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ASPECTS OF DEVELOPING AN INNOVATIVE, ENERGY-EFFICIENT, LOW-EMISSION CO-GENERATOR

Purpose. To develop a model and construct an experimental, innovative co-generator with high energy efficiency and low emissions. This involves developing a system that can efficiently generate both electricity and heat simultaneously while minimizing emissions, contributing to sustainability efforts, and addressing energy demands in a more environmentally friendly manner.

Methodology. To achieve the goal, a system approach is utilized, enabling the selection of modelling types for the development of an experimental, cutting-edge co-generation system capable of efficiently producing both electricity and heat with superior energy efficiency and minimal emissions. For this purpose, the following steps were completed: processing and summarizing available literature and patent sources, analysing scientific and technical papers on the selection and application of modelling types in co-generation systems, and considering principles and individual approaches to input data formation for mathematical modelling. This process enables the selection of a mechanism and the creation of simulation models for effective energy production at various enterprises.

Findings. Assessment is performed of the energy efficiency of the co-generator system under various operating conditions, comparing it with existing conventional methods of electricity and heat generation. Results are presented of performance testing to determine the system's capability to simultaneously generate electricity and heat efficiently, considering factors such as output stability, load responsiveness, and overall reliability. Identification and evaluation are performed of innovative technologies and methodologies integrated into the co-generator design, highlighting their effectiveness in enhancing energy efficiency and reducing emissions. Insights into any operational challenges encountered during the construction, testing, and optimization phases, along with proposed solutions or improvements to solve these problems. The analysis of the overall environmental impact of deploying the co-generator showed potential benefits in terms of reduced greenhouse gas emissions and local air quality improvement.

Originality. Using a combination of scientific approaches encompassing physics and heat transfer engineering, in accordance with the first law of thermodynamics, such as the conservation laws of energy and entropy, and principles of heat exchange employed to transfer heat between different mediums, gas kinetics have yielded values for the energy transformation coefficient, indicating qualitative characteristics of fuel thermolysis and power generation as the final product.

Practical value. The results provide for developing a comprehensive model of an advanced co-generation system capable of efficiently producing both electricity and heat with superior energy efficiency and minimal emissions. It also entails determining the types of models for mathematical modelling at all management levels and establishing a new method for input data formation for both technologies and their subsystems, incorporating additional technological implementations.

Keywords: *energy generation, co-generator, environmental impacts, systematic prototype, meticulous conceptual design*

Introduction. Devices and systems for generating electricity are increasingly gaining popularity, not only in areas with limited access to electrical grids but also in regions where grid access exists [1]. This is important where energy prices set by distributors are prohibitively high, making it economically viable to install individual energy generators. This trend is observed across industrial and service facilities of varying scales, as well as in individual households [2].

In industrial settings, a major factor prompting a partial or complete shift away from grid electricity is the limitation in connection capacity. Often, the power demand of a new plant exceeds the capacity of the existing distribution network, making it impossible for the distributor to connect the facility to the grid [3]. In such instances, the distributor calculates the costs associated with upgrading the connection, often involving the replacement of electric cables or the construction of new transformer stations. Consequently, connection costs can escalate to several dozen, hundred thousand, or even several million zlotys (The implementation of the project is planned in Poland).

One solution to this challenge is the installation of generators, which, when connected to the internal network, take on the role of the primary power source. Simultaneously, the external power distribution network needs to be isolated to avoid disruption to its operation. Individual energy producers connected to the grid with inverters that synchronize phase frequency and voltage can supply electricity to the external grid, provided a bilateral agreement with the distributor is in place. Currently, energy companies often enter such contracts, particularly for solar photovoltaic systems, under a presumption framework.

Cogeneration stands out as one of the solutions to the environmental challenges faced by the energy industry. In the case of small-scale or distributed cogeneration, a key advantage is in the ability to produce energy at the point of use, thereby reducing losses associated with energy transmission across networks. It is estimated that losses in electricity transmission can be as high as 8 % [4].

Thus, the actual research aims to provide new approaches in the construction of an experimental, innovative co-generator of electricity and heat with high energy efficiency and low emissions, which can help alleviate the problem of decreasing energy generation from fossil fuels [5].

Literature review. The construction of an experimental, innovative co-generator of electricity and heat with high energy efficiency and low emissions signifies a notable progression in sustainable energy technology. This co-generator endeavours to optimize energy efficiency through the integration of advanced technologies and design principles, aiming to minimize energy losses and maximize fuel utilization for both electricity and heat generation [6]. Additionally, a primary goal is to reduce emissions during operation by using clean combustion technologies. This includes advanced combustion chambers and emission control systems designed to lower pollutants such as carbon dioxide, nitrogen oxides, and particulate matter [7].

