Technical Sciences, 2018, 21(2), 117–129

UNIWERSYTET WARMIŃSKO-MAZURSKI W OLSZTYNIE

Quarterly peer-reviewed scientific journal
ISSN 1505-4675
e-ISSN 2083-4527
TECHNICAL SCIENCES
Homepage: www.uwm.edu.pl/techsci/

AN ANALYSIS OF THE POWER DEMAND AND ELECTRICITY CONSUMPTION OF AUTOMATIC PELLET BOILER

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Received 5 July 2017; accepted 8 November 2017; available online 22 March 2018.

Key words: automatic pellet boiler, electricity consumption, power demand.

Abstract

Pellet boilers are increasingly popular on the market, largely due to the fact that their use does not demand constant control by the user, but is reduced only to replenishing fuel and cleaning the combustion chamber and heat exchanger every few days. However, this functionality creates additional costs in terms of power consumption due to the work of boiler components, such as the pellet igniter, screw conveyors motors, fan, pump and controller. The purpose of this research was the analysis of the power demand and energy consumption of the electricity devices installed on the automatic pellet boiler in two operating modes, determining the total energy consumption and costs of electricity due to heating seasons in each mode. In the first mode, the boiler worked with modulated power, and in the second the boiler was working with nominal power. To carry out the mentioned research, a pellet boiler installed in the AGH UST Laboratory of Renewable Energy Sources in Miękinia was used. All the data obtained was used to simulate the total electricity consumption during one standard heating season and the costs involved. In the first case the boiler consumed 623,195 kWh of electricity per heating season and in the second the boiler consumed 304,503 kWh electricity per heating season. Although electricity consumption in the modulated mode is higher, the total cost of heating is lower, due to lower fuel consumption.

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Introduction

Today, when sustainable energy usage is a key element of the modern world and the EU has set itself the 3×20 target to achieve, the growth in renewable energy usage and improvements of energy efficiency is so important (RUOKAMO 2016), the pellet boilers can help to achieve each of the three goals, which emphasize the reduction of greenhouse gas emissions, growth in renewable energy usage and improvements of energy efficiency.

In recent years, pellets have become an important fuel for heat and electricity production in Europe. Pellets have a higher fuel density and hence demand less transportation and storage surface. In comparison with unprocessed biomass, pellets present a lower moisture content, higher effective heating value, uniform shape, clear burning and reduction of ashes (MOLA-YUDEGO et al. 2014). An increase in the Polish market of pellet boilers has also been observed. In 2014, 26,000 units of biomass boilers were sold and 14% of the total amount were pellet boilers (IEO 2015). Automatic solid fuel boilers need electricity to work, and the amount of the electricity is rarely stated by producers. Due to their fully automatic workings, the ease of boiler use, the small amount of ash and lack of pollution in the boiler room, all combine to make the pellet boiler increasingly popular (GÓRECKI et al. 2015).

Pellet boilers are devices which produce the lowest emissions of air pollutants compared to other solid fuel boilers, but the problem of hazardous substances in flue gas cannot be eliminated (BIERANOWSKI, OLKOWSKI 2009, MUSIL-SCHLÄFFER et al. 2010). Most pellet boilers offered on the market are of the fifth best class according to PN-EN 303-5:2012 standard (KACZMARCZYK et al. 2015). The nominal heating power efficiency currently produced pellet boilers is over 90% (SCHWARZ et al. 2011). According to CARLON et al. (2015) the annual efficiency (measured as a quotient heat produced by the boiler and energy consumed in the fuel) for standard house from 2004 was 83%, when efficiency during the standard testing conditions in nominal load was 93.2% and during the part load was 90.9%. The boiler work in modulating power mode.

