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Operational Problems: Biomass Boilers with Oversized Output

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Output of fossil fuel fired industrial boilers is usually designed to meet expected maximum heat requirements of heated system. This design solution cannot be applied on biomass boilers since operational range of standard industrial biomass boilers is set to operate above 30 % of boiler nominal capacity. Biomass boilers must be operated in the most stable mode possible, without any major changes to the output, in order to achieve expected efficiency and low amounts of pollutants in flue gas. Biomass boilers operated in real-life premises are often designed to meet a significant portion of the maximum expected heat requirements of the system, which leads to oversized boilers with serious operational problems.

This paper sums up recommendations for selection of optimum biomass boiler output which have been published in literature, and also presents major undesirable features associated with operation of oversized boilers. The presented study focuses on research of 1 - 5 MW biomass boilers with inclined moving grate. But majority of obtained results may be applied on all types of energy sources combusting biomass. A case study from wood-processing industry demonstrates concrete operational difficulties. The paper further discusses possible measures for improvement of operational features of oversized boilers.

1. Introduction

There has been an increased pressure in Europe to reduce consumption of primary sources of energy; this strategy should diminish dependency of European countries on imports of energy. Directive 2012/27/EU, one of the latest documents implemented by the EU to promote energy efficiency, established a common framework within the EU countries to increase energy efficiency by 20 % compared to projections from 2007. This strategy helps the industry by reducing operating costs and increasing the competitiveness. Energy supplied to industry and buildings sectors represents almost two thirds of final energy consumption in the EU in 2013 (Eurostat, 2014). At the same time, more than 45 % of sources of energy in the EU is consumed for production of heat and cold (Euroheat and Power Association, 2014). The significant share of heat production in consumption of primary sources of energy is a global phenomenon. According to International Energy Agency (2012), heat production represented more than 47 % of final energy consumption in 2009. And yet a potential for increase of heat-producing plants efficiency is enormous. For example, consider the fact that in 2010, roughly 75 % commercial steam boilers were running for over 30 y (International Energy Agency, 2010).

This work is focused on medium biomass boilers (1 - 5 MW) which are one of the most demanding heat sources in terms of operations. The obstacles to smooth operations of these boilers lie in the properties of the fuel they use which is unstable (Boriouchkine et al., 2014), and achieving high efficiency and good quality of combustion of fossil fuels is thus complicated (Sartor et al., 2014). At the same time, biomass boilers are difficult to maintain. Operators of plants and facilities with biomass boilers have suffered serious energy losses because the installed boilers are not properly operated (Palmer et al., 2011). An economical operation is most closely linked with a quality of the biomass combustion. This means that the operations will respect a designed output range of the boiler. The output range of medium biomass boilers (combusting pellets and wood chips) extends from 30 to 100 % of the rated output. Moreover, biomass

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boilers are sensitive to sudden changes of output. Quality of the combustion significantly decreases at a lower output or output sudden changes. Efficiency of the boiler is then lower than the efficiency specified by the manufacturer (Schwarz et al., 2011), and investments into the facility do not meet the expected returns. Failure to comply with required emission limits is another consequence of operating the boiler at low outputs.

It may be assumed that a number of poorly operated industrial boilers is rather high. The EU has been long promoting the biomass boilers as an environmentally-friendly source of energy. The current common framework for promotion of renewable sources of energy, including biomass, is defined in Directive 2009/28/EC which sets out to achieve 20 % share of renewable energy sources in total energy production by 2020. European investors commonly opt for biomass boilers since they are subsidized by a state. However, investors go for this type of boilers even if the biomass boilers are not suitable for a given application and oftentimes, they purchase a high-capacity biomass boiler instead of combining a biomass and gas boiler. Despite author's experience with a high number of oversized biomass boilers, there are not many research papers dealing with this issue. This paper presents a short, yet comprehensive summary of the adverse consequences of operating an oversized biomass boiler. An overview and evaluation of available measures to counteract these consequences are also provided. Each chapter is accompanied by concrete experiences from a case study.

