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Industrial Energy Conservation through Boiler Operation Efficiency Improvement

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INDUSTRIAL ENERGY CONSERVATION THROUGH BOILER OPERATION EFFICIENCY IMPROVEMENT

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Abstract

A method of determining the minimum amount of oxygen in the flue gas which results in the most efficient combustion is discussed. Results of field test are presented. The magnitude of the stack gas losses is dependent on the stack gas composition determined by the fuel and quantity of excess air and the stack temperature.

1. INTRODUCTION

A few fuel conservation measures can help extract more usable work from every BTU of fuel energy and save 5% to 7% in operating fuel bills at the same time. Boilers use a large amount of the energy consumed in the United States (U.S.). The energy required to produce process steam in industry is 16.7 percent of the total U.S. consumption. Steam is also produced in hospitals, schools, hotels, etc. Combining the institutional users with the industrial steam requirements, the energy used to produce steam in industry and institutions is approximately 20 per cent of the total U.S. energy consumption.

Due to the large amounts of energy consumed by boilers, it is an important piece of equipment to consider in an energy conservation program. The paper includes the necessary information for saving energy in a boiler plant.

The authors believe that the best motivation for energy conservation action lies in a healthy financial return on the investment of time and money by industry. Throughout, reference is made to the economic benefit of the suggestions made. Those responsible for boiler operation are reminded that there are no "short cuts" to the procedures described in the text of this paper. Since most of the hydrocarbon fuels consumed by American industry is used in producing steam or process heat, it follows naturally that fuel costs represent a substantial percentage of plant operating costs. What's more, the percentage is rising.

When fuels were cheap and plentiful, few plants had fuel conservation programs. Time and capital were invested in increasing production rather than reducing fuel bills or conserving energy. The boilers installed in most plants today are not tuned to the maximum efficiency level. America's habit of wasting fuel continues today as it has in the past.

2. BACKGROUND

2.1 OTHER BOILER PROGRAMS

Boiler adjustment procedures to minimize air pollution and to achieve efficient use of fuel is presented in references (1). This is a manual that provides general guidelines for use by industry boiler operations to reduce stack emission of nitrogen oxides and improve boiler operating efficiency. These guidelines deal primarily with boiler adjustments to reduce stack emissions. Mainly oxides of nitrogen generally referred to as "NO_x" are the polluting emissions from boilers. These compounds plus the new substances formed when they combine with other pollutants in the air are an important element in what is commonly referred to as "smog".

A study and a pilot program conducted by Auburn University in the State of Alabama indicated that a 6% increase in boiler efficiency could be realized with negligible capital expenditure, and that an additional 6% could be obtained with small capital investment (2).

A program conducted in the State of Louisiana similar to the one in Alabama indicated that the increase in boiler efficiency of approximately 4% could be obtained with negligible capital cost (3).

3. TUNING INDUSTRIAL BOILERS FOR HIGH EFFICIENCY OPERATION

Industrial boilers currently account for 20 percent of all the energy consumed in the United States. An increase in industrial boiler efficiency would therefore significantly impact energy conservation nationwide as well as reduce industries' fuel costs. This tuning procedure begins with a simplified discussion of the fuel burning process to provide the boiler operator with a basic understanding of the major combustion related factors important to efficiency. The techniques for improving boiler efficiency are then discussed in detail and instructions are provided to assist the boiler operator in applying them to a particular boiler.

3.1 FUNDAMENTALS OF COMBUSTION

The heat energy in all fossil fuels (oils, natural gases, and coals) is released during the combustion process as the carbon and hydrogen in the fuel react with oxygen to produce a flame. The burning of carbon and hydrogen with oxygen would ideally produce an exhaust gas consisting of carbon dioxide (CO_2) and water vapor (H_2O) which are considered ideal combustion byproducts. However, real combustion differs from this ideal situation due to the more complex make-up of the fuel itself plus the non-ideal characteristics of the actual burning process or non-ideal burner. The result is indicated by additional gaseous and solid materials from the boiler. Some are products of incomplete combustion and are important from an efficiency view point, since they represent a waste of fuel that is lost from the boiler through the stack.

