

# **GUIDELINES FOR INDUSTRIAL BOILER PERFORMANCE IMPROVEMENT**

## **BOILER ADJUSTMENT PROCEDURES TO MINIMIZE AIR POLLUTION AND TO ACHIEVE EFFICIENT USE OF FUEL**

### **GUIDELINES INTENDED FOR USE**

- By personnel responsible for boiler operation to perform an efficiency and emissions tune-up**
- By plant engineers to initiate maintenance and efficiency monitoring practices**
- As a supplement to manufacturer's service instructions**

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## FOREWORD

This guide has been published by the American Boiler Manufacturers Association (ABMA) to provide operators and owners of industrial boilers with information as to techniques and procedures to operate such boilers economically and in an environmentally satisfactory manner.

The guide was prepared under joint EPA/FEA contract and reviewed by an ABMA Technical Committee. It is based on a program of field tests conducted as a part of research into factors affecting performance of stoker fired boilers.

The contents of this guide are offered as guidance only. The American Boiler Manufacturers Association does not assume responsibility or liability for consequences arising from the implementation or failure to implement the guidance contained herein. The contents of this guide should not be construed as an endorsement by ABMA of any product or manufacturer.

This guide is intended as a supplement to the manuals furnished by the equipment manufacturers who should be consulted regarding operational or equipment problems.

The research on which this guide is based was conducted under a program co-funded by the United States Department of Energy and the United States Environmental Protection Agency who should be credited for their perception of the need for such a research project.



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The guideline manual was prepared from several sources of information within KVB, Inc. The principal authors were Dale E. Shore and Michael W. McElroy.

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## SECTION 1.0

### INTRODUCTION

The purpose of this manual is to provide general guidelines for use by industrial boiler operators to reduce stack emissions of nitrogen oxides and improve boiler operating efficiency. These guidelines deal primarily with boiler adjustments which are typically within the control of boiler operators and plant engineering personnel. However, other techniques are also described in the Appendices which will usually require the assistance of outside combustion specialists due to the more critical dependence on specific boiler design, operating conditions and fuel characteristics.

Since efficiency and emissions are sensitive to many of the same boiler operating parameters, it is essential that both of these areas be simultaneously treated in one integrated set of guidelines. The recommended procedures in this report are based on the results of U.S. Environmental Protection Agency (EPA) and Federal Energy Administration (FEA) sponsored programs (Refs. 1 and 2) during which various nitrogen oxides reduction methods were evaluated in the field and improvements in boiler efficiency were demonstrated.

Oxides of nitrogen are a major contributor to the total air pollution problem existing in industrial areas. Generally referred to as "NO<sub>x</sub>", this gaseous pollutant includes both nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>), although NO<sub>2</sub> generally comprises only five percent or less of the total NO<sub>x</sub> 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".

Boilers used in industry produce a significant fraction of the total industrial emissions of NO<sub>x</sub>. In fact, industrial boilers produce 50 percent of the NO<sub>x</sub> emitted from all stationary industrial combustion sources (Ref. 3). A reduction in emissions from just this single industrial source would obviously contribute greatly to improving the national air quality.

Industrial boilers currently account for over 15 percent of all the energy consumed in the United States, or more than 11 quadrillion Btu's per year (Ref. 2). An increase in industrial boiler efficiency would therefore significantly impact energy conservation nationwide as well as reduce industries' fuel costs. The EPA and FEA sponsored field test programs revealed that improvements in efficiency of up to several percent were frequently possible by simply adjusting the fuel/air ratio to minimize stack gas heat losses.

During the two-year EPA field test program, substantial reductions in nitrogen oxides emissions were achieved through careful adjustment of existing boiler equipment. Usually little or no deleterious effects on combustion controls or boiler reliability occurred when the optimum adjustments were established. In fact, substantial improvements in boiler efficiency often accompany "low NO<sub>x</sub>" operation. However, adjustments for improved efficiency occasionally conflicted with attempts to reduce emissions, requiring a tradeoff between emissions and fuel usage, or preferably the application of alternate NO<sub>x</sub> emission controls.

This guide begins with a simplified discussion of the fuel burning process to provide the boiler

operator with a basic understanding of NO<sub>x</sub> formation in the boiler and the major combustion-related factors important to efficiency. With this background, the techniques for reducing NO<sub>x</sub> and improving boiler efficiency are then discussed in detail and instructions are provided to assist the boiler operator in applying them to a particular boiler installation. Emphasis is on reducing the boiler excess air to the lowest practical level. This will require that the operator have a working knowledge of the boiler's combustion control system and the required flue gas analysis instrumentation necessary to perform the boiler adjustments safely and effectively. It is important that this entire guide be read and understood before attempting any boiler adjustment or modifications.

## IMPORTANT NOTICE

To be generally applicable to all industrial boiler installations, these guidelines could not be prepared as a self-contained document. Due to the wide variety of combustion control systems, burner designs and furnace geometries in use, and the variation in operating demands, it will be necessary that these guidelines be supplemented by other information sources available to boiler operating personnel. These might include:

- The Plant Engineering Staff
- Boiler Operating and Maintenance Manuals
- Boiler Equipment Manufacturers and Their Service Organizations

In addition, local and national boiler safety codes must be observed at all times. Any apparent contradiction between these codes, the boiler manuals, and the guidelines, must be resolved before proceeding. It is also intended that these guidelines be used for equipment fired with conventional fuels (i.e., hard coals, #2 through #6 fuel oils, and natural gas.) Although many of the concepts and recommendations will be applicable to other fuels, these may require special considerations and procedures which have not been addressed in these guidelines.