2. Designing a Suitable Boiler Capacity

Biomass boilers are specifically designed to combust wood. Compared to gas boilers, biomass boilers have a larger combustion chamber and a more sophisticated supply of combustion air. Due to a limited speed of biomass combustion, the output of the boilers cannot change quickly. It may take 10-30 min to adjust the output of the boiler. They should be operated in a stable mode without any sudden changes of consumption.

In order to design a boiler with a right capacity, the real consumption of heat must be known. Thermal power changes not only throughout the year but also throughout every working day. Therefore a boiler capacity should be designed using a cumulative heat load demand diagram during the year and a daily heat load demand (Sartor et al., 2014). Design of the boiler capacity should reflect information about long-term heat load demand in various seasons and fluctuations of power demand during a day. Heat consumption data covering a long period of time are always a great advantage. This is often the case when an old boiler is replaced with a new one. If there is no previous experience and the operators are to run a fully new source of heat, the heat load demand must be calculated. Calculations of heat systems use a curve for expected heat load demand and an estimate of heat loss of a consumer compared to current ambient temperature. Calculations of heat load demand of technological processes use a rated power input and an operation time schedule. The so called multi-fuel system is often recommended: the biomass boiler provides basic, year-round heat supply while higher outputs and fluctuations in heat demand are covered with a secondary heat source, such as a gas boiler.

Most of biomass boiler designers do not take account for a cumulative heat load demand during the year. The boiler capacity is often designed to cover maximum expected heat requirements of the system. But maximum heat is required only several days a year during a heating season or in short intervals during operation of technological processes (discontinuous manufacturing processes). Actual heat consumption is lower by several orders than the maximum rated capacity, which results in boilers running at low outputs.

This problem was encountered in a wood-processing plant in the Czech Republic. The capacity of the boiler was defined using a sum of rated capacities of all operating devices (namely furnaces), which amounted to ca. 1,800 kW. The engineers designed a 2,500 kW boiler with an obviously sufficient output reserve. It was a big mistake to design a boiler using only a theoretical maximum heat demand. The actual operation of the boiler revealed that a real heat demand in a heating season amounts to ca. 600 kW (ca. 20 % of rated capacity) and ca. 200 kW in summer. It is shown in a diagram of cumulative heat load demand (Figure 1), where y axis represents required thermal power of the facilities and x axis represents cumulative heat load demand throughout the year. The boiler has been long operated in an unsuitable output range and therefore the continuous control of the output is problematic. The boiler is repeatedly shut down and the so called cycling frequently occurs.

Owners of the wood-processing plant, analysed in the case study, expected a business growth and related increase in heat demand for wood-processing, therefore the engineers oversized the boiler capacity. Later, the expansion was stopped by financial crisis. Visions of business growth and expansion are a common fallacy for oversizing a boiler capacity (US Department of Energy, 2012).