Theoretical research in the construction of an experimental, innovative co-generator of electricity and heat with high energy efficiency and low emissions involves studying the principles and concepts underlying the design and development of such a system [8]. This research focuses on analysing existing technologies, mathematical models, and theoretical frameworks to inform the construction process. It explores innovative approaches to optimize energy efficiency, minimize emissions, and enhance overall performance. Additionally, theoretical research involves investigating potential challenges and proposing solutions to advance the development of sustainable energy solutions [9].

The technical implementation of constructing a co-generator of electricity and heat with high energy efficiency and low emissions involves the integration of advanced technologies and engineering principles. This includes selecting appropriate components such as combustion chambers, turbines, and heat exchangers to optimize energy conversion processes [10]. Additionally, advanced control systems and emission reduction technologies are incorporated to ensure minimal environmental impact. Rigorous testing and optimization processes are employed to validate the system's performance under various operating conditions [11]. The construction also involves adherence to stringent standards and regulations to guarantee safety and efficiency. Overall, the technical implementation focuses on achieving optimal energy efficiency and emissions reduction while maintaining reliability and scalability [12].

All models of 2g co-generators are characterized by high efficiency rates. It is well known that the electric power co-generators of 20 and 50 kW have particularly high efficiency rates above 100 %, considering the total electrical and thermal power. Electrical energy is supplied in the form of a stabilized 3-phase current 3×380 V, while thermal energy is provided in the form of a thermal engine cooling liquid of the order of 80 degrees Celsius. With an electric power of 20 kW, the useful thermal power is 44 kW, so the total electric and thermal power is 64 kW with a fuel energy of 62 kW, which gives a total cogeneration efficiency of 102.4 %. The highest efficiency ratio of the engine is 109.6 at 50 % electric power [13].

With an electrical power output of 50 kW and a useful thermal power output of 104 kW, the co-generator generates a combined electrical and thermal power of 154 kW, utilizing a fuel energy input of 145 kW, resulting in an overall cogeneration efficiency of 106.3 %. The engine achieves its peak efficiency of 106.8 % at an electrical power output of 75 %. Conversely, a co-generator with a 20 kW electrical power output experiences a slight efficiency decreases to 101.4 at 50 % power output.

Regarding the thermal parameters of the co-generator, they align with typical specifications for 4-stroke combustion engines, meeting standard requirements for building heating systems and domestic hot water heating. The engine produces a heating fluid suitable for use in radiator or forced-air heating systems [14]. While current standards do not mandate temperatures as high as those provided by the engine (around 80 degrees Celsius), temperature adjustment can be easily achieved through mixing techniques. Furthermore, the high-temperature heat source presents an advantage for domestic hot water heating systems requiring cyclic overheating, with a minimum heat source temperature of 60 degrees Celsius. Maintaining a temperature of 80 degrees Celsius simplifies this process technically [15].

Moreover, the co-generator embodies innovation in energy generation by incorporating cutting-edge technologies and methodologies [16]. This includes the exploration of novel design concepts, advanced materials, and innovative control systems to enhance overall performance and efficiency while minimizing environmental impact [17, 18]. As an experimental endeavour, the project involves prototyping and testing of new components or systems to validate their real-world performance [19]. This iterative process facilitates refinement and optimization of the co-generator design to achieve desired energy efficiency and emission reduction targets, contributing significantly to sustainable energy practices and environmental conservation efforts [18, 20].

The executed research on phenomenon of systems approach is utilized, enabling the selection of modelling types for the development of an experimental, cutting-edge co-generation system capable of efficiently producing both electricity and heat with superior energy efficiency and minimal emissions by means of widely applied industrial, laboratory and theoretical methods, suggestions about scientific problem, which previously has not had methods of its decision.

Unsolved aspects of the problem. The equipment operates on several fundamental principles related to internal combustion, thermodynamics, electrical generation, and heat transfer. The internal combustion engine functions through a four-stroke cycle: intake, compression, power, and exhaust [21]. During the intake stroke, a mixture of air and fuel is drawn into the cylinder. This mixture is then compressed during the compression stroke. During the power stroke, the compressed mixture is ignited, causing an explosion that drives the piston. Finally, the exhaust stroke expels the burnt gases from the cylinder [22].

To manage heat effectively, the engine utilizes an air-cooling system [23]. The cylinder and head are equipped with fins that increase surface area, allowing air to flow over them and dissipate heat. This cooling mechanism ensures the engine maintains optimal operating temperatures [8, 24]. Additionally, an air-water heat exchanger is installed at the exhaust outlet to transfer heat from the exhaust gases to water. This recovered heat can be used for other applications, such as heating, thus enhancing the system's overall efficiency [25].

