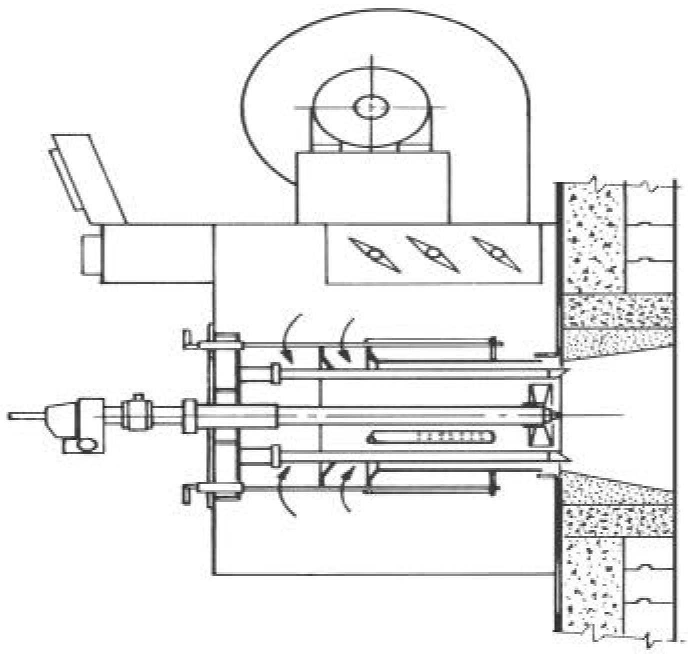
Tech Paper #924

Improving Boiler Room Efficiencies

A Seminar on the ways and means of increasing boiler room efficiencies.



Drawing courtesy of Coen Burner

Combustion Control Strategies For Single and Dual Element Power Burners

Presented by

David C. Farthing

Federal Corporation

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A Message from the speaker

Energy costs today are at there highest in recent history. Gaining whatever efficiencies may be found in thermal processes can help to stabilize the effects of rising energy cost.

Also today's economic and environmental demands dictate that we get the greatest practical efficiencies from our plants. To do this we must have a basic understanding of what those efficiencies are and how we may implement them.

My hope for you today is, that you will leave this seminar with a clearer understanding of some of the economically and technically feasible opportunities you have to improve your steam plant.

Regards,
David C. Farthing
Industrial Sales Manager
Federal Corporation

Introduction

Improved efficiency can have many connotations everything from fuel savings, improved equipment operation and useful life span, to labor and manpower savings. This paper will focus on combustion control and energy savings through the practice of combustion efficiency management. The strategies presented will have both technical and economic feasibility discussions presented with them.

Steam Plant Optimization & Automation

Steam plant optimization is the overall improvement of the plant's operation. The most common strategies used to accomplish this task includes, and generally focuses on, the improvement of primary equipment operating efficiency, i.e. fuel and energy savings. In heavy commercial and industrial boiler applications these efficiencies are normally found in the application of waste heat recovery equipment, systems and process automation, and improved operating practices.

