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13. DEVELOPMENT OF CONTROL SYSTEM FOR CENTRAL HEATING BOILER

As a result of legislative action in the European Union and its individual member states, the demand for high-quality equipment has grown in recent years with respect to the individual heating sector, particularly from the perspective of high energy efficiency and environmental protection, as well as convenience and inexpensiveness of operation.

In 2013, the European Commission adopted a Clean Air Policy Package for Europe [1]. This package of measures aims to achieve full compliance with existing air quality legislation by 2020 and further improve Europe's air quality by 2030 and thereafter [2].

The gradual withdrawal of coal from energy production necessitates the application of low-emissions sources of energy production, such as wind and solar energy, water (rivers, tides and sea waves), biomass, new nuclear power plants, as well as extension of the lifetime of existing sources that can operate in a safe manner [3].

The high level of air pollution caused by solid fuel combustion installations, particularly those with outdated, traditional designs, makes it necessary to design and implement heating systems based on renewable energy sources and heating systems with modern central heating boilers. The International Energy Agency (IEA) forecasts that, in 2040, 60% of heat will be generated from renewable energy sources, i.e. pellet in boilers and furnaces, biogas, biomethane and biofuels [4, 5].

Article [6] shows a system based on solar thermal collectors, a biomass boiler and an innovative reversible hybrid heat pump/ORC concept for addressing heating, cooling and domestic hot water demand of residential buildings. The main findings from the SDEWES conferences of 2021 within the field of renewable energy and the systems analyses used to design complex renewable energy systems are presented in [7]. The computer model was developed in order to build a system for process control in the building's heating system with installation using renewable energy sources – a solar photovoltaic panel, a HHO gas generator and a pellet boiler is presented in [8].

The implementation of the anti-smog act is to lead to improvement of air quality in individual regions of Poland. This is an amendment to the Environmental Protection Law

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(art. 96) [9]. The provisions of this act are to contribute to improvement of our health and enhance our living standard. The anti-smog act indicates the types of heating equipment approved for use and the types of fuels prohibited from use, in short, what can be burned and in what. In the case of buildings heated with a solid-fuel boiler (coal or pellet), the anti-smog act permits the use of class 5 flue gas purity boilers, i.e. those that have a certificate issued in compliance with standard PN-EN 303-5:2012 [10] or boilers meeting the requirements of eco-design according to the Regulation of the European Commission [11].

Existing heating systems must be continuously modified and optimized to meet technological requirements concerning the efficiency of using the energy of fuels in burners and the affordability of implementing new solutions.

In this chapters the results of work involving the development of a control system for a modern central heating boiler utilizing a renewable energy source – biomass are presented and discussed.

13.1. HEATING SYSTEM WITH CENTRAL HEATING BOILER UTILIZING A RENEWABLE ENERGY SOURCE – BIOMASS

13.1.1. DEVELOPMENT OF A CENTRAL HEATING AND DOMESTIC HOT WATER INSTALLATION SCHEMATIC

A simplified schematic diagram of the installation, with two central heating circulations (circulation 1, circulation 2), domestic hot water circulation, and with additional floor heating, is presented in Fig. 13.1. To improve the diagram's readability, the protective installation in the form of collector pipes, safety pipes, etc. is not shown.

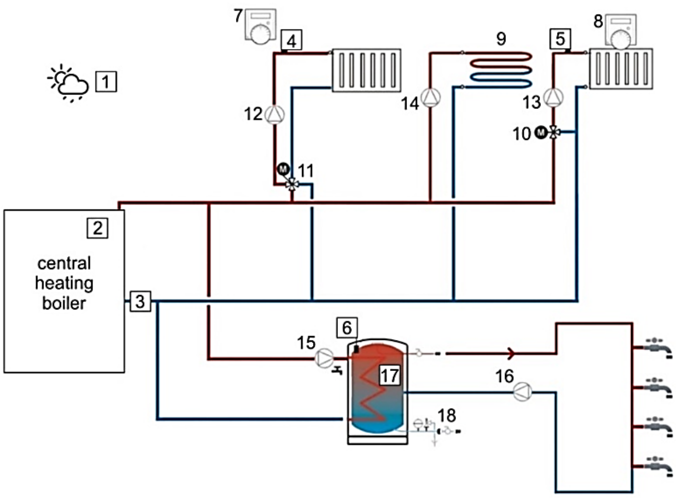

Fig. 13.1. Schematic diagram of central heating and domestic hot water installation [14]

