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# ПРИНЦИПЫ МОДЕЛИРОВАНИЯ ПИРОЛИЗНЫХ КОТЛОВ
# PRINCIPLES OF PYROLYSIS BOILERS MODELING

**Аннотация.** В статье исследованы основные принципы функционирования пиролизных реакторов, а также их преимущества и недостатки. Отмечены и выделены ключевые проблемы, возникающие при их функционировании и предложен эффективный подход к моделированию теплообменной системы с пиролизным котлом. На основе универсальной модели системы теплопередачи реализована адаптированная система теплопередачи. Система является инновационной и достаточно эффективной. Имитационная модель системы теплообмена с пиролизным реактором позволит инженерам и специалистам выявлять более эффективные и быстрые методы теплопередачи. Предпринята попытка прояснить текущие события и перспективы эксплуатации реакторов и предложить эффективные методы и модели. Эти предложения должны существенно повысить скорость и эффективность процесса.

**Abstract.** In the article examines the fundamental operating principles of pyrolysis reactors, as well as their advantages and disadvantages. Key operational challenges are highlighted and identified, and an effective approach to modeling a heat exchange system with a pyrolysis boiler is proposed. Based on the universal model of the heat transfer system, an adapted heat transfer system is implemented. The system is innovative and quite effective. The simulation model of a heat-exchange system with a pyrolysis reactor will enable engineers and specialists to identify more efficient and rapid heat-transfer methods. Attempts to clarify the current state and prospects of pyrolysis reactor operation and propose effective advanced methods and models. These proposals should significantly improve the speed and efficiency of the process.

**Ключевые слова:** Пиролизный котел (реактор), теплообменная система, имитационная модель, система теплопередачи, модель теплообменника.

**Keywords:** Pyrolysis boiler (reactor), heat exchange system, imitation model, heat transfer system, heat exchanger model.

In the context of ever-increasing energy prices and the desire to reduce pollutant emissions, the efficient use issue of renewable energy sources is becoming increasingly important [1-7]. Pyrolysis is the thermochemical decomposition of organic materials in the absence of oxygen. This results in a mixture of hydrocarbon gases, liquids, and solid residues that can be used to generate energy. One of the main advantages of pyrolysis boilers is their environmental friendliness. Unlike traditional boilers that burn coal or oil, pyrolysis boilers produce significantly less smoke and harmful emissions such as sulfur dioxide and nitrogen. This helps improve air quality and reduce environmental pollution. Furthermore, pyrolysis boilers contribute to increasing regional energy independence. Biomass used as fuel is a renewable resource and can reduce dependence on energy imports.

The relevance of this article is due to rising energy prices (oil, natural gas, and electricity), as well as increased construction outside of city centers. The main challenge with a pyrolysis boiler is determining the ratio of air flow to the formation and combustion of pyrolysis gases. With the correct ratio, the amount of pyrolysis gas and oxygen remaining in the boiler flue is minimal. In this case, the output is maximized. To reduce costs, these sensors can be replaced with more affordable temperature sensors.

The technological apparatus that creates the conditions for producing gas by pyrolyzing wood fuel is called a gasifier boiler. The chamber containing the fuel is called a reactor or combustion chamber. Initially, the fuel is combusted at a low temperature. Once the required temperature is reached, pyrolysis of the fuel occurs, and pyrolysis gases are released from the wood, including methane, ethane, propane, carbon monoxide, and others. The gases released during pyrolysis are fed into the combustion chamber through a special pipe, controlled by the oxygen pressure entering the reactor. The gas released in the combustion chamber mixes with the already heated oxygen and burns completely. Combustion occurs at high temperatures, which can reach 110-1200°C. High temperatures are achieved by burning gas. This heat contacts a heat exchanger and heats the water passing through it. Figure 1 shows the design of a pyrolysis boiler.

This offers the following advantages:

- generates more heat. Burning conventional fuel produces significantly less heat. High heat output is achieved through gas combustion. Furthermore, combustion of gases uses less oxygen;
- there is virtually no combustion odor, or only a very small amount;
- fuel burns almost completely, leaving no residue. This results in less ash formation.
- efficiency reaches 90%;
- very long boiler life. Refueling time ranges from 8 to 12 hours;
- some pyrolysis boilers can burn not only wood but also other polymers.