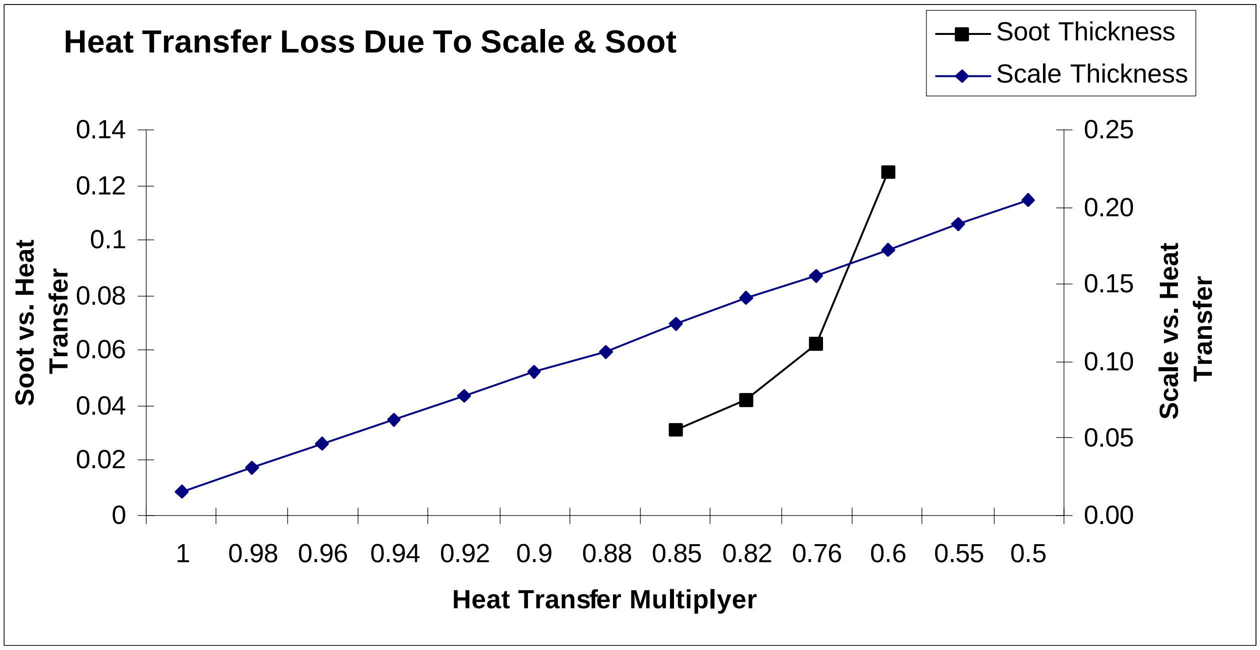
The use of more advanced automatic control systems for combustion control has proven to be an excellent example of systems and process automation success. The new control systems available today help improve overall combustion efficiency and burner stability over varying loads and demands. The most sophisticated systems can eliminate the need for operator input during load changes while maintaining safe and reliable fuel/air ratio control.

The strategies presented in this paper apply to both single and dual fuel burners.

Keeping It Clean

One of the myths that need's to be cleared-up before we go forward is the effect of boiler and plant cleanliness on improving efficiency. Keeping boiler furnace and watersides clean does not improve efficiency. Keeping these surfaces clean maintains the factory delivered efficiency of the equipment. That is the efficiency rating the equipment *was designed to have* and shipped from the factory with. Allowing these surfaces to become dirty or scaled lowers the original design efficiency, thus requiring more energy to accomplish the same amount of work.

As can be seen in the chart below, a waterside scale build-up of .03 inch can result in a 2% loss of thermal efficiency. Increase the scale thickness to 0.095 inch and you can expect losses of 10% or greater.



© David Farthing's TechStuff Rev.12 'The effect of Scale & Soot Build-up on Heat Transfer in Boilers'

Conversely soot build-up in the furnace of .02 inch can result in as much as a 15% loss in thermal efficiency. Keeping these fireside and waterside surfaces in good order is paramount to efficient operations.

Additionally a clean plant lowers the risk of accidents and allows the operating staff more efficient access to equipment and operating environments. It's just plain common sense and good practice. It is also the first place to look when implementing any thermal efficiency improvement program.

The Combustion Process

The most common fuels used in single burner commercial and industrial boilers are natural gas and #2 oil. Both of these fuels consist of carbon and hydrogen. Combustion is the rapid oxidation of the fuel to release the chemical heat energy in the carbon and hydrogen. Stoichiometric, or perfect, combustion occurs when the exact proportions of fuel and oxygen are mixed to obtain complete conversion of the chemical energy in the carbon and hydrogen in the fuel to yield maximum heat energy. These ideal proportions of fuel and oxygen vary directly with the BTU content of the fuel. Too much excess oxygen only serves to cool the flame while too little oxygen results in incomplete combustion and sooting of the furnace or delayed combustion, which can result in a furnace explosion.

Fuel	Caloric Value	Ideal Volumetric Air / Fuel Ratio
Natural Gas	900 – 1050 BTU/CuFt.	9.71 CuFt. Air to 1 CuFt. Fuel
#2 Fuel Oil	138-140,000 BTU/ Gal.	9579 CuFt. Air to 1 Gallon Fuel

Because of specific design restrictions or lag times inherent in current burner design, a certain amount of excess air (oxygen) is always required to insure complete combustion in the furnace chamber. These restrictions take the form of delays in fuel and air flow due to friction losses in piping or lag times in the flow control elements. Additional influences may be in the form of site location elevation and the effects of combustion air temperature, humidity and availability.

These design restrictions dictate some form of fuel-air metering control for safe and efficient combustion control. The systems available for this task vary in sophistication from the simplest fixed position control system to the elegant metered-cross limited fuel-air ratio control systems. This paper discusses the benefits of several of these systems as they apply to single burner packaged boilers.

