ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫНЫҢ
Қ. И. Сәтпаев атындағы Қазақ ұлттық техникалық зерттеу университеті

# Х А Б А Р Л А Р Ы

# ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Казахский национальный исследовательский
технический университет им. К. И. Сатпаева

# N E W S

OF THE ACADEMY OF SCIENCES
OF THE REPUBLIC OF KAZAKHSTAN
Kazakh national research technical university
named after K. I. Satpayev

## SERIES
## OF GEOLOGY AND TECHNICAL SCIENCES

**3 (435)**

**MAY – JUNE 2019**

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

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**«ҚР ҰҒА Хабарлары. Геология мен техникалық ғылымдар сериясы».**
**ISSN 2518-170X (Online),**
**ISSN 2224-5278 (Print)**
Меншіктенуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.).
Қазақстан республикасының Мәдениет пен ақпарат министрлігінің Ақпарат және мұрағат комитетінде 30.04.2010 ж. берілген **№10892-Ж** мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Мерзімділігі: жылына 6 рет.
Тиражы: 300 дана.

Редакцияның мекенжайы: 050010, Алматы қ., Шевченко көш., 28, 219 бөл., 220, тел.: 272-13-19, 272-13-18,
http://www.geolog-technical.kz/index.php/en/

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Редакцияның мекенжайы: Қазақстан, 050010, Алматы қ., Қабанбай батыра көш., 69а.
Қ. И. Сәтбаев атындағы геология ғылымдар институты, 334 бөлме. Тел.: 291-59-38.

Типографияның мекенжайы: «Аруна» ЖК, Алматы қ., Муратбаева көш., 75.

**«Известия НАН РК. Серия геологии и технических наук».**
**ISSN 2518-170X (Online),**
**ISSN 2224-5278 (Print)**
Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан (г. Алматы)
Свидетельство о постановке на учет периодического печатного издания в Комитете информации и архивов Министерства культуры и информации Республики Казахстан **№10892-Ж,** выданное 30.04.2010 г.

Периодичность: 6 раз в год
Тираж: 300 экземпляров

Адрес редакции: 050010, г. Алматы, ул. Шевченко, 28, ком. 219, 220, тел.: 272-13-19, 272-13-18,
http://nauka-nanrk.kz /geology-technical.kz

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Адрес редакции: Казахстан, 050010, г. Алматы, ул. Кабанбай батыра, 69а.
Институт геологических наук им. К. И. Сатпаева, комната 334. Тел.: 291-59-38.

Адрес типографии: ИП «Аруна», г. Алматы, ул. Муратбаева, 75

**News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.**
**ISSN 2518-170X (Online),**
**ISSN 2224-5278 (Print)**
Owner: RPA "National Academy of Sciences of the Republic of Kazakhstan" (Almaty)
The certificate of registration of a periodic printed publication in the Committee of information and archives of the Ministry of culture and information of the Republic of Kazakhstan N 10892-Ж, issued 30.04.2010

Periodicity: 6 times a year
Circulation: 300 copies

Editorial address: 28, Shevchenko str., of. 219, 220, Almaty, 050010, tel. 272-13-19, 272-13-18,
http://nauka-nanrk.kz/geology-technical.kz

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Editorial address: Institute of Geological Sciences named after K.I. Satpayev
69a, Kabanbai batyr str., of. 334, Almaty, 050010, Kazakhstan, tel.: 291-59-38.

Address of printing house: ST "Aruna", 75, Muratbayev str, Almaty

**N E W S**
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
**SERIES OF GEOLOGY AND TECHNICAL SCIENCES**
ISSN 2224-5278
Volume 3, Number 435 (2019), 136 – 143 **https://doi.org/10.32014/2019.2518-170X.79**

UDC 621.311.22

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# MULTI-FUEL POWER STATION OF ULTRA-LOW POWER WITH EXTERNAL COMBUSTION THERMAL ENGINE, CAPABLE EFFICIENTLY OPERATE IN THE CONDITIONS OF RURAL AREAS OF KAZAKHSTAN

**Abstract.** The problem of effective electric supply is not solved in full until now. One way to solve this problem is development a micro thermal power plant, that capable operate on virtually any fuel. The use of own energy source will allow to reduce its development cost. Significantly increase the reliability of electricity supply and ensure its uninterrupted supply to the consumer. The proposed by us power plant is driven by a heat engine with an external heat supply. Some results of computer simulation of an engine with an external heat supply, which works according to the Stirling principle, are given. The design features of the engine under development are considered.