Widely used electrical generation in this equipment is facilitated by an AC generator, which converts mechanical energy from the engine into electrical energy. As the engine drives the generator, it produces alternating current (AC) electricity. To ensure stable and suitable voltage output, a rectifier converts the AC to direct current (DC), and a six-diode regulator maintains a consistent voltage output, typically at 3×380 V. This regulation is crucial for providing reliable and safe electrical power for various applications.

Also, it is well known that the integration of these mechanical and electrical systems maximizes efficiency and effectiveness. The engine and generator design aims to reduce energy losses and ensure the efficient conversion of fuel energy into mechanical and electrical energy. The rectifier and voltage regulator ensure stable electrical output, minimizing losses and maintaining reliable power delivery. By combining these principles, the equipment provides efficient power generation with effective cooling and heat recovery, meeting various power demands while ensuring operational efficiency and safety.

Despite the robust design and functionality, several unsolved areas in this research warrant further investigation. Improving the thermal efficiency of the engine through advanced materials and optimizing heat recovery processes could enhance overall system performance. Reducing emissions, exploring alternative fuels, and enhancing the efficiency of the AC generator and rectification process are critical areas for development. Additionally, developing advanced control systems, noise reduction technologies, and improving the durability and cost-effectiveness of the engine components are essential for future advancements. Addressing these challenges could lead to significant improvements in the efficiency, sustainability, and overall performance of four-stroke internal combustion engines equipped with air-cooling systems, AC generators, and heat recovery units.

Purpose of the investigation is to comprehensively analyse the components of an experimental and innovative co-generator of electricity and heat. This co-generator is engineered with the purpose of achieving superior energy efficiency while simultaneously minimizing the emission of hazardous substances into the environment.

Methods. To form the models, and the methodology for constructing an experimental, innovative co-generator of electricity and heat with high energy efficiency and low emission the authors have provided the next steps of the research:

1. Extensive review of existing literature, patents, and research papers related to co-generators of electricity and heat was conducted, focusing on high energy efficiency and low emissions. Insights were gained into previous methodologies, designs, and technologies utilized in similar projects.

2. The conceptual design for the experimental co-generator was developed based on the findings from the literature review. Factors such as energy conversion mechanisms, fuel types, combustion processes, heat recovery systems, and emission control technologies were considered.

3. Appropriate components for the co-generator, including engines, turbines, boilers, heat exchangers, exhaust systems, and emission control devices, were identified and selected. Principles of compatibility, efficiency, and reliability were applied in the selection process [26]. A combination of scientific approaches was used encompassing physics and heat transfer engineering, in accordance with the first law of thermodynamics.

4. The prototype of the co-generator was constructed based on the conceptual design. Computer-aided design (CAD) software was used for detailed modelling and simulation to optimize component placement, airflow, heat transfer, and overall system performance.

5. Suitable materials for construction, considering factors such as durability, thermal conductivity, corrosion resistance, and cost-effectiveness, were chosen. Components were fabricated using appropriate manufacturing techniques to ensure precision and quality.

6. The prototype co-generator was assembled, and all components were integrated into a functional system. Comprehensive testing was conducted to evaluate performance metrics such as energy efficiency, power output, heat generation, emissions levels, and operational stability.

7. Test results were analysed to assess the effectiveness of the co-generator in achieving high energy efficiency and low emissions. Comparison with theoretical predictions and performance targets was made to identify areas for improvement.

8. Based on the analysis of test results, the design and operational parameters of the co-generator were optimized to enhance performance and address any identified issues or limitations. Necessary adjustments and refinements were made to further improve energy efficiency and reduce emissions.

9. The optimized design was validated through additional testing and verification procedures to ensure reliability, safety, and compliance with regulatory standards and environmental regulations.

All aspects of the research methodology, including design specifications, test procedures, experimental data, analysis results, and conclusions, were documented. A comprehensive report summarizing the findings and recommendations for future research and development efforts was prepared [27].

During the modelling phase, an exhaustive analysis is conducted on the cogeneration energy production system, which integrates components of an experimental and innovative electricity and heat co-generator. Additionally, these subsystems are individually assessed. Presently, it remains challenging for a single finite model to fully encapsulate all facets of industrial implementation. This difficulty becomes particularly apparent when modelling complex thermochemical transformations [28].