Combustion Strategies

Fixed Position Parallel Control

Fixed Position Parallel Control (FPC), also known as Jack-Shaft Control, is perhaps the simplest form of combustion control found on power-burner boilers. This control strategy incorporates a single positioning motor, which drives both the fuel and air positioning devices via an interconnected single mechanical linkage, the jack-shaft.

The simplicity of the FPC control strategy makes it a very economical choice for small burners with modest firing rate changes. However the fact that the fuel and air are fixed means that the fuel/air ratio is also fixed. Because of this fixed position arrangement the burner has no way to compensate for environmental changes such as combustion air temperature or fuel pressure. Additionally, the FPC strategy has no feedback to the control element to insure that the fuel and air end devices are actually functioning and in the correct position. This could lead to a crossover condition in which the fuel crosses over the air flow and results in a fuel rich furnace or other burner efficiency loses.

To help prevent a fuel rich furnace the FPC system is normally setup to allow additional excess oxygen to the furnace, in the range of 4.5 to 8%. In practice the excess oxygen is normally set at 6% to compensate for seasonal air temperature changes. This excess air results in lower thermal efficiency by burdening the burner with unnecessary air, which only serves to cool the furnace.

Parallel Positioning Control Systems

Parallel Positioning Control (PPC) systems function very much like a Fixed Position Parallel system except that the fuel and air end devices are separated and driven by their individual positioners. Modern PPC systems incorporate an end-device positioning signal, which ensures the fuel and air positioners have moved to their pre-specified positions for a specific firing rate. This signal, while not actually proving final end device position and true fuel/air ratio flow, is a marked improvement over FPC systems.

The new systems are gaining wide acceptance with many users who have traditionally used FPC systems and are seeking an economic means to improve overall combustion efficiency. The modern PPC system is suitable for boilers ranging from 100 through 900 Boiler horsepower with relatively stable loads.

Modern electronic positioning PPC systems can hold excess oxygen levels to within 4-6% on many applications. It should be noted however that the PPC control strategy should be used with caution in applications with extremely fast load swings, as controllers and positioners which might be set too tightly may not properly respond and still maintain a safe fuel/air ratio on large and fast upsets.

Series Metered Control System

The Series Metered Control (SMC) system is common on larger boilers (above 750 Bhp) where load changes are neither large nor frequent. In this application both the fuel and the air are metered. The Boiler Master regulates air flow by setting the air flow setpoint. The air flow controller then cascades the air flow signal to the fuel controller as its remote setpoint. A ratio algorithm is applied to the remote setpoint signal sent to the fuel controller to adjust the fuel/air ratio. The ratio algorithm compares the remote setpoint cascaded to the fuel controller by the air flow and positions the fuel flow control valve to maintain the specified ratio between the two.

This ratio algorithm has an inherent lag in it due to the fact that the air controller is always directing the fuel controller’s function; air always leads fuel. This lag provides a desirable lean furnace on demand rise, as the air controller must respond to the Boiler Master before sending a remote setpoint to the fuel controller. However on a fast falling demand the lag between the air controller and fuel controller can result in the air flow overshooting the fuel flow resulting in a fuel rich furnace.

Because of this lag characteristic the Series Control system is adequate for near steady state conditions due its inability to react to fast falling load swings. Fast swings can result in incomplete combustion due to setpoint overshoot and end device lag times. To compensate for these possible overshoots and lag times, excess oxygen levels in series control systems are normally set between 5-8%. The use of an Oxygen trim system is then incorporated to adjust the excess oxygen levels down to 3-4% during steady state operation.

Metered Parallel Positioning Control

Boilers operating at 1000 boiler horsepower and above commonly incorporate the Metered Parallel Positioning control system. The Metered Parallel Positioning Control (MPPC) operates the fuel and air control loops in parallel (as opposed to series) from a single setpoint generated by the Boiler Master controller. The combustion air setpoint is ratioed which establishes the fuel/air proportions.

By allowing for customization of the fuel/air ratio the amount of excess oxygen in the exhaust gases may be reduced to about 5-6% as opposed to the 8% normally found in the Series Metered Control strategy.

The MPPC system relies on near identical response from both the air and fuel control loops to prevent fuel rich or air rich mixtures in the furnace. The difficulty in maintaining this near identical response limits the application of the MPPC system to applications with modest and relatively slow demand swings.

