Planning and Setup for the Implementation of Coal and Wood Co-Fired Boilers

Christopher D. Gump

Problem Report submitted to the
College of Engineering and Mineral Resources
at West Virginia University
in partial fulfillment of the requirements
for the degree of

Master of Science
in
Industrial Engineering

Committee:
Bhaskaran Gopalakrishnan, Ph.D., Chair
Wafik Iskander, Ph.D.
Kenneth Means, Ph.D.

Department of Industrial Management and Systems Engineering

Morgantown, West Virginia

2007

Keywords: Boiler, Coal, Wood, Energy

ABSTRACT

Planning and Setup for the Implementation of Coal and Wood Co-Fired Boilers

Christopher D. Gump

Coal and wood co-fired boiler technology has been significantly advancing in the past years, but many of their capabilities remain unknown to much of the industry today. The term "co-firing", when used by members of the biomass or utility communities, has come to mean mixing a modest amount of clean, dry sawdust with coal and burning the sawdust coal mixture in the existing coal firing equipment of a large, coal-burning, utility boiler.

What does not exist in the world of co-fired boilers is a software or guideline that allows one to observe the energy saving opportunities available, when installing a boiler of this type, which would make this technology more appealing to industry. The work that is being proposed here would be to create a computer software program to allow coal-wood co-fired boilers to be sized, priced, implemented, and operated properly based on the information provided by the user. Information about the equipment that is required for the boiler replacement project is provided. Along with these features, the software would allow the user to observe energy savings that would be available upon installation as compared to other types of boilers. The energy savings that are available as a result of implementing these types of boilers present very significant cost savings. This report outlines how these savings are realized, and which steps must be taken to ensure the proper operation of the boiler to achieve these savings.

A sensitivity analysis has also been performed on the implementation of coal-wood co-fired boilers in order to determine which key factors affect the project payback period the most. The key factors that are considered in the analysis are the boiler size, the annual operating hours, and the current fuel cost rate. An additional analysis is done on the boiler size and the annual operating hours at the same time. This analysis allows for the user to determine if their current facility falls into the feasible range for implementing a coal-wood co-fired boiler system.

The future work that should be done in this field is outlined as well. Research steps that must be taken in order to further advance this type of technology and related technology is outlined and explained.

Table of Contents

CHAPTER 1

Introduction…… Page 1
Capabilities of Coal-Wood Co-Fired Boilers…… Page 2
What is Biomass?…… Page 3
Boilers…… Page 4
Water-Tube Boilers…… **Page 4**
Fire-Tube Boilers…… **Page 5**
Fuel…… Page 7
Fuel Feed, Storage, and Preparation Systems…… **Page 7**
Blending the Coal-Wood Fuel Mixture…… **Page 8**
Fuel Storage and Feeding Systems…… **Page 9**
Ash Removal…… **Page 11**
Elimination of Fuel Dust in Boiler Exhaust…… **Page 11**
Electrostatic Precipitators…… **Page 11**
Nitrogen Oxide Formulation…… **Page 12**
Emissions and Pollution Control Technologies…… **Page 13**

Need for Research…… Page 17

Research Objectives…… Page 17

CHAPTER 2

Literature Review…… Page 20
Improved Process Control…… Page 20
Performance of Co-Firing Wood and Coal…… Page 21
Co-Pulverizing and Co-Firing…… **Page 21**
Nitrogen Oxide Emissions…… **Page 22**
Corrosion in Superheaters…… **Page 23**
Summary…… **Page 24**

CHAPTER 3

Research Approach & Software Programming…… Page 25
Software Input: Fuel Parameters…… Page 25
Software Input: Facility Parameters…… Page 26
Financial Aspects of the Computer Software…… Page 26
Software Output…… Page 27
Programming the Software…… Page 27
Programming Difficulties…… **Page 27**

Software Input………………………………………………….… **Page 29**
Software Output……………………………………………….….. **Page 31**
Calculations and Database…………………………...………… **Page 32**
Conclusions…………………………………………………………… Page 32

CHAPTER 4

System Execution and Results……………………………………….……… Page 33
Example Input………………………………………………………… Page 33
Example Output……………………………………………………… Page 35
Capacities and Cost……………………………………...……… Page 37
Installation of the New Boiler…………………………...…… Page 40
Determining the Best Conditions for Implementation……………….. Page 41
The Affect of Boiler Size…………………………………………… **Page 41**
The Affect of Operating Hours…………………………………… **Page 43**
The Affect of Fuel Cost…………………………...……… **Page 44**
The Affect of Boiler Size and Annual Operating Hours……...….. **Page 45**
Conclusion……………………………………………….………… Page 46

CHAPTER 5

Conclusions and Future Work…………………………………………… Page 48
Conclusion……………………………………………………….. Page 48

BIBLIOGRAPHY………...……..…………………….……………………….. **Page 51**

Supplementary Material: Excel Spreadsheet - Click here to access the file

List of Figures

Page

Figure 1.1: Schematic Diagram of a Marine-Type Water Tube Boiler……….…………**5**
Figure 1.2: Schematic Diagram of a Horizontal Fire-Tube Boiler……….……………………**6**
Figure 1.3: Picture of a Typical Coal Pulverizer……….……………………………...**7**
Figure 1.4: Storage Bin with Walking Floor and Metered Screw Feed Configuration…..**9**
Figure 1.5: An Example of a Metered Screw Feed System….…………………………**10**
Figure 1.6: An Example of a Walking Floor Feed System…….………………………..**10**
Figure 1.7: Typical Electrostatic Precipitator Box…………….………………………..**12**
Figure 1.8: Schematic Diagram of a low-NOx Burner……….…………………………**14**
Figure 1.9: Process Diagram for Computer Software Program….……………………...**19**
Figure 2.1: Precipitator used to Control Emissions from a Wood Fired Boiler…...……**23**
Figure 2.2: Example of Steel Corrosion...………………………………………………**24**
Figure 3.1: Fuel Type Pulldown Menu From Software…...……………………………**29**
Figure 4.1: A Screen Shot from the Software Displaying Parameters to this Point…….**34**
Figure 4.2: A Screen Shot from the Software Displaying Output to this Point…...……**37**
Figure 4.3: Screen Shot Showing Sizing and Pricing Parameters and Project Payback Period…………………….………………………………………….……**40**
Figure 4.4: Plot of Boiler Size vs. Project Payback Period……...……………………...**42**
Figure 4.5: Plot of Annual Operating Hours vs. Project Payback Period…...…………..**43**
Figure 4.6: Plot of Fuel Rate vs. Project Payback Period……...………………………..**45**
Figure 4.7: Plot of Boiler Size and Annual Operating Hours vs. Project Payback Period……………………….…………………………………………………**46**

CHAPTER 1

Introduction

Coal and wood co-fired boiler technology has been significantly advancing in the past years, but many of their capabilities remain unknown to much of the industry today. The term "co-firing", when used by members of the biomass or utility communities, has come to mean mixing a modest amount of clean, dry sawdust with coal and burning the sawdust coal mixture in the existing coal firing equipment of a large, coal-burning, utility boiler.

What does not exist in the world of co-fired boilers is a software or guideline that allows one to observe the energy saving opportunities available, when installing a boiler of this type, which would make this technology more appealing to industry. The work that is being proposed here would create a computer program to allow coal-wood co-fired boilers to be sized, priced, implemented, and operated properly based on the information provided by the user. Along with these features, the software would allow the user to observe energy savings that would be available upon installation as compared to other types of boilers.

Without this computer software, a number of available benefits are not being utilized. Because of the high price of many traditional fuels such as natural gas and electricity, financial losses are occurring in the high costs paid for fuel. Because these fuels are in such high demand, the cost continues to rise with the increasing demand. As traditional fuel sources continue to be used, they are also continuing to be depleted. As the supply of these types of fuels become less and less, the cost will continue to rise.

Because there is not a large demand for coal and wood fuels at this point in time, and it does not seem that these fuels will ever be a dominate energy source, the cost for these fuels as compared to the previously mentioned traditional fuels is much lower. Therefore, the financial savings that can be achieved are significant.

Without this computer software, these factors may continue to go unnoticed. Without the industry being informed of alternative fuel capabilities, the industry will continue to deplete the current fuel supplies at increasing rates. This will continue to become more of a serious problem if alternatives are not developed in the near future. This software will help to initialize the interest in these types of alternative fuels, which will hopefully lead to further investigation and research in the field of alternative fuel use. Any new technology and techniques that can be developed to utilized alternative fuel sources and lessen the load on traditional fuels will benefit economy and environment worldwide.

Before one can properly understand the functions and capabilities of wood-coal co-fired boilers, there is a large amount of background information on these boilers that should first be understood by the user of the computer software.

Capabilities of Coal-Wood Co-Fired Boilers

Capabilities possessed by coal-wood co-fired boilers as compared to traditional fuel burning boilers are that coal-wood fired boilers allow for the use of waste wood such as sawdust, wood pellets, and any other types of waste wood that would otherwise be disposed of in a non-efficient manner. The wood must be converted into sawdust before being used in the co-firing process. The major capability of coal-wood co-fired boilers is the opportunity for major energy savings. Burning these alternative fuel sources helps to conserve more in-demand energy sources like natural gas, oils, and electricity. The energy conservation opportunities that co-fired coal and wood and other biomass fuels present are too significant to be unexplored. The cost of coal, wood and other biomass fuels is much lower than traditional fuel sources such as natural gas, electricity, and many other typically more expensive fuels. Therein lies the greatest savings opportunity for implementing coal-wood co-fired boilers. Implementing these types of alternative fuel boilers into a given facility can be simpler than most companies believe. The feed and storage systems for alternative fuel sources are usually simple systems that can be implemented at a reasonable cost. Other than these storage systems, the boiler setup is quite similar to any other traditional boiler configuration. Companies can sometimes be discouraged by the thought of implementing a boiler system burning alternative fuels. This study and resulting calculation software should help to encourage the use of alternative fuels which will allow companies to save money and resources. There are a number of different equipment options and configurations for implementing a coal-wood co-fired boiler system, and this study will serve as a guide for installing coal-wood co-fired boiler systems in certain facilities.

What is Biomass?

Coal-wood co-fired boilers are considered as "solid-fuel" fired boilers. This includes coal and wood as well as many other biomass fuels. Biomass, in terms of the energy production industry, refers to living and recently living biological material which can be used as fuel. Most commonly, biomass refers to plant matter grown for use as biofuel, but also includes plant or animal matter used for production of fibres, chemicals or heat. Biomass may also include biodegradable wastes that can be burnt as fuel. It excludes organic material which has been transformed by geological processes into substances such as coal or petroleum. It is usually measured by dry weight. Biomass is grown from several plants, including switchgrass, hemp, corn, willow and sugarcane. This study will focus primarily on coal and wood co-fired boiler applications[1].

Boilers

There is a variety of different size and capacity boiler systems available today. This study will consider coal-wood co-fired boilers in the range of 15 HP to 800HP (~0.5 MMBtu/hr to ~26.8 MMBtu/hr), as most boilers used in industry fall within this range of capacity. Typical coal-wood co-fired boiler do not react very quickly to drastic changes in steam demand. Therefore, these types of boilers are more suitable for opertions that operate under steady load conditions. The size and needs of various facilities will dictate the size of each piece of equipment will be best suited for that specific facility. Along with the different size boilers, there is a number of different designs. Two particular designs are a water tube boiler design, and a fire tube boiler design.