Conducted research allows us to find the optimal parameters of the structural parts of the heat engine. Accurately establish the geometrical dimensions of the piston and displacer, as well as the magnitude of their stroke with the optimum value of the phase shift.

**Keywords:** thermal power plant, Stirling engine, cogeneration, thermal energy, integrated production, alternative energy.

**The general part and a preliminary analysis of the development level of the engine with external heat supply.** The Stirling engine (SE), proposed as an alternative to the steam engine at the beginning of the nineteenth century, has undergone many stages of development and transformation, and now arouses sufficient interest among inventors. New SE designs are being created and new technologies are being used to create them. Today several models can serious compete with internal combustion engines (ICE), for example, by technical and environmental indicators. Despite all achievements and advantages they still did not find wide application as electric machines or internal combustion engines, but there are a number of serious reasons for this. Working fluid (gas or liquid) moves in enclosed volume in a cycle of the periodic heating and cooling of the working fluid. For its work suitable particular any fuel or heat source [1]. Thereby this unique of its kind thermal engine has high efficient equal a maximum effective of thermal engines, but in reality, in practice it is extremely difficult to achieve.

In historical terms, heat engine offered and patented in 1816 (English patent № 4081) by catholic priest Robert Stirling, served as a push in the development of this direction. Heat engines, which use heated air in their work, were already used in the 17th century, he only improved the design and suggested using a regenerator, which he called "economy". Modernization allows reducing weight and achieving an efficiency about 10%. This nod allowed increasing efficiency and created competition for the steam engine, it gave opportunity to introduce them at a number of enterprises. First of all, it was safe in terms of allowing an explosion, which was not uncommon for steam engines of that time. His engine was made from cast iron weighing one ton and produced 1kW, at that time, it could provide decent competition to a steam engine [2]. The lack of wear-resistant seals and heat-resistant steels did not allow Stirling to achieve

success in efficiency, and the rapid development of ICE and electric motors in the early 20th century completely drove them out of the market, but with the development of technologies and materials, engineers in 50-60 years of the last century again showed interest in them. The development of new SE designs continues to this day. For example, the Philips company, which produced compact electric generators based on an engine with an external heat supply operating on the Stirling cycle with an efficiency of about 30%, achieved particular success, which is not yet achievable for most modern gasoline power plants with ICE [3]. New machines had higher efficiency by increasing the pressure in the working cavity (in cylinders and chambers), which significantly improved the indicator "weight / size / power".

Our review showed that more than two centuries of history of the development they have gone through several stages of transformation and significant structural changes that have increased their efficiency. Today, engineers from various countries around the world have created dozens of designs of heat engines with an external heat supply (EEHS), working on the Stirling cycle. It would be more correct to say that these heat engines combine only a number of essential features related to external heat supply and the Stirling thermal cycle. Stirling himself is not the author of all development. On the contrary, his heat engine was largely imperfect, what he himself wrote about, and modern engines with external heat supply in some structures have nothing to do with the proposed invention. In the scientific literature, completely different in design EEHS, about which there was no speech in his works, are attributed to the authorship of Stirling.

There are main types of Stirling heat engines: alpha, beta and gamma, but more promising at present for use in the energy sector are free-piston and thermo-acoustic machines, because they have higher efficiency and better indicators of weight and dimensions per unit of power [4]. Stirling engine used in cases when a small heat energy converter is needed, simple in design, or when the efficiency of other heat engines is lower, for example if the temperature differences is not sufficient for the operation of a steam or gas turbine.

Stirling engine can be used to convert thermal energy into mechanic and then into electric. On them pin hopes on the creation of solar electrical installations. They are used as stand-alone generators for tourists. Some companies produce generators, which are powered by gas burners.

There are several advantages of using the EEHS for a multi-fuel micro power plant:

1. multi-fuel capability and ability to work on a locally available fuel;
2. considerable service life of 20,000 hours;
3. the possibility of cogeneration of heat and integrated energy production;
4. from 3 to 6 times lower cost generated kW power;
5. full autonomy and independence from the rates and market conditions of the oil and natural gas market;
6. high environmental performance of Euro – 5 and higher, that meets the most stringent international environmental standards;
7. the payback period of cogeneration plants is 2-4 years;
8. no need for laying and maintenance of electrical grids in the electrification of remote areas;
9. a significant reduction in the cost of regional budgets for the purchase of imported fuel.