3.1.1 SOURCE OF OXYGEN

Air is the convenient and only slightly varying source of oxygen for nearly all industrial combustion processes. The composition of air is approximately 21% oxygen (O_2) and 78% nitrogen (N_2) by volume with small amounts of other gases present. Under ideal combustion conditions there is a so-called "theoretical" or stoichiometric amount of air which will completely burn a given amount of fuel with no excess air remaining. In practice, however, more air than the theoretical amount must be supplied to the burner to ensure complete combustion of the fuel. The actual quantity of excess air required at a particular boiler depends on many factors such as fuel type and composition, furnace design, the design and adjustment of the burners, boiler firing rate, and control system used on boiler. If stoichiometric air is not provided, unburned fuel, smoke and other products of incomplete combustion such as carbon monoxide (CO) and soot are emitted from the stack, resulting in pollution, wasted fuel energy, and a potential for explosion. If the fuel lean case is now considered, where excess air is supplied to the burner, the boiler efficiency will be reduced because some energy is used to heat the unneeded air which is exhausted out the stack.

3.1.2 COMBUSTION EXCESS AIR

Since the excess air is an important boiler operating variable, it will be discussed in detail along with methods available for determining the excess air at the boiler.

Fuel and air flow measurements at the boiler would provide a method to determine the air/fuel ratio and excess air, but these measurements are not available at most industrial boiler installations. An indirect method for determining boiler excess air utilizes measurements of gases in the stack and the known chemical relationships between their concentration (percent by volume on dry bases) and percent excess air for a particular fuel.

Excess air is indicated by the presence of oxygen in the flue gas. As the excess air is increased at the boiler the oxygen concentration in the stack gases would also increase. Figure 1 shows this relationship between excess O_2 and excess air for typical natural gas, oils and coal fuels.

3.1.3 COMBUSTION CARBON DIOXIDE

Boiler operations normally determine the boiler firing conditions based on stack CO_2 measurements. The CO_2 versus excess air dependence is also shown in Figure 1. We recommend using excess O_2 to establish the state of combustion onee a boiler is tuned. The use of excess O_2 is preferred for the following reasons:

(1) The relation between O_2 and excess air is only a slight function of fuel composition. This is shown in Figure 1. CO_2 versus excess air shows a wide variation with fuel type.

(2) The excess O_2 measured in the stack gases is the actual surplus of oxygen which may be used for combustion. CO_2 is a product of combustion and approaches some constant value (depending on fuel composition) as excess O_2 approaches zero.

(3) Measurement of CO_2 requires a much greater accuracy than excess O_2 to establish the combustion efficiency.

3.2 PERFORMANCE EVALUATION

A number of performance-calculation procedures are practiced today. In some companies, the performance of each unit is checked periodically by extensive heat-rate tests. Techniques and procedures for performing such evaluations are presented in ASME PERFORMANCE TEST CODES. In some cases these procedures are too stringent, and it will be possible to modify and/or relax them and still obtain an acceptable test result.

All procedures are based on the steady-state steady-flow energy equation:

