

CASE EXAMPLE TWO

INDUSTRIAL BOILER

INTRODUCTION

A coal-fired industrial boiler is used to produce steam for an industrial process in a rural community. The boiler is rated to produce 200,000 lb steam/h (heat output of 210×10^6 Btu/h) for heating and process operations at an industrial facility. In this case example the nature of the industrial process is not important nor does its operating characteristics have much of an effect on the operation of the boiler. In general, the process does not require significant short term load changes and the steam production requirements are relatively constant. For the purposes of this example, short variations in steam demand should not be a consideration.

The purpose of this example is to provide the student the opportunity to develop permit conditions for an existing source that has had operating problems and must apply for a permit renewal. Industrial boilers are one of the most common source types to be permitted by various regulatory agencies. The coal-fired boiler is controlled for particulate matter emissions through the use of a fabric filter. There are currently no regulatory requirements to control sulfur dioxide emissions except through the use of low sulfur coal. There are no other regulatory requirements for other criteria pollutants. For the purposes of this only particulate and sulfur dioxide emissions are to be considered in developing permit emission limitations.

PROCESS DESCRIPTION

The coal fired boiler burns coal in the boiler furnace zone to produce heat which is transferred through the boiler heat exchange surfaces to generate steam. The boiler is nominally rated to produce 200,000 lb steam/h at a pressure of 250 pounds per square inch gauge (psig) and a temperature of 450°F. The boiler uses a travelling grate, spreader stoker design to feed and burn coal in the boiler. A brief description of the travelling grate spreader design is provided below. The steam produced by the boiler is used in the industrial plant for process heating as well as space heating.

The coal is fed to the boiler through four "spreaders" located on the front of the boiler. Coal is fed to each spreader through a chute from a large overhead coal bunker. The spreaders distribute or "throw" the coal evenly across the cross the grate if the spreaders are properly adjusted. The grate is a continuous loop of plates that move from the rear toward the front of the boiler. An even bed thickness of coal and ash must be established across the entire cross section of the grate to ensure proper combustion. The spreader stoker design typically allows for approximately half of the coal to burn in suspension while larger lumps of coal typically fall to the grate to be burned. Combustion air is provided through the grates by underfire air and through air nozzles located on the front and back wall of the boiler (overfire air). The overfire air system is designed to provide not only combustion air, but turbulence for more complete combustion of the coal. Typically, 50 to 60 percent of the total combustion air, including the excess combustion air required for complete combustion, is provided by the underfire air system. It is important to have an even fuel distribution on the grates because the underfire air would seek the path of least resistance through the grates and fuel/ash bed. As the fuel combusts on the grate, residual ash is left behind. Some of this ash is suspended into the gas stream carried by the underfire air and combustion gases. More coal falls upon the ash layer and burns and gradually builds an ash layer several inches thick. This ash layer moves towards the front wall of the boiler on the travelling grate. At the front of the boiler where the grate loop begins its return to the back wall, the ash is drop into an ash hopper and ash handling system.

The remainder of the coal (usually the finer coal particles) are burned in suspension above the grate. The residual ash from the coal burned in suspension is generally carried out of the furnace. However, because a substantial portion of the coal is burned on the grates and the ash is left on the grates, the quantity of flyash generated is typically 30 to 60 percent of the total potential ash generated in the boiler. (Note: pulverized coal boilers typically have anywhere from 80 to 95 percent of the ash suspended as flyash for the particulate control system to remove.

The boiler design is capable of producing steam very efficient and can respond fairly rapidly to load changes. However, the boiler is sensitive to an number of parameters including excess air, overfire/underfire air ratio, and coal size distribution. Of these coal size is most difficult to control and requires the purchase of coal with the proper size characteristics to reduce the potential for combustion problems. Coal that is excessively large and/or fine can cause incomplete combustion and excessive carbon carryover. The coal

size must range between 1/4 inch and 1 1/2 inch. Normally handling of coal will generate enough fine material for proper suspension firing.

The combustion gases pass a series of heat transfer surfaces to produce steam in the boiler. In addition, the combustion gases pass through a heat exchanger to preheat the overfire air. Underfire air is not preheated to cool the grates and prevent excessive "burnout" of the grates due to the intense heat. The typical combustion gas exit temperature ranges between 325 and 400°F depending upon the percent excess air and the heat transfer efficiency of the boiler tube surfaces.