## SECTION 2.0

### FUNDAMENTALS OF COMBUSTION

The heat energy in all fossil fuels (coals, fuel oils, and natural gases) is released during the combustion process as the carbon and hydrogen in the fuel react with oxygen to produce a high temperature flame. The burning of carbon and hydrogen with oxygen would ideally produce an exhaust gas consisting of carbon dioxide ( $\text{CO}_2$ ) and water vapor ( $\text{H}_2\text{O}$ ) which are considered harmless combustion byproducts. Unfortunately, real combustion systems differ 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. As a result, the exhaust products from industrial boilers contain additional gaseous and solid materials, some of which are identified as serious environmental pollutants (see Appendix D). Some are products of incomplete combustion and are important from an efficiency standpoint, since they represent a waste of available heat that is lost from the boiler stack.

Air is the convenient and non-varying source of oxygen for nearly all industrial combustion processes. The composition of air is roughly 21% oxygen ( $\text{O}_2$ ) and 78% nitrogen ( $\text{N}_2$ ) by volume with traces of other gases including argon and carbon dioxide. Under perfect combustion conditions, there is a so-called "theoretical 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 burning 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, boiler firing rate, and the design and adjustment of the burners. If enough air is not provided, unburned fuel, smoke and other products of incomplete combustion such as carbon monoxide ( $\text{CO}$ ) and soot are emitted from the stack, resulting in pollution, wasted fuel energy, and a potential for explosion. In the case of coal fired boilers, the quantity of unburned fuel in the refuse also increases. If too much excess air is supplied to the burner, the boiler efficiency will be reduced because some fuel is used simply to heat the unneeded air which is exhausted out the stack. The amount of excess air can also influence the formation and emission of nitrogen oxides ( $\text{NO}_x$ ) as discussed in a later section.

#### 2.1 FURNACE EXCESS AIR

Excess air is a primary boiler operating variable and an important element in the following discussions. It is therefore appropriate to include a brief discussion of this term and the methods available for determining the quantity of excess air at the boiler.

Accurate fuel and air flow measurements would provide a direct determination of the boiler air/fuel ratio and excess air, but these measurements are frequently not available at industrial boiler installations. An alternate means for determining boiler excess air utilizes measurements of specific gases in the stack and the known relationships between their concentration and percent excess air for a particular fuel.

Excess air in the boiler is evident from the presence of oxygen in the flue gas. This oxygen content is customarily referred to as excess oxygen, excess  $\text{O}_2$  or stack  $\text{O}_2$ . However, the terms "excess air" and "excess  $\text{O}_2$ " should not be confused to mean the same thing. As the

excess air is increased at the boiler, one would expect that the oxygen concentration in the stack gases would also increase, and, indeed, this is the case. Figure 1 shows this relationship between excess  $O_2$  and excess air for typical natural gas, oil and high grade coal fuels.