The electricity demand of pellet boilers depends on the thermal power and equipment of the boiler. From 1^{st} April 2017 energy labeling for solid fuels boilers has become obligatory. According to EU Commission Regulation No. 2015 /1187 solid fuel boilers may exist in the class from G to A++, and from 26^{th} September 2019 the energy labels will be from class D to A+++. The electricity consumed by the boiler has a large influence on the final result of the energy label. Defining real electricity consumption is important to demonstrate the impact on the total costs caused by the consumption of energy by a pellet boiler. Data obtained are necessary to check real power and electricity consumption. The knowledge about power and electricity consumption is necessary for designing a self-supplying electricity system for a pellet boiler.

The main aim of the investigation was to determine the electricity consumption and power demand by a pellet boiler in the various operating modes of the boiler. The values are important for further research and the construction of a prototype of an energy generator for supplying the boiler. Furthermore, the total energy consumed by a pellet boiler and the costs of electricity was investigated. The costs generated by a pellet boiler are important for users. The results were discussed and the cheapest mode of pellet boiler operation was indicated.

Material and methods

Description of pellet boiler

The measurements were conducted in 2016 in the educational boiler room in the AGH UST Laboratory of Energy Sources and Energy Saving in Miękinia. The fully automatic pellet boiler with a nominal power 25 kW was used to carry out the research. It is a high-performance device (89–92%) and fulfills the requirements of a fifth-class boiler according to the PN EN 303-5:2012 standard. In the pellet boiler, there is a burner with modulated power ranging from 5 to 25 kW. The burner has an electric resistance igniter for the automatic ignition of pellets, a stoker feeding system to fuel supply to the grate and a moving grate for improving deash. The ash is removed from the burner by the air stream and the moving grate, which moves every five minutes. The ash is collected in the ash box and must be removed manually about every two weeks. The functionality of the pellet boiler is controlled by an electronic controller (technical documentation of pellet boiler, on-line).

The electric devices contained in a boiler are:
- pellet igniter,
- screw conveyors motors,
- fan,
- pump,
- controller.

The working parameters of particular components were set by the boiler installer.

The pellet boiler has four working stages. The first stage is ignition. It starts with switching on the fan, which removes ash from the burner. Then a starting dose of fuel is supplied to the burner, and the igniter is activated. The purpose of this step is to warm up the fuel to ignition temperature. The igniter works until a signal from the light sensor appears and the fan in this operating mode is in constant operation. The fuel is transported from hopper to burner using two different screw conveyors and these devices work periodically.

After ignition, the boiler goes into the heating operation mode. During the heating operation mode, the screw conveyor motor, fan and stoker are working. The circulation pumps are activated when the boiler obtain the expected temperature (in the analyzed case, only the central heating pump). The burner can work at four power levels. While working at nominal power, parameters such as time of fuel supply and airflow power are set by the user. In case of lower power usage etc. ½; ¼; ⅛, the time of fuel supply and fan power are properly reduced. The burner works with nominal power as long as the boiler water temperature remains at 7°C below the expected temperature. Above this temperature, the controller modulates the burner power.

When the expected temperature is reached, the boiler switches to extinguishing mode. During this stage, fuel is not supplied and the fan begins working at full power to finish burning the last fuel and to blow ash from the burner.

After extinguishing mode, the burner goes over to standby mode, while the controller measures the temperature of the water supply. When the temperature is lower than the expected temperature minus the modulation temperature, the boiler starts the ignition process again.

A simplified algorithm for the operation of the pellet boiler is shown on Figure 1. When the process starts, a controller measures the light intensity on the burner. If the measurement is higher than 200 [–] the boiler runs, otherwise an outflow water temperature measurement is conducted. The controller starts the ignition mode when the outlet water temperature is lower than the set temperature minus the outflow water hysteresis, otherwise the controller is on standby. Ignition end when the light intensity on the burner is higher than 200 [–] and then the heating mode operation is initiated. Heating power in this mode is independent of the current temperature of water exiting from the boiler. When this temperature exceeds a set temperature, the extinguishing mode begins. The last stage is standby mode where the controller measures light intensity on the burner and the temperature of outflow water. The working stage depends on the settings of the device parameters and current heat power demands of the building.