And disadvantages:

- sensitivity to fuel moisture. When burning one kilogram of wood with 25% moisture content, the boiler output is 4 kW, while when burning one kilogram of wood with 50% moisture content, the output is 2 kW;
- the circulating water temperature must be kept between 50-60°C. Otherwise, condensation will form in the unit, which will shorten its service life.

Figure 1 shows the technological structure of the heat transfer system of a pyrolysis boiler. The object of this article is a pyrolysis boiler control system. The subject of the study is the development of a combustion control algorithm for a pyrolysis boiler without a gas sensor. Various software packages will be used to accomplish the objectives, including *MATLAB Simulink*, *MS Word*, *MS Visio*, and others.

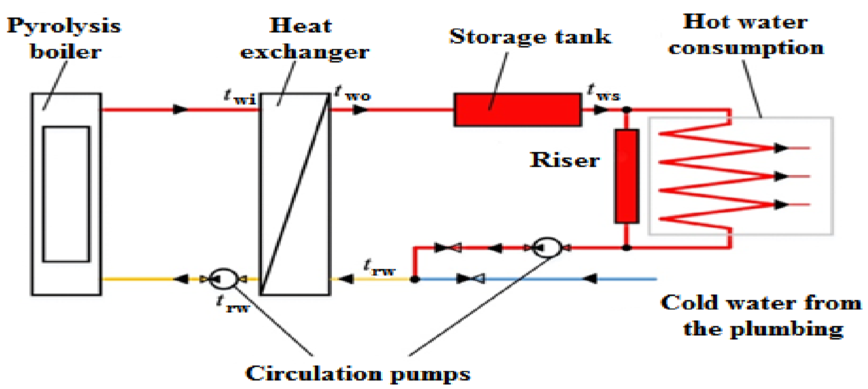


Figure 1. Technological structure for the heat transfer system of a pyrolysis boiler

Here $t_{wi}$ is the water temperature at the inlet in the heat exchange system, $t_{wo}$ is the water temperature at the outlet of the internal circuit for the heat exchange system, $t_{ws}$ is the water temperature at the outlet of the intermediate storage tank, $t_{rw}$ is the return water temperature at the inlet of the internal circuit for the heat exchange system.

The *MATLAB Simulink* software package was used to create the simulation model. To formalize the system under study, simple arithmetic expressions in the Simulink package can be used to create a mini-model. The simulation utilized *Transfer Fcn* integrating links, constants, and *Scope* oscillography blocks.

For the first equation of the differential equation system, assume the following:

- $t_{max}$ is the theoretical maximum water heating temperature (600 °C);
- $t_{room}$ is the ambient room temperature (20 °C);
- the boiler heating time constant is assumed to be 300 s.

Then we get the following model (Figure 2).

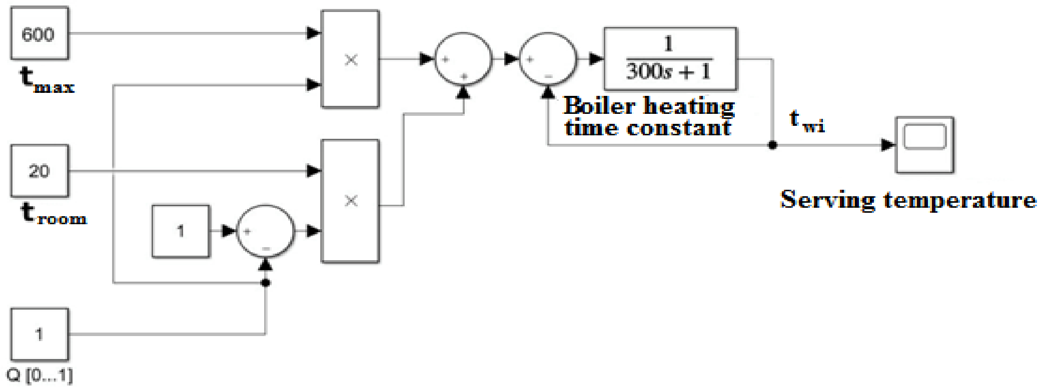


Figure 2. Pyrolysis boiler model

The following is accepted:

- $k_t$ is the heat exchanger efficiency coefficient equal to 0.9;
- the time constant in the heat exchanger is 210 s.

The heat exchanger model is presented in Figure 3.