The following components are marked in Fig. 13.1: external temp. sensor (1), boiler water temp. sensor (2), temp. sensor for water returning from installation to boiler (3), temp. sensors of central heating supply in loop 1 (4), temp. sensors of central heating supply in loop 2 (5), domestic hot water temperature sensor (6), room regulator 1 (7), room regulator 2 (8), floor heating (9), 3-way valve with drive (10), 4-way valve with drive (11), circulating pump of central heating loop 1 (12), circulating pump of central heating loop 2 (13), circulating pump of floor heating loop (14), domestic hot water circulating pump 1 (15), domestic hot water circulating pump 2 (16), domestic hot water tank (17), cold water supply from network (18).

The heating installation should be open, i.e. must be equipped with a collector vessel as well as with: safety, collector, overflow, signaling and venting pipes. The collector vessel, safety pipes, collector pipe, signaling pipe and overflow pipe must be placed in a space where the air temperature is greater than zero. If heating loops 1 and 2 and the domestic hot water circulation are active in the installation and equipped, accordingly, with circulating pumps (12), (13), (14), (15), then the appropriate temperature sensors (4), (5) and (6) must also be installed. Temp. sensors of central heating supply in loop 1 (4) and loop 2 (5) are indispensable if the controller is to support the actuator of the mixing valve for the given loop. Optionally, room regulators (7, 8) make it possible to maintain a set temperature in rooms, as desired by the residents.

13.1.2. CENTRAL HEATING BOILER UTILIZING A RENEWABLE ENERGY SOURCE – BIOMASS

The central heating boiler is presented in Fig. 13.2. The boiler consists of two main components standing next to each other: the boiler proper (1) and fuel tank (2) with a unit of feeders. The application of two feeders made it possible to separate the fuel dispenser from the combustion chamber. Thanks to this, there is no possibility of flashback to the fuel dispenser, and moreover, it does not have to be tightly closed. The main feeder (3) is a spring revolving slowly in a pipe, moving fuel from the lower part of the dispenser upward, from where it falls through pipe (4) onto a second feeder (worm), which feeds fuel to the combustion chamber.

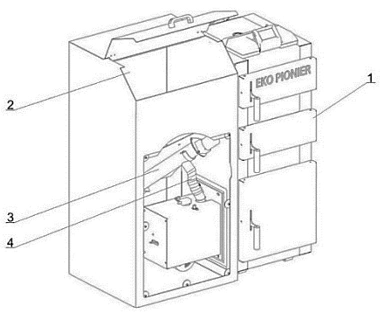

Fig. 13.2. Appearance of boiler with removed guard of feeders [14]

Figure 13.3 presents the cross-section of the central heating boiler. The following are marked in Fig. 13.3: burner inlet (1), insulation (2), water jacket (3), flue gas swirler (4), exterior housing (5), exhaust fan (6), water temperature sensor in boiler (7), boiler controller (8), small door for boiler cleanout (9), large door to combustion chamber (10).

The boiler is equipped with two fans: an intake blower, supplying the appropriate amount of air to the combustion chamber, and exhaust fan (6), making it possible to discharge flue gas through the furnace flue to the chimney. There are 2 holes at the top of the boiler. The hole on the right side (viewing from the front), is intended for insertion of the boiler water temperature sensor (9), and the hole on the left side serves for installation of the capillary tube of the boiler's resettable thermal protection.