Description of measurements

Power demand and energy consumption were measured by a single-phase electricity meter using the RS485 communication protocol to send data to a computer. Measurements of power demand were made separately for each device and in every mode of the operation of the pellet boiler.

Electricity consumption measurements were also conducted during every operating mode: initiating the burner, working with modulated power, extinguishing and standing by. The received values were read for ten minutes and recorded automatically every five seconds. In later considerations, averaged values were used.

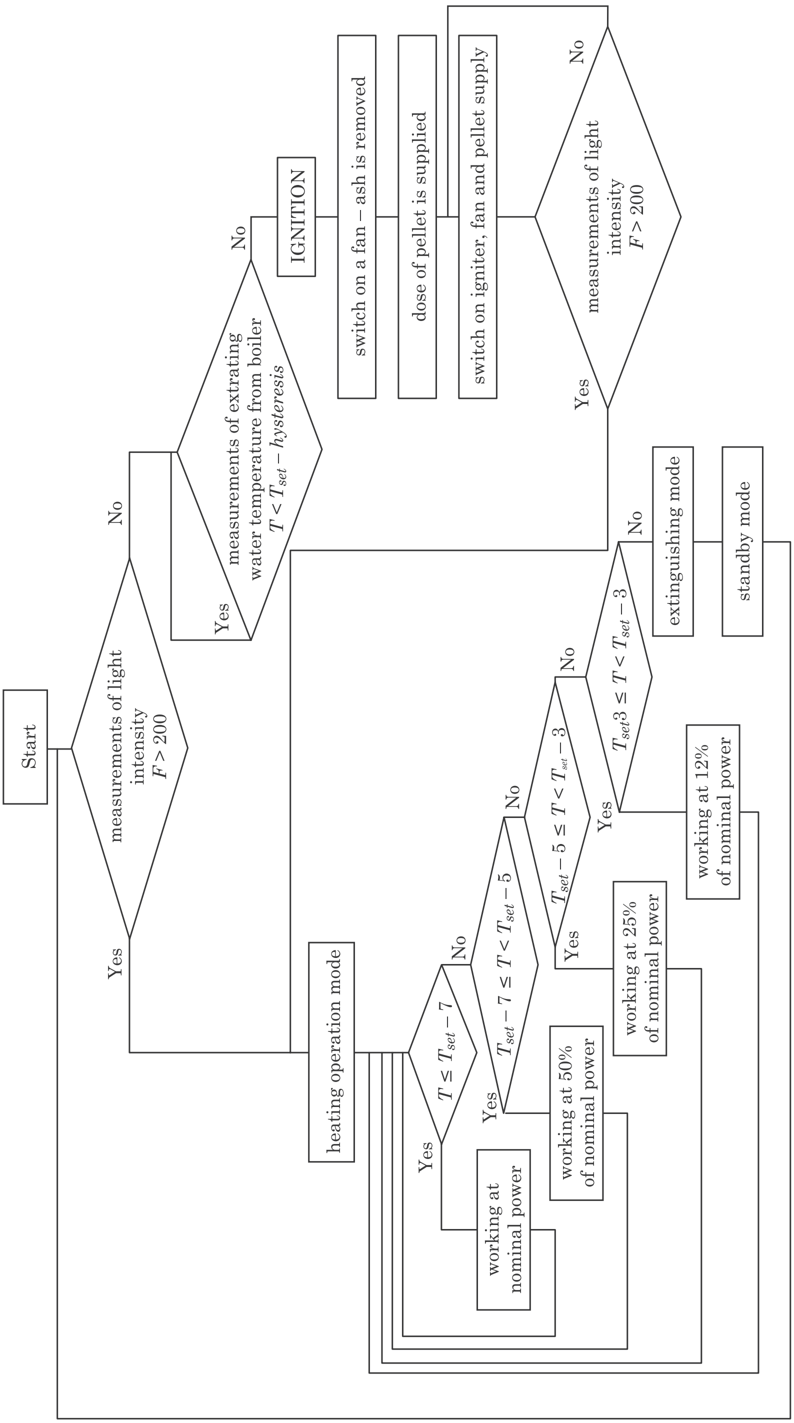

Fig. 1. Pellet boiler's work algorithm. F is a value of light intensity readied by photoresistor, $F \in$ <0,1000>. T_{set} is a value of set temperature. T is a current temperature

Simulation

The calculations of the energy consumption under the two different operation systems (modulated and constant power) of the boiler were conducted.

