Boiler Control
– improving efficiency of boiler systems

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Abstract

AB Regin wishes to determine whether their existing controller platforms can be used to implement a control system for boilers. The control system should be flexible in terms of boiler size, boiler fuel and boiler type. In order to implement such a controller, information on the various processes must be gathered. The most common and effective control schemes are described, along with how they can be implemented for different types of boiler systems. A boiler controller is implement on the EXOcompact platform from AB Regin. A control algorithm is outlined and implemented for a fictional system. The system is then simulated using a demo kit from Regin. Some tests are performed to verify that the function of the control system is acceptable, and the results are discussed along with some suggestions for future development.

Objectives

The goal of the masters thesis is to provide fundamental knowledge on the principles involved in boiler systems. The most effective ways of boiler optimization will be covered in depth along with a discussion on how they can be implemented in a controller. This information will then be used to determine which optimization techniques should be included in a controller. A second goal is to implement a proof of concept controller on one of AB Regin's existing controller platforms.

Combustion control

The efficiency of a boiler system is important in several ways. The constantly rising cost of fuel used means that by increasing the efficiency by several percent, substantial savings can be made on a yearly basis. By maximizing the amount of energy extracted from the fuel, not only does the fuel usage decrease and thereby reduce cost but it also has a significant effect on the emissions from the system. Improving the efficiency of the combustion process can severely reduce the amount of harmful compounds, such as particle matter, in the flue gas. Combustion control can be divided into three major sections, load control, fuel control and air control (CIPEC, 2001).

Load control calculates the setpoints for both the air and fuel controllers. The function of the load controller may differ somewhat depending on the size and setup of the boiler system. The main characteristic that determines the load control method is whether the system is operating with steam or hot water. In systems that produce hot water, the main control parameters are the temperatures of the inlet and outlet feedwater, and in some cases the outdoor temperature as well. In steam systems on the other hand, the main parameter is the steam pressure, and many systems also use the steam flow and inlet and outlet temperatures (Elliot, 1997).

Fuel control are usually rather simple in design, but vary slightly in complexity depending on the type of fuel.
For systems firing gaseous fuels, the main parameter is the flow rate which is controlled by

valves. By measuring the flow rate through these valves the amount of energy delivered to the boiler can be very accurately controlled. To ensure that the gas supplied to the burner is at the correct pressure there may be need for pressure controllers or pressure boosters to decrease or increase the pressure, respectively (Woodruff, Lammers, & Lammers, 2005).

For liquid fuels the control is slightly more complex, since it is pumped to the burner. In order to get satisfactory operation from the burner the fuel needs to be supplied at a certain pressure. The fuel pumps must therefore be controlled in combination with valves to maintain this fuel pressure. Depending on the type of fuel used, some additional monitoring may be needed. For example, when using fuel oils, the oil temperature must be controlled (Woodruff et al., 2005).

Because of the diverse ways in which solid fuels can be handled in burners, the controls vary somewhat as well. From a control standpoint boilers using stoker systems can be considered to have two controllable variables; amount of fuel fed into the burner and the movement of the grate. In pulverizers and fluidized bed systems the controllable parameter is the amount of fuel fed into the system (Woodruff et al., 2005).

Air control is one of the most critical factors when it comes to efficient boiler operation, and two of the most effective control strategies are excess air control and staged combustion.

The idea behind excess air control is to identify the point where losses from unburnt fuel and heat losses in the flue are minimized. For each burner, fuel and load, there exists a specific optimal oxygen concentration in the flue gas to minimize both heat losses and losses through unburnt fuel, depending on several characteristics of the system. Excess air is controlled by measuring oxygen with sensors placed in strategic locations in the flue, and adjusting the air flow rate to achieve a certain set-point in oxygen. To improve the control of excess air even further, other compounds in the flue can be measured as well and used to make the control more precise (Turner & Doty, 2007).

Staged combustion involves introducing then combustion air in two or more stages. Using this technique, the formation of NO_x is greatly reduced, as well as promoting a complete combustion and can also improve the control of excess air (Ehleskog, Lundborg, Schuster, & Wrangensten, 2002; Oland, 2002).

Implementation

In order to implement this proof of concept solution, a system must first be specified. The system to be used in this controller implementation is chosen to be a solid fuel watertube boiler, which is used to produce steam. A cross-section of the boiler system is shown in Figure 1. The numbers in the figure mark some of the main components of the system:
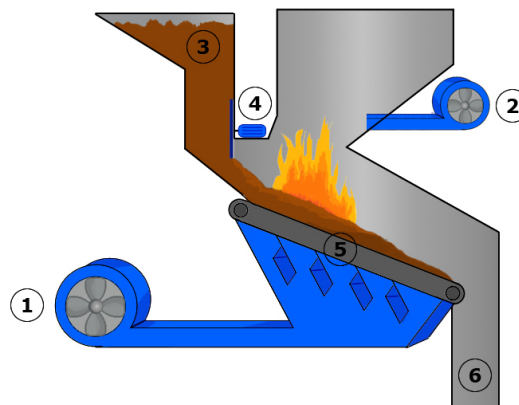

Figure 1: A cross-section of the simulated boiler system. The labels are explained in the text.