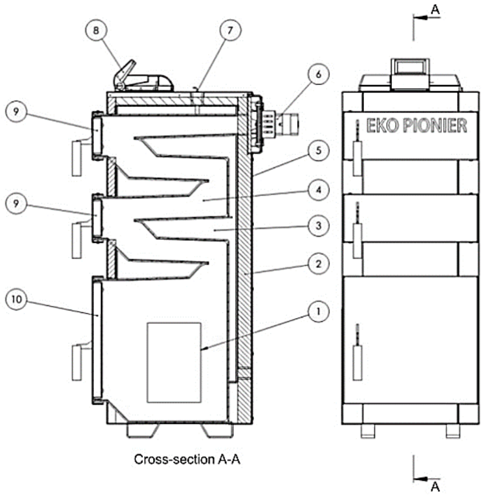

Fig. 13.3. Cross-section of the central heating boiler [14]

The flue is situated on the top rear of the boiler, with two holes: the larger one serves for fastening of the lambda sensor, and the smaller one for fastening of the flue gas temperature sensor (Fig. 13.4). The lambda sensor makes it possible to measure oxygen content in flue gas. This enables precise dosage of the fuel-air mixture at individual stages of the biomass combustion process. The flue gas temperature sensor has an additional clamping ring, preventing the sensor from being pushed into the flue.

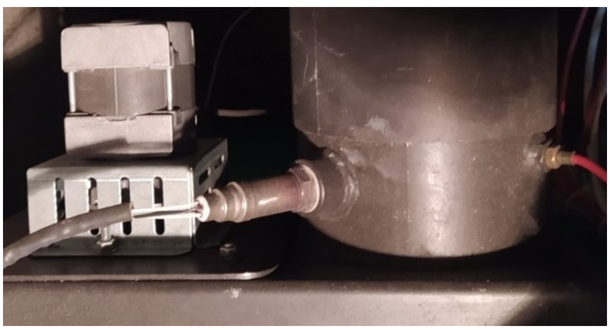

Fig. 13.4. Lambda sensor and flue gas temperature sensor

1.3. BURNER FOR CENTRAL HEATING BOILER

Figure 13.5 shows the prepared 3D model of the burner for the central heating boiler. The model was prepared using SOLIDWORKS software. The burner's principle of operation is described in works [12, 13].

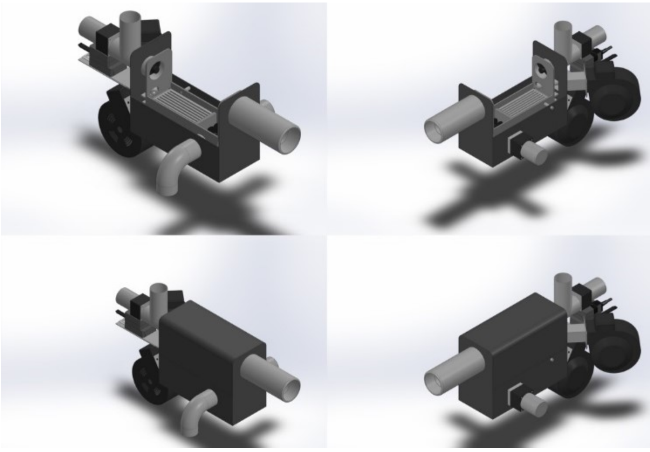

Fig. 13.5. 3D model of burner for central heating boiler

13.2. DEVELOPMENT OF CONTROL SYSTEM FOR CENTRAL HEATING BOILER

13.2.1. STAGES OF CONTROL SYSTEM DEVELOPMENT

Development of the control system for the central heating boiler was carried out according to the following stages:

- designing of control system,
- selection of appropriate equipment and software,
- preliminary preparation of PLC, HMI software for the combustion process,
- installation of automation (input automation components, controller, actuators),
- installation of indispensable cabling for communication and control of system components (fuel feeder, exhaust fan, igniter fan, igniter),
- final preparation of PLC software for the combustion process,
- analysis of the created control system's operation in the burner – boiler system,
- process optimization and necessary corrections of the PLC code,
- final preparation of human – machine interface (HMI),
- final start-up,
- tests of safety systems,
- realization of checklist and CE certification,
- development of documentation.

13.2.2. ASSUMPTIONS FOR DEVELOPMENT OF CONTROL SYSTEM FOR CENTRAL HEATING BOILER

The control system of the central heating boiler should make it possible to following assumptions.