Water-Tube Boilers

A water tube boiler design is a boiler in which water circulates in tubes that are heated by external fire. Water tube boilers are used for high-pressure boiler systems. The fuel is burned inside the furnace, which creates hot gas that heats up the water in the steam-generating tubes. In many instances, natural gas or air is pumped into the furnace in order to increase combustion efficiency. This is very commonplace in most boiler designs, no matter the specific type. Utility boilers rely on the water filled tubes that make up the walls of the furnace to generate steam. The heated water then rises into the steam drum. Here, saturated steam is drawn off the top of the drum. In some designs, the steam re-enters the furnace through a superheater in order to become superheated. Cool water at the bottom of the steam drum returns to the feedwater drum via large-bore downcomer tubes, where it helps to pre-heat the feedwater supply. To increase the efficiency of the boiler, the exhaust gases are also used to pre-heat the air blown into the furnace and warm the feed water supply[1]. A Schematic diagram of a marine-type water tube boiler is presented in Figure 1.1.

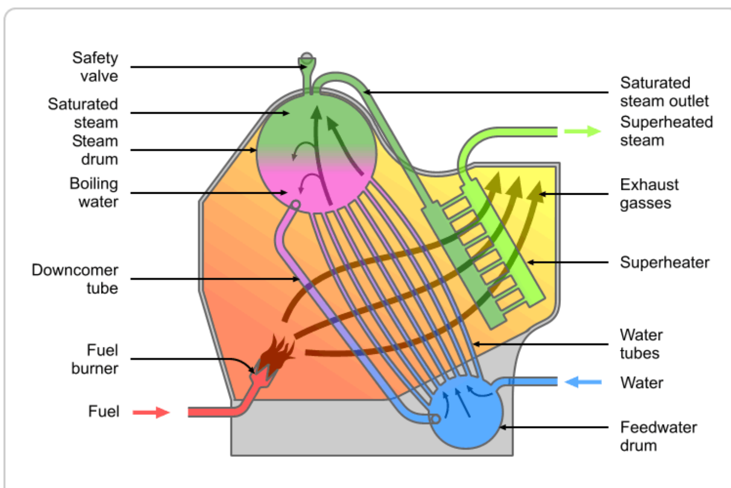


Figure 1.1: Schematic Diagram of a Marine-Type Water Tube Boiler
Source: www.wikipedia.org[1]

Fire-Tube Boilers

A fire tube boiler is a boiler in which hot gases from the burning fire pass through one or more tubes within the boiler. A fire tube boiler can be configured to be horizontal or vertical. This type of boiler is considered to be "traditional" or "old" among modern designs. These boilers were mainly used in locomotives with a horizontal configuration. In this type of boiler, fuel is burnt in a firebox to produce hot combustion gases. The firebox is enclosed by a cooling jacket of water which is connected to a long, cylindrical boiler tube. The hot gas is directed along a series of fire tubes, or flues, that go into the boiler and heat the water, which generates saturated steam. The steam then rises to the highest point of the boiler, which is called the steam dome, where it is collected. The steam dome is where the regulator that controls the exit of the steam from the boiler is located. In many designs, the steam passes into a superheater in order to dry the steam and heat it to superheated steam. Exhaust gases are released through a stack, and may be used to pre-heat the feed water to increase the efficiency of the boiler. Many modern industrial boilers use fans to provide forced draughting of the boiler[1]. A schematic diagram of a horizontally configured fire tube boiler is shown in Figure 1.2.

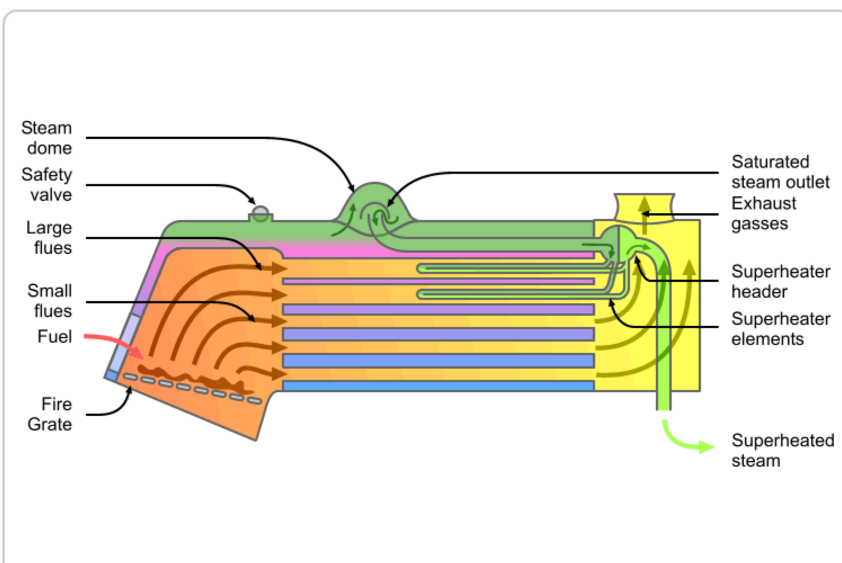


Figure 1.2: Schematic Diagram of a Horizontal Fire-Tube Boiler
Source: www.wikipedia.org[1]

This diagram shows how the flues are configured within the fire-tube boiler, and how the water tubes are surrounded by the heating elements. The steam moves to the highest point of the boiler which is called the steam dome. The saturated steam is then fed to the superheater, where it is converted to superheated steam, and then fed to the process.

Fuel

Most coal-wood boilers burn sawdust with different grades of pulverized coal. The grade of the coal is determined by the composition of the coal, which can be made up of a combination of several different elements.

Fuel Feed, Storage, and Preparation Systems

If a coal pulvrerizing system is required on site, the capacity of the pulverizer is estimated in the software as well. If the wood fuel is to be mixed in with the coal in the pulverizer, only wood in the form of sawdust can be inserted into the pulverizer. Costs of wood grinder equipment will is considered as well if wood fuel is not readily available in dust form.

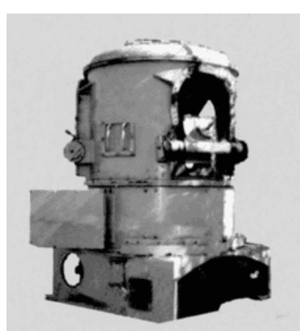


Figure 1.3: Picture of a Typical Coal Pulverizer
Source: Wabash Power Equipment Company; www.wabashpower.com[2]

Figure 1.3 shows a picture of what a basic industrial coal pulverizer looks like. The coal is fed into the machine in various forms, and it is crushed into a dust form of fuel. The wood dust can also be added to the coal in the pulverizer as long as it is in the dust form as to not cause any clogging.

Blending the Coal-Wood Fuel Mixture

The moisture content of the wood sawdust to be burned with the pulverized coal must be less than 20% by weight. The coal is pulverized, and then the wood dust is mixed in with the pulverized coal. If wood dust is not readily available, a grinder can be implemented to convert solid wood to wood dust on site. The blends are typically about 3% wood and 97% coal. The moisture content of the mixture becomes important when emissions are considered. A dryer fuel mixture produces less emissions, which is better. The wood can either be fed to the coal pulverizer to be mixed there, or there can be separate feeding systems for the wood and the coal. This can potentially help to reduce problems that might be incurred when feeding the wood into the pulverizer. Problems that can occur when the wood is fed into the coal pulverizer include clogging and other difficulties in the feed. Boilers can be manually fed, or elaborate feeding systems can be used in order to automatically feed the furnace[3].

In some cases, the wood that is obtained for use in the fuel may be above the recommended moisture content level of 20%. In this case, a system could possibly be set up that would use the boiler exhaust heat to preheat the wood fuel in order to bring the moisture content to a level below 20%. This would be possible by means of a heat recovery system that would be discussed with a manufacturer or engineer working on the project. The heat that is being released from the boiler system through the exhaust stack could be recovered and used as to not expend extra energy on drying the wood.

Fuel Storage and Feeding Systems

In many cases, coal-wood fuel storage bins are used that can store the fuel for extended periods. This can depend on the type of facility or the location of the facility as it is not always applicable to have large amounts of fuel on hand. Problems such as freezing and spontaneous combustion can arise, therefore, most facilities do not keep more than a few days' worth of fuel supply in the storage bin. A common method of fuel storage and feed involves various sized storage bins which use a walking floor feed system to feed the fuel along the bottom of the bin to a metered screw feed system which then transports the fuel directly to the boiler. An example of this configuration is shown in Figure 1.4.

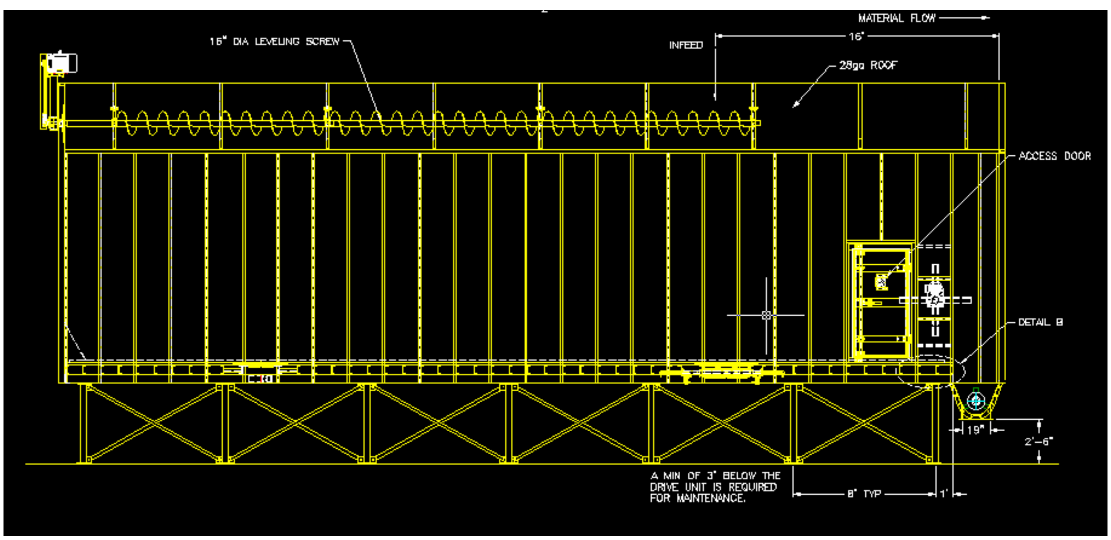


Figure 1.4: Storage Bin with Walking Floor and Metered Screw Feed Configuration
Drawing Supplied by: Keith Walking Floor Manufacturing

A metered screw has an auger mechanism that feeds the coal-wood fuel down a chamber and into the furnace by rotating. The blades of the screw carry the coal-wood fuel in metered amounts so the furnace is being constantly fed with the proper fuel supply. The walking floor feeding system has a number of blades that continuously move the fuel in controlled amounts along the bottom of the fuel storage bin. As the blades move back and forth, while only moving the fuel in one direction of its two direction path of motion, the coal-wood fuel is slowly moved in a constant motion.

An example of a metered screw feed system is shown in Figure 1.5, and an example of a walking floor feed system is shown in Figure 1.6. Figure 1.5 shows how a metered screw feeding system works and how it is possible to measure exactly the rate in which the fuel is fed into the system by the spacing and turning rate of the screw.

Figure 1.5: An Example of a Metered Screw Feed System
Source: www.woodnet.org.uk[4]

Figure 1.6 shows how a walking floor feeding system is configured. Like a metered screw system, the rate at which the fuel is fed can be adjusted.

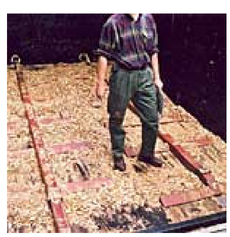


Figure 1.6: An Example of a Walking Floor Feed System
Source: WOODFUELwales; www.woodfuelwales.tthosting.co.uk[5]

Ash Removal

Coal-wood co-fired boilers are equipped with a metered screw auger at the bottom of the firing chamber of the boiler. The auger operates continuously to move ash out of the chamber constantly. The ash is then transported to a disposal receptacle located adjacent to the boiler. A combination of conveyors and the screw augers can be used for effective ash removal.