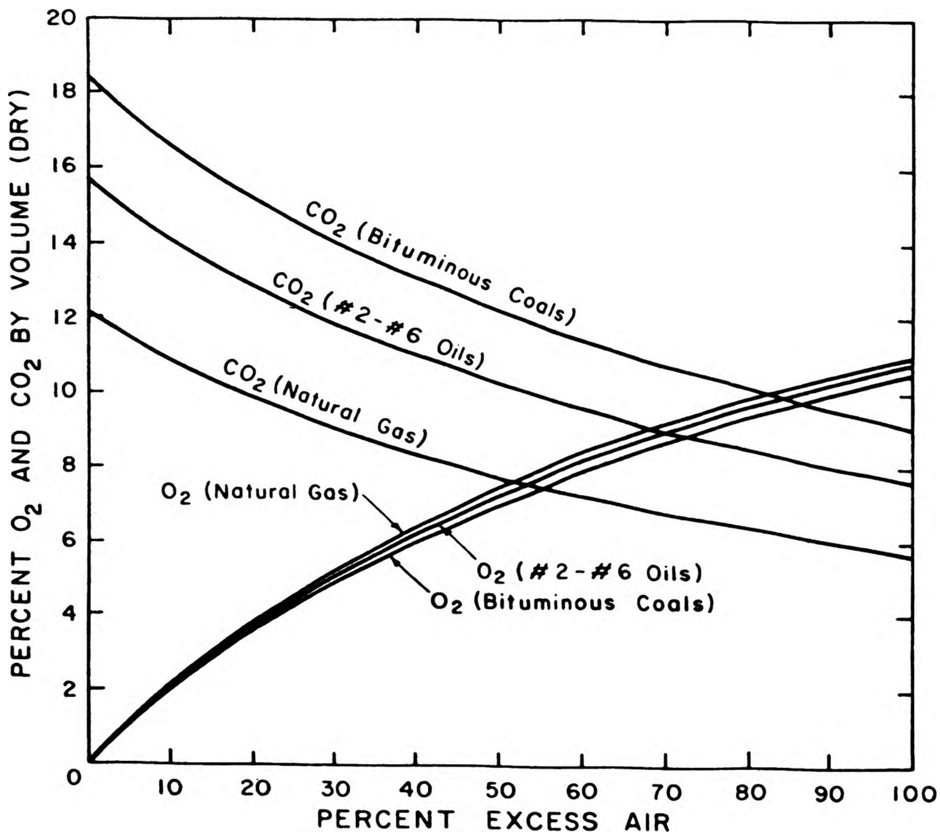

Figure 1. Boiler excess air and stack gas concentrations of excess oxygen (O_2) and carbon dioxide (CO_2) for typical fuel compositions.

Sum of the energy into the boiler = Sum of the energy out of the boiler

An acceptable definition of efficiency is then devised, and the methods of making the necessary measurements for completing the energy balance are established.

There are two procedures which are used to determine the efficiency of steam generation plants. The <u>direct method</u> measures energy transfer to the water and the amount of fuel consumed. The <u>indirect method</u> is a measure of the combustion efficiency. The indirect method is the most accepted method of determining boiler efficiencies in the field. This method might be termed the flue gas analysis approach since the major heat losses are based on the measured flue gas conditions at the boiler exit together with an analysis of the fuel composition.

3.3 TUNING BOILERS FOR PEAK EFFICIENCY

First, inspections need to be performed on burner, combustion controls, and furnace to verify that these components are functioning according to design. Secondly, to improve efficiency by establishing the lowest level of excess oxygen at which the boiler or burner can operate safely. Since most industrial boilers operate over a wide load range, tests must be run at several firing rates to determine the minimum excess-oxygen level for each. Once this procedure is completed the combustion-control system is considered tuned for optimum fuel economy.

At each firing rate tested, excess oxygen in the flue gas should be varied from approximately 1% above the normal operating point, down to where the boiler starts to smoke, or to where CO exceeds 500PPM. This establishes the minimum oxygen point. The smoke limit condition generally applies to coal and oil firing, since smoking usually occurs before CO reaches significant levels. The CO limit normally pertains to gaseous fuels.

A proven method for determining the minimum levels of excess oxygen required for combustion involves developing CO/oxygen and smoke/oxygen curves, similar to those shown in Figures 2 and 3. Based on actual test conducted at each firing rate, these curves show how boiler CO and smoke levels change as excess oxygen is varied.