1. Primary fan: Primary air is supplied beneath the fuel grate by means of a single fan. The air flow is then divided into five zones to promote a better combustion, and this is achieved by means of vent dampers.

2. Secondary fan: Secondary air is supplied above the combustion air, from an independent fan.

3. Fuel hopper: In order to monitor that there exists enough fuel, a level indicator signals low fuel level.

4. Fuel gate: The flow of fuel from the hopper is controlled by a gate that can be

moved up or down, and is driven by a motor.

5. Grate: The grate is driven by a motor and uses a conveyor belt setup. The grate is 0.5 m wide and 2 m long, amounting to an area of 1 m^2.

6. Ash pit: Ash is discharged at the end of the grate.

Figure 2: Block diagram for the overall control system.

There is a number of variables that must be monitored in a boiler system for safety reasons as well as to ensure acceptable operation. In the event that these values violate their respective conditions, an alarm should be signaled. In this system an alarm is raised on the event that the O_2 level falls outside a predetermined interval. An alarm should also be raised in case the pressure in the steam dome exceeds a specified limit. Finally, a level sensor in the fuel hopper raises an alarm in the event that the fuel level is dangerously low.

The parameters used in the proof of concept implementation are listed in Table 1

Table 1: Control parameters

Signal	I/O	Type
Steam Pressure	Input	Analog
O_2	Input	Analog
Undergrate Pressure	Input	Analog
Overgrate Pressure	Input	Analog
Flue Gas Temperature	Input	Analog
Fuel Level	Input	Digital
Primary Air Flow	Output	Analog
Secondary Air Flow	Output	Analog
Fuel Gate Position	Output	Analog
Grate Speed	Output	Analog

The control algorithm implemented in this phase is composed of an air controller, a fuel controller and a load controller that provides set-points for the first two controllers. Figure 2 shows the configuration of the control system in a block diagram.
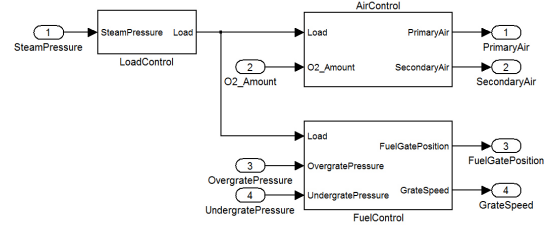
The load controller is a fairly simple controller, using a PI controller to determine the load. The controller has a predetermined set-point for the pressure in the steam dome. The measured pressure is used to determine the error, which in turn is fed to the PI controller.

The air controller module is slightly more complex, but also uses a PI regulator. The signal from the load controller is divided between the primary and secondary air signals, so that 70 % of the total air is provided through primary air, and the remaining 30 % are supplied as secondary air. The measured O_2 concentration and the O_2 set-point are fed into a PI controller. The output from the PID controller is then used to adjust the secondary air signal, according to oxygen needs.

The fuel controller is the most complex of the three controllers. The air pressure above and below the grate is measured, and these values are used to estimate the fuel bed thickness. This thickness estimation is then converted to a value that is used as an input to a PI controller where the load signal is the set-point value. The output from the PI controller is then fed to both the fuel gate and to the grate motor.

Once the program has been compiled and loaded to the EXOcompact, testing is performed to verify that all requirements are fulfilled. By using a demo kit to change the inputs the behavior of each controller section is monitored. Several test iterations reveal that all requirements are in fact fulfilled. Since all requirements were fulfilled, the implementation is considered a success.

Discussion

The goal of the work has been to investigate various techniques that improve the efficiency of boiler systems. Improvement in these boiler systems takes different forms, such as reducing the operational and maintenance costs, reducing the fuel consumption or reducing the emission of polluting gases to the environment. Initially, an extensive study was performed on the technical background associated with boiler systems. For small scale systems, only the simplest techniques such as O_2 control are commonly used, while the larger scale systems make use of a wide range of control techniques. Because the overall goal of this thesis is to gather information on the techniques that are available and how these work, it is difficult to make a definite choice regarding which techniques should be included in a controller. To be able to make such a choice, a detailed cost based analysis of each of the techniques needs to be performed. This analysis should also take into account whether the goal of the techniques is to reduce for example fuel cost, or other operational costs of a boiler system, or if it aims at making the system in question more environmentally friendly by reducing emissions.

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