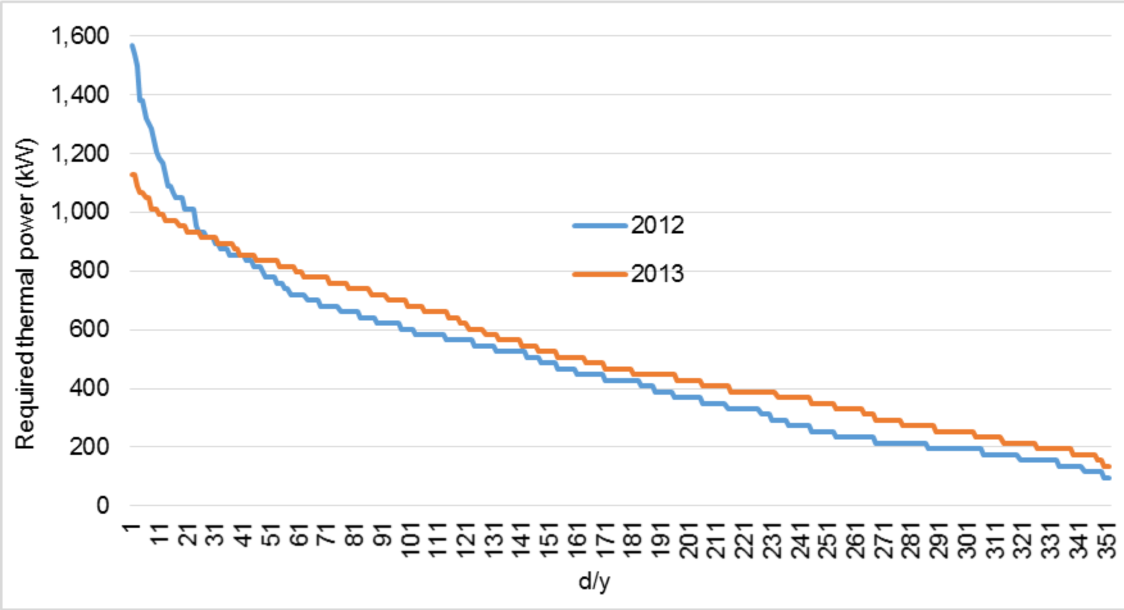

Figure 1: Diagram of cumulative heat load demand in 2012 and 2013 in a wood-processing plant

3. Operating problems of Oversized Boilers

Most of modern biomass boilers manufacturers claim that the boiler output may be reduced to ca. 30 % of the rated capacity. Yet the construction of the combustion chamber and heat exchanger in the biomass boiler are optimized to match the rated capacity. A decrease in output results in decrease in combustion quality since the grate is not sufficiently covered with fuel and the temperature does not allow for a complete oxidation of combustibles. Therefore, the overall efficiency of the boiler is reduced. Due to declining thermal power of the boiler, the increase in fixed heat losses is another reason for low boiler efficiency. Adverse effects of a low boiler output on boiler efficiency are obvious in Figure 2.

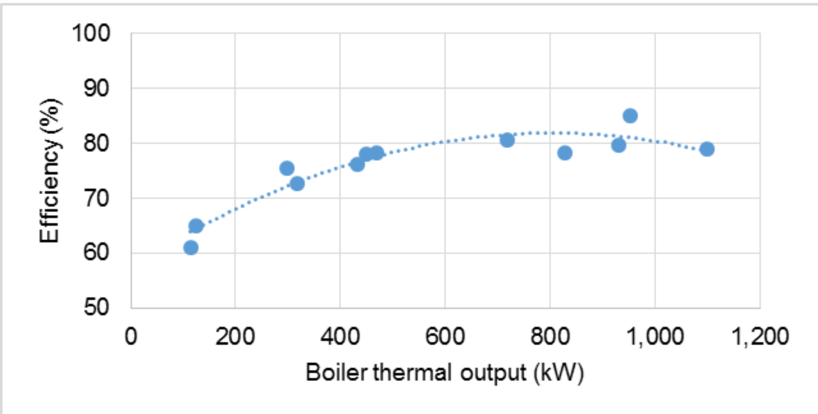

Figure 2: Efficiency of a 2.5 MW biomass boiler in relation to output

Boiler efficiency ranges from 60 - 80 % and higher efficiency equals higher outputs. However, boiler is rarely run at a high output range (over 700 kW). If the boiler does run in a high output range, the operations are unstable which may be the cause of non-rising efficiency trend for outputs over 800 kW. The boiler reached the designed efficiency, i.e. 84 %, only once when the output reached ca. 950 kW.

Another consequence of lowered combustion quality are pollutants in flue gas. The said boiler was measured for emissions at 830 kW. The measuring showed a very poor combustion quality despite the fact that the output was sufficiently high to provide relatively good boiler efficiency. Among the most concentrated pollutants was CO which basically reached emission limits (590 mg/m^3 in The Czech Republic). This value proves that the conversion of CO to CO_2 is not complete despite the fact that there is enough oxygen in the flue gas. Average O_2 concentrations reached ca. 13.2 %. It may be assumed that the main cause of high emission concentrations is insufficient mixing of combustion air and flue gas. Most combustion air passes through a grate with low heat loss (and no fuel). Figure 3 illustrates this issue.