In a different time, a number of foreign companies were very active in researching and developing new designs of SE or an engine with an external heat supply, for example, “Philips” (Netherlands), “General Motors Co”, “Ford Motor Co.”, “NASA Lewis Research Center”, “Los Alamos National Laboratory” (USA), “ MAN-MBW ”(Germany), “ Mitsubishi Electric Corp.”, “Toshiba Corp. ”(Japan). During the last decade, work on the creation of Stirling engines also began in the “Daimler Benz” and “Cummins Power Generation” (CPG) [5]. In a different time, many research and practical experiments have been carried out on the use of the Stirling engine for various needs, including the power generation [6]. At present, several large companies engaged in the development of cogeneration-type power plants are active in Russia, for example, LLC Information Technology Company “Stirling-Technology”. The market has products manufactured by OJSC Machine-Building Plant Arsenal, SPO Geliymash, etc. The EEHS manufactured by these enterprises are not Russian developments, but are copies of cryogenic machines previously produced by the Dutch firms NV Philips Gloeilampenfabrieken (Phillips) and “Werkspoor”. In Russia, due to the economic crisis, an extremely unfavorable innovative atmosphere and scientific organizations have emerged, in which work on the creation of new EEHS, for example, Bauman MSTU, ARSRIHT, OSTU,

St. Petersburg State Technical University (Polytechnic University), CRDRI were forced to close their programs due to financial difficulties. At the same time, in the countries of the European Union, the United States and Japan over the past 15 years, positive results have been achieved in the creation of high-performance Stirling machines, for example, of a thermoacoustic type with linear generators. In the beginning of 21-th century, a number of experimental researches were made by experts of LLC IRC Stirling technology, as a result of which a new methodology was developed for designing and calculating machines of this cycle. This methodology includes some know-hows among them: a unique method of two-level multiparameter optimization of Stirling engines; structural synthesis of Stirling machines based on the method of functional-exergy analysis of complex heat-mechanical devices and optimal design. Based on offered technical decisions, in 1994-2003 years more than 150 applications for alleged inventions have been filed by experts of LLC IRC Stirling technology. Particular attention was paid to the elaboration of individual units of Stirling machines and their design, an also the creation of new schematic diagrams of installations of various functional purposes. Practice has shown that optimal design will significantly reduce the total unit cost of machines with their pilot and mass production. The proposed technical solutions, taking into account the fact that Stirling machines are less expensive to operate, make it possible to increase their economic profitability in comparison with traditional energy converters. Further widespread Stirling machines will be associated with the development of the theory of designing multi-cylinder machines of this cycle, what will allow to create engines and refrigerators with a productivity up to 1000 kW.

**Some problems associated with the creation of high-performance Stirling machines.** Analyzed by us foreign experience in creating of high-performance the EEHS and Stirling engines showed that without accurate mathematic simulation of working processes and optimal designing of main knots the tweaking of projected machines is turning into long-term, exhausting, investigational study with low probability of successful result. The leading developments of companies in the European Union, the USA and Japan are based on the theoretical and experimental studies of their scientists from universities and technological park who are engaged in the development of certain types of Stirling machines. There are not fully solved technical problems related to the design of individual components, especially seals, power control, etc. There are problems caused by the use of various working fluids, such as low efficiency of air during heating and prevention of leakage of hydrogen, which is the most efficient working fluid. There are constructions using helium as a working fluid; it is much more efficient than air, but it has superfluidity which places increased demands on the sealing elements of the working piston of the propellant rod, etc., and this affects the cost of manufacturing of the EEHS. In contradistinction to ICE, the seals work in the dry friction mode, because the lubricant can severely contaminate the working fluid and adversely affect the operation of the EEHS, therefore the seals should have a low friction coefficient and high wear resistance. Work continues on the design of promising and new FEPT structures, which are being introduced into production, for example, free-piston, which do not have the drawbacks of classic EEHSs. To achieve high efficiency a high level of production technology and quality of materials is required, and this increases their cost, making them not available for mass general use. For example, WhisperGen company (New Zealand) has developed for the European market a microthermal power plant of a cogeneration type with an external combustion heat engine (Stirling engine), costing about 8 thousand euros, but if we consider its delivery to Kazakhstan, the price will increase by at least 50%. This unit is able to generate complex electrical power - 1 kW and heat - 5.5 kW, that may be enough for a small rural house. This technique is not available to the villager because of the high cost and the lack of natural gas for its work, this makes it unclaimed in the countryside. High cost generated by the need to use heat-resistant alloys and non-ferrous metals, welding and soldering. Considerable funds are invested in the manufacture of the regenerator and the nozzle for it, because it is necessary on the one hand high heat capacity, and on the other hand, low hydraulic resistance. Production requires high-tech equipment and highly skilled workers, and this also significantly increases the cost. High technology intensity and manufacturability of production, and also use of expensive materials is the main deterrent to the wide distribution of modern EEHS. For the creation of competitively manufactured EEHS on the world market, it can be achieved only as a result of synthesis of advanced scientific research and high professional constructive study of the main components, and also advanced production technology.

