 8 Large boiler, small tester Combustion efficiency testing is done the same way on all boilers and furnaces. Here, a test is conducted high on a large stack. The probe is located at the arrow, the tester is in the foreground. All these people are relaxing. It takes only one person to run the test.

If the flue contains a draft hood or atmospheric damper, tap the gas sample well below the point of entry of outside air. Turbulence in the flue may cause ambient air to backflow to the probe. Such backflow is especially likely to occur near bends in the ductwork.

Leakage of extraneous air into the flue is likely to occur if the boiler has an induced-draft fan, i.e., a fan that sucks combustion gases through the boiler rather than blowing them through. If you insert the probe at a point between the boiler outlet and the induced-draft fan, the induced-draft fan will draw outside air into the test hole. Air will enter at any leaks that exists in the flue ahead of the test probe. To avoid this problem, examine the boiler breeching ahead of the test hole, and plug any leaks. Drill the test hole as close to the boiler or economizer outlet as possible.

Errors from Sensing the Wrong Gases

A particular type of sensor may respond to more than one substance in the flue gas. This leads to a false reading if you are expecting to test for one substance but your tester registers another. The most common problem is that hydrogen and hydrogen sulfide register as carbon monoxide with some electrochemical carbon monoxide sensors. This is not a problem with clean fuels, which produce only carbon dioxide and water vapor as their principal end products. Beware of false readings when burning fuels, such as high-sulfur oil and coal, which produce gases other than carbon dioxide and water.

Errors Due to Internal Steam Leaks

If a boiler has an internal steam leak, the steam mixes with the flue gases. The steam is cooler than the combustion gases and lowers the temperature at the test point, giving an erroneously high efficiency calculation. If the steam leak is large, it may become apparent from an efficiency reading that seems abnormally high, especially at low loads. The rate of steam leakage remains constant at all firing rates, as long as the boiler pressure remains constant. Therefore, the error caused by the escaping steam is larger at low firing rates. If a boiler has a steam leak large enough to be detected by an efficiency test, it should be shut down immediately and repaired.

How to Test Boilers with Flue Gas Recirculation

To reduce the production of nitrogen oxides during the combustion process, many boilers now recirculate a portion of the flue gas. Exhaust gas is drawn from the flue with a fan and it is injected back into the boiler at the burner. The flue gas contains little oxygen and it is relatively cool. The purpose of this is to reduce the peak combustion temperature, since nitrogen oxides are formed mainly at high combustion temperatures.

Flue gas recirculation does not cause any problems with combustion efficiency testing. Efficiency testing works by measuring what goes into the boiler and what comes out. Recirculation is a process that occurs entirely within the boiler. Therefore, any effect that recirculation may have on efficiency is included in the flue gas analysis. Recirculation does not affect where you should tap your flue gas sample.

How to Test Boilers with Economizers and Air Preheaters

Economizers and air preheaters (covered in Subsection 1.7) are devices for capturing additional heat from the flue gases after they leave the boiler. The recovered heat typically is used to heat feedwater or combustion air, respectively. These devices lower the flue gas temperature, so they affect the efficiency test.

With both types of units, the proper place to measure the flue gas temperature is at the outlet of the heat recovery device, rather than at the outlet of the boiler.

With a combustion air preheater, the place to measure inlet air temperature is at the inlet to the air preheater, not the inlet to the burner. In other words, do not measure the temperature of the heated air produced by the preheater.

With a combustion air preheater of the heat wheel type, the flue gas test may yield an erroneously high efficiency. This is because the rotation of the wheel carries a certain amount of cool ambient air into the exhaust stream. Some types of heat wheels have purge sections that deliberately recirculate a portion of the incoming air into the exhaust from the heat wheel. Furthermore, different portions of the heat wheel are at different temperatures, so the flue gas temperature leaving the heat wheel is non-uniform. There is no practical way to make an accurate correction for these factors.

Preparation and Testing Conditions

When you first start your efficiency testing program, do a test under optimum conditions to establish a baseline for future tests. Do the baseline test with the boiler in peak condition, and across the entire load range of the boiler. Compare later tests to this baseline. When the boiler efficiency falls too far below your measured baseline, it is time to take corrective action.

For this baseline test, expect to spend considerably more effort and time inspecting the boiler plant and correcting deficiencies than in doing the testing itself. Adjust, clean, and repair all parts of the boiler that affect efficiency. Clean firesides and watersides. Clean and adjust burners. Remove all looseness from air and fuel control linkages. Check the combustion air supply. Adjust flue draft. And so forth. Refer to the other Subsections for the Measures that optimize the efficiency of your particular types of boilers.

Do the tests while the boiler has a steady load. If the system is used primarily for comfort heating, you may not have enough load to test your boilers during warm weather. It is easier to conduct tests in a plant that has more than one boiler, so the boiler being tested can shift load to and from the other boilers.

Do not attempt to create a load on the boiler by warming it from a cold state. This produces an efficiency reading that is artificially high, because the flue gases are being cooled by the mass of the boiler and water.

You have to make certain adjustments to the boiler plant while the boiler is operating. For example, determine the optimum fuel oil heater temperature by adjusting the fuel oil temperature for peak boiler efficiency. Make these adjustments as the test progresses.

How Often to Repeat Efficiency Tests

The most common reason for a decline in efficiency is accumulation of fouling on firesides, watersides, and burners. Fouling accumulates at a fairly predictable rate, if the boiler has no defects. The appropriate interval for combustion efficiency testing depends on the type of boiler and the type of fuel. A simple gas-fired boiler with atmospheric burners may hold its efficiency for years without adjustment, and with minimal maintenance. On the other hand, a large pressure-fired boiler burning a variety of fuels may have a noticeable drift in efficiency over a period of days or weeks.

Even if the boiler has recently been cleaned, test for efficiency and make adjustments whenever anything changes that can reduce efficiency. For example, test efficiency when changing from one type of fuel to another, when changing batches of fuel, and when slack in the linkages controlling air-fuel ratio becomes apparent. If controls are subject to drift, determine the length of time that it takes a significant error to accumulate. (If drift is serious, improve the control system as recommended by Measures 1.3.2 and 1.3.3.)

ECONOMICS

SAVINGS POTENTIAL: *2 to 10 percent of fuel cost, typically. Credit the savings to the specific actions that you take to improve efficiency, such as optimizing the air-fuel ratio, optimizing fuel oil viscosity, etc.*

COST: *You can purchase a good chemical combustion efficiency test kit that measures oxygen, carbon dioxide, and smoke for less than $500. A chemical carbon monoxide tester costs less than $300. Electronic testers of reasonable quality cost from $1,000 to several thousand dollars. Also, consider the cost of the actions that you take to improve efficiency.*

PAYBACK PERIOD: *Very short, to several years, depending on the amount of fuel consumed by the boiler and its tendency to lose efficiency.*

TRAPS & TRICKS

TRAINING AND ADMINISTRATION: *Efficiency testing does not require a high level of skill, but it does require practice and strict adherence to the instructions. If you delegate this responsibility to others, make sure that they are well trained.*

SELECTING THE EQUIPMENT: *Don't skimp on the quality of the test equipment. If your budget is limited, get a proven chemical test kit. The quality of electronic test equipment varies. Higher price does not necessarily mean better accuracy. High-quality electronic testers are easy to use and reduce the opportunity for mistakes.*

KEEP IT UP: *Efficiency testing is easy to forget. Schedule periodic review of testing procedures. Verify that testing is done properly, that results are recorded, and that appropriate action is taken.*