Figure 3: Fuel and ashes layer in 2.5 MW boiler operated at ca. 0.2 MW

Operating biomass boilers at low outputs also affects a cleaning of secondary combustion chamber and a heat exchanger. These parts of the boiler are subject to intensive fouling and have to be cleaned more often than usual. The researched boiler is cleaned frequently, every week.

4. How to Eliminate the Operational Problems

Subsequent elimination of problems related to operations of oversized biomass boilers requires advanced technology and high investments. There are 3 areas that help correct the operational problems (Figure 4).

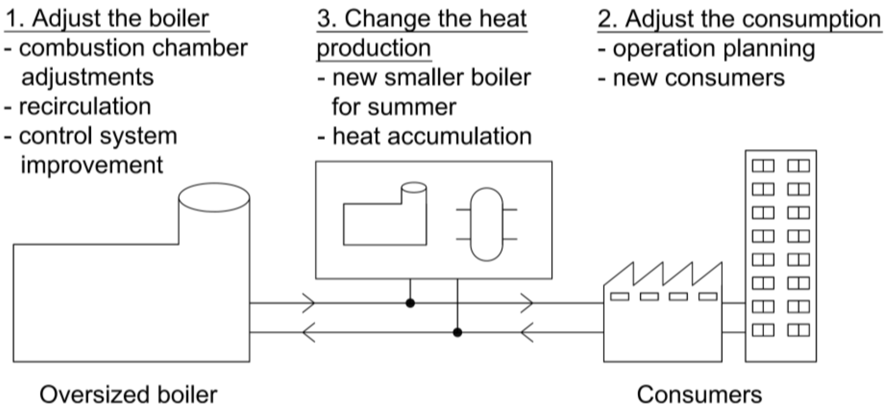

Figure 4: Three categories of measures for effective operation of oversized biomass boilers

4.1 Adjust the boiler

Adjusting a boiler increases combustion quality. The adjustments may target either the construction or the technology of the boiler. Basic construction of the boiler may be adjusted by changing dimensions of the combustion chamber and changing dimensions and locations of inlet orifices supplying combustion air. These secondary alterations require advanced technology and high investments but benefits remain uncertain. Adjustments of the boiler technology target optimization of the combustion process using available regulation features. This includes changes to combustion air flow rate (Quintero-Marquez et al.,

2014) and changes to grate shift speed in boilers with a moving grate. Dry fuels with a high heating value may be additionally moistened before they enter the combustion chamber.

The so called recirculation of flue-gas is a specific technology adjustment (Palmer et al., 2011). It returns some of the flue gas back into the combustion chamber. This helps lower the amount of fresh air (high in oxygen) supplied into the chamber. In general, lowering the oxygen concentrations in the flue gas leaving the boiler greatly increases overall efficiency of the system. Recirculation of flue-gas further provides dryer fuel and promotes gasification of the fuel at the grate. Recirculated flue gas may be supplied above the end of a combustion grate as well as below the front part.

Adjusting a control system may also significantly improve operations of the boiler at low outputs. If the consumption changes often, we may stabilize the boiler by measuring the heat demand directly by the key consumers. A control circuit is supplemented with an auxiliary inputs with a signals coming from a heat meters installed by the most important consumers. Controller receiving the signal then increases output of the boiler on time and the effect of these changes of consumption is eliminated. Installing a lambda probe may also help optimize the combustion. The probe monitors concentrations of O_2 in flue gas. If the concentrations exceed a defined threshold (commonly 10 %), the regulator reduces flow rate of combustion air (Quintero-Marquez et al., 2014). Other sophisticated approaches include use of mathematical models of the boiler in control systems (Máša et al., 2011) but they are not very common in the practice and applications are only theoretical (Liukkonen and Hiltunen, 2014).