**Development of a multi-fuel power plant of ultra-low power with a heat engine of external combustion.** The aim of our scientific work is the development of the engine with external heat supply for micro electric multi-fuel capable operating effectively in rural areas of Kazakhstan.

We set our future task to develop a series of micro power plants with a capacity from 1 to 100 kW based on a free-piston external combustion engine and a linear generator for powering rural residents of Kazakhstan. Our work was performed in the framework of the project "Micro thermal power plant of coherence type with heat recovery" (No. AP05131751).

This type of heat engine was invented in the 50s of the last century by "Sunpower" company in the USA. Design turned so successful from the entire Stirling family that NASA engineers developed several options for their use on spacecraft. German engineers have made a number of developments for their use in everyday life; it can work as a generator, pump and thermocompressor [7].

Earlier, a number of recommendations were formulated on the use of the Stirling engine for energy supply to rural consumers, and also gave the main results of the research [8].

The compact cogeneration power plant is capable producing electrical and thermal energy, at a ratio of 1/5 kW, with an efficiency of 10-20% and 40-50%, respectively, by types of energy. In the future, carrying out work to improve and optimize the design parameters to achieve the integrated efficiency about 90%. This unit will produce heat energy about 5 times more than electric energy, because the heat energy of the cooling water and exhaust gases is used for the needs of the consumers' heat supply.

The effectiveness of the Stirling engine in cogeneration plants, compared to ICE, caused by feature of its heat balance. Figure 1 shows the layout of a multi-fuel micro-power station with a power of 1 kW with an engine with an external heat supply, in three possible variants, based on the use of the energy-saving Tandyr effect. This unit produces 1 kW/h of electrical energy and 5-6 kW/h of heat, which is more fully sufficient for a small rural house. The cooling circuit operates in the summer, and in the cold season it is replaced by the heating system of a residential house. The unit operates on the accumulation of electrical and thermal energy. Aggregators allow you to achieve stability in its work and provide maximum load

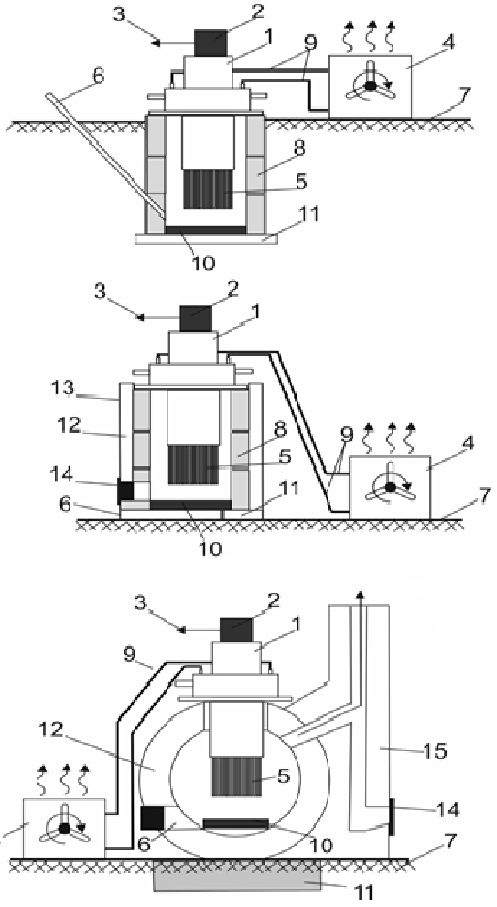


Figure 1 – Possible options for the layout of a multi-fuel power plant with a power of 1 kW with an engine with an external heat supply

peaks, and also to balance the volumes of energy produced and consumed with minimal losses. The unit is mounted in a furnace or “Tandyr” which is preliminarily pre-fired. The unit can also operate in a continuous mode while maintaining the process of burning the fuel.