For the creation of the analytical model, the processes conducted in the co-generator during the power and heat energy generation were analysed. Modelling the operation of a co-generator of electricity and heat, particularly one that emphasizes high energy efficiency and low emissions, involves several principles from thermodynamics, fluid mechanics, combustion, and heat transfer [29, 30]. These principles are integrated within simulation frameworks to predict performance, optimize operations, and reduce emissions. Of course, it operates according to the principles of energy balance. Therefore, the first and second laws of thermodynamics must be applied to its operation. They are used to calculate the energy balance in the system, ensuring energy conservation and aiding in determining the efficiency of energy conversion and the distribution of energy between electrical and thermal outputs. It is crucial for evaluating the quality of energy transformations within the co-generation system, assessing irreversibility, and calculating the exergy efficiency, which measures how well the system converts available energy into work.

Models based on heat transfer principles are used to design and optimize heat exchangers for recovering waste heat from exhaust gases, which is crucial for achieving high overall energy efficiency. In this context, mechanisms such as radiation, convection, and conduction are considered for heat recovery, equipment design, and insulation to minimize energy losses, ensuring a comprehensive approach to enhancing the system's performance [18, 29].

To determine the magnitude of energy transformation, it is proposed to use the transformation coefficient ($\mathscr{E}$), which shows the amount of electrical energy obtained from thermal energy

$$\mathscr{E} = P_t / P_e,$$

where P_t is parameters of the thermal power in time, kW · h; P_e – parameters of the electrical power in time, kW · h.

In other case, the transformation coefficient ($\mathscr{E}$), also known as the energy conversion efficiency, represents the ratio of useful electrical energy output to the total thermal energy input. In other words, it quantifies how effectively thermal energy can be converted into electrical energy. This coefficient varies depending on the specific technology or process used for energy conversion.

For example, at earliest *1960th* it was identified that in conventional steam turbines used in power plants, the energy conversion efficiency can range from around 30 to 40 %, meaning that only 30 to 40 % of the thermal energy input is converted into electrical energy. However, newer technologies such as combined cycle gas turbines can achieve higher efficiencies, often exceeding 50 %.

It is important to note that in our case, such coefficient will be the subject of the research and development efforts aimed at improving performance and reducing environmental impact. Therefore, the transformation coefficient E varies and will show the efficiency of developed equipment.

In the realm of fluid mechanics, the analysis of the flow of working fluids – such as air, water, and steam – through components like turbines, compressors, heat exchangers, and piping is pivotal. Utilizing principles of fluid dynamics, this analysis aims to optimize both design and operation to minimize pressure losses and maximize efficiency. Concurrently, models focused on combustion efficiency and emission predictions play a crucial role. These models are designed to predict the completeness of fuel combustion, optimizing the air-to-fuel ratio to enhance energy output while reducing unburnt fuel losses. Furthermore, detailed chemical kinetic models are employed to forecast the formation of pollutants such as NO_x, CO, and particulate matter. This predictive capability is instrumental in designing systems and operational strategies that effectively reduce emissions, thereby addressing both efficiency and environmental concerns in a cohesive manner.

Based on the analysis conducted, the objective of the project is as follows: to develop the electricity through the experimental co-generator using various scientific methodologies, including principles from physics and heat transfer engineering, which are utilized in alignment with the first law of thermodynamics. These methodologies incorporate the conservation laws of energy and entropy, as well as principles of heat exchange. At the end we construct an experimental, innovative co-generator of electricity and heat with high energy efficiency and low emissions.

Statement of basic materials. Constructing an experimental co-generator powered by alternative fuels such as LPG (liquefied petroleum gas), natural gas, and gasoline involved several critical steps and considerations. The process began with thorough the research and design principles, where existing cogeneration systems and components were extensively reviewed to inform the design process. We aimed to create the system capable of accommodating multiple fuel sources while considering factors such as efficiency, emissions, and compatibility with different fuels.

Following the research phase, the project moved into the critical component selection stage, where a meticulous process was undertaken to choose the most suitable engines, generators, fuel delivery systems, and control mechanisms. This phase required a thorough evaluation of various options to ensure that each component met the specific requirements of the cogeneration system. The selection process focused on finding components that not only performed efficiently but also integrated seamlessly with the chosen fuels. Each component's compatibility with the fuel types and its role in the overall design were key factors considered to achieve optimal system performance.

During this stage, special attention was given to how each selected component would interact within the system to ensure that the cogeneration setup functioned cohesively and efficiently. The compatibility of components with the chosen fuels was a primary consideration, as it directly influenced the system's operational effectiveness and reliability. By carefully selecting components that matched the system's design and fuel specifications, the project aimed to create a robust and effective cogeneration system. This careful planning and selection were essential for achieving the desired performance and efficiency outcomes, paving the way for successful implementation and operation.

Attention then turned to the fuel storage and handling, where requirements for safely storing and managing each fuel type were determined. Safety measures were implemented to prevent potential hazards, such as leaks, spills, and accidents, with dedicated storage tanks or containers installed for LPG, natural gas, and gasoline.