Elimination of Fuel Dust in the Boiler Exhaust

The exhaust gas from the boiler will contain ash and dust from the furnace which must be removed. The most efficient methods of dust and ash removal from the exhaust gas must be used to meet Environmental Protection Standards. There are a number of methods, techniques, and pieces of equipment available for the removal of dust, ash, and harmful NOx and SOx emissions.

Electrostatic Precipitators

One way to prevent this dust from exiting the boiler with the exhaust gas is by implementing an electrostatic precipitator. The precipitator is a large box that removes the dust from the exhaust gas. The dust laden gases are drawn into one side of the box. Inside, high voltage electrodes impart a negative charge to the particles entrained in the gas. These negatively charged particles are then attracted to a grounded collecting surface which is positively charged. The gas then leaves the gas up to 99.9% cleaner than when it entered. Inside the box, the particles from the continuing flow of dust build up on the collecting plates. At periodic intervals, the plates are rapped, causing particles to fall into hoppers. The particles are then removed from the hoppers[1]. A typical electrostatic precipitator is shown in Figure 1.7. The diagram shows a cut-away view of an electrostatic precipitator including all of the components, the path of the exhaust gases into the precipitator, and the collection hoppers at the bottom. The scale of the size of the unit can be compared to the manhole and railings located at the top.

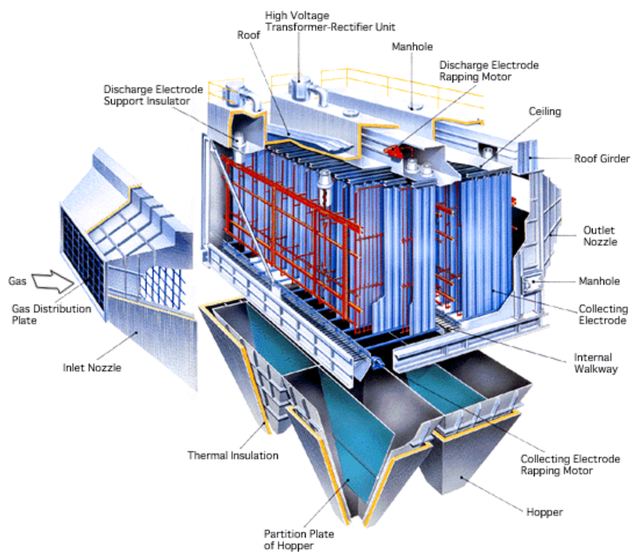


Figure 1.7: Typical Electrostatic Precipitator Box
Source: Mitsubishi Heavy Industries, LTD.; www.mhi.co.jp[6]

Nitrogen Oxide Formation

NOx formation in combustion is an issue in every type of boiler application, but NOx emissions become an even more important area when it comes to coal-wood and other biomass burning boiler applications. NOx emissions are very harmful to the environment if they are not controlled properly. They contribute to acid rain, create harmful levels of ozone, and reduce visibility. Industrial applications such as coal-wood co-fired boilers must meet clean air regulations set forth by the Environmental Protection Agency and the United States Government. There are a number of techniques and technologies that have been used in various boiler applications to achieve the high standards set forth. There are primary and secondary control technologies available to reduce NOx emissions in boiler applications. Primary control technologies reduce the NOx emissions produced in the primary combustion zone while secondary control technologies reduce NOx emissions present in the flue gas away from the primary combustion zone.

Emissions and Pollution Control Technologies

Primary control technologies that exist in industry today are low-NOx burners, or LNB, and OFA, or over-fire air, which is also referred to as air staging. A control system may implement one or both of these technologies to effectively control NOx emissions. A LNB limits NOx formation by controlling the stoichiometric and temperature profiles of the combustion process[7]. This type of control is achieved by using features that regulate the aerodynamic distribution and mixing of fuel and air, which can yield a number of various conditions. Conditions that could be yielded are reduced oxygen in the primary flame zone, which will limit the thermal and fuel NOx formations, reduced flame temperature, which also limits thermal NOx formation, and reduced residence time at peak temperature, which also limits thermal NOx formation[7]. Low-NOx burners have been installed in nearly 75 percent of large U.S. coal-fired power plants. They have typically been effective in reducing nitrogen oxides by 40 to 60 percent. A diagram of a LNB burner is shown in Figure 1.8.

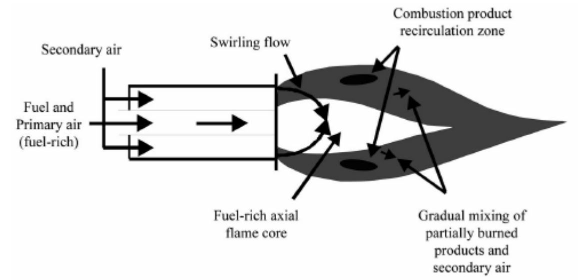


Figure 1.8: Schematic Diagram of a low-NOx Burner
Source: Nitrogen Oxides Emission Control Options for Coal-Fired Electric Utility Boilers; Srivastava, et al, Journal of the Air & Waste Management Association[7]

OFA is a combustion control technology in which a fraction, 5-20%, of the total combustion air is diverted from the burners and injected through ports located downstream of the top burner level[7]. OFA is used along with operating the burners at a lower than normal air to fuel ratio which helps to reduce NOx formation. Along with this condition, the OFA is added to obtain complete combustion[7].

In 1990, new amendments to the Clean Air Act mandated that nationwide caps be placed on the release of sulfur dioxide and nitrogen oxides from coal-burning power plants. In some areas of the United States, particularly the eastern portion of the Nation, many states must implement plans to reduce nitrogen oxides to even greater levels than those mandated by the nationwide cap. To reduce NOx pollutants to these levels, scientists have developed devices that work similar to a catalytic converter used to reduce automobile emissions. Called “selective catalytic reduction” systems, they are installed downstream of the coal boiler. Exhaust gases, prior to going up the smokestack, pass through the system where anhydrous ammonia reacts with the NOx and converts it to harmless nitrogen and water[8]. SCR is a postcombustion NOx reduction technology in which NH_3 is added to the flue gas, which then passes through layers of a catalyst. The

NH_3 and NOx react on the surface of the catalyst, forming N_2 and water. SCR reactions are generally effective in a temperature range of 650–750°F [7].

With growing concerns over the control of NOx emissions, multiple steps are being taken to further test and experiment with new techniques for more efficiently controlling NOx emissions. New control technologies that are under development by the Department of Energy at this point in time include layered NOx control for cyclone boilers, oxygen-enhanced combustion, refinements for low-NOx tangential firing systems, and preheat combustion.

SOx, or Sulfur Oxide emissions, are another pollutant of major concern. Sulfur oxides combine with water vapor in the air to form dilute acids that can fall to earth as acid rain. pollution control device called a “flue gas desulfurization unit” or “scrubber.” Rather than removing sulfur from coal before it was burned, scrubbers worked at the “back end” of a power plant, removing sulfur in the form of sulfur dioxide (or SO_2) that was present in the flue gas exiting the coal boiler[8].

Scrubbers can reduce sulfur emissions by 90 percent or more. They are essentially large towers in which aqueous mixtures of lime or limestone “sorbents” are sprayed through the flue gases exiting a coal boiler. The lime/limestone absorbs the sulfur from the flue gas. Treatment processes have been developed that produce a dry powder that can be used to make wallboard and for other commercial purposes[8].

In 1977 Congress passed a new Clean Air Act that essentially mandated that all new coal-fired power plants install scrubbers. By 1981, 52 of the Nation's 380 coal-burning utility plants had installed 84 scrubber systems. Today, more than 190 scrubbers are operating at 110 U.S. coal-fired power plants. Modern scrubbers have also shown varying degrees of effectiveness in reducing other pollutants, including particulates, acid gases, and in some cases, mercury and other heavy metals[8].

Reburning is another type of emissions control technology. Using reburning techniques, up to 25% of the total fuel heat input is provided by injecting a secondary fuel above the main combustion zone to produce a slightly fuel-rich reburn zone with a stoichiometry of ~90% theoretical air. Combustion of reburning fuel at fuel-rich conditions results in hydrocarbon fragments, which react with a portion of incoming NOx to form hydrogen cyanide, isocyanic acid, isocyanate, and other nitrogen-containing species. These species are ultimately reduced to N_2. Finally, completion air is added above the reburn zone to complete burnout of reburning fuel[7].

Using many or all of these pollution control technologies is absolutely necessary to meeting clean air regulations set forth by the Federal Government and the EPA. Implementing these technologies, most of which come standard on any coal-fired boiler equipment, will allow the equipment to operate safely and within the limitations set by regulating bodies.

When coal-wood fired boilers are implemented properly, a vast amount of energy savings can be gained due to not having to supply the boiler with natural gas, steam, or electricity as in the past. Industry has not explored or utilized this technology to the fullest extent as of yet because in some cases, the configuration required just does not meet the capabilities of a given facility. With more research, information, and advances in this technology, along with high traditional utility costs, coal-wood co-fired boilers will become more abundant in industry as businesses attempt to eliminate increasing utility costs.

Need for Research

A set of standards that show energy saving opportunities available for installation of coal-wood co-fired boilers does not exist. Making these opportunities available will help to make this type of technology more appealing to industry. Fuels such as natural gas, electricity, and oils are being depleted more rapidly, and the exploration of alternative fuel sources is becoming more important. Without the knowledge of the capabilities of certain alternative fuel sources such as coal and wood, these areas of technology will continue to be un-utilized.

Negative assumptions that are made about alternative fuels such as coal cause a lot of the industry to ignore energy conservation possibilities. Many of these assumptions are based on coal and wood performance in the past. New technologies and techniques have made it possible for fuels of this nature to be used much more effectively and efficiently.

An initial interest in this area could help to promote further research and investigation. Without the initial effort to discover energy and cost savings, there will not be much incentive to spend resources on bettering the already existing alternative fuel technology.

The information provided here will allow the user of the computer software to understand the information required to use the software properly, and will also allow the understanding of the software output. The technical information given here is sufficient for understanding the basic concepts of boiler operation, fuel management, waste control and disposal, and pollution control. The information will help to determine the feasibility of a coal-wood co-fired boiler equipment installation at a given facility.

Research Objectives

1. Develop a model to assist in evaluation and implementation of coal-wood co-fired boilers.

2. Synthesize information to enable coal-wood co-fired boiler use.

3. Determine best conditions for coal-wood co-fired boiler implementation.

The process diagram which outlines the computer software developed is shown in Figure 1.9.