Caution is required on the operator's part when reducing air/fuel ratio near the CO or smoke limits - that is, one must carefully monitor instruments and controls, flame appearance, and stack conditions simultaneously. Decrease the excess oxygen level in very small increments until there is enough data to establish the curves shown in Figures 2 and 3.

A high minimum-oxygen reading is sometimes to be expected depending on the air register position, a burner malfunction, or other fuel related problems. But remember that different minimum-oxygen requirements are expected from different burner designs. Many burners exhibit a higher minimum-oxygen level at low firing rates than they do at high firing rates. Therefore, it is difficult to specify a range of minimum oxygen levels that would be considered normal for all boilers.

Results of boiler testing at many industrial sites, allow you to judge whether the minimum-oxygen levels you measure are typical values. The data: For liquid fuels, 2-4%; for natural gas is 0.5-3%; for pulverized coal, 3-6%; and for stoker-fired coal, 4-8%.

The next step is to determine the necessary operating margin above minimize-oxygen where the boiler can be operated routinely. Typical margins above minimum-oxygen may range from 0.5% to 2% depending on the characteristics of the particular boiler-control system and the fuel being burned. If the boiler is to be operated at a constant firing rate for extended periods, the smallest possible margin should be selected.

3.3.1 A STEP-BY-STEP PROCEDURE FOR TUNING BOILER

(1) Select a normal firing rate and switch combustion controls to manual operation.

(2) Record stack and boiler data such as pressure, temperatures, etc., and observe flame conditions. If you find that the excess oxygen in the flue gas is at the lower end of the range of typical minimum values, and if CO and smoke are at acceptable levels, the boiler is most likely at peak efficiency at this particular firing rate.

(3) Increase air flow to the furnace until readings of excess oxygen at the stack increase by 1%.

(4) Reduce air flow in small increments. Record stack excess-oxygen reading, smoke, the concentration of CO in flue gas, and stack temperature following each small change. Remember not to reduce air flow by throttling the burner air registers, because this alters the fuel and air mixing characteristics.

(5) Continue to reduce air flow until you reach one of these limits:

- Unacceptable flame conditions or flame instability.
- High level of CO in the flue gas as shown in Figure 3.
- Smoking limit reached at stack as shown in Figure 2.
- Equipment related problems such as low windbox/furnace pressure.

(6) Develop smoke/O_2 or CO/O_2 characteristics curves, like those shown in Figures 2 and 3, using the data obtained at each air-flow setting.

(7) Find the minimum excess-oxygen level for your boiler from these curves from step (6) but do not adjust the burner controls to this value. This may be the point of maximum efficiency, it usually is impractical to operate the boiler at this setting, because of the tendency to smoke, or to increase CO to dangerously high levels, as load changes, changes in fuel properties, changes in ambient conditions, play in automatic controls.

(8) Establish the necessary margin in excess-oxygen above the minimum value. Add this to the minimum value and reset burner controls to operate automatically at the established level.

(9) Repeat steps (1)-(8) for each firing rate for a normal operating range.

4. REFERENCES

(1) "Guidelines for Industrial Boiler Performance Improvement", KVB, INC., January 1977; NTIS No. PB 264 543.

(2) "Measuring and Improving the Efficiency of Boilers" - A Manual for Determining Energy Conservation in Steam Generating Power Plants", by David F. Dyer and Glennon Maples, Auburn University, Auburn, Alabama.

(3) "Boiler Efficiency Improvement Seminar and Workshop Manual", by Dupree Maples and Gerald D. Whitehouse, Louisiana State University, Baton Rouge, Louisiana.

5. BIOGRAPHIES

DUPREE MAPLES, Professor of Mechanical Engineering, Louisiana State University. Dr. Maples earned his Bachelor's and Master's degrees at Mississippi State University and his Ph.D. in Mechanical Engineering at Oklahoma State University. He has industrial experience with Exxon and academic experience with Mississippi State University, Oklahoma State University and Louisiana State University. He has served as project leader on several governmental and industrial research and development projects and is actively involved in consulting in the areas of heat transfer and energy conservation. He is a member of AIAA and ASEE.