- Automate the fuel ignition process in the burner using an electric heater (igniter) and fan generating a stream of hot air.
- Control of combustion process parameters:
  - dosing of the appropriate fuel-air mixture at individual stages of the biomass combustion process, i.e. feeding of a specific amount of fuel and supply of required portions of air from the environment to sustain biomass combustion,
  - the process of cleaning the grate situated in the gasifying chamber, which should be performed automatically at regular time intervals (cyclically).
- Constant-value (programmed) temperature regulation in individual rooms of the building, at the set level.
- Constant-value (programmed) regulation of domestic hot water temperature.
- In the case where water in the boiler reaches a temperature of 95°C, the fuel (pellet) feeder and intake blower should be disconnected, and in addition, an alarm sound signal should be activated. Restart of the furnace requires the user's intervention.
- Damage to any of the temperature sensors should result in suspension or limitation of the boiler's operation and in the activation of an alarm sound signal.

13.2.3. SELECTION OF AUTOMATION COMPONENTS

Based on adopted assumptions and analysis of components of the heating system individual automation components were selected for the designed control system: input automation components (table 13.1), actuators (table 13.2) and FuzzyLogic 500 controller – Cherokee [15].

Actuators entering into the burner's equipment: intake blower, igniter, motor of ash collector feeder. Actuators entering into the boiler's equipment: exhaust fan, motor of fuel feeder. Other components of the control system, i.e. circulating pumps of central heating loops, circulating pump of floor heating loop, circulating pumps of domestic hot water, water valve actuators, mixing valve actuator, are selected depending on the sizes of central heating installation components, i.e. diameters of pipes in the hydraulic installation and the investor's budget.

Figure 13.6 presents the connections of individual input components and actuators to the terminals of the selected controller. The controller was integrated with a graphical, color and touch LCD, enabling value changes of the most important parameters and monitoring of other parameters involved in boiler operation.
According to the adopted assumption concerning protections:

- the controller controls the operation of sensors, and in the event where any sensor is damaged, the boiler's operation is suspended or limited, an interrupted sound signal is generated, and the appropriate message is displayed on the screen,

- if water temperature in the boiler exceeds 95 ℃, the boiler's active thermal protection will be engaged, and an interrupted sound signal will be activated. The controller sends the signal for disconnection of fuel feeders, the igniter and intake blower, thanks to which the burning process is interrupted. To restart the boiler, the RESET button on the controller's housing must be pressed.

Individual input automation components of the control system are listed in table 13.1.

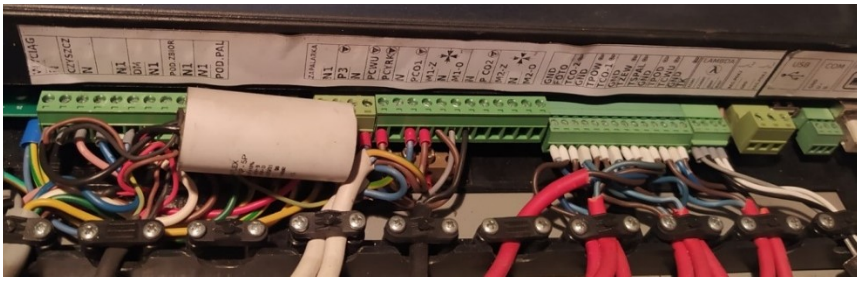

Fig. 13.6. Input and output terminals of the FuzzyLogic 500 controller – Cherokee

Table 13.1. Input automation components

Designation	Component	Installation site
TK	Boiler water temperature sensor	Boiler's jacket or point where the highest boiler water temp. is present
TCWU	Domestic hot water temperature sensor	Measuring hole of domestic hot water tank
TPOD	Feeder temperature sensor	Fastened by a band on the worm feeder in such a way that it adheres well to the surface
FOTO	Flame brightness sensor (optional)	In a special sleeve in the burner's wall
TSPAL	Flue gas temperature sensor	In the top rear part, in the flue (Fig. 13.4)
TCO1 TCO2	Central heating supply temperature sensors in loop 1 / in loop 2	Fastened by a clamping ring to outlet pipes after the pumps and valves
LAMBDA	Lambda sensor	In the top rear part, in the flue, in a special sleeve (Fig. 13.4)
TZEW	Outside temperature sensor	Fastened to the exterior wall of the building, on the north side, far from heat sources (window, door), and in such a manner, that it is not directly exposed to sunlight.
REG. POK.	Room regulator	Situate far from heat sources in the room (TV, window, heater, etc.) where the set temperature is to be maintained; according to the guidelines of the selected device's manufacturer.
TPOW	Temperature sensor of water returning to the boiler	Fastened in direct contact with the return pipe, as close to the boiler as possible, and shielded with heat-resistant foam.