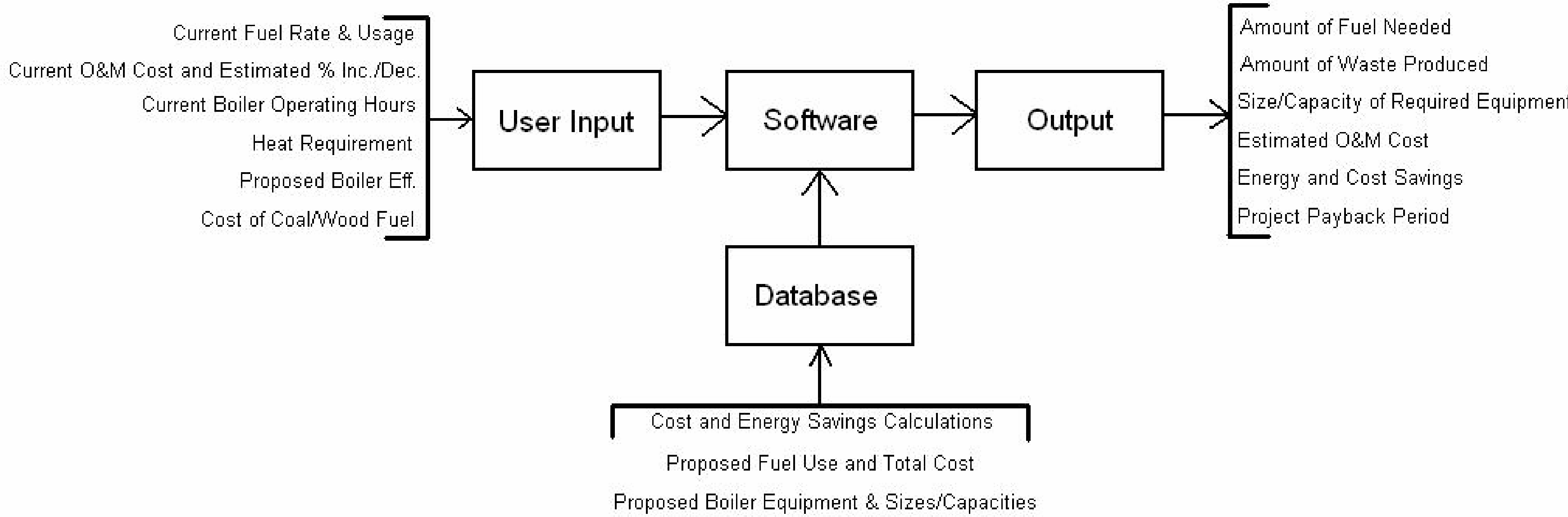


Figure 1.9: Process Diagram for Computer Software Program

CHAPTER 2

Literature Review

After conducting a literature review on the topic of coal-wood co-fired boilers, there does not seem to be much work done in the past that focuses specifically on the concept of modeling a system for the implementation of coal and wood fired boilers at specific facilities. Most of the work done in this field is concerned with emissions and environmental compliance, coal-wood co-fired boiler process control, reducing corrosion in boilers, and co-combustions with other solid fuels. There does not seem to be any model constructed that would assist in sizing a boiler and other equipment involved for any specific types of facilities. There is a number of studies and reports on the topic of coal-wood co-fired boilers that knowledge can be gained from.

Improved Process Control

One major area of research is in improved process control of industrial coal-wood burning boilers. Reports and research in this area focus on the conceptual and feasibility stage development of improved process control methods for coal-wood co-fired water tube boilers. Process control can become quite a challenge due to the fact that the nature of the fuel is highly variable[9]. Along with the fuel being variable, the boiler designs necessary to burn certain types of fuel vary as well. Frequent load swings required to meet changing process demands also add to the variability of the steam generation process. Though there have been advances in controls technology and microprocessor-based control systems, these problems are not being addressed in any effective manner in industry as a whole. To stabilize the operations and to reduce vulnerability to coal-wood fuel variations, it has become common to add fossil fuels such as oil or natural gas and to also pump air into the furnace at excessive amounts to increase combustion efficiency. Air pumped into the combustion zone, which helps to increase combustion efficiency as well as decrease emissions, is rarely used at the optimal condition[10]. Models have been constructed to attempt to determine more effective methods for process control by developing robust controllers. The controllers that are proposed have the objective of increasing the responsiveness to load changes, reducing the variability of controlled parameters, and improving efficiency of the boiler by reducing fuel consumption[11]. With many of these boilers used throughout industry, energy saving opportunities are quite substantial.

Performance of Co-Firing Wood and Coal

Co-firing wood and coal together in boilers has been a major area of research in the boiler industry. Studies and experiments are still being performed to track the performance of coal and wood mixtures and the emissions that result from burning. Co-firing of wood with coal is thought by some to be one of the best methods of utilizing wood as a biomass fuel[12].

Co-Pulverizing and Co-Firing

Tests on co-pulverizing and co-firing have been conducted to explore the possibility of fueling a boiler with a coal-wood mixture. The wood was pulverized for the experiments by feeding it into a vertical spindle type mill at up to 3% by weight together with coal. The tests were successfully performed with an increase of power consumption of the mill. Combustion tests were conducted with the pulverized fuel obtained, which resulted in good combustion efficiency and low NOx emission. A result of these tests show that co-firing with wood biomass by a small percent in pulverized coal fired boilers is possible with minimum installation of new equipment [12].

Nitrogen Oxide Emissions

An important field of study concerning wood fired boilers is in the area of NOx, or nitrogen oxides emissions. Factors examined in reports included fuel nitrogen content, total heat input, percentage boiler heat input from waste water treatment plant residuals and fossil fuels, boiler exit or stack oxygen content, and stack CO. A number of wood burning boilers were analyzed using NOx emission monitors. Using only data collected from days when wood heat input represented 90% or more of the total daily boiler heat input, the results showed that NOx emissions showed no relationship to either total boiler heat input or boiler exit O_2 concentrations[13]. Overall, the test results show that NOx emissions from wood fired boilers are mainly affected by the nitrogen content of the wood fuels, although, a simple relationship between wood fuel nitrogen content and NOx emissions does not appear to exist. This is because specific boiler design factors and operating conditions can have some affect on NOx emissions. Many facilities have very sophisticated systems, such as precipitators, which were discussed in the introduction, to reduce and control emissions from wood fired boilers. A picture of a precipitator in operation is shown in Figure 2.1. The image shows the size of a typical electrostatic precipitator used at an industrial facility.

Figure 2.1: Precipitator used to Control Emissions from a Wood Fired Boiler
Source: HAMON Research-Cottrell; hamon-researchcottrell.com[14]

Corrosion in Superheaters

A major field of research is corrosion, mainly in superheaters, in wood fired boilers. One of the major drawbacks to the combustion of 100% biomass in boilers is the increase in the fouling and corrosion of superheaters. Studies have shown that typical superheater steels in boilers using 100% wood fuel and having steam temperature higher than 480^{o}C (~896^{o}F) do not last much longer than 20,000 hours, or about four operating years before they must be replaced[15]. This rapid corrosion leads to increased maintenance costs, significant deposit formations which lead to a decrease in efficiency, and an increase in unplanned outages. Some measures have been implemented in order to reduce superheat corrosion. Most biomass fuels have a high content of alkali metals and chlorine, but they contain very little sulfur compared to fossil fuels. Potassium chloride, which is found in the gas phase, condenses on the superheater tubes and forms complex alkali salts with iron and other elements in the steel. These salts have very low melting points and are very corrosive. The corrosion caused by these salts can be lessened by using an instrument which measures alkali chloride content in the flue gases. Using the measurements, ammonium sulfate can be added to the flue gases. When sprayed into the flue gases, the ammoniuim sulfate converts the potassium chloride to potassium sulfate, which is much less corrosive. This method is effective in greatly reducing the deposition rates of the potassium chloride, and decreasing the corrosion rate for superheat materials by 50%[15]. An example of what affect corrosion can have on steel is shown in Figure 2.2.

Figure 2.2: Example of Steel Corrosion
Source: Miles Halpin, Associate of the Royal British Society of Sculptors, www.sculptures.freeserve.co.uk[16]

Summary

Most of the studies and reports that exist focus on improving already existing wood fired boiler designs. There does not seem to be much research conducted on developing a standard system model for installing a new wood fired boiler system, or for calculating and projecting potential energy savings. More research and development in this area could greatly serve industry by increasing interest in wood and biomass fuel energy. There is great energy saving potential in this technology, and if industry is able to get a feel for opportunities that exist, it may help lead to overall energy conservation on a very large scale in the future.

CHAPTER 3

Research Approach & Software Programming

The overall objective of this project is developing a computer software that will assist in sizing, pricing, and implementing coal-wood co-fired boilers at specific facilities. The software includes cost estimations for current fuel sources, as well as projected costs for wood and coal fuel. Though estimates for fuel costs are provided in the software, the user may override these values if they are known. This will allow for more accurate results. Energy cost savings result from the use of the coal-wood fuel mixture as compared to the current fuel being used. The software also considers other costs associated with implementing a coal-wood co-fired boiler including boiler cost, fuel storage and handling equipment cost, other various pieces of equipment costs, and increased operation and maintenance cost.

Software Input: Fuel Parameters

The software allows the user to enter their current boiler fuel usage and fuel cost rate. This allows for accurate energy savings calculations that pertain specifically to the facility being analyzed. The fuel types that will be considered for current costs are #2 Fuel Oil, #6 Fuel Oil, Kerosene, Propane, Natural Gas, and Electricity. The energy cost savings between the current and proposed fuel types are generated by the software using the user input and values within the software database.

Software Input: Facility Parameters

The software allows the user to enter boiler and facility parameters including annual operation and maintenance cost, annul boiler hours of operation, number of weeks per year of boiler operation, and boiler heat requirement. These values provide the parameters required to determine the amount of energy cost savings that can be achieved by installing a coal-wood co-fired boiler. The number of weeks of operation per year allows the program to determine how much fuel supply is required to facilitate one week of boiler operation. The details of what parameters are necessary for the software to provide accurate output and the values and calculations involved are presented in Chapter 4, which covers how the software was programmed.

Financial Aspects of the Computer Software

The software allows the user to enter the estimated percent increase or decrease in the current operation and maintenance costs for the boiler system. This will help in determining the project payback period. The software user can enter the cost of each piece of equipment specific to their facility. When a cost estimate is obtained from a manufacturer, this cost can be entered into the program to help estimate the simple payback period more accurately. Allowing the user to enter the cost of each piece of equipment allows for the customization of the program to fit the user’s needs specifically. If a certain piece of equipment is not required, the cost will not be included in the economic analysis.

Software Output

When the computer software and research have been completed, the finished model provides an accurate estimate of the capacity and size of the boiler design and equipment, the expected annual energy savings, and the estimated costs of fuel and operation & maintenance. There is much research that must be conducted in order to ensure the accuracy of the software. Much data must be collected for building the model, but the outcome will greatly help to benefit those who are interested in implementing a coal-wood co-fired boiler system but are not familiar with costs, equipment, and other factors associated with the process.

In preparation for developing the computer software, a vast amount of research was conducted, along with various data collection. Data has been collected to obtain specific boiler parameters for different size and capacity boilers.

Programming the Software

The title of the software is the "Coal-Wood Co-Fired Boiler Feasibility Program." The software was done using the Microsoft Excel software. The goal of the software was to be as user friendly as possible, while maintaining a high degree of detail and accuracy.

Programming Difficulties

A number of difficulties were endured while constructing the software program. A logical sequence of parameters to be entered and displayed had to be developed before and during the programming process. Designs and configurations that were considered before the actual programming began were changed and adjusted throughout the program design. The input and output cells in the software had to be labeled clearly for the user so there would be no confusion during program use. User friendliness was an important factor considered during the design of the software. One of the main aspects of the software is the clarity of which parameters are to be entered in specific locations and where nothing should be entered by the user.

The calculation and lookup parts of the software also presented a number of difficulties during design. Each of the calculations that are entered into the program had to be perfectly linked to other cells in the calculation. These cells were then locked to disallow any modification to the equations or code. The cells that provide sizing output for the boiler and accompanying equipment have lookup coding which link to separate worksheets within the software design. In these worksheets, all of the data needed for sizing the equipment in the software is present. The cells take the values calculated by the program, then lookup the corresponding value on the data worksheets. The cell then displays the size or capacity from the data sheet which correspond with calculated values. For example, for the boiler size cell, the calculation of the exact boiler size is done, and then the cell that has the exact calculated value refers to the data sheet which has this exact value in one column of data. The proposed boiler size that this value corresponds to is listed in the next data column, and this value is displayed in the software program as the proposed boiler size.