Particulate matter is removed from the combustion gas by a plenum pulse fabric filter. A plenum pulse fabric filter is a hybrid design with characteristics of a reverse air and pulse jet fabric filter. The fabric filter has 840 felted fiberglass bags installed. Each bag is 14 feet in length and 6 inches in diameter. Under normal full load conditions the estimated gas volume is 130,000 ACFM at 325°F. Ash collected by the fabric filter and from the boiler grates is conveyed to an ash storage silo. The ash is landfilled off-site. The coal is shipped to the plant by truck by a local supplier. The sulfur content of the coal is less than 1.0 percent by weight. A typical coal analysis is shown below.

<u>Coal Analysis</u>	<u>% weight</u>
<i>Carbon</i>	<i>71.53</i>
<i>Hydrogen</i>	<i>5.05</i>
<i>Oxygen</i>	<i>4.93</i>
<i>Nitrogen</i>	<i>1.50</i>
<i>Sulfur</i>	<i>0.91</i>
<i>Ash</i>	<i>10.00</i>
<i>Moisture</i>	<i>6.08</i>

Heat Content: 12,500 Btu/lb

The boiler was designed to operate at a nominal 84.6 percent thermal efficiency. The design calls for operation at 7.5 percent oxygen in the combustion gas (56 percent excess air). This value is somewhat lower than may normally be encountered for this design. However, since load changes are not of concern operation at this excess air level is achievable.

OPERATING HISTORY

The boiler is the only boiler operated at the facility. Thus, when the boiler goes off-line the plant must shutdown. The plant has operated the boiler since 1974. Initially the particulate matter emissions were controlled using a low energy wet scrubber. The scrubber was removed in 1978 when the results of several stack tests indicated that the scrubber performance could not consistently achieve the regulatory emission limitation of 0.10 lb/10⁶ Btu. The fabric filter was installed under a consent order and compliance with the emission limit was demonstrated by several stack tests conducted from 1978 through 1985. Annual stack testing requirements were dropped in 1986 and replaced with biannual testing. Semi-annual inspections by the agency indicated no particular problems with the boiler operation or opacity. Bag life averaged between two and three years from 1978 to 1990.

The plant renegotiated its coal supply contract in 1990. The basic coal specifications listed above remained the same. The plant negotiated a reduction in coal costs by \$5/ton delivered. Shortly after the new contract was negotiated, plant operators noted that the boiler efficiency seemed to drop. It became more difficult to achieve full steam production from the boiler and coal feed rates appeared to increase. The plant did not directly measure the hourly or daily feed rate for the coal. The fans worked harder to move the gas volume through the boiler. Although boiler maintenance was generally good throughout the years, normal wear and tear had caused the boiler to gradual lose some of its initial thermal efficiency. It was not unusual for the boiler exhaust combustion gas to be at 10 percent oxygen (92 percent excess air) and 375°F.

The apparent increase in the consumption of coal caused the plant to test the coal to determine if the coal characteristics had changed as a result of the new contract with the coal supplier. Periodic sampling by the plant showed that the coal characteristics had not changed and the results of the ultimate analysis sent to an independent laboratory verified the coal characteristics reported by the coal supplier. Since the results provided by the coal supplier and the independent testing laboratory were in agreement, the plants concern over the apparent increase in coal consumption diminished. Furthermore, the production of steam was not the final product although it was essential to the production operations at the plant.

The pressure drop across the fabric filter gradually increased over a two month period to more than 10 inches of water. The high pressure drop made it nearly impossible to achieve full steam flow and still maintain the boiler under slight negative pressure. The plant increased the cleaning frequency and intensity to attempt to clean the bags. Although this

helped somewhat, it did not reduce the pressure drop back to its typical 5 inches of water that had been typical of the operation on a day-to-day basis. The pressure drop did diminish several weeks later with a substantial increase in opacity. The opacity increased from a typical 0-5 percent level to between 30 and 50 percent. The state agency cited the plant for several violations of the opacity standard. The plant finally shutdown four months after burning coal received after the new coal contract was signed. The plant maintenance personnel found numerous holes in the bags. The bags that were replaced had approximately 14 months of operating time.

The pattern discussed above has continued requiring bag replacement every three months and a one week shutdown every quarter. The plant has been cited on three occasions by the state agency for violation of the 40 percent opacity standard for existing boilers. The plant now requires a renewal of its operating permit.