Like the Series system, the traditional MPPC system does not have any feedback to the opposing flow controllers, i.e. fuel does not recognize air and air does not recognize fuel. This absence of feedback can result in a combustion imbalance on large or very fast load swings, resulting in either a fuel rich or lean furnace. To compensate for the lack of feedback found in the MPPC, these systems are normally set-up with additional excess air to over compensate for fuel flow during setpoint excursions. This functionality is used to maintain an air rich furnace on transition.

Cross-Limited Metered Control

Cross-Limited Metered Parallel Positioning Control, (a.k.a. Cross-Limited Control (CLC) or Lead-Lag Control), improves on the MPPC strategy by interlocking the fuel/air ratio control through High and Low selectors. This interlock function prevents a fuel rich furnace by forcing the fuel to follow air flow on a rising demand, and forcing air to follow fuel on a falling demand.

The CLC system is a dynamic system, which easily compensates for differences in response times of the fuel and air end devices. This flexibility allows its use in systems which experience sudden and large load swings, as well as very precise control at steady state operation.

The CLC operates as follows. In steady state, the steam demand signal, fuel flow and air flow signals to the High and Low selectors are equal. Upon a demand increase the **Low** selector applied to the fuel loop forces the fuel flow to follow the lower of either the air flow or steam demand setpoint. Conversely on a falling demand the **High** selector applied to the air controller forces the air flow to follow the higher of either the fuel flow or demand setpoint. This High/Low selector function insures that the burner transitions are always air rich/fuel lean thus preventing a fuel rich furnace environment.

The Cross-Limited Control system can easily maintain excess oxygen levels in gas burners to 3-4% and 2.5-3% in #2 oil systems. Additionally since fuel flow can not increase (cross-limited) until air flow has begun to increase, fuel can not overshoot air flow.

Because of the CLC system's capability for close tolerance in control it is suited for all sizes of boilers, which can support the systems cost economically. Additionally the CLC system is readily adapted to Oxygen Trim control as well as being suited for low NOx burner applications.

Example #1 Upgrading a MPPC to a CLC system

The following example is a comparison of a Metered Parallel system to a Cross Limited combustion control system.

Fuel (Gas =1, Oil =2)	**1**
Rated Boiler Hp	**1175**
Name Plate Efficiency	**76.00%**
Current O2 % as found	**5.50%**
Normal Firing Rate NFR (0-100)	**67%**
Recommended O2% @ NFR	**2.75%**
Average Hours/Day Run Time	**12**
Average Days/Month Run Time	**22**
Fuel Cost/Therm from billings	**0.414**
Average Combustion Air Temp	**80**
Stack Temp at Firing Rate	**625**
Net Flue Gas Temp Rise	**545**
As Found Thermal Efficiency	**76.0%**
New Calculated Thermal Efficiency	**77.9%**
New Stack Temp	**611**
Net Efficiency Gain	**2.44%**
Current Cost to Operate Per Month	$ 37,887.35
New Cost to Operate Per Month	$ 36,963.26
Savings Per Month	**$ 924.08**
Savings Per Year	**$ 11,088.98**

Financial Analysis of Example #1

Project Name	**Converting From MPPC to CLC control 1175 Bhp @ 67% firing rate**	
Initial Cost of Investment Materials		**$ 7,800.00**
Initial Cost of Investment Installation		**$ 4,860.00**
Annual Pay Back Expected from this investment		**$ 11,089.00**
Base Line Years to Payout		**1.14**
Fixed Cost of Money in percent to be used for this exercise		**6.85%**
How many Years will the Project be Amortized over?		**5**
First Year Cost of Money		**$ 107.61**
Second Year Cost of Money		**$ 53.81**
Third Year Cost of Money		**$ 35.87**
Fourth Year Cost of Money		**$ 26.90**
Fifth Year Cost of Money		**$ 21.52**
Estimated Cost of Perishables during first five years of ownership		**$ 560.00**
NET Years to Payout		**1.21**
Expected Life Span of Investment		**15.00**
***Total Dollars Returned Over Life of Investment**		**$ 151,189.28**

Example #2 Converting a FPC to a PPC system Small Boiler

The following example is a comparison of a Fixed Position Control to a Parallel Position combustion control system.