Designations of individual actuators are found on the controller's terminals (Fig. 13.6) and listed in table 13.2. Components responsible for the burner's operation (fans, feeders and igniter) should be connected to points N and N1.

Table 13.2. Actuators

Designation	Component
WYCIĄG	Exhaust fan
POW. WTÓRNE	Intake blower
PODAJ. 2	Connection point for feeder found in burner
PODAJ. 1	Connection point for feeder supplying fuel directly from the tank (main feeder)
ZAP	Igniter
P3 or P. DODATK	Additional pump (e.g. for floor heating)
PCWU	Domestic hot water pump
PCYRK	Circulating pump working according to a user-defined weekly schedule
PCO1 and PCO2	Central heating pumps
M1Z and M1O M2Z and M2O	Connection points of mixing valve actuator. The digit in the description signifies the loop in which the actuator is found (1 or 2), and the letter at the end specifies the function of the connection point (Z for closing and O for opening).
N	Connection point to neutral power supply busbar
N1	Connection point to burner's neutral power supply busbar

2.4. DEVELOPMENT OF HMI

The layout of the human-machine interface (HMI) panel, enabling value changes of the most important parameters and monitoring of other parameters involved in boiler operation, is shown in Fig. 13.7. Figure 13.8 presents a touch LCD display integrated with the FuzzyLogic 500 – Cherokee controller.

a) b)

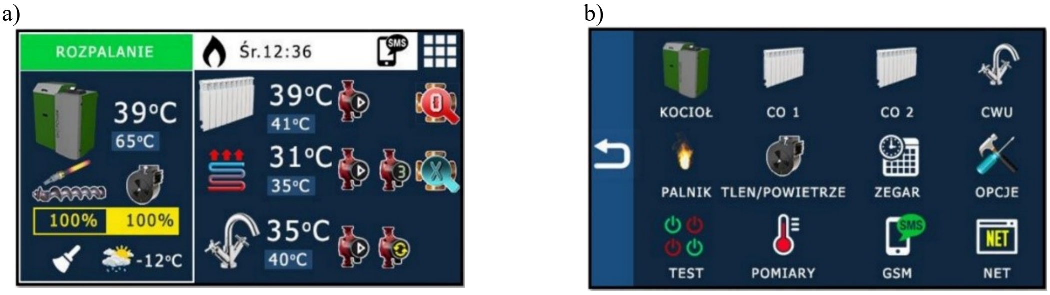

Fig. 13.7. Design of HMI panel layout: a) main screen; b) main menu [15]

a) b)

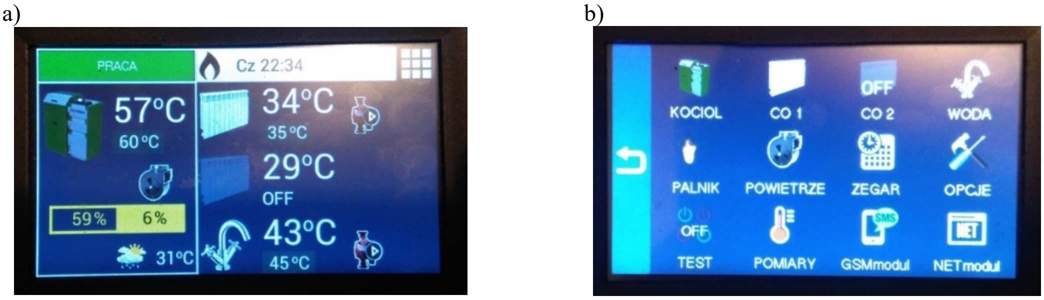

Fig. 13.8. LCD display integrated with FuzzyLogic 500 – Cherokee controller: a) main screen; b) main menu

13.3. TESTS OF THE CONTROL SYSTEM FOR CENTRAL HEATING BOILER

13.3.1. GOAL OF THE TESTS

The goal of the tests of the control system for the central heating boiler was to verify assumptions accepted at the control system designing stage. To meet this goal, the correctness of operation of the central heating boiler with the designed and developed control system was checked under normal operating conditions. Moreover, the quality of burning of pelletized biomass fuels was checked.