With the information provided, is it possible to determine the possible cause(s) of the bag failure? Does it seem possible to develop a new permit to accommodate the routine replacement of the bags? _____

SUPPLEMENTAL INFORMATION

The plant operated for more than one year with the cyclic failure of the bags before turning attention to the cause of the failure rather than treating the symptoms. Although the plant did have the coal tested to determine if the heating value (Btu/lb) and/or ash content had changed significantly, they were looking at the wrong parameter. The symptoms indicated several other alternate failure modes including improper air balance in the boiler or improper fuel distribution on the grates, both of which would increase the fuel requirements to maintain steam demand. Other possible failure modes include tube leaks that were allowing excessive moisture in to the gas stream causing "mud" formation on the bags and high pressure drop and leakage of the air heater that increase the oxygen content of the combustion gas and lower thermal efficiency.

After six changes of the bags over a twenty month period the plant began to search for the cause of the problem rather than treating the symptoms. Although the plant was generally in compliance with the opacity regulations, the particulate emissions probably exceeded the allowable emission rate of 0.10 lb/ 10⁶ Btu approximately half of the time. The plant reviewed the available records and concluded that there was a significant performance change associated with the "new" coal even though the coal analysis indicated that it had the same characteristics as the "old" coal. The records indicated that the quantity of coal purchased had increased and that the apparent efficiency of the boiler had been dramatically reduced.

Analysis of the combustion gas composition and gas temperature did not show excessive thermal losses as a result of too much excess air although there was room for improvement. The gas analysis did show, however, that carbon monoxide levels leaving the boiler were higher than expected and indicated incomplete combustion. An ash sample was obtained from the boiler grates and the fabric filter. These were analyzed for combustible content.

The ash sample from the boiler grates (bottom ash) were normal with only a slight residual carbon content. The flyash sample, however, was very high in combustible content and a measured heat content of 7800 Btu/lb. This heat content is not desirable, particularly when compared to the average as-fired heat content of 12,500 Btu/lb. The high combustible content indicated that extremely poor combustion was occurring in the boiler that was causing the loss of thermal efficiency. Since no major changes had been made to the boiler operation, it seemed apparent that the efficiency loss was associated with the coal. The

symptoms indicated only one possible cause for the degradation in boiler performance: improper coal size.

As mentioned previously, coal size is one of the most important operating considerations for stoker-fired boilers. A sample of the as-received coal was tested for size characteristics using a standard ASTM sieve screening method. The as-received coal contained more than 70 percent "fines" (those particles that would pass through a 1/4 inch screen mesh). The typical recommendation for the percentage of fines is 20-35 percent as-fired. To achieve this coal size distribution, coal must be received with less than 10 percent fines since handling of the coal will generate the necessary fines. The maximum top size was 1 1/4 inches which was consistent with coal size recommendations.

The plant did not violate any of its permit conditions by changing the coal. The performance of the boiler diminished substantially, however. The estimated thermal efficiency was 69.9 percent. Achieving the same heat output as when the boiler was operating well meant that the heat input had to increase to just over 300×10^6 Btu/h. The increased heat input also meant an increase in the gas volume through the fabric filter and the excessive carbon carryover overwhelmed the cleaning system because of the much higher concentration of particles in the gas stream and because the particles were "sticky." The cost of fuel increased by more than \$140,000/yr even though the cost of the coal was less by \$5/ton. In addition, there was the cost of bag replacement, maintenance personnel and lost production. The overall cost to the plant was in excess of \$1 million.

The reason for the dramatic change in coal characteristics was an oversight by the plant (and the state agency) concerning the operating characteristics of the boiler and the fabric filter. Previously the plant had been receiving coal that had been screened at the coal processing plant to the proper size for satisfactory boiler operation. In negotiating a lower price for the coal, the wrong parameters were examined. The coal the plant was receiving contained much of the fine coal not wanted by other coal consumers in the area. The coal supplier was willing to provide a cost incentive for the plant to burn this coal. The focus on the heat content, ash content, and sulfur content overlooked the fact that the boiler was unable to burn the coal properly. Furthermore, the boiler emission limits were stated in lb/ 10^6 Btu and the increased heat input meant that the actual lb/h emission rate increased.

With the information provided above develop permit conditions to answer the following questions.

QUESTIONS

1. From the information above determine the design air-to-cloth ratio for the fabric filter: _____

Estimate the air-to-cloth ratio at 375°F and 300×10^6 Btu/h (you may use a multiplier of 1.23 for the increase due to excess air):

Are these values appropriate for a pulse type cleaning system? Explain your reason(s): _____

2. The previous permits included limitations on the quantity of steam that could be produced (heat output). Develop a permit condition or conditions that will establish a limit for the heat input. Remember to include the method for determination and the averaging time. The plant has temperature and combustion gas oxygen monitors installed. _____

6. Develop specific requirements to address the coal sizing problem. The largest coal size should not exceed 1-1/4 inches.