Fuel (Gas =1, Oil =2)	1
Rated Boiler Hp	450
Name Plate Efficiency	78.00%
Current O2 % as found	6.50%
Normal Firing Rate NFR (0-100)	70%
Recommended O2% @ NFR	2.50%
Average Hours/Day Run Time	12
Average Days/Month Run Time	22
Fuel Cost/Therm from billings	0.414
Average Combustion Air Temp	80
Stack Temp at Firing Rate	625
Net Flue Gas Temp Rise	545
As Found Thermal Efficiency	75.2%
New Calculated Thermal Efficiency	77.9%
New Stack Temp	605
Net Efficiency Gain	3.47%
Current Cost to Operate Per Month	$ 15,321.02
New Cost to Operate Per Month	$ 14,790.00
Savings Per Month	**$ 531.02**
Savings Per Year	**$ 6,372.29**

Financial Analysis of Example #2

Project Name	**Converting From FPC to PPC control 450 Bhp @ 70% firing rate**	
Initial Cost of Investment Materials		**$ 19,291.00**
Initial Cost of Investment Installation		**$ 18,326.00**
Annual Pay Back Expected from this investment		**$ 6,372.00**
Base Line Years to Payout		**5.90**
Fixed Cost of Money in percent to be used for this exercise		**6.85%**
How many Years will the Project be Amortized over?		**5**
First Year Cost of Money		**$ 2,140.28**
Second Year Cost of Money		**$ 1,070.14**
Third Year Cost of Money		**$ 713.43**
Fourth Year Cost of Money		**$ 535.07**
Fifth Year Cost of Money		**$ 428.06**
Estimated Cost of Perishables during first five years of ownership		**$ 560.00**
NET Years to Payout		**6.76**
Expected Life Span of Investment		**15.00**
***Total Dollars Returned Over Life of Investment**		**$ 50,836.02**

Example #3 Converting a FPC to a PPC system Medium Boiler

The following example is a comparison of a Fixed Position Control to a Parallel Position combustion control system.

Fuel (Gas =1, Oil =2)	1
Rated Boiler Hp	850
Name Plate Efficiency	78.00%
Current O2 % as found	6.00%
Normal Firing Rate NFR (0-100)	72%
Recommended O2% @ NFR	**2.50%**
Average Hours/Day Run Time	12
Average Days/Month Run Time	22
Fuel Cost/Therm from billings	0.414
Average Combustion Air Temp	80
Stack Temp at Firing Rate	625
Net Flue Gas Temp Rise	**545**
As Found Thermal Efficiency	**75.6%**
New Calculated Thermal Efficiency	**77.9%**
New Stack Temp	**608**
Net Efficiency Gain	**2.95%**
Current Cost to Operate Per Month	$ 29,609.07
New Cost to Operate Per Month	$ 28,734.86
Savings Per Month	**$ 874.21**
Savings Per Year	**$ 10,490.50**

Financial Analysis of Example #3

Project Name	**Converting From FPC to PPC control 850 Bhp @ 72% firing rate**
Initial Cost of Investment Materials	**$ 19,291.00**
Initial Cost of Investment Installation	**$ 18,326.00**
Annual Pay Back Expected from this investment	**$ 10,490.00**
Base Line Years to Payout	**3.59**
Fixed Cost of Money in percent to be used for this exercise	**6.85%**
How many Years will the Project be Amortized over?	**5**
First Year Cost of Money	**$ 1,858.20**
Second Year Cost of Money	**$ 929.10**
Third Year Cost of Money	**$ 619.40**
Fourth Year Cost of Money	**$ 464.55**
Fifth Year Cost of Money	**$ 371.64**
Estimated Cost of Perishables during first five years of ownership	**$ 560.00**
NET Years to Payout	**4.04**
Expected Life Span of Investment	**15.00**
***Total Dollars Returned Over Life of Investment**	**$ 113,250.11**

Conclusion

While there are many factors effecting return on investment, such as fuel cost, run time and thermal effeicency of the boiler in question, as can be seen from the examples we have evaluated, increasing plant efficiencies through combustion management does pay back. It is important however, to do a total financial analysis of the project for the actual payback period. This is especially important when the cost of the total project… materials, installation, and documentation is to be considered.

About the Author

David C. Farthing

Mr. Farthing combines his twenty-eight years of experience in thermal processes with a degree in General Engineering Technology from Oklahoma State University as well as a degree in Business from the University of Central Oklahoma. He is both a practitioner and academic in the field of boilers and thermal process control systems, as Sales Manager for Federal Corporation and adjunct instructor of '*Boiler Construction, Operations, and Maintenance'* for Oklahoma State University, Oklahoma City campus.

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