Adjustments to the boiler usually cannot solve all problems of oversized boilers. Biomass boiler is optimized to meet a particular capacity and all components as well as a control system setting reflects that capacity. Overall efficiency of the adjusted boiler is always lower compared to operations at the original rated capacity.

4.2 Adjust the consumption

Adjustments to the consumption means that an oversized boiler produces high output for a certain period of time (close to the rated capacity) and is then shut down. During the shut-down, the fuel is supplied only in minimum amounts so that the boiler does not burn out. This measure has a positive impact on amount of pollutants. Manufacturing plants adjust their heat consumption by scheduling their heat demands. Devices are turned on and off so that their heat consumption add up or at least connect. The aim is to combine devices into short time intervals. One on the great benefits is that the adjustment requires zero investments. If there is enough fuel in the plant (such as waste wood), the energy system may be supplemented with a new device such as a cogeneration unit using excess heat from the biomass boiler. Hot-water system may use an ORC (Prando et al., 2015) unit while steam system may use a steam turbine or a steam engine (Sartor et al., 2014). Return on investment is dependent on how much the technology is actually used throughout the year and continuous operations with minimum amount of shutdowns provide the highest efficiency.

4.3 Change the heat production

Heat storage and shutdown of an oversized boiler during a heating season may also be classified as changes to the boiler design concept. Heat storage is an attractive method used in commercial facilities to increase the overall efficiency of the heating system. During a heating season, the biomass boiler is running at maximum output and fills the heat storage tank. During heat demand peaks, heat supplied by the boiler is combined with the stored heat or heat produced by a small gas boiler. During a summer, the biomass boiler is operated at minimum heat output. It satisfies a demand for heat and fills the heat storage tank. Once the storage is full, the boiler enters an idle mode until the storage is empty again (Mouchira et al., 2014). Dimensions of the heat storage tank must always be designed in relation to a particular boiler and demands of the heating system. Properly designed heat storage tank stabilizes the biomass boiler and thus increases its efficiency and quality of combustion. A control system is obviously a must for smooth running of the whole system (Palmer et al., 2011). Heat storage is useful in heating systems which do not require high water temperatures and are not sensitive to temperature drop during emptying of the storage tank. The storage may be a part of the design of the heat source itself.

Shutdown of an oversized boiler during a non-heating season is plausible only if the difference in heat demand between a summer and a winter is significant. The efficiency of a boiler operated at low outputs during a non-heating season may be critically low (see Figure 2) and the whole operations may become uneconomical. In general, it may be wiser to shut the boiler down for a summer season and replace it with an alternative source of heat. A gas condensing boiler is especially useful here. If there is enough biomass throughout a summer season, a small-capacity biomass boiler may also be installed.

Adjustments to consumption together with conceptual changes help operate an oversized boiler at an originally designed capacity. The efficiency of the boiler is high and the pollutants are low. Whenever possible, the adjustments to the consumption and conceptual changes should be preferred to interferences with the boiler construction and technology.

The boiler analysed in the case study was adjusted by employing a heat storage tank during a heating season and by shutdown during a non-heating season. These measures were evaluated using operational data from the past in order to design a proper source of heat to satisfy demand in the non-heating season. Wood-processing plants are known to produce biomass as a waste product and it is therefore available year-round. Evaluation must also include analysis of fuel consumption.

5. Conclusion

Designing a proper capacity of the biomass boiler is a crucial part in integration of the boiler in the facility. An oversized boiler has a decreased efficiency and produces lots of pollutants. Operators of the boiler may even fail to comply with emission limits and have to shut-down the boiler. There are technical and operational adjustments that can help eliminate these problems. It is good to prefer the measures which respect the designed output range of the boiler. In this paper, we tried to warn the designers to not oversize biomass boilers. Boiler oversizing often occurs if the some of the investments come from public subsidies. Selection of the proper capacity must be a responsible decision since an ill-sized biomass boiler causes operational troubles its whole life and the life itself may be shortened, too. Proper sizing is at the core of all plans for economic profit and positive environmental impact.

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