Throughout the construction process, from engine conversion and adaptation to integration it and testing, meticulous care was taken to ensure the co-generator operated reliably and efficiently on each fuel type. Control and monitoring systems were developed to manage fuel selection, engine operation, and emissions tracking, with safety features integrated to address emergencies or malfunctions.

Compliance with emissions regulations and comprehensive documentation and reporting of the construction process and performance metrics were deemed essential. Continuous improvement was also emphasized, with ongoing monitoring, upgrades, and staying abreast of advancements in alternative fuels and cogeneration technology to enhance efficiency, reliability, and environmental performance over time.

Creating an experimental co-generator powered by alternative fuels demanded careful planning, engineering expertise, and adherence to safety and regulatory standards. By following these steps and considering the unique characteristics of each fuel type, a versatile and sustainable energy solution for various applications was achieved.

A four-stroke combustion engine (cylinder and head), air-cooled, equipped with an alternating current generator, efficiently converts fuel into electricity. The engine operates through four strokes: intake, compression, power and exhaust. During the intake stroke, the piston draws in a mixture of air and fuel. During the compression stroke, the mixture is compressed by the upwardly moving piston. The power stroke ignites the mixture with the spark plug, causing an explosion that pushes the piston down to produce power. Finally, on the exhaust stroke, the piston expels the burnt gases through the exhaust outlet.

The engine is designed with fins on the cylinder and head to increase surface area, allowing air to flow over them and dissipate heat, preventing overheating. This air-cooling system ensures that the engine is maintained at optimal operating temperature. The mechanical energy produced by the engine is transferred to an AC generator, which produces alternating current (AC). This process effectively converts engine power into usable electrical energy.

To ensure a stable and appropriate output voltage, the system uses a rectifier and a six-diode regulator. The rectifier converts the alternating current generated by the motor to direct current (DC), while the six-diode regulator maintains a constant output voltage of 3×380 V, ensuring reliable power delivery for a variety of applications. This regulation is critical to maintaining the efficiency and safety of the electrical system.

Additionally, an air-water heat exchanger was installed at the exhaust gas outlet to obtain thermal energy from the exhaust gases and increase the efficiency of the system. This device transfers heat from hot exhaust gases to water, which can then be used for other purposes, such as heating. By using waste heat from exhaust gases, the heat exchanger not only improves the overall efficiency of the system, but also contributes to energy savings. This combination of efficient power generation, effective heat recovery makes the equipment versatile and reliable in applications requiring reliable power sources.

As a result, we obtain an electrothermal co-generator:

- electricity 3 × 380 V;
- heat generator:
- air heating above 80 °C (from the cylinder and head);
- water heating from 25 to 45 °C (from exhaust gases).

The constructive features are;

- four-stroke internal combustion engine;
- air-cooled (cylinder and head) with an AC generator;
- rectifier and six-diode regulator – with 3 × 380 V voltage regulators;
- an air-water heat exchanger, which is installed at the exhaust outlet. The overview of the designed co-generator is presented in Figure.

The principles of operation for an experimental co-generator involve the use of alternative fuels, including LPG, natural gas, bioethanol, and gasoline. This system is designed to harness the benefits of cogeneration, a process that simultaneously generates electricity and useful heat from the same en-

Fig. Overview of the experimental co-generator of own design with a capacity of 2 kW powered by alternative fuels: LPG, natural gas, gasoline ergy source. By leveraging these various fuels, the co-generator aims to optimize efficiency and reduce emissions, tailored to the combustion characteristics of each type of fuel.

The fundamental concepts of cogeneration are pivotal in this experimental setup, as they directly influence the system's ability to generate energy efficiently. Cogeneration involves the simultaneous production of electricity and useful heat from a single energy source, which maximizes the overall energy output and reduces waste. In this context, understanding these core principles is essential for optimizing the system's performance and ensuring that it operates at peak efficiency.

The distinct combustion properties of each fuel type – such as LPG, natural gas, bioethanol, and gasoline – play a significant role in how the co-generator functions. Each fuel has unique characteristics that affect its combustion process, impacting both the energy production and the heat generation. By carefully studying these properties, the co-generator system can be precisely adjusted and fine-tuned. This adaptability enhances the system's efficiency and makes it a more versatile and environmentally friendly solution for energy production, aligning with contemporary goals of sustainability and reduced emissions.

The operation of the experimental co-generator begins with fuel combustion, utilizing LPG, natural gas, bioethanol or gasoline. Each fuel type's combustion characteristics, including ignition temperature and energy content, influence this process. As the fuel combusts within the engine, heat energy is released, which is then harnessed to drive a generator piston reciprocation. This mechanical energy is converted into electricity, suitable for powering various electrical devices or feeding into the grid for broader distribution.