The data presenting the typical yearly weather and statistical climate information for Krakow to calculate energy consumption was collected from the Ministry of Infrastructure and Construction website (www.miib.pl, on-line).

Simulations were conducted in a developed spreadsheet for a theoretical single family detached home. All parameters of the building were assumed, internal gains were 20 kWh/m^{2}a and external (solar) gains were 50 kWh/m^{2}a. The heat energy demand is 25 kW and heating area is 250 m^2. The location is in the third climate zone (according to standard PN-EN 12831) with an external design temperature equaling –20°C. The analysis was performed with the assumption that the heating season lasts for nine months – from September to May.

In the first scenario the controller modulates the power of boiler to maintain a constant temperature inside the building (20°C). The burner can work at full-power or with reduced power (50%, 25%, 12,5%). The controller chooses the intervals of work with appropriate power to cover the temporary heating power demands of the building. The temperature inside the building can increase above 20°C only when the temperature outside is higher than 20°C. The boiler switches on when the risk of an inside temperature reduction below 20°C occurs.

The second scenario assumes the boiler working with nominal power (25 kW), in order to maintain a temperature inside the building between 20°C and 22°C. This scenario also assumes that heat will be accumulated in the building's construction. An established range of temperature changes are dictated by thermal comfort inside the building. The boiler is turned on when temperature inside the building drops below 20°C and it is turned off when the temperature inside the building increases above 22°C.

The assumption of different temperatures for both scenarios is deliberate. In a scenario with modulating power the indoor temperature is possible to achieve by choosing boiler power properly while in a scenario with constant power it is necessary to assume that the temperature range inside of the building is changing. It is due to the building's construction acting as an accumulator of energy produced by the boiler and it is a disadvantage of this solution.

Results and discussion

Results of laboratory tests

The results of the measurements of power demand are shown in Table 1. The igniter has the highest power consumption among the all components of boiler. The pump can work with three different power values, depending on flow resistances occurring in central heating installation. The measurement of the grate's motor and controller's monitor did not result in any power consumption, due to their small power demands. For this reason, the controller's monitor power demand was not taken into consideration in further calculations and the grate's motor power demand was taken from technical documentation. The average values of power demand are presented in Table 1.

Table 1

Results of measurements of power demand (average values)

Device		Power [W]
Fan		25
Pellet igniter		215
Fuel hopper conveyor motor		31
Mechanical stoker		32
Grate motor		2
Pump	speed III	78
	speed II	62
	speed I	55

During measurement the pellet boiler worked continuously with a nominal heating power (25 kW) for 85 minutes and consumed 0.13 kWh of energy. Minimal power demand was 23 W (when only the fan was working) and maximal power demand was 362 W (when creating an ignition, the fan and screw conveyor motors are working). The average power demand of the pellet boiler was 91 W. According to research conducted in the Austrian Bioenergy Centre GmbH, different pellet boilers at full load and under electrical demand give results ranging from 0.2 to 1.8% nominal heat capacity (MOSER et al. 2006). According to LAICANE et al. (2015), for a 15 kW pellet boiler, the electricity power demand is 150 W. During winter the boiler works 24 hours per day to ensure continuous operation. The electricity demand in pellet boilers also depends on the operation mode. For example, a 10 kW boiler in the on/off mode can consume as much as 172 W, but in modulating power mode, when the same boiler can work with constant heating power at 3 kW, the power demand can be reduced to 95 W (HALLER, KONERSMANN 2008). The tested boiler showed a lower power demand than quoted examples.