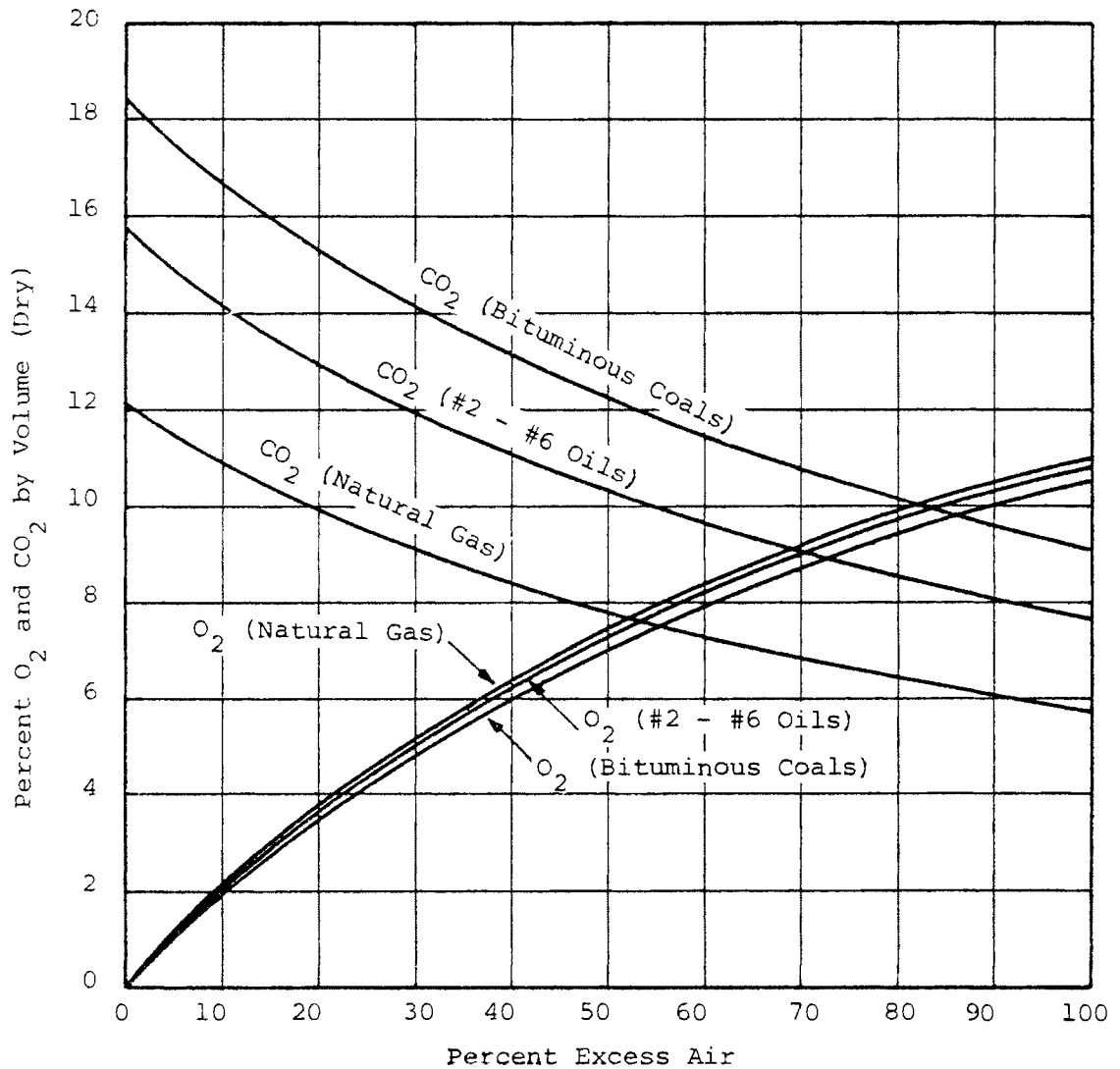


Figure 1. Relationship between boiler excess air and stack gas concentrations of excess oxygen (O<sub>2</sub>) and carbon dioxide (CO<sub>2</sub>) for typical fuel compositions.

Some boiler operators are accustomed to judging boiler firing conditions based on stack CO<sub>2</sub> measurements (as opposed to using excess O<sub>2</sub>) and the CO<sub>2</sub> versus excess air dependence is also shown in Figure 1. While both approaches are equally valid for determining boiler excess air, the use of excess O<sub>2</sub> is preferred for the following reasons:

1. The relation between O<sub>2</sub> and excess air is not highly affected by fuel composition. This is evident in Figure 1 where the O<sub>2</sub> versus excess air curves for natural gas, oil and coal fuels are nearly coincident. On the other hand, CO<sub>2</sub> versus excess air curves exhibit a wide variation with fuel type.
2. Measurement of CO<sub>2</sub> requires a much greater precision than excess O<sub>2</sub> measurements to obtain the same accuracy in excess air. This is especially true when firing with low excess air which is generally the preferred condition for high boiler efficiencies. For example, suppose it is desired to establish the excess air to within  $\pm 2$  percent excess air. If the boiler is operating in the region of 20 percent excess air on oil fuel, the CO<sub>2</sub> would have to be measured to within  $\pm 1.5\%$  accuracy ( $13.0 \pm .2$  percent CO<sub>2</sub>), while an O<sub>2</sub> measurement accuracy of only  $\pm 8\%$  ( $3.7 \pm .3$  percent O<sub>2</sub>) would be required.
3. CO<sub>2</sub> is a product of combustion whereas excess O<sub>2</sub> is more immediately associated with excess air conditions in the boiler. The excess O<sub>2</sub> measured in the stack gases is the actual surplus of oxygen in the furnace available for the combustion process. As lower and lower excess air is present in the furnace, the excess O<sub>2</sub> approaches zero (regardless of fuel type) while the CO<sub>2</sub> increases, approaching some constant value which is dependent on the fuel composition.
4. Instrumentation for excess O<sub>2</sub> measurements is generally less expensive and more reliable as a class than CO<sub>2</sub> instrumentation. Many continuous CO<sub>2</sub> instruments are of a NDIR type which is more expensive and not very portable.

In the following sections of this manual, excess O<sub>2</sub> will be used exclusively as an indicator for excess air. It is strongly recommended that the use of excess O<sub>2</sub> be adopted by all boiler operators. However, for those who still prefer to think in terms of CO<sub>2</sub>, it is possible to convert O<sub>2</sub> to CO<sub>2</sub> using curves such as those in Figure 1 for the particular fuel being fired.

One final note concerns the interpretation of boiler excess air as it relates to excess air at the burner. For boilers with a single burner, the percent excess air at the burner is said to be the same as the boiler excess air (percent excess air at the stack). For multi-burner boilers, the situation can be complicated if the fuel and air are not equally distributed to all the burners. With equal fuel and air distribution, the fuel/air ratio and percent excess air at all burners is the same and equal to the percent boiler excess air. However, when the fuel and/or air varies from burner to burner (due to dissimilar air register settings, eroded fuel injection orifices, coal pipe obstructions, etc.), the fuel/air ratio and burner excess air will also vary. The use of "overfire" air or other air injection ports away from the burner region will of course result in less excess air at the burner than indicated by the stack O<sub>2</sub>. This situation generally occurs only with stoker fired boilers where the concept of burner excess air is not usually applicable due to the non-uniform or time-dependent nature of solid fuel bed burning. In this case, stack excess

O<sub>2</sub> is still an important measurement.

Casing or setting air leaks on induced or balanced draft units can also distort the O<sub>2</sub> readings. In these cases comparison of overfire O<sub>2</sub> and stack O<sub>2</sub> readings can verify the presence of air infiltration to the furnace.

## 2.2 NITROGEN OXIDES

Combustion temperatures on the order of 3500°F are reached in the flame zone of industrial boilers. When oxygen and nitrogen are both present at such high temperatures, a fraction of these will combine to form NO<sub>x</sub>. Nitrogen oxides formed in this manner are difficult to prevent altogether, since all three ingredients (oxygen, nitrogen and high temperature) are integral parts of the combustion process. Nitrogen is the major constituent in the combustion air and its elimination would be very impractical. Most of the NO<sub>x</sub> reduction techniques described in the following sections are generally viewed to be effective as a result of lower peak flame temperature, reduced availability of oxygen in the flame or a combination of both. Oxygen and temperature are important flame parameters affecting stability, radiant heat release, combustible burnout, flame appearance and other boiler operation related factors. Therefore, the successful application of NO<sub>x</sub> reduction techniques involve more than just reducing NO<sub>x</sub> emission levels.