Preparing the software program to include all of the needed factors for effective execution was a very detailed process. Each calculation must include all of the factors necessary, and every parameter that is entered or calculated is used in a calculation somewhere throughout the program.

Another difficult task that is performed in the software is the conversion necessary if the user is currently using an electric heating system. The pulldown menu utilized on the first line of the program allows the user to select their current fuel source. Every unit of fuel that is in the menu is in MMBtu/yr except for the electric heating option, which is in kWh/yr. The pulldown menu allows for a unit conversion from kWh/yr to MMBtu/yr if the electric option is selected. This is a simple step that will ensure proper and consistent software operation regardless of the current fuel being used.

Software Input

The first set of parameters to be entered into the software by the user concern the current boiler annual fuel usage. The input and output boxes are highlighted to classify them properly. This makes it easy for the user to understand which boxes are for input. A pulldown menu option is utilized so the user can choose which type of fuel the current boiler is operating with. The function of the pulldown menu is to set the units for the user to enter their annual boiler fuel usage. All of the units are in MMBTU/yr except for if the user currently has an electric heater, in which the units would be converted to kWh/yr as determined by the pulldown menu. The user is then able to enter their current fuel cost. The pulldown menu used in the software is shown in Figure 3.1.

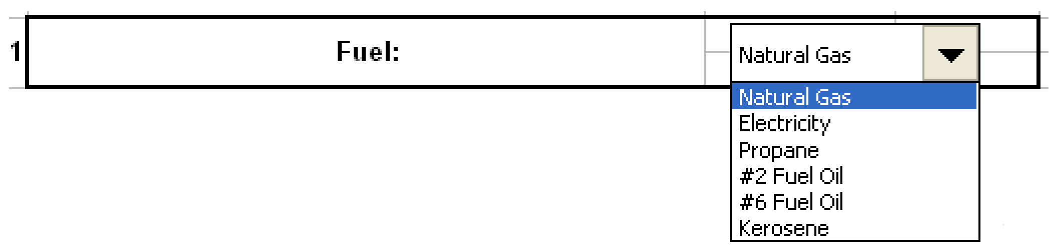


Figure 3.1: Fuel Type Pulldown Menu From Software

Other boiler parameters included in the user input section for the current boiler include annual operation and maintenance cost, annual boiler operating hours, the number of weeks per year the boiler is in operation, and the boiler heat requirement.

The boiler heat requirement allows for the software to determine the amount of heat required and the amount of fuel needed to meet this requirement using the coal-wood co-fired boiler. The average efficiency of most coal-wood co-fired boilers is approximately 80%. This value is entered into the software initially, but is very easily over-ridden by the user if they know the actual efficiency of the new coal-wood co-fired boiler to be installed. The efficiency and the heat requirement allow the software to calculate the MMBTU/hr of fuel necessary to operate the boiler. Using the annual hours of boiler operation entered earlier, the software can then determine the annual amount of coal-wood fuel necessary to operate the boiler at the desired condition.

Using the average MMBTU/lb values for coal and dry wood dust, the weight of each component of the coal-wood fuel mixture can be determined. Since the mixture is 97% by weight coal and 3% by weight wood, the total weight, in tons, of fuel is calculated in the software. The average cost per ton of coal and per dry ton of wood dust are entered into the software, but the costs can be over-ridden by the user if a more accurate value is known. This allows the software to calculate the annual fuel cost for the proposed coal-wood boiler. Since it is much cheaper in terms of fuel cost to operate a boiler with coal and wood as opposed to other more common fuels, significant energy cost savings are realized.

As the user enters cost estimates for necessary equipment based on the sizes and capacities provided by the output of the software, and the estimated increase or decrease in operation & maintenance cost is entered by the user, the project payback period can be determined based on the total cost of the project and the proposed energy cost savings.

Software Output

As all of the required parameters are entered by the user, the software can provide very accurate information on the proposed boiler replacement project. After the previously mentioned parameters have been entered, the software can accurately estimate the proposed capacities for a number of pieces of important equipment such as the capacity of the boiler itself in horsepower, the amount of fuel needed per year and on a per week basis, the proposed storage unit capacity, the proposed waste receptacle capacity, and the proposed electrostatic precipitator capacity. Also, the annual estimated operation and maintenance cost is determined. Taking the total equipment cost along with the annual energy savings and the annual operation & maintenance increase or decrease, the project payback period can be determined. That is, the amount of time it will take for the initial investment to be recovered in terms of energy cost savings is determined in terms of months and years.

The accuracy in equipment size and capacity will allow the user to obtain the most accurate price quotes possible on all major pieces of equipment. Allowing the user to speak with manufacturers about their specific steam generation process will allow them to obtain the most accurate prices possible.

Calculations and Database

All of the calculations necessary are done within the software. The sizing and capacity calculations are based on the parameters entered by the user. The sizing of the boiler is performed by determining the capacity in terms of horsepower, and then selecting the next highest rated boiler in terms of horsepower. The boiler ratings are given in increments of 25 horsepower in the range of 15 to 800 horsepower. The next highest rated boiler is selected because boilers rated for the exact horsepower required will probably not exist, and to meet a heat requirement, a higher rated horsepower is needed so it is ensured that the boiler will be operating within its rated capacity.

Conclusions

All of the parameters given by the software and entered into the software are vital to implementing a coal-wood co-fired boiler. The sizing and capacity determination of the boiler and accompanying equipment will allow for accurate pricing. The ability to contact manufacturers about implementing a coal-wood boiler and having specific parameters prepared beforehand will allow for much more detailed and accurate quotes. Most manufacturers require specific project parameters before they can prepare an accurate quote. Having exact parameters will make for a much smoother process of acquiring cost estimates for the various equipment.

CHAPTER 4

System Execution and Results

This chapter will walk through an example of how the user would go about using the software program most effectively. Example parameters will be entered into the program. Through research, various cost estimates have been obtained for the major pieces of equipment. The cost estimates obtained will be used strictly for the example case and will not remain in the software.

Example Input

For the example case, it is determined that the user's current boiler is a natural gas boiler which uses 97,750 MMBTU/yr. All of the user input boxes, aside from the pulldown menu, are shaded gray. All of the output boxes are shaded in yellow. Since this is not an electric heater, the conversion is not necessary via the pulldown menu. The first step is to select the Natural Gas option from the pulldown menu in Line 1 of the software. The annual boiler usage of 97,750 MMBTU/yr is entered in Line 2. The value will remain the same in Line 3. The only time the value would change in Line 3 is if an electric heater was used, in which Line 3 would show the converted units of kWh/yr from Line 2 in MMBTU/yr. The user's fuel rate is entered in Line 4 in units of $/MMBTU. Line 5 shows the calculated annual boiler fuel cost in dollars. The user then enters the current operation and maintenance cost in Line 6. In Line 7, the annual boiler operation hours are entered. The user then enters the approximate, while being as accurate as possible, number of weeks per year that the boiler is in operation on Line 8. This value is used for the calculation of the storage bin capacity, which calculates the capacity of the bin needed to store approximately one week worth of fuel supply. The user then enters the boiler output on Line 9 in units of MMBTU/hr.

For this example, the user's fuel rate is $13/MMBTU. The annual operation and maintenance costs total $100,000 per year. The annual boiler operation hours are 5,000 hours, the number of weeks per year of boiler operation is 30, and the boiler heat requirement as specified by the user is 17.6 MMBTU/hr.

Line 10 displays the total annual boiler cost based on the parameters entered to this point. Figure 4.1 shows a screen shot of the program which includes all of the values entered and calculated to this point.

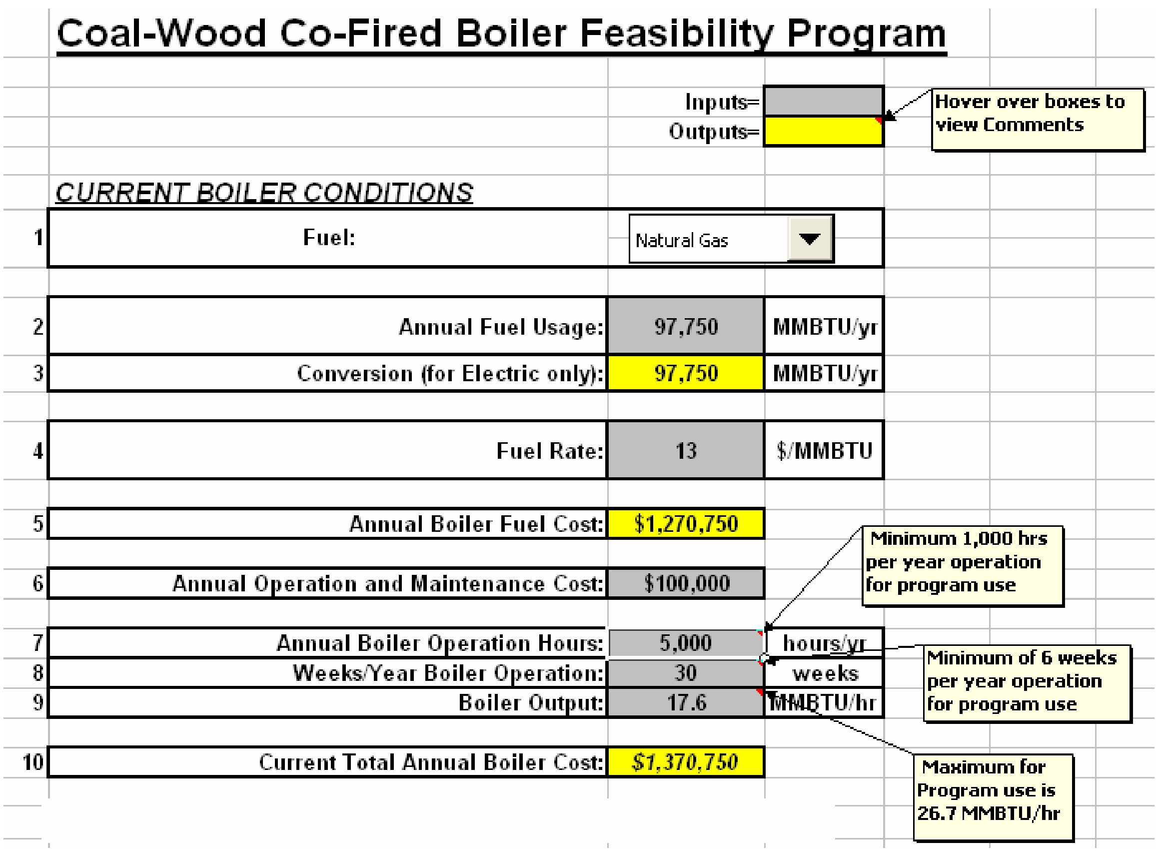


Figure 4.1: A Screen Shot from the Software Displaying Parameters to this Point

The comments that are visible on the screen in this shot can be seen in the software by hovering over the boxes which have the red mark in the upper right corner of the box.