The proposed cogeneration system is designed to maximize energy efficiency by capturing waste heat generated during combustion. This waste heat could be utilized for various purposes, such as water or air heating or industrial processes, through a heat recovery system. The co-generator is engineered to be versatile, capable of operating on multiple fuel types, with fuel selection based on factors like availability, cost, and environmental considerations. Sophisticated control and monitoring systems manage the co-generator's operation, while integrated safety features ensure reliable and secure operation, including automatic shutdown mechanisms and safeguards against fuel leaks or malfunctions. Regulatory compliance with relevant emissions standards is essential. So, we propose to use the emission control devices or systems to minimize pollutants and ensure adherence to environmental regulations, which will be the scope of our further research.

The technical and technological parameters of the proposed experimental co-generator encompass various aspects crucial to its design, operation, and performance. According to well-established principles, the fundamental operating parameters of the engine in the co-generator include:

1. Effective power N_e.
2. Torque M_o.
3. Specific fuel consumption g_e.
4. Rotational speed n.

These parameters are interrelated and collectively define the operational characteristics and efficiency of the co-generator, guiding its design and optimization for effective performance. Net power (effective power) N_e is the power measured at the end of the crankshaft at a fixed engine speed, equipped with a complete intake and exhaust system. The unit of power is the watt (W). Electrical power is most often given in kilowatts (kW). According to the standard formulas, the effective power (N_e) can be written as

$$N_e = (p_e \cdot V_{ss} \cdot n)/(30 \cdot \tau),$$

where N_e is the effective power (in kilowatts, kW); p_e is the effective mean pressure (in bar or pascals, Pa); V_{ss} is the swept volume or displacement volume of the engine (in liters or cubic meters); n is the engine speed (in revolutions per minute, RPM); τ is the number of working strokes per cycle (for a four-stroke engine, $\tau = 2$; for a two-stroke engine, $\tau = 1$).

A typical gasoline automotive engine operates at around 25 to 30 % of thermal efficiency. About 70–75 % is rejected as waste heat without being converted into useful work, i.e., work delivered to wheels.

When we rewrite the expression for thermal efficiency using the compression ratio, we conclude the air-standard Otto cycle thermal efficiency is a function of compression ratio

$$k = c_p/c_v.$$

So, we may present the dependence of the Thermal Efficiency – Otto Cycle as the dependence thermal efficiency to the compression ratio. In general, the thermal efficiency, η_{th}, of any heat engine is defined as the ratio of the work it does, W, to the heat input at the high temperature, Q_H.

The thermal efficiency, η_{th}, represents the fraction of heat, Q_H, converted to work. Since energy is conserved according to the first law of thermodynamics and energy cannot be converted to work completely, the heat input, Q_H, must be equal to the work done, W, plus the heat that must be dissipated as waste heat Q_C into the environment

Understanding the relationships between various factors in motor systems is essential for the effective design and optimization of such systems, particularly when electrical and thermal efficiency are critical considerations. By comprehensively analyzing how different variables interact, engineers and designers can make informed decisions about the system's architecture and performance characteristics. This knowledge is crucial for accurately predicting power requirements, planning energy consumption strategies, and managing heat dissipation, whether in industrial, commercial, or residential settings. Such insights ensure that the system operates efficiently and meets the specific demands of its application.

The proper analysis and application of this data can significantly enhance the design of motor systems. By tailoring the system to address the precise needs of energy efficiency and heat management, designers can achieve optimal performance. This not only leads to more effective motor systems but also results in tangible benefits such as energy savings and reduced operational costs. In the long run, these improvements contribute to a more sustainable and economically viable operation, aligning with both environmental goals and budgetary considerations.

The technical parameters revolve around several key aspects. Firstly, power output, measured in kilowatts (kW), depends on factors like engine size, combustion efficiency, and generator capacity. In our case the final power capacity is 2 kW and maximum thermal capacity is 4.4 kW. Fuel consumption varies based on the fuel type, engine efficiency, and load demand. Efficiency showcases how effectively the co-generator converts fuel energy into electrical power. The heat recovery efficiency measures the system's ability to capture and utilize waste heat for heating water or space, indicating the portion of recovered heat energy. The main operative parameters are presented in Table.