Equal consideration must be given to these other factors to assure safe, reliable and efficient operation. This aspect of implementing low NO<sub>x</sub> firing will involve a certain amount of subjective interpretation of flame conditions in the furnace coupled with an evaluation of boiler efficiency, steam conditions and other boiler operational factors.

Nitrogen oxides produced by the combining of atmospheric nitrogen and oxygen under the influence of high flame temperatures is generally referred to as "thermal NO<sub>x</sub>". Conventional solid and liquid fuels (even some natural gas fuels) contain quantities of nitrogen bearing compounds. A fraction of this nitrogen also combines with oxygen in the flame to produce what is called "fuel nitrogen NO<sub>x</sub>" or simply "fuel NO<sub>x</sub>". This "fuel NO<sub>x</sub>" plus the "thermal NO<sub>x</sub>" make up the total NO<sub>x</sub> emitted from the stack. In some cases with a high nitrogen content fuel, the "fuel NO<sub>x</sub>" can contribute more than half of the total NO<sub>x</sub> emissions.

The formation of "fuel NO<sub>x</sub>" is not presently well understood. There is some evidence that "fuel NO<sub>x</sub>" can be reduced by lowering the available oxygen in the flame. Switching to a fuel which contains less nitrogen has also produced lower total NO<sub>x</sub>; however, this is not always predictable for fuel variations within the same fuel type (i.e., #6 oils, bituminous coals, etc.). It should also be mentioned that measurements of total NO<sub>x</sub> at the stack or furnace outlet will not distinguish between "thermal NO<sub>x</sub>" and "fuel NO<sub>x</sub>". NO<sub>x</sub> variations measured under various boiler operating modes may result from combined effects on both NO<sub>x</sub> components.

Finally, while oxygen availability and flame temperature appear to be the major combustion parameters affecting NO<sub>x</sub> formation, the absolute levels of NO<sub>x</sub> emitted from the stack will also depend on a variety of other factors. As described later on, different types of fuels generally exhibit a different range of NO<sub>x</sub> emissions. This is due to differences in fuel nitrogen already mentioned plus fundamental differences in the fuel burning characteristics, general requirements of the associated burning equipment (stoker versus oil gun) and so on. For a

particular fuel composition, boiler-to-boiler variation in NO<sub>x</sub> emissions also suggest the importance of burner and furnace design and the specific flow patterns of the flame within the furnace. At any given boiler with a constant fuel, the NO<sub>x</sub> emissions are also generally dependent on firing rate.

## 2.3 BOILER EFFICIENCY

The term “boiler efficiency” as used in this manual pertains to the thoroughness by which the boiler extracts the total available heat energy from the fuel. Some loss of heat from the boiler is unavoidable and as a consequence, boiler efficiency is always less than 100%. However, some of these efficiency losses can be minimized or eliminated by proper operating and maintenance practices.

Boiler efficiency losses arise from four major sources:

1. Heat carried away (out the stack) by the hot flue gases. This loss is usually called “dry flue gas” loss. Hotter stack temperatures and larger quantities of excess air increase this loss.
2. Latent heat of water vapor present in the flue gas. (Water vapor results from the combustion of hydrogen contained in the fuel and from moisture present in the fuel and combustion air.) This loss arises from the fact that water vapor contains more heat energy than an equal weight of liquid water. The latent heat would be recovered only if the water vapor were allowed to condense out before the flue gases leave the boiler. Since this would be impractical in conventional boiler systems, (due to corrosion problems and reduced plum rise), the latent heat is not considered recoverable.
3. Unburned fuel and products of incomplete combustion. These include solid combustibles in refuse, carbon carryover from the furnace, and all other solid and gaseous combustible material carried away in the flue gases. This loss is usually referred to as “combustible loss” or “unburned fuel loss.” Improperly adjusted burning equipment or an inadequate quantity of excess air can lead to rapid increases in combustible losses.
4. Heat lost from the boiler jacket through its insulation. This is generally termed “radiation loss” and includes heat radiated to the boiler room and the heat picked up by the ambient air in contact with the boiler surfaces. The quantity of heat lost in this manner is fairly constant at different boiler firing rates and as a result, becomes an increasingly higher percentage of the total heat losses at the lower firing rates. Deteriorated insulation and furnace wall refractory will also increase these losses at all loads.

Figures 2 and 3 illustrate how the various efficiency losses are affected by changes in excess O<sub>2</sub> and firing rate. These results are based on actual measurements at a 13,000 lb/hr boiler fired with natural gas but the general trends are also representative of many natural gas, oil and coal fired boilers. Of course, the actual values of the various efficiency losses will be different depending on specific fuel properties, boiler/burner design, operating conditions, etc.

At each firing rate the highest boiler efficiency is achieved by firing with the lowest practical excess  $O_2$ . For the particular example in Figure 2, the point of maximum efficiency occurred at about .5% excess  $O_2$  where the total efficiency losses were at a minimum. (Excess  $O_2$  levels at peak efficiency can vary significantly from boiler to boiler and with different fuels. These can be determined at a boiler by a test procedure described in Sections 3.0 and 4.0). A further reduction in excess  $O_2$  caused rapid increases in carbon monoxide and other combustibles which resulted in a very rapid deterioration in efficiency.

With high excess  $O_2$ , some fuel is used to heat unneeded excess air to the stack temperature where it is carried out the stack (resulting in higher “dry flue gas” losses and reduced efficiency). It might at first seem that large quantities of excess air would mix with the flame and cool it, resulting in a lower stack gas temperature. In practice, however, the reverse is true. High excess air does cool the flame and cool the furnace. But, at the same time, the boiler must fire more fuel to generate the same quantity of steam and proportionately greater amounts of air are fed through the burner. Consequently, greater amounts of gas pass through the boiler so quickly that they retain their heat instead of transferring it to the tubes. This explains why stack temperatures generally increase as the excess  $O_2$  is raised, contributing to reduced efficiency.