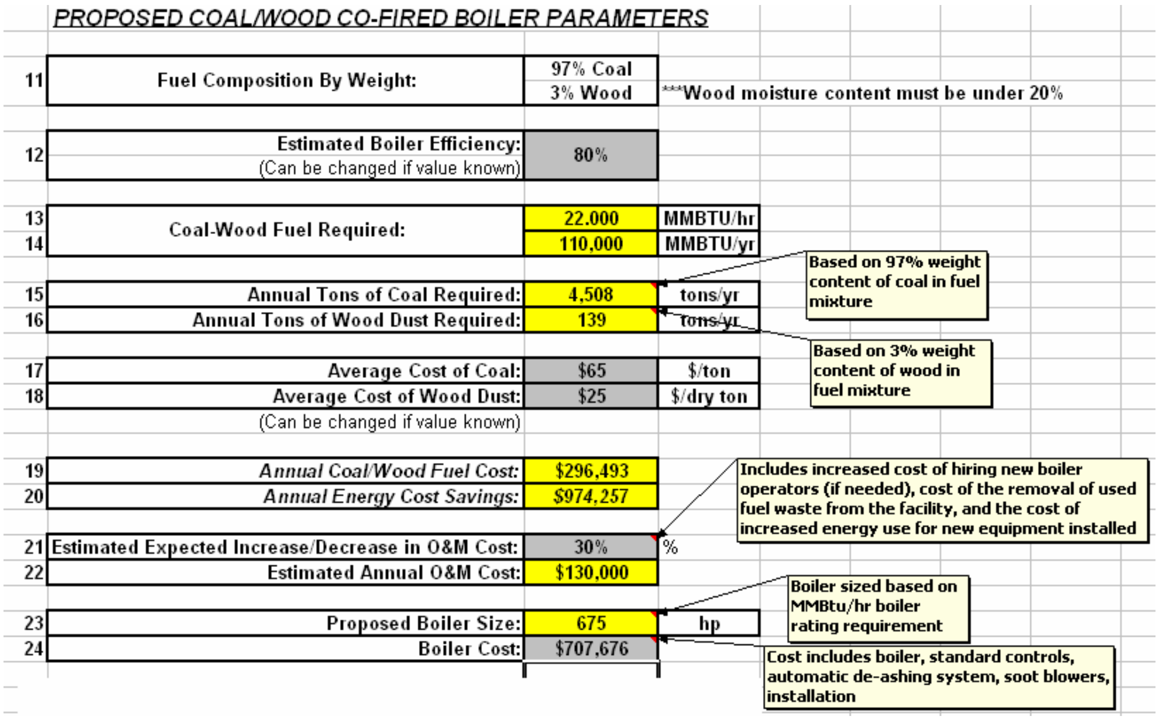
Example Output

The next section of the software program shows the Proposed Coal-Wood Co-fired boiler parameters. Line 11 shows the recommended fuel mixture of 97% coal and 3% wood by weight. The wood moisture content should be under 20% for the fuel to perform efficiently. Above this moisture content, the NOx emissions reach a more dangerous level, and the fuel will not perform as efficiently. The dryer the fuel mixture is, the more efficiently it will perform. The user then has the option of leaving the estimated proposed boiler efficiency of 80% in the input box of Line 12, or changing the efficiency to a known value. For this example, a boiler efficiency of 80% is used. Lines 13 and 14 display the amount of coal-wood fuel required in terms of MMBTU/hr and MMBTU/yr. The example values of coal-wood fuel required are calculated to be 22 MMBTU/hr and 110,000 MMBTU/yr. Lines 15 and 16 display how much coal and wood fuel is needed per year in units of tons/yr. The values calculated here are 4,508 tons/yr of coal, and 139 dry tons/yr of wood dust. The average cost of coal and wood dust are shown on Lines 16 and 17 respectively. The default values in the software, which can be over-ridden by the user, are used for the example and they are $65/ton for coal and $25/dry ton for wood. Using the average values, the annual coal-wood fuel cost is calculated to be $296,493, as shown in Line 19. Line 20 shows the annual energy cost savings, which are calculated to be $974,257 for this example.

Line 21 allows for the user to enter the expected percent increase or decrease in operation and maintenance cost for the new coal-wood co-fired boiler. This increase in operations and maintenance cost includes the hiring of any new boiler operators that may be needed, the annual cost for the removal and proper disposal of the waste fuel after it has been burned, and the cost of any energy that is required to operate any new equipment that is needed to operate the new boiler and accompanying system. In this case, the O&M costs will increase 30%. Line 22 then displays the expected O&M cost based on the current cost entered in Line 6.

Using the amount of energy input required to operate the proposed boiler which was entered in Line 9, the rated capacity of the boiler can be specified. The capacity of the boiler for this example is calculated to be exactly 657 hp. Using the incremented system of boiler ratings, a 675 hp boiler is recommended for this project. This value is shown in Line 23 of the software. Using the estimated cost data obtained, the cost of this boiler, which includes standard controls, soot blowers, built in ash removal, low-NOx emission technologies, and installation is found to be $707,676, as shown on Line 24 of the software.

Figure 4.2 shows a screen shot of the software showing the parameters entered and obtained to this point for the proposed boiler.



PROPOSED COAL/WOOD CO-FIRED BOILER PARAMETERS

11	Fuel Composition By Weight:	97% Coal	
		3% Wood	***Wood moisture content must be under 20%
12	Estimated Boiler Efficiency: (Can be changed if value known)	80%	
13	Coal-Wood Fuel Required:	22.000	MMBTU/hr
14		110,000	MMBTU/yr
15	Annual Tons of Coal Required:	4,508	tons/yr
16	Annual Tons of Wood Dust Required:	139	tons/yr
17	Average Cost of Coal:	$65	$/ton
18	Average Cost of Wood Dust: (Can be changed if value known)	$25	$/dry ton
19	*Annual Coal/Wood Fuel Cost:*	$296,493	
20	*Annual Energy Cost Savings:*	$974,257	
21	Estimated Expected Increase/Decrease in O&M Cost:	30%	%
22	Estimated Annual O&M Cost:	$130,000	
23	Proposed Boiler Size:	675	hp
24	Boiler Cost:	$707,676	

Based on 97% weight content of coal in fuel mixture

Based on 3% weight content of wood in fuel mixture

Includes increased cost of hiring new boiler operators (if needed), cost of the removal of used fuel waste from the facility, and the cost of increased energy use for new equipment installed

Boiler sized based on MMBtu/hr boiler rating requirement

Cost includes boiler, standard controls, automatic de-ashing system, soot blowers, installation

Figure 4.2: A Screen Shot from the Software Displaying Output to this Point

Capacities and Costs

The next section of the software focuses on sizing the various pieces of equipment involved with the boiler replacement project, and also allowing the user to estimate the cost for these pieces of equipment. Line 25 calculates the tons/week of fuel usage based on the number of weeks the boiler operates per year as specified earlier. Line 26 uses this value, and based on the average density of coal, calculates the volume of the storage bin required to hold approximately a one week supply of fuel. The fuel bin includes a walking floor along the bottom of the unit which moves the fuel to one end, and a metered screw auger system which then moves the fuel into the boiler from the bin. For this example, the storage bin size is calculated to be 6,000 ft^3, with a projected cost of $122,422, which is displayed on Line 27. This cost includes the storage bin, standard controls, and installation.

The waste receptacle and the waste collection controls are then sized on Lines 28 through 30. Line 28 calculates the volume of the receptacle needed based on an average value of 12.4% of coal by weight remaining after it has been burned[17]. Using the density of coal ash, the tons/yr and tons/week are calculated. The waste bin is sized to be able to hold approximately one week of ash waste. For the example, the volume is calculated to be 1,000 ft^3, with an estimated cost of $50,000, as shown on Line 31. This cost includes the waste receptacle, standard controls, and installation.

Lines 32 through 33 focus on sizing and pricing the electrostatic precipitator used for dust collection. The capacity is calculated based on the ideal intake air to fuel ratio of 16:1. Since the volumetric flow of the fuel intake is known, the density of air can be used to calculate the volume of air intake to the boiler. This will also be the volumetric flow rate of the exhaust gas out of the boiler. The electrostatic precipitator is sized based on this flow capacity. For this example, the capacity of the precipitator required is 6,617ft^3/min, with an estimated cost of $313,000. This cost includes the electrostatic precipitator, standard controls, and installation. Line 34 estimates the cost of the flue gas desulfurization, or "scrubber" unit. The cost is estimated to be $200,000. This cost includes the desulfurization unit, standard controls, and installation.

Based on the amount of fuel needed per hour to operate the boiler, the capacity of the coal pulverizer and the wood grinder equipment can be determined. Line 35 shows the capacity in lb/hr of the wood grinder, which is 56 lb/hr for this example. Line 36 estimates the cost of the grinder to be $60,000. The coal pulverizer is determined to require a capacity of 1,803 lb/hr, which has an estimated cost of $140,000, as shown in

Lines 37 and 38 respectively. Both of these costs include the grinder and pulverizer along with standard controls, and installation.

Line 39 shows the calculated total annual operation and maintenance cost of $130,000, and Line 40 shows the total equipment cost, which is $1,593,000. Taking the current O&M cost plus the current fuel cost, and subtracting the proposed O&M cost plus the proposed fuel cost, and dividing the total project equipment cost with this value, the project payback period can be calculated. Line 41 is the estimated cost for engineering, planning, and design for the project. These are the costs that are paid to the company that is supplying the architectural planning for the project, and who are organizing and planning all of the construction that will take place. The project could not move forward without this aspect, which makes these costs necessary. The estimated cost for this example is $500,000. Line 42 allows the user to enter any salvage value that is received for the sale of any boiler and related equipment from their current setup. This cost is subtracted from the total equipment cost when the project payback calculation is done. The estimated salvage value used for the example problem is $60,000. Line 43 shows the project payback period for this example to be 2.15 years, or about 26 months.

Figure 4.3 shows a screen shot from the software containing all of the equipment sizing and pricing parameters, and the payback values.

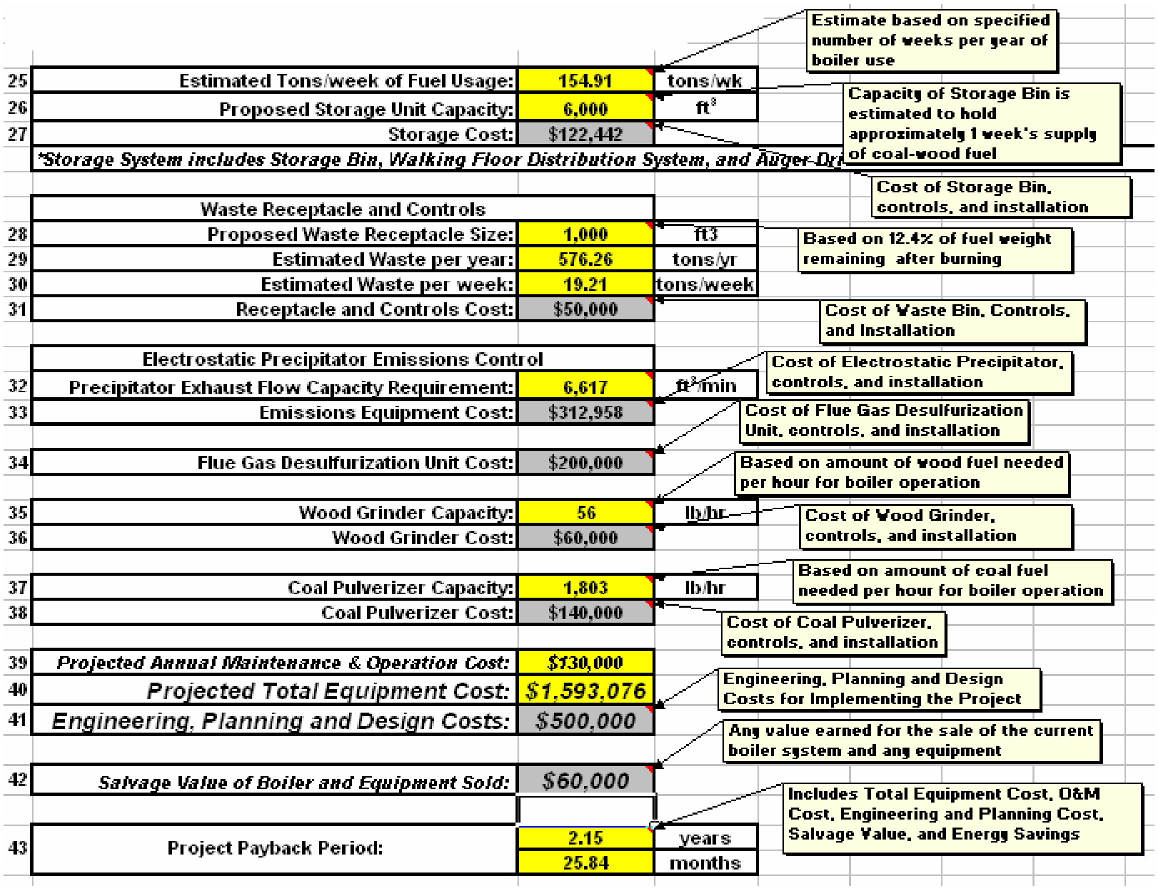


Figure 4.3: Screen Shot Showing Sizing and Pricing Parameters and Project Payback Period

Installation of the New Boiler

The installation of the boiler by professionals will include installation and preparation of the facility for the new boiler. Electrical power feeds may have to be reconfigured to meet the needs of the new boiler. Also, the reconfiguration of chimneys, piping, and insulation may be required for the new boiler. The current boiler will be removed by the professionals, along with the removal of electrical power that is no longer required, and removal of the current fuel lines. The engineers involved with the installation will ensure proper operation and owner training will most likely be provided.