Simulation results

The results of calculations from both scenarios are presented in Table 2 and Table 3. A simulation of a scenario in which the boiler is working with modulated power showed that the boiler would work for 6,134 hours and would be switched off 356 times. In this time it would consume 623,195 kWh energy at a cost of 405.08 PLN (0.65 PLN for 1 kWh). The highest power consumption during the heating season was caused by the central heating pump (more than 402 kWh). Energy consumption by the circulating pump alone represented 64.57 percent of the total energy consumption by the heating installation.

In the second case (working at only 25 kW heating power) the pellet boiler would work 2,596 hours and be switched off 143 times. During the operation, the boiler would consume 304,503 kWh of energy, at a cost of 197.93 PLN. As before, the highest consumer of energy was the circulating pump. It represents 53 percent of the total energy consumption in this mode.

Due to the hysteresis of the internal temperature of 2 K, in the nominal operating mode, the number of boiler launches was lower than in the modulated mode. In the case of lowering the internal temperature hysteresis, the number of boiler outputs for nominal power would far exceed that of a boiler with modulated power.

In fact, the amount of energy and cost of electricity consumption depends on many factors. The first one is the climatic zone in which the building is located. The colder the climate, the higher the heat demand and the resulting longer working of the boiler and higher costs. The second factor are the applied sets of devices which are installed in the boiler and their individual parameters (the number of pumps, an additional mechanism to remove ash and soot, etc.). The mentioned simulations assumed two extreme ways of using the boiler while the real energy consumption would depend on user habits and expected thermal comfort.

The analysis of the total cost of heating has also been conducted. Pellet boiler a seasonal efficiency in the first scenario is assumed as 75% and in the second case is assumed as 83% (according similar conditions as the CARLON et al. 2015). In the first scenario efficiency is reduced by reason of part load working and twice more ignitions. To assume more detailed efficiencies for the considered boiler there are need conduct experimental tests of the system (CARLON et al. 2016). The cost of the pellets would be 8,847.30 PLN if the boiler would work with modulated power and 8,474.20 PLN if the boiler would work with constant power. In the scenario with modulated power, the total cost would be 9,252.38 PLN. In the second scenario, the total cost would be 8,672.13 PLN and lower by 6.67% than the first scenario. Although maintaining a higher temperature in the building (from 20°C to 22°C instead a constant 20°C), the total costs of heating would be lower, because the boiler efficiency is higher and thus cause lower fuel consumption. All costs are presented in Table 4.

Table 2

Energy consumption of a particular electric devices during a heating season where the controller modulates the boiler power

Phase	Device	Function	Power [W]		Time [s]	Energy consump-tion [kWh]	Cost [PLN]	Share [%]
Ignition	fan	scavenge	28		10,680	0.083	0.05	0.01
		working	24		32,040	0.214	0.14	0.03
	fuel hopper conveyor motor	fuel supply	31		10,680	0.092	0.06	0.01
	mechanical stoker	fuel supply	32		10,680	0.095	0.06	0.02
	pellet igniter	ignition	215		32,040	1.914	1.24	0.31
Operating mode	fan	working at 100% of power	29		1,296,142	10.441	6.79	1.68
		working at 50% of power	27		10,648,838	79.866	51.91	12.82
		working at 25% of power	26		7,386,292	53.345	34.67	8.56
		working at 12.5% of power	24		2,752,085	18.347	11.93	2.94
	fuel hopper conveyor motor	fuel supply	31	25 kW	457,623	8.008	5.21	1.29
				12.5 kW	1,879,868	32.898	21.38	5.28
	mechanical stoker		32	6.25 kW	651,961	11.409	7.42	1.83
				3.125 kW	121,458	2.126	1.38	0.34
	grate motor	cleaning the burner	2		1,752,647	0.974	0.63	0.16
	pump	speed III	78		–	–	–	
		speed II	62		22,083,358	380.324	247.21	61.03
		speed I	55		–	–	–	–
Extin-guishing	mechanical stoker	exhaustion of stoker	32		14,240	0.127	0.08	0.02
	fan	scavenge	29		106,800	0.860	0.56	0.14
	pump	speed III	78		–	–	–	–
		speed II	62		1,281,600	22.072	14.35	3.54
		speed I	55		–	–	–	–
				SUM	25,194,269	623.195	405.08	100.00