It would be desirable to operate at the point of peak efficiency at each firing rate to minimize fuel wastage. However, as described later in this manual, there are certain limitations in typical boiler combustion controls which require that boilers be operated at some point slightly below peak efficiency to avoid combustibles and potentially unsafe conditions.

Figure 3 illustrates that there are significant changes in efficiency losses as the firing rate is varied. Especially obvious are the “radiation loss” which increases at lower firing rates and the “dry flue gas” loss which increases at higher firing rates. These characteristics and the “total efficiency loss” curve shown in the figure are very representative of many industrial boilers. Lowest losses (highest efficiencies) occur over the range of firing rate from approximately 50% to 80% of capacity. Operating the boiler in this range as much of the time as possible would therefore be desirable from a fuel efficiency standpoint.

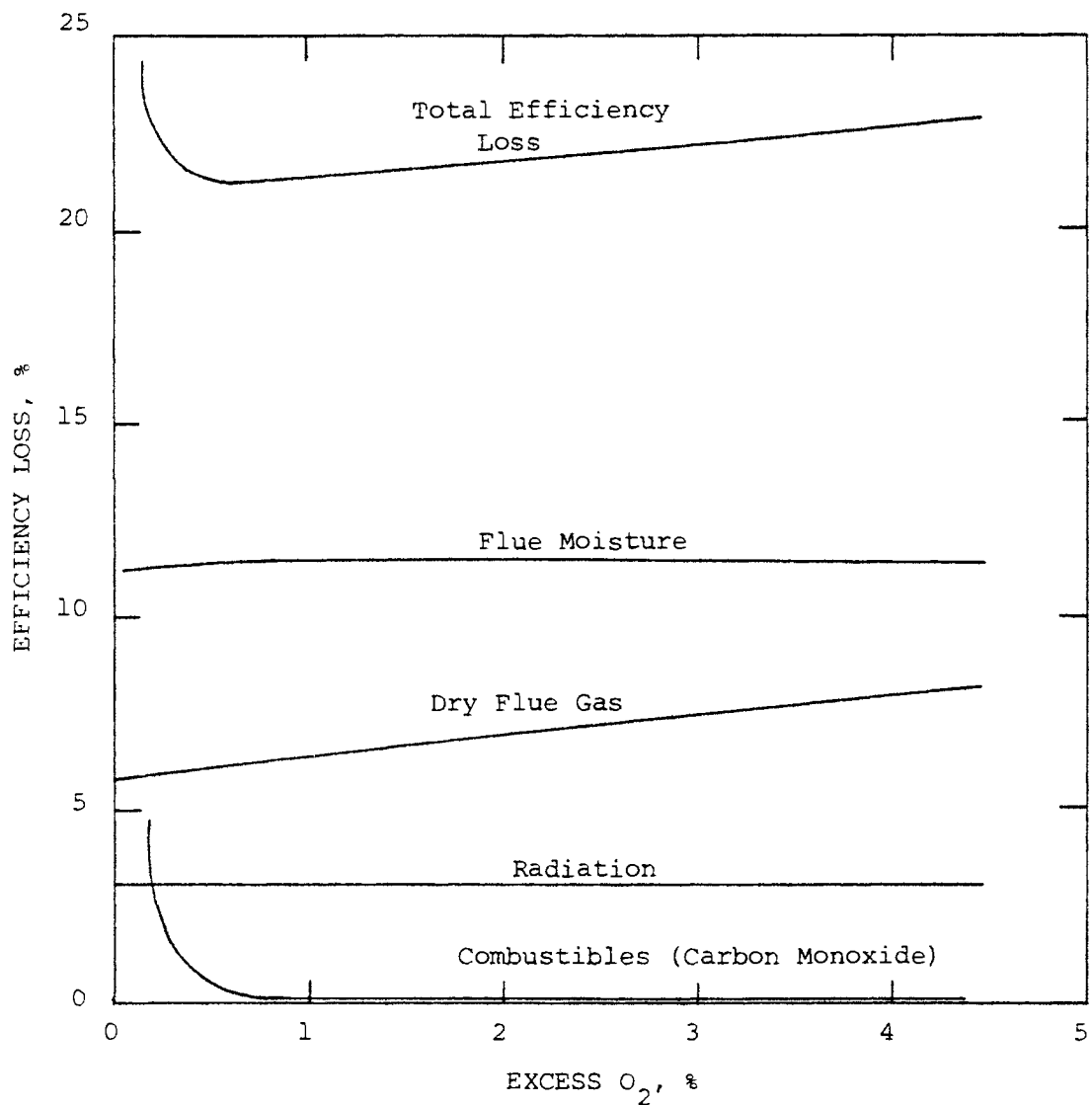


Figure 2. Variation in boiler efficiency losses with changes in excess O<sub>2</sub>.