Determining the Best Conditions for Implementation

A sensitivity analysis on the software program was performed to determine which key factors have the greatest affect on the project payback period. The costs entered while varying each of the key parameters are based on estimates determined from contacting various manufacturers similar to the example software execution in the previous sections. The key parameters that were adjusted to determine their affect on the project payback period were the boiler size, the annual operating hours of the boiler, and the current fuel unit cost.

The Affect of Boiler Size

To determine the affect of the boiler size on the project payback period, parameters were entered for boiler sizes between 100 and 800 horsepower in increments of 100 hp. The boiler that is considered for this analysis is a natural gas boiler with an efficiency of 87%. The current fuel rate is $13/MMBtu. The boiler operates for 5,000 hours a year, and approximately 30 weeks per year. The boiler MMBtu/hr rating is adjusted to correspond to the boiler size in horsepower. Using the theoretical efficiency, the MMBtu/yr is calculated and entered as well. The annual operation and maintenance cost is estimated for each boiler size starting with $50,000/yr for the 100 hp boiler and increasing in $10,000 increments up to the 800 hp boiler. The O&M cost is increased in increments of 5% starting at 20% for the 100 hp boiler. The waste receptacle and controls cost is estimated as $30,000 for the 100 hp boiler and increased in increments of $10,000 for each boiler size up to 800 hp. The cost of the wood grinder is estimated to be $50,000 and the coal pulverizer is estimated to cost $100,000 for the 100 hp boiler, and are each increased in increments of $10,000 up to the 800 hp boiler size. Given all of these conditions, the project payback period was determined for each boiler size. Each boiler size is plotted against the project payback period, and this plot is presented in Figure 4.4.

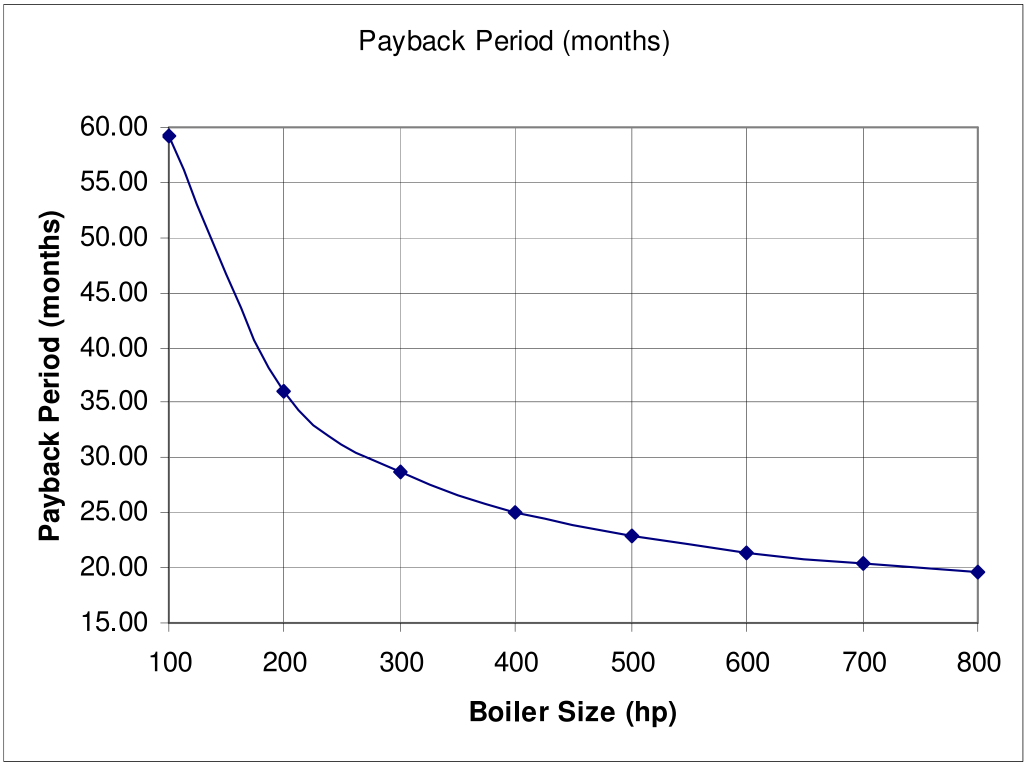


Figure 4.4: Plot of Boiler Size vs. Project Payback Period

From the plot, it is determined that the larger the boiler rating, the shorter the project payback period will be. This is because the larger that the boiler is, the more fuel that is required. When more fuel is required for the boiler operation, there is a greater opportunity for energy savings. Because of the significant difference in cost between natural gas and the coal-wood fuel, the energy savings increase as well as the boiler size increases. From the plot, it can be determined that coal-wood co-fired boilers are quite feasible in terms of project payback throughout the 100 to 800 hp range, but they are most feasible at larger capacities, specifically 300 hp or more.

The Affect of Operating Hours

The sensitivity analysis of the affect that varying annual operating hours has on the project payback period was tested. From the previous analysis on the affect of the boiler size, the 400 hp boiler size is selected for varying the annual operating hours. All of the parameters for the 400 hp boiler are entered into the program, and the annual operating hours and the approximate weeks of operation per year are varied in the range of 1,000 hours per year and 8,760 hours per year in increments of 500 hours. As the annual operating hours are varied, the annual fuel usage is varied as well corresponding to the operating hours being used, the current efficiency, which is 87%, and the heat requirement. As the annual operating hours were varied, and the plot of operating hours vs. project payback period was constructed, it is determined that the greater the annual operating hours are, the shorter the project payback period will be. This plot is shown in Figure 4.5.

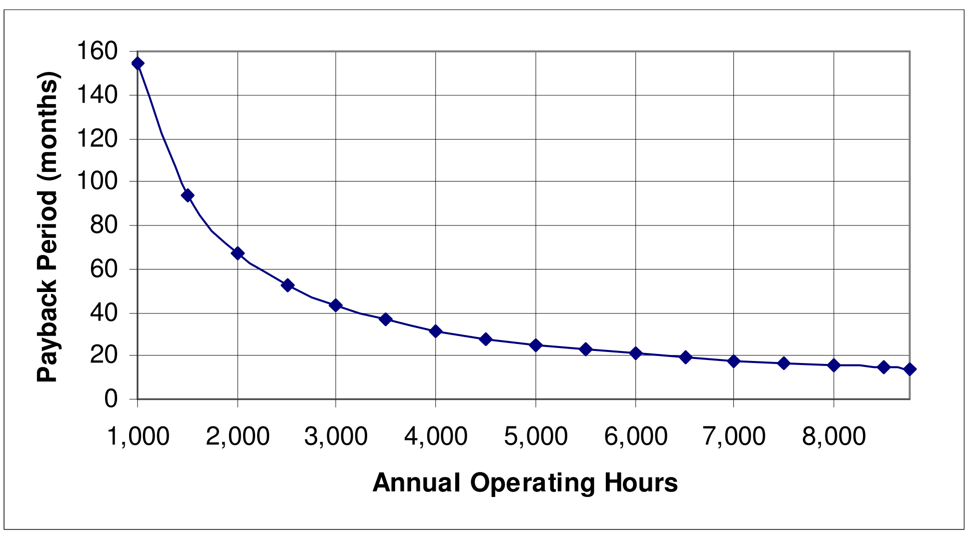


Figure 4.5: Plot of Annual Operating Hours vs. Project Payback Period

From the plot, it is determined that as the annual operating hours increase, the project payback period decreases. Implementing a coal-wood co-fired boiler is most feasible in the range of 3,000 to 8,760 annual operating hours. This is because as the annual operating hours increase, the annual energy cost savings increases as well. The project investment is paid back by the energy cost savings, and the amount of fuel used per year is where the energy cost savings comes from. The amount of fuel used increases as the hours of boiler operation per year increases, therefore, this generates more cost savings. The greater the energy cost savings is, the shorter the payback period will be.

The Affect of Fuel Cost

The fuel cost that the user is currently paying for their boiler has an affect on the project payback period as well. If the user is paying a relatively low cost for their current fuel, which in this case is natural gas, the implementation of a coal-wood boiler may not be feasible as they would not be able to realize enough savings necessary to obtain a reasonable project payback period. The sensitivity analysis on this factor is performed in the range of \$5/MMBtu to \$25/MMBtu for the natural gas cost. Again, the 400 hp boiler and parameters are used for 5,000 annual operating hours. The plot of the fuel rate vs. the project payback period was constructed and is shown in Figure 4.6.

From the plot, it is determined, as was previously predicted, that the project payback period is shorter as the current fuel unit cost increases. This is because with the average unit cost of natural gas already being higher than the equivalent unit cost of the coal-wood fuel, as the cost is increased beyond the average, it is obvious that the fuel cost savings would increase. From the plot, it is determined that the fuel cost that allows for the most feasible implementation of a coal-wood co-fired boiler is approximately \$10/MMBtu and greater.

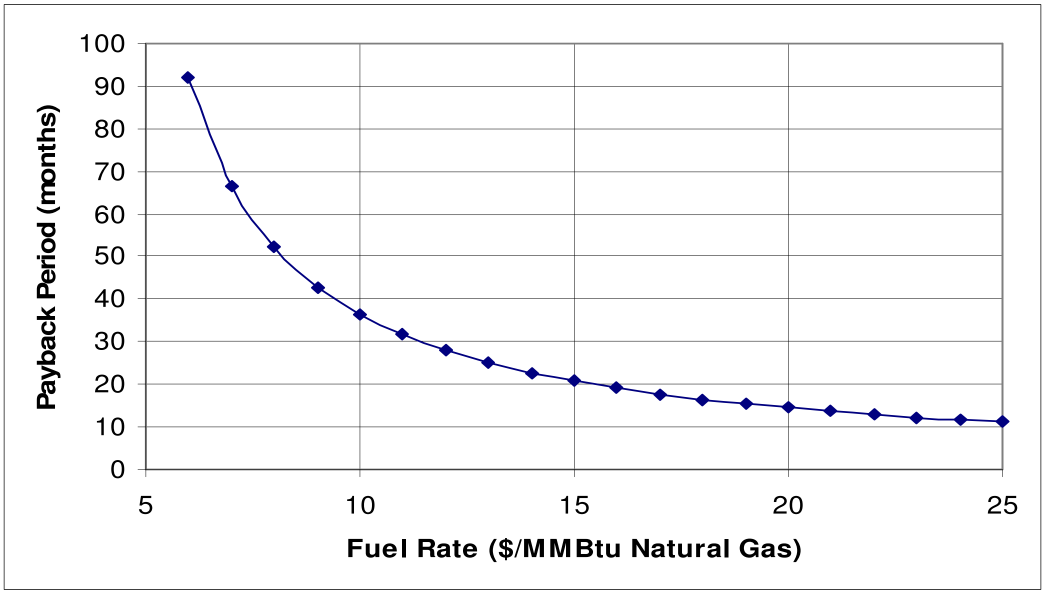


Figure 4.6: Plot of Fuel Rate vs. Project Payback Period

The Affect of Boiler Size and Annual Operating Hours

A sensitivity analysis was performed on two different factors at the same time. Boiler size and annual operating hours were compared against each other to see the affect on the project payback period. The sensitivity analysis considered annual operating hours between 1,000 and 8,760 hours per year along with boilers in the range of 100 to 800 hp.