The research focuses on analysing the relationship between motor power load and the corresponding electrical and thermal heating power requirements. The data is summarized in a table showing the motor power load at three different per-

Table

Operative parameters of the heat recovery efficiency

Parameters\No of research	1	2	3
Motor power load, %	50	75	100
Electrical power, kW	1.0	1.5	2.0
Thermal Heating power, kW	2.9	3.7	4.4
Total efficiency/electrical + thermal, %	110.0	106.0	102.5

centages (50, 75 and 100 %) along with the associated electrical and thermal heating power values for each load. This provides insight into how the power demands change as the load on the motor varies. It is necessary to mention that the exhaust temperature after the heat exchanger is 40 °C, and the cooling air flow after the cylinder and motor head exchanger is also 40 °C.

At a motor power load of 50 %, the electrical power consumption is 1.0 kW, and the thermal heating power required is 2.9 kW. When the load increases to 75 %, the electrical power consumption rises to 1.5 kW, and the thermal heating power required increases to 3.7 kW. At a full load of 100 %, the electrical power reaches 2.0 kW, and the thermal heating power needed is 4.4 kW. Additionally, it is noted that the exhaust temperature after the heat exchanger is consistently 40 degrees Celsius, as is the cooling air flow after the cylinder and motor head exchanger.

The electrical power values represent the amount of electrical energy consumed by the motor to operate at the specified power loads. On the other hand, the thermal heating power values indicate the amount of heat energy generated or required for thermal processes when the motor operates at the specified power loads. These two sets of values, along with the exhaust and cooling air flow temperatures, are critical for understanding the overall energy consumption and heat management of the motor system.

From the data, it is observed that as the motor power load increases, both the electrical power and thermal heating power requirements also increase. The increase in electrical power consumption is linear with respect to the motor power load, showing an incremental rise of 0.5 kW for each 25 % increase in load. However, the thermal heating power shows a progressive increase with increments that are not uniform, suggesting a possible nonlinear relationship or additional factors influencing the thermal power requirements. The consistent exhaust and cooling air flow temperatures suggest effective heat management at these points.

Emissions play a critical role, with compliance to regulations and implementation of emission control technologies being essential. So, we paid the special attention to these parameters. Start-up time influences responsiveness, while reliability and maintenance parameters assess uninterrupted operation and maintenance requirements. Flexibility determines the co-generator's adaptability to varying conditions and demands, including fuel types and integration with renewable energy sources or storage systems. Furthermore, the sophistication of the control and monitoring system optimizes performance, efficiency, and emissions, ensuring safe and stable operation. For grid-connected or microgrid integration, parameters related to synchronization, voltage regulation, and islanding capability are crucial for seamless operation within the electrical grid.

These technical and technological parameters are integral in defining the capabilities and overall performance of an experimental co-generator powered by alternative fuels. They encompass a wide range of factors, including the efficiency of energy conversion, the combustion characteristics of different fuels, and the system's ability to manage and utilize generated heat effectively. By thoroughly analysing these parameters, engineers and designers can evaluate the co-generator's suitability for different applications, ensuring it meets the specific demands and constraints of each scenario.

Moreover, these parameters serve as a critical guide throughout the design, development, and implementation stages of the co-generator. They inform key decisions about system configuration, component selection, and operational strategies, ensuring that the final product is well-adapted to its intended use. Properly addressing these technical and technological considerations is essential for optimizing the co-generator's performance and achieving its goals in terms of efficiency, reliability, and environmental impact. This comprehensive approach helps in tailoring the system to different applications, whether for industrial, commercial, or residential purposes, enhancing its overall effectiveness and value.

Conclusions. The experimental co-generator operates on multiple alternative fuels, including LPG, natural gas, bioethanol, and gasoline, leveraging the fundamental principles of cogeneration and the unique combustion properties of each fuel type. The combustion process begins with the ignition of the selected fuel, releasing heat energy that drives the generator piston to produce electricity. The efficiency and performance of the co-generator are influenced by the combustion characteristics of each fuel, such as ignition temperature and energy content, enabling the system to convert mechanical energy into electrical power effectively.

A key feature of the co-generator is its ability to maximize energy efficiency through the capture and utilization of waste heat produced during combustion. This waste heat can be redirected for various applications, such as heating water or air, or supporting industrial processes, via an integrated heat recovery system. This dual-purpose design ensures that the co-generator harnesses both electrical and thermal energy, enhancing overall efficiency and reducing energy waste.

Technically, the co-generator is designed with a power output capacity of 2 kW and a maximum thermal capacity of 4.4 kW. The efficiency parameters, including electrical and thermal outputs, are carefully measured at different motor power loads (50, 75 and 100 %) as detailed in Table. The total system efficiency, which combines electrical and thermal outputs, ranges from 102.5 to 110.0 %, demonstrating the system's capability to adapt to varying power demands while maintaining high efficiency.