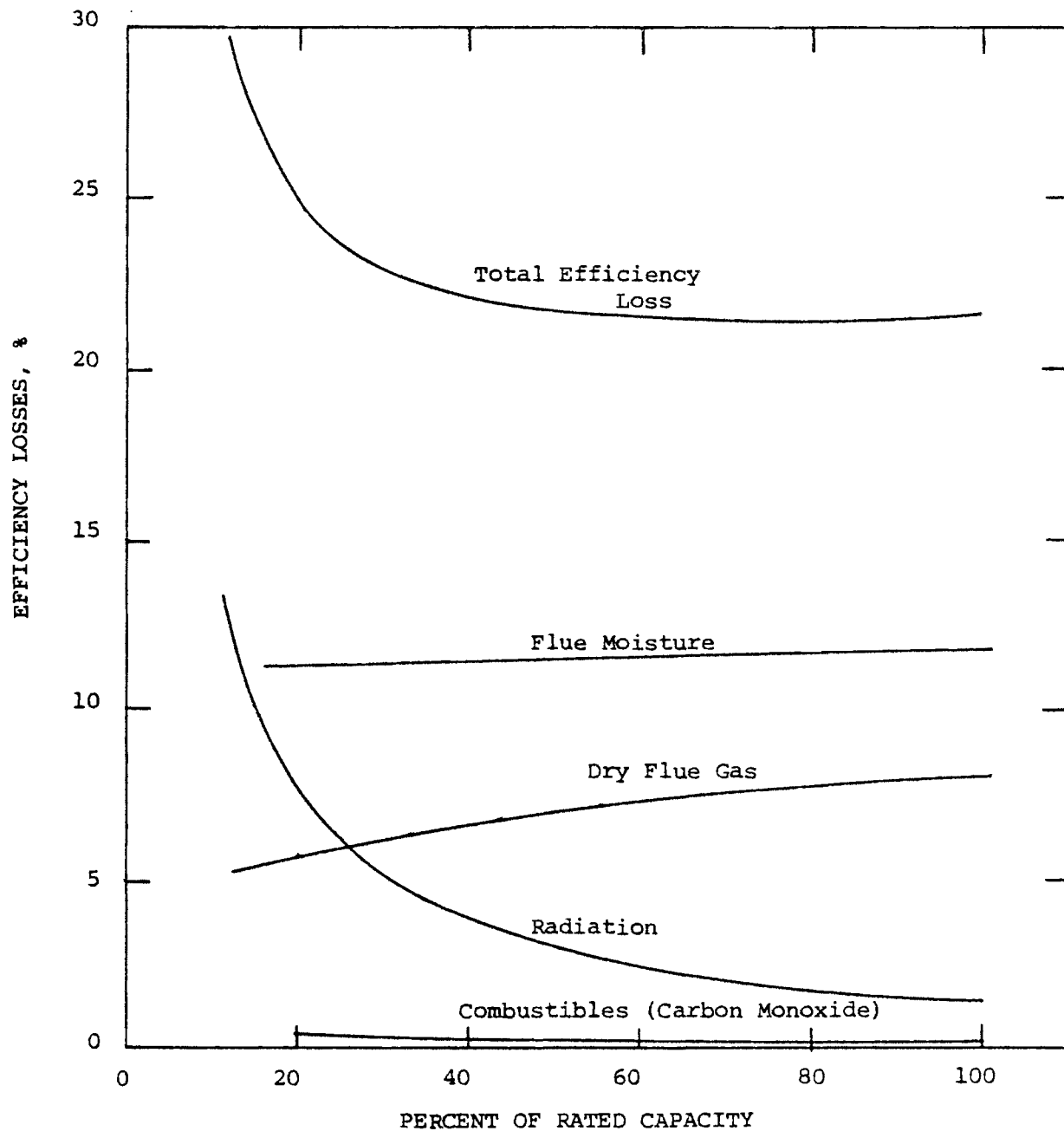


Figure 3. Variation in boiler efficiency losses with changes in boiler firing rate.