From the plot, it is determined that the project payback period is shorter as the boiler size and the annual operating hours increases. This could have been predicted from observing the sensitivity analysis for each of these two factors above. As the amount of operating hours increases, the payback shortens, and as the boiler size increases, the payback shortens as well. Combining these two key factors gave the expected outcome. From the plot, it is determined that the combinations that allow for the most feasible conditions for a boiler replacement project are in the range of about 5,000 to 8,760 hours and between boiler sizes of 200 to 300 hp. The plot generated for this analysis is shown in Figure 4.7.

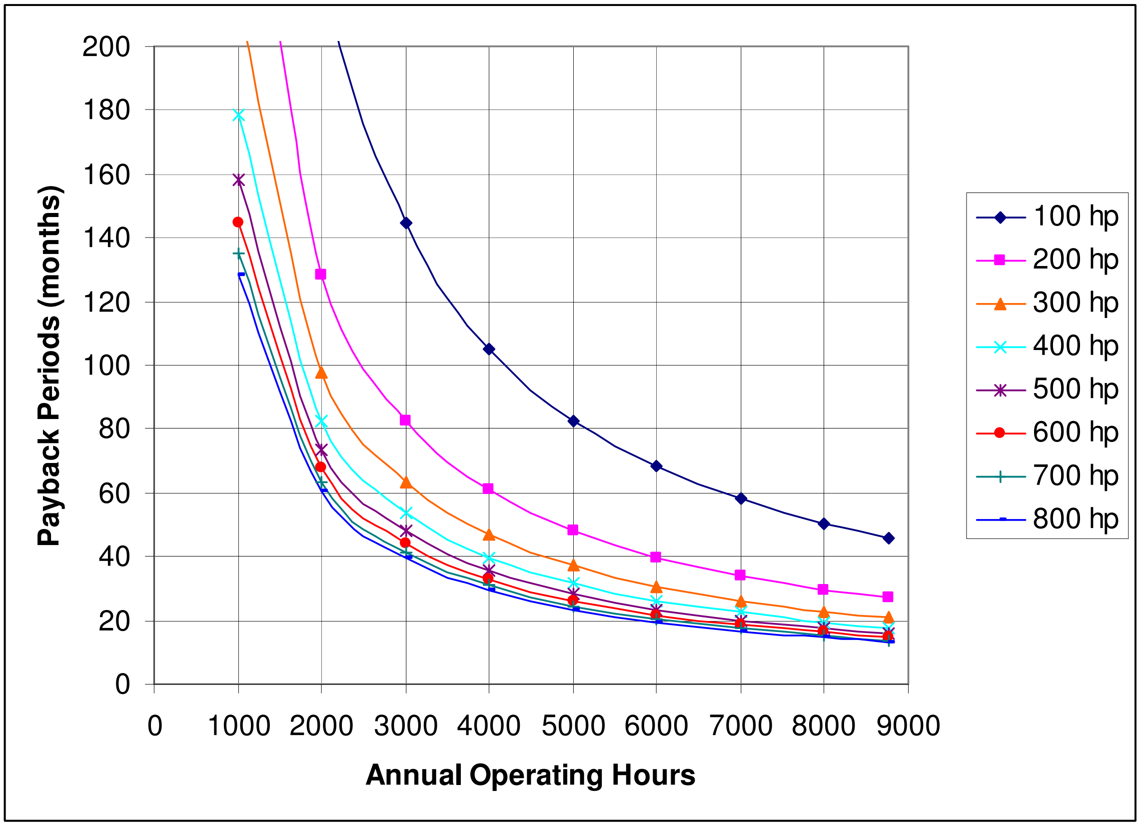


Figure 4.7: Plot of Boiler Size and Annual Operating Hours vs. Project Payback Period

Conclusion

After executing the software, analyzing the results, and performing the sensitivity analysis, the best conditions for implementing a coal-wood co-fired boiler have been determined. From the sensitivity analysis, it is known that the best conditions for implementing a coal-wood boiler is for boiler sizes greater than 300 hp, annual operating hours greater than 3,000, and fuel rates of about $10/MMBtu and greater. This analysis also helps to give the user an idea of what to expect before using the software, or if implementing a coal-wood boiler is a reasonable idea to begin with. The user can view the plots presented to determine where their current boiler falls into the range of project payback. The user can then use the program with their specific parameters to obtain the specific project payback period.

CHAPTER 5

Future Work

Work should be done to continue the research conducted in this study to further develop and improve alternative fuel technology. The more time and resources that are spent in this area will only further benefit the industry. Rapidly decreasing fuel sources such as natural gas and other oils will be spared if this technology is utilized more. More efficient and safer pollution control technologies are in development, which will only make coal, wood, and other alternative fuels more viable in today's industry.

Possible areas that could be explored more in the future are the possibility of better storage systems which would prevent any freezing or spontaneous combustion problems that are currently a threat, better pollution and emission control technologies, more efficient equipment, including the boiler itself, and more manufacturer and contractor familiarity in the alternative fuel and biomass field.

More knowledge in this field would also help to drive down costs for equipment. Also, if this type of technology were to become more popular, perhaps companies would make a point to produce ready made coal and wood fuels for purchase instead of companies having to prepare the fuel themselves, and having to worry about moisture content and condition of the fuel they are using.

Conclusion

The software program is valuable for determining if the current conditions are good for the feasible implementation of a coal-wood co-fired boiler. The user can easily review the sensitivity analysis results before entering any parameter into the software program to determine if their current conditions meet those that would likely produce the desired project payback period. Different companies and projects have varied desired project payback periods, and the software program will allow the user to determine which conditions will allow for the desired payback period. Allowing the user to know what size and capacity equipment will be necessary to meet their needs will make the process of obtaining accurate price quotes much easier than inquiring without any prior knowledge. Obtaining accurate price quotes and having a good plan are essential in determining the projected project payback period. Without knowing all the components and costs that are included in a boiler replacement project, many factors can be left out which will affect the payback period when they are later realized. Knowing all equipment and costs aspects of a project before beginning any actual work is very important to meeting the goals and budget of the project. This software program informs the user of all the factors and components involved in the coal-wood co-fired boiler implementation process, and will allow for a smooth transition between planning and construction.

There is a great need for this research because in industry today, utilities such as natural gas and electricity are being used and abused in extremely high amounts. Any conservation measure that can be implemented to help save these utilities is a benefit to the environment, and to the user. High use of electricity and natural gas drives the cost of these utilities higher. Any amount of these utilities that can be conserved will help to control the rising costs of these utilities. The dollar savings to the companies gives the best incentive to implement measures such as installing a coal-wood co-fired boiler system. One of the reasons that these boilers are rarely used in industry as compared to traditionally fueled boilers is because of the factor of fearing the unknown. Companies believe that it is too difficult to install a new system for the fear of having to remove all of the existing equipment and replacing it. Also, when companies are unaware of the cost savings available, there is no incentive for them to explore the opportunity of alternative fuel sources. This computer software will allow the user to see the energy and dollar saving opportunities, and they will be further encouraged to explore coal-wood fuel opportunities. The software will allow the user to see what will best suit their facility before any other outside party is involved. This gives the user independence and a strong voice in the decision making for the installation of a new coal-wood co-fired boiler system. This software will greatly help to shed light on one of the best sources of alternative fuel uses available, and the user will be well aware of the possibilities and opportunities that can be obtained by their facility. If more work and research is conducted in this field, there could be the possibility of developing a standardized model for sizing and implementing these types of boilers in the future. A standardized model could possibly be hosted on the Department of Energy website, or other similar sites as a very valuable tool for implementing coal-wood co-fired boilers, and also other types of biomass and alternative fuels. Manufacturers and energy assessment teams can use this as a good tool for calculating energy savings and sizing equipment as well. When more work and research is conducted in this field, the model could be fine tuned to make it as accurate as possible. The computer software being constructed in this project could serve as a launch pad for building an entire database of standardized models for alternative fuel sources in the boiler field.

Bibliography

1. *www.wikipedia.org*

2. Coal Pulverizer Image: Wabash Power Equipment Co.; www.wabashpower.com

3. *Externally Co-Firing Existing Boilers with the Products of Combustion of Various Solid Wastes;* Lefcort, M.D., Heuristic Engineering, Inc., Vancouver, BC, 1999

4. Metered Screw Feeding System Image: www.woodnet.org.uk

5. Walking Floor Feeding System Image: WOODFUELwales; www.woodfuelwales.tthosting.co.uk

6. *Mitsubishi Heavy Industries, LTD.; www.mhi.co.jp*

7. *Nitrogen Oxides Emission Control Options for Coal-Fired Electric Utility Boilers;* Srivastava, R.K., et al, Journal of the Air & Waste Management Association, Volume 55, September, 2005

8. *"Key Issues & Mandates: Secure & Reliable Energy Supplies - Coal Becomes a 'Future Fuel'",* National Energy Technology Laboratory, http://www.netl.doe.gov/KeyIssues/future_fuel.html

9. *Improved Process Control of Industrial Wood Waste Boilers;* Process Control Solutions, Inc., Tallahassee, FL., Department of Energy, Washington, DC, 2004

10. *Industrial wood-fired boiler optimization and emissions compliance;* Kaminski, et al, Pollution Engineering Journal, Cahner Publishing Co., Volume 34, Issue n4, 2002

11. *Modelling and advanced control of industrial wood waste boilers;* Meeker Jr., Richard H., Selekwa, Majura F., American Society of Mechanical Engineers, 2003

12. *Wood biomass as a substitute for coal in thermal power plants;* Yoshitaka, E., Kiga, T., Japan Society Mechanical Engineering, Tokyo, Japan, 2003

13. *An analysis of factors affecting long-duration NO_x emissions from wood-fired boilers;* Anonymous, NCASI Technical Bulletin Journal, Issue n 914, National Council of the Paper Industry for Air and Stream Improvement, 2006

14. Electrostatic Precipitator Image: HAMON Research-Cottrell; hamon-researchcottrell.com

15. *Reducing superheater corrosion in wood-fired boilers;* Henderson, P., et al, Materials and Corrosion Journal, Volume 57, Issue 2, Wiley-VCH Verlag GmbH, Germany, 2006

16. Steel Corrosion Image: Miles Halpan, Associate of the Royal British Society of Sculptors; www.sculptures.freeserve.co.uk

17. *"Chemistry in the Coal Industry,"* John Packer and Dr. Vincent Gray with information from "Coal Research Analysis Update," Coal Research Association of New Zealand Inc., 1998.

18. Boiler Efficiency Improvement, Dyer, Maple and Maxwell, Boiler Efficiency Institute, Auburn, Alabama, 1981. p. 4-31.

19. Cost Estimates for Example cases provided by Advanced Recycling Equipment, Inc., and Keith Manufacturing, Inc.