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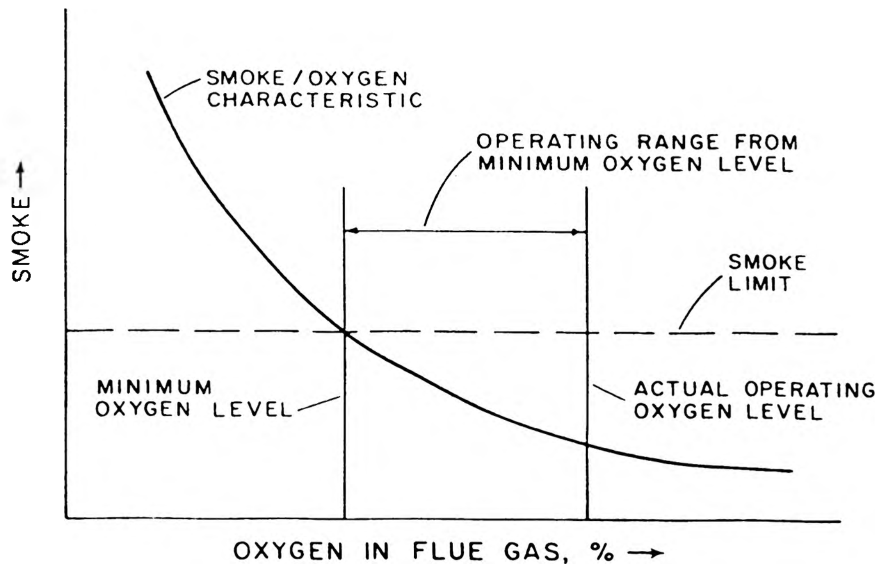

Figure 2. Smoke/oxygen characteristics to identify the minimum amount of excess oxygen required for combustion of liquid and solid fuels for an actual burner being fired.

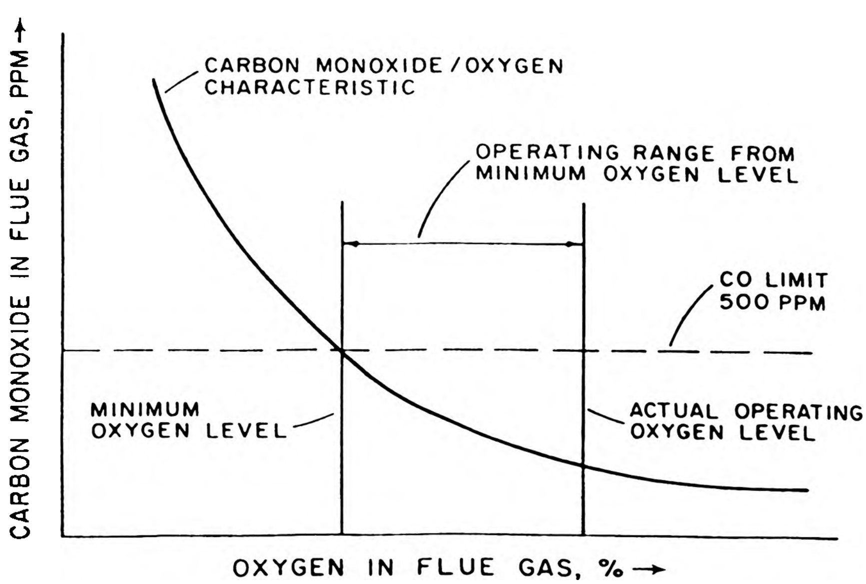

Figure 3. CO/oxygen characteristics to identify the minimum amount of excess oxygen required for combustion of gaseous fuels for an actual burner being fired.