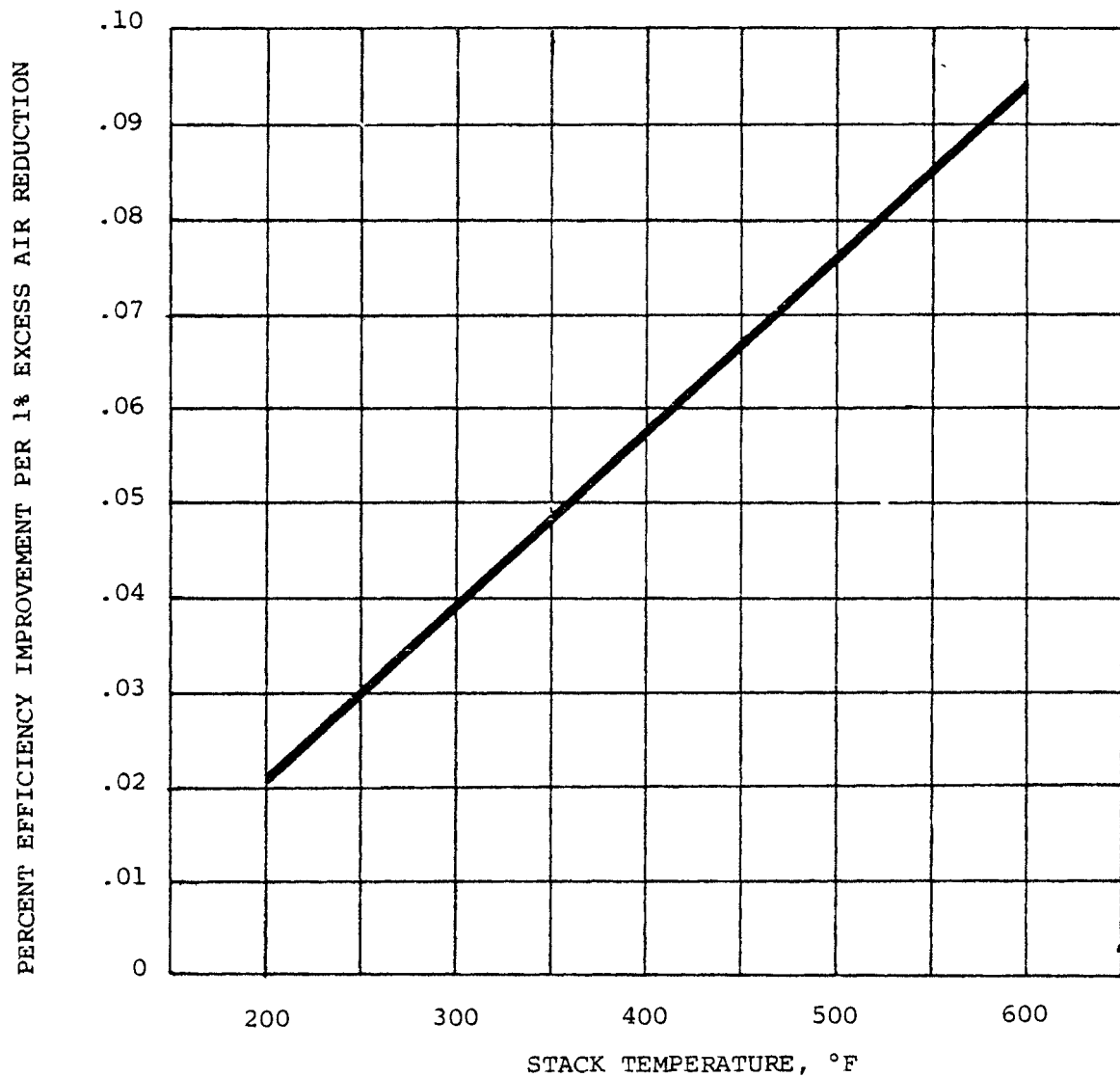


Figure 4. Curve showing percent efficiency improvement per every one percent reduction in excess air. Valid for estimating efficiency improvements on typical natural gas, #2 through #6 oils and coal fuels.

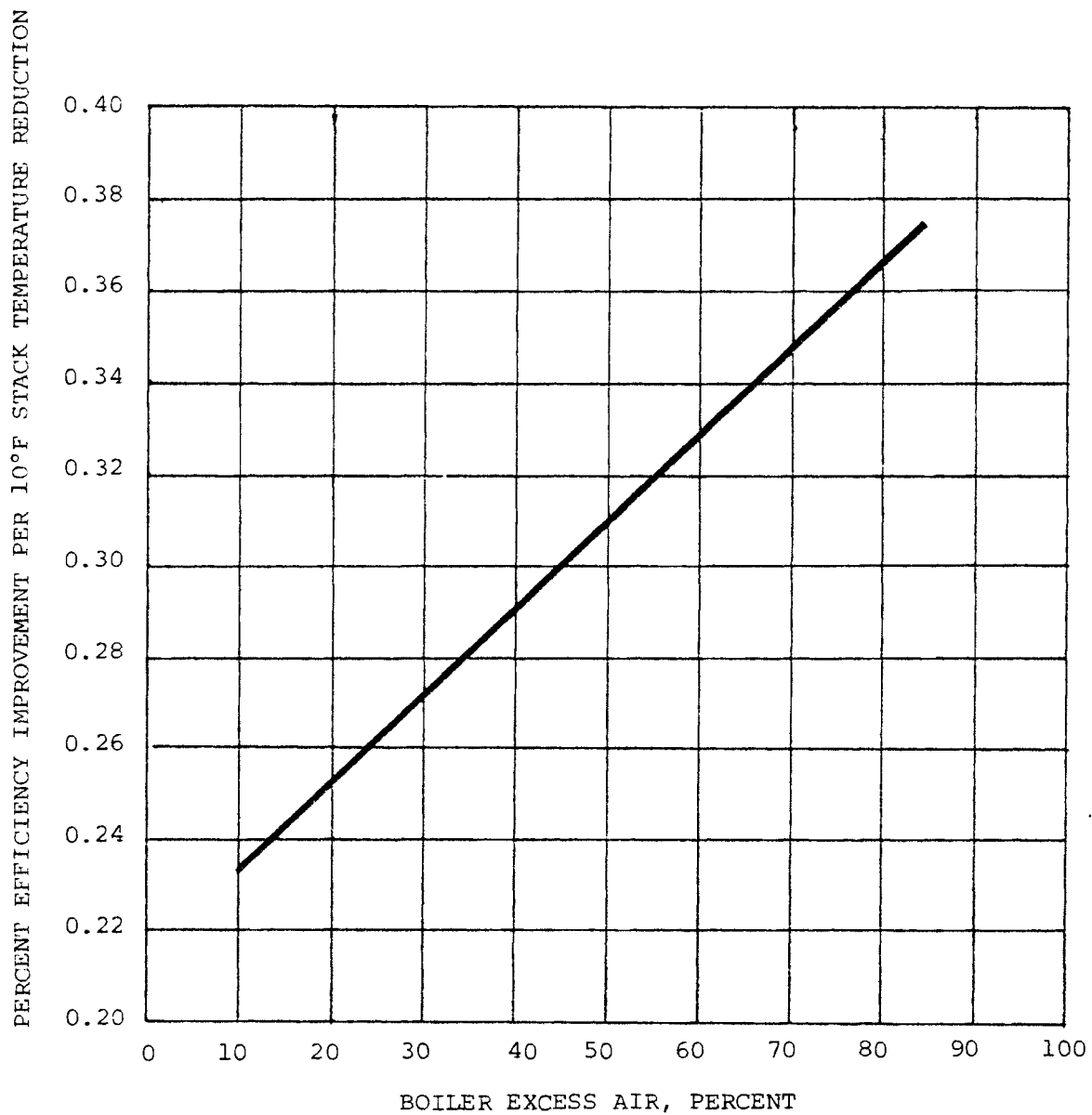


Figure 5. Curve showing percent efficiency improvement per every 10°F drop in stack temperature. Valid for estimating efficiency improvements on typical natural gas, #2 through #6 oils and coal fuels.