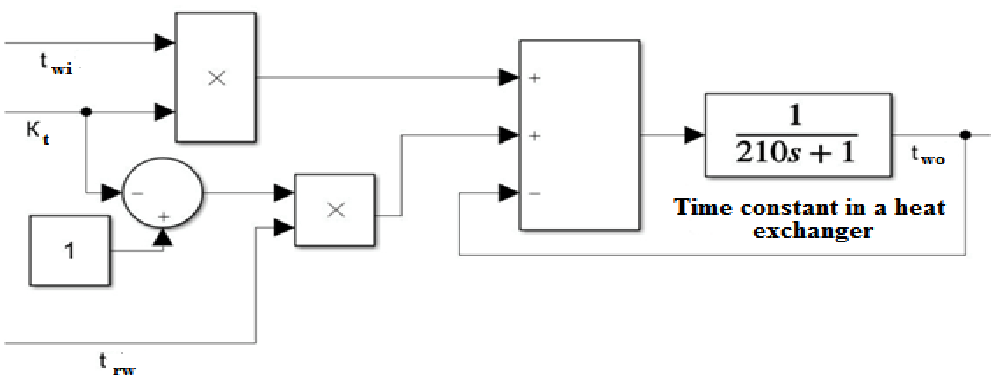


Figure 3. Heat exchanger model

Based on the data obtained, it can be concluded that this system has some delay time from the start of the air flow supply to the start of the temperature change, that is, an aperiodic second-order transient process with a delay is obtained. During the simulation, it was found that to clearly model the disturbing effect on the system, it is necessary to change either the cold water influence coefficient or the cold water temperature. It's also easy to see that as heat consumption increases, the amplitude of temperature change varies across different parameters. This is explained by the fact that, according to the Newton-Richmann cooling law, the cooling rate is proportional to the temperature difference between the heated body and the environment, up to the temperature at which it is being cooled. That is, the greater the temperature difference, the faster the coolant cools.

Thus, as a result of a comprehensive study and analysis of the pyrolysis boiler's operating conditions and principles, a imitation model of the pyrolysis boiler's heat exchange system was obtained, and a PID controller was simulated for this system. It was found that the methodology applied in simplifying the second-order model, integrating and tuning PID controllers, works for the system under consideration. The resulting model is suitable for further research, such as developing an algorithm for selecting the optimal air quantity.

*References:*

1. Melikov E.A. Control of parallel-connected pyrolysis furnaces. “Applied Issues of Exact Sciences”, VI International Scientific Practical Conference of Graduate and Postgraduate Students, Lectures (in Russian), Armavir, Russia, 2022, pp. 175-177.

2. Abbaszada H.N., Melikov E.A. Statement and method for solving the optimization problem of a pyrolysis furnace. Materials of IV International scientific and practical conference (“Readings of A.I. Bulatov”), 2020, vol. 5, pp. 173-175.

3. Abbaszada H.N., Melikov E.A. Approach to solving the optimization problem non-stationary reactor complex. "Information systems and technologies: Achievements and perspectives" Proceedings of the II International Scientific Conference, Sumgayit, Azerbaijan, 2020, pp. 103-104.

4. Safarova A.A., Melikov E.A., Magerramova T.M. Principles of modeling and optimal control of a fraction purification reactor from micro impurities, III International scientific and practical conference "Technologies, materials science and engineering" (EEA-III-2024), AIP Conference Proceedings, AIP Publishing, vol. 3243, Issue 1, 2024, 020014. https://doi.org/10.1063/5.0247869

5. Guseinov I.A., Kurbanov Z.G., Melikov E.A., Efendiev A.I., Efendiev I.R. Nonstationary Multistage Process Control in the Petrochemical Industry. Journal of Computer and Systems Sciences International, Pleiades Publishing, Ltd., 2014, Vol. 53, No. 4, pp. 556-564. https://doi.org/10.1134/S1064230714030095

6. Melikov E.A. Principles of optimizing the control of propylene purification process from acetylene derivatives. Proceedings of the 7th International conference on control and optimization with industrial applications (COIA-2020), Edited by Fikret, A.; Tamar, B. Vol. II, 2, pp. 272-274.

7. Shilin A.A., Bukreev V.G. Nelinejnaya matematicheskaya model teplopotrebleniya c uchetom kharakteristik elementov teplovogo uzla // Nauchny`j vestnik NGTU, 2012, No. 2 (47), pp. 107-114.