Safety and reliability are paramount in the co-generator's design, featuring sophisticated control and monitoring systems to manage its operation. Integrated safety features include automatic shutdown mechanisms and safeguards against fuel leaks or malfunctions, ensuring secure operation. Additionally, emission control devices are proposed to minimize pollutants, ensuring compliance with environmental regulations. Future research will focus on optimizing these emission control systems to meet stringent standards.

Heat and cooling management is effectively handled within the system, with the exhaust temperature after the heat exchanger maintained at 40 °C, and the cooling air flow after the cylinder and motor head exchanger also at 40 °C. This consistent temperature regulation indicates efficient heat management, contributing to the overall reliability and performance of the co-generator. Through these design and operational features, the co-generator demonstrates a versatile and efficient approach to energy production, capable of adapting to various fuels and applications.

The successful conversion of an electric generator into a co-generator, carried out by the authors of the publication, significantly affects its usefulness, economics, and environmental benefits. Firstly, in term of the generator – thanks to the modernization of the carburetor by installing a multi-function carburetor for LPG gas – we achieve efficient operation on environmentally friendly fuel compared to traditional gasoline. Moreover, the design of the co-generator allows the production of not only electricity, but also heat, which is not used in traditional generators. As a result of engine modernization, we obtain over three times more useful energy from the same amount of fuel, considering the electricity and heat generated. A co-generator can be effectively used in residential construction, producing electricity to supply buildings with electricity for domestic needs, and the heat can be used for space heating of buildings along with heating domestic hot water. Even greater economic benefits can be obtained by coupling a co-generator with a heat pump, which will significantly reduce the cost of heating the building compared to traditional heat pump heating systems.

This work contains the results of the individual research.

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Аспекти розробки інноваційного енергоефективного когенератора з низьким рівнем викидів

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Мета. Розробити модель і побудувати експериментальний інноваційний когенератор із високою енергоефективністю та низькою кількістю викидів. Це включає в себе розробку системи, що може ефективно виробляти електричну та теплову енергію одночасно, мінімізуючи викиди, сприяючи зусиллям щодо сталого розвитку та задовольняючи енергоспоживання більш екологічно чистим способом.

Методика. Для досягнення мети використовується системний підхід, що дозволяє вибрати типи моделювання для розробки експериментальної, високотехнологічної когенераційної системи, здатної ефективно виробляти електроенергію та тепло з більшою енергоефективністю й мінімальними викидами. Для цього виконані наступні етапи: обробка та узагальнення наявних літературних і патентних джерел, аналіз науково-технічних робіт щодо вибору й застосування типів моделювання в когенераційних системах, аналіз принципів та індивідуальних підходів до формування вхідних даних для математичного моделювання. Цей процес дозволяє вибрати механізм і створити імітаційні моделі ефективного виробництва енергії на різних підприємствах.

Результати. Дана оцінка енергетичної ефективності когенераційної системи за різних умов експлуатації, порівняння її з існуючими традиційними методами виробництва електроенергії та тепла. Наведені результати перевірки експлуатаційних параметрів з метою визначення здатності системи одночасно ефективно виробляти електроенергію й тепло, ураховуючи такі фактори як вихідна стабільність, реакція на навантаження й загальна надійність. Виявлення та оцінка інноваційних технологій і методологій, інтегрованих у конструкцію когенератора, підкреслюючи їхню результативність у підвищенні енергоефективності та скороченні викидів. Обґрунтоване розуміння будь-яких операційних проблем, що виникли на етапах будівництва, тестування та оптимізації, а також запропоновані рішення або заходи з удосконалення для вирішення цих проблем. Аналіз загального впливу на навколишнє середовище впровадження когенератора показав потенційні переваги з точки зору скорочення викидів парникових газів і покращення якості повітря на місцевому рівні.

Наукова новизна. На основі комбінації наукових підходів, що охоплюють фізику й техніку теплообміну, відповідно до першого закону термодинаміки, наприклад, законів збереження енергії та ентропії, а також принципів теплообміну, які використовуються для передачі тепла між різними середовищами, кінетика газу дала змогу отримати значення коефіцієнта трансформації енергії, що свідчить про якісні характеристики термолізу палива та виробництва електроенергії як кінцевого продукту.

Практична значимість. Результати передбачають розробку комплексної моделі вдосконаленої когенераційної системи, здатної ефективно виробляти як електроенергію, так і тепло зі значною енергоефективністю й мінімальними викидами. Це також передбачає визначення типів моделей для математичного моделювання на всіх рівнях управління та встановлення нового методу формування вхідних даних як для технологій, так і для їх підсистем, включаючи додаткові технологічні реалізації.

Ключові слова: *виробництво енергії, когенератор, вплив на довкілля, систематичний прототип, ретельний концептуальний дизайн*

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