Later in this manual, the basic approach and test equipment necessary to identify the point of maximum efficiency will be described in detail. Once this information is available for a particular boiler, it can be used together with NO<sub>x</sub> emissions measurements to determine the optimum boiler operating practice for high efficiency and reduced NO<sub>x</sub>.

The efficiency improvement for a boiler at each firing rate will depend on the reductions in excess O<sub>2</sub> possible and the stack temperatures. To aid in determining the actual efficiency improvements, Figure 4 gives the approximate percent efficiency improvement corresponding to each 1% reduction in excess air. Since reductions in excess O<sub>2</sub> will be measured directly, use Figure 1 to convert excess O<sub>2</sub> to excess air and then determine the efficiency improvement at the proper stack temperature. For example, if the excess O<sub>2</sub> was reduced from 6% to 3.5%, from Figure 1 it is determined that the excess air dropped from 40% to 20%, a 20% total change. If the stack temperature was 400°F, the efficiency improvement was 20 times .058 or 1.16 percent.

Reductions in stack temperature will also generally occur as the excess O<sub>2</sub> is lowered. To account for this effect, perform the previous calculation using the initial stack temperature and add to this improvement the efficiency improvement obtained from Figure 5. This additional improvement from Figure 5 is the effect of reduced temperature and is determined using the final lower excess air level. To illustrate, if in the previous example, the stack temperature dropped from 400°F to 370°F, as the excess O<sub>2</sub> was lowered from 6% to 3.5%, the effect due to the 30°F lower stack temperature would be 3 times .252 which equals .76 percent. The total improvement in efficiency is then 1.16 plus .76 for a total improvement of approximately 1.92 percent. Figures 4 and 5 can be used to estimate efficiency improvements achieved at constant firing rates on natural gas, #2 through #6 oils and common bituminous and subbituminous coals.

Some boiler operators who use these guidelines may find that their boilers' efficiency can be improved by 1 or 2 percent which might at first seem to be a small improvement having little effect on total fuel costs. However, even for the smallest boilers, these seemingly small improvements can lead to significant annual fuel savings which easily justifies the time and effort spent in achieving the improvements. Consider, for example, a 10,000 lb/hr boiler that is operated year-round with an average annual loading of one-half full capacity. If the efficiency is improved by 2 percent over the boiler operating range, the annual fuel consumption will decrease by 2.5 percent, assuming the boiler efficiency is approximately 80 percent. (Percent fuel reduction equals efficiency improvement times 100, divided by the efficiency.) If the boiler is fired with #6 oil costing \$2.00 per million Btu, the annual fuel savings would be nearly \$2,800. For larger boilers, this savings would increase in proportion to the size of the boiler (\$28,000 for a 100,000 lb/hr boiler and so on).

## SECTION 3.0

### PREPARATION FOR BOILER TESTS

To reduce NO<sub>x</sub> emissions and improve boiler operating efficiencies, it will be necessary to determine how NO<sub>x</sub> and efficiency vary as boiler adjustments are made. To successfully

accomplish this will require a preliminary boiler inspection to assess the existing condition of the furnace, burner equipment and firing parameters. Completing any necessary repairs and adjustments will insure that the subsequent efficiency and emission results are representative of the most favorable, as-designed, condition of the boiler. In some cases, this first step will itself directly lead to efficiency improvements and reduced NOx emissions.

The other essential part of the efficiency improvement/NOx reduction guidelines involves the actual testing to establish the optimum boiler adjustments. Discussion items will include boiler instrumentation, visual furnace observation, stack emission measurements and data sheets. Some of these areas involve procedures and equipment which have not traditionally been a part of routine boiler operating practice. Since much of this material may be new to most industrial boiler operators, a discussion of these items before describing the step-by-step test procedure would be helpful.

### 3.1 PRELIMINARY BOILER INSPECTION

Even when boiler equipment is in poor operating condition, “best” boiler settings for improved efficiency and reduced NOx emissions can still be found under these conditions using the test procedures in the following section of the manual. However, it is stressed that these efficiency and NOx emission improvements obtained under a deteriorated state of the boiler can be substantially less than the improvements achieved when the boiler equipment is in proper working order. To attain maximum fuel savings and lowest stack emissions, it is essential that the condition of the boiler be examined prior to testing and that any necessary repairs or maintenance be completed.

A comprehensive list of maintenance items which can affect boiler efficiency and NOx emissions is provided in Reference 4. This list is a useful supplement to the manufacturer’s boiler operating and maintenance manual and both should be used to ready the boiler for the efficiency and emission tests. Prior to making extensive adjustments and/or repairs, the manufacturers’ field service department or other combustion consultants should be consulted. Some of the more common items to be included in the preliminary boiler inspection are summarized below.

#### 3.1.1 Burners

For oil firing, make sure that the atomizer is the proper design and size for the type of oil and burner geometry. (There may have been a mix-up between boilers when oil tips were removed at the cleaning bench.) Inspect the oil tip passages and orifices for excessive erosion and remove any coke or gum deposits to assure a proper oil spray pattern. Check to see that oil temperatures at the burner are at recommended levels. (See Section 4.3) Atomizing steam, if used, must be at the proper pressure. Make sure that burner diffusers are not burned off or broken and are properly located with respect to the oil gun tip. Also check that the oil gun is positioned properly within the burner throat. Any damaged or missing burner throat refractory should be replaced. Oil strainers should be in place and clean.

When firing natural gas, inspect the gas injection orifices and verify that all passages are unobstructed. Filters and moisture traps should be in place, clean, and operating to prevent plugging of gas orifices. Proper location and orientation of diffusers, spuds, gas canes, etc.