Table 3

Energy consumption of a particular electric devices during a heating season where the boiler is working with nominal power

Phase	Device	Function	Power [W]	Time [s]	Energy consumption [kWh]	Cost [PLN]	Share [%]
Ignition	fan	scavenge	28	4,290	0.033	0.02	0.01
		working	24	12,870	0.086	0.06	0.03
	fuel hopper conveyor motor	fuel supply	31	4,290	0.037	0.02	0.01
	mechanical stoker	fuel supply	32	4,290	0.038	0.02	0.01
	pellet igniter	ignition	215	12,870	0.769	0.50	0.25
Operating mode	fan	working at 100% of power	29	9,342,000	75.255	48.92	24.71
		working at 50% of power	27	–	–	–	
		working at 250% of power	26	–	–	–	
		working at 12.5% of power	24	–	–	–	
	fuel hopper conveyor motor	fuel supply	31	3,298,337	57.721	37.52	18.96
	mechanical stoker	fuel supply	32				0.00
	grate motor	cleaning the burner	2	741,429	0.412	0.27	0.14
	pump	speed III	78	–	–	–	
		speed II	62	9,342,000	160.890	104.58	52.84
		speed I	55	–	–	–	
Extin-guishing	mechanical stoker	exhaus-tion of stoker	32	5,720	0.051	0.03	0.02
	fan	scavenge	29	42,900	0.346	0.22	0.11
	pump	speed III	78	–	–	–	
		speed II	62	514,800	8.866	5.76	2.91
		speed I	55	–	–	–	
			SUM	23,325,796	304.503	197.93	100.00

Table 4

Results of the analysis of the total cost of heating, including the cost of fuel

Scenario	Heat demand [kWh]	The boiler efficiency [–]	The amount of energy supplied as pellets [kWh]	The energy value of pellets [kWh/kg]	The weight of pellets [t]	The price of pellets [PLN/t]	The cost of pellets [PLN]	The cost of electricity [PLN]	The share of electricity in costs [%]	Total costs [PLN]
Constant power 25 kW	50,241	0.83	60,531	5	12.106	700	8,474.20	197.93	2.34	8,672.13
Modulated power	47,397	0.75	63,196		12.639		8,847.30	405.08	4.58	9,252.38

Conclusions

In this paper the power demand of particular devices of a pellet boiler and an average power demand of the whole boiler are specified, amounting to 91 W. The highest electricity consumption from all of the electric devices installed in the pellet boiler comes from the circulating pump. Circulating pumps working in an installation should be high-quality pumps of the highest energy class and thus low power consumption.

The cost of the power consumption of a pellet boiler is strongly dependent on its manner of usage. The paper presents the electricity consumption of a pellet boiler in two extremely different ways of using boilers. The foregoing calculations have shown that the cost of electricity in a scenario where the boiler works at nominal power is half as cheap. Unfortunately, it is associated with a lower level of comfort, due to the temperature fluctuations of 2°C a few hours. Despite the fluctuations of temperature occurs, the final energy consumption and the costs are lower when the boiler works with constant power and this is caused by burning less fuel connected with higher boiler efficiency. Modulating power boiler increase thermal comfort inside the building but raises costs of exploitation. Buffer tank usage could be solve the problem with lower thermal comfort connected with using constant power pellet boiler. But it could increase the pellet consumption due to decrease overall system efficiency.

The analysis of power demand and energy consumption of particular pellet boilers devices will be used to conduct further investigations about alternative power supplies for these kinds of boilers.

Acknowledgments
The paper was prepared under AGH-UST statutory research grant No. 11.11.140.031.

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