The heating system of the boiler integrated with the FuzzyLogic 500 – Cherokee controller [15], cooperating with the input automation components and actuators presented in section 13.2.3, was tested. The technical specifications of the tested boiler are identical to those of the EP-12 boiler [14].

13.3.2. TEST RESULTS

As a result of tests performed for set water temperatures in individual loops (central heating, domestic hot water), correct operation of the following was determined: pelletized biomass feeding system, automatic fuel ignition system, system for stoking the combustion process in the gasifying chamber, automatic grate cleaning system, system feeding air to the mixing chamber. Moreover, the correctness of operation of protection systems was checked, i.e.:

- in the case of simulated damage to selected sensors, the boiler's operation was suspended or limited, and an interrupted sound signal was generated. The appropriate message was displayed on the LCD screen,
- in the case of exceeded boiler water temperature (95°C), forced for testing purposes, the boiler's active thermal protection was engaged, and an interrupted sound signal was generated. Fuel feeders, the igniter and intake blower were disconnected, thanks to which the burning process was interrupted. Boiler restart was possible after pressing the RESET button on the controller's housing.

Simultaneously, the quality of the combustion process in the burner chambers was checked, and emissions of harmful substances were measured. As a result of conducted tests, high quality of the combustion process was determined, and contents of harmful substances (Carbon monoxide (CO), particulate matter) were determined to be at an acceptable level, according to PN-EN 303-5:2012 [10] and eco-design requirements as per the Regulation of the European Commission [11].

13.4. CONCLUSIONS

Air pollution is the most harmful to health and the environment out of all types of pollution. Boiler designs with modern burners, fired by biomass, should be characterized by high energy efficiency and compliance with environmental protection standards. The efficiency of the combustion process is determined by the amount of heat obtained. The quality of the combustion process can be evaluated by the efficiency of the fuel processing equipment. The higher the efficiency, the more energy is obtained from combustion of a unit of fuel. One should also remember that, for the purpose of minimizing environmental hazards, besides modern boiler and burner designs, selection of fuel of proper quality and correct selection of flue gas discharge installations, the designing and implementation of an appropriate control system is also necessary. Inadequate control system solutions result in elevated emissions of harmful substances into the atmosphere and reduces the efficiency of the combustion process, which increases operating costs as a result. Some conclusions are presented in the following points.

- The selected FuzzyLogic 500 – Cherokee advanced microprocessor controller is intended for the regulation of the boiler's operating parameters according to adopted assumptions.
- Real-time clock functions make it possible to configure weekly work schedules for circulating pumps and the burner.
- Optional room regulators make it possible to maintain a set temperature in rooms, as desired by the residents.
- Measurement of flue gas temperature and oxygen content in flue gas by the lambda sensor makes it possible to achieve high energy efficiency of the boiler. The lambda sensor is the most important component responsible for the combustion process and increases the boiler's operating efficiency substantially. This directly leads to limitation of its operating costs and adverse environmental impact.
- The designed and implemented control system fulfills the adopted assumptions. The automatically modified time of fuel feeding and amount of supplied air, appropriate for current conditions and required for proper performance of the combustion process, significantly raises its eco-friendliness and efficiency, which consequently translates to economical boiler operation.
- The designed control system and burner construction ensure high quality of the combustion process and harmful substances at an acceptable level, according to PN-EN 303-5:2012 [10] and eco-design.
- Having in mind the above advantages of the heating boilers utilizing a renewable energy source – biomass with selected FuzzyLogic 500 microprocessor controller, electrostatic precipitators used for the removal of fly ash are not required. Commercial designs of electrostatic precipitators used for the removal of fly ash particles from small residential boilers are presented in the publication [15].

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