The installation consists of: free-piston engine of external combustion 1; linear AC generator of permanent magnet 2 and cable line 3 with a voltage of 220 V. The cable connects to an AC220 / DC24V converter, for charging a battery with a capacity of approximately 200 A/h; cooling system (heating) 4, the more efficiently it works, the higher the efficiency of entire installation; working fluid heater 5 made of stainless heat-resistant steel; air supply system 6; the foundation of the earth is 7; brickwork of refractory bricks 8; pipeline for cooling system 9; fire grate 10; concrete base of the furnace 11; heat insulation 12; lining 13; cleaning hatch 14; chimney to remove combustion products 15.

Installation works in the following way, under the action of high temperature from 300 to 7000 power unit based on a free piston external combustion engine 1 drives the linear ac generator on permanent magnet 2, the generated current through the cable line 3 with a voltage of 220 V is fed to an AC-DC converter AC220 / DC24V which has a charge controller and charges the batteries with a minimum capacity of 200 A/h, it is desirable to increase the battery capacity by 2-3 times to eliminate the shortage of electricity and Avoid emergency shutdown of the autonomous system when the battery is low. If there are several powerful receivers in the house, then it is necessary to separately calculate the capacity necessary for their work. Direct current can be directly delivered to consumers, such as LED electric lamps, and partially inverted to drive the refrigerator and washing machine. The important point of the effective operation of the installation is the cooling (heating) system 4, the more efficiently it works, the higher the efficiency of the entire installation, therefore it is better to cool the working fluid than to increase the temperature of the heater. The cooling system is connected through pipelines 9 and is divided into direct and reverse; automobile antifreeze can be used as a coolant. An electric pump (pump) is used to circulate the coolant, and the house heating system is connected via a heat exchanger. For storage of excess heat energy is required tank with thermal insulation capacity of 200 - 500 liters.

The heater of the working fluid 5 directly senses the heat and must be made of heat-resistant steel, to increase efficiency, it is equipped with additional tubular heaters and an internal regenerator. To ensure the process of burning fuel furnace or "Tandyr" should be equipped with air supply 6. The important point is the design of the furnace itself, the main thing is its quality should be energy saving and heat preservation, that is why special attention is paid to thermal insulation.

Electric scheme of the unit is shown in figure 2, the basic idea is to divide the load into variable and constant. This will avoid unnecessary transformations and losses, because most modern household electrical equipment operates on direct current, for example, a laptop or a cell phone.

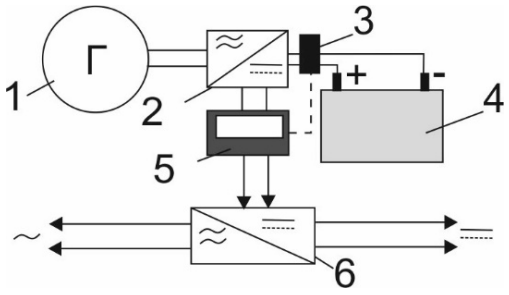


Figure 2 –Electric generation scheme

LED electric lamps can also operate on DC without a driver. AC is only needed for the refrigerator, washing machine, microwave, therefore, an inverter is provided for them. The system of generating electrical energy comprises a linear synchronous AC generator 1, made on permanent magnets, a semiconductor AC rectifier 2, battery charge controller with relays 3 and 5, battery 4, switchgear 6 for dividing the load into alternating current with power from the inverter and to direct current to supply the DC load directly from the battery.

To conduct research, we developed an experimental motor with an external heat supply, presented in figure 3, the power of an electric generator with permanent magnets is 100 watts.

Figure 3 – Experimental laboratory installation with a capacity of 100 W

Helium is used as a working fuel with the addition of a small percentage of water, which allows creating pressure up to 12 MPa.

We have carried out computer simulation of free piston engine, obtained results will help to create an optimal design with the highest possible efficiency. A number of dependencies, affecting the power associated with the temperature of the heater and cooler, diameter and stroke of pistons phase and other parameters installed.Separately, experiments allowing construct a Carnot closed thermal cycle diagram and consider the dependence of pressure and volume at different positions of the pistons have been carried out. The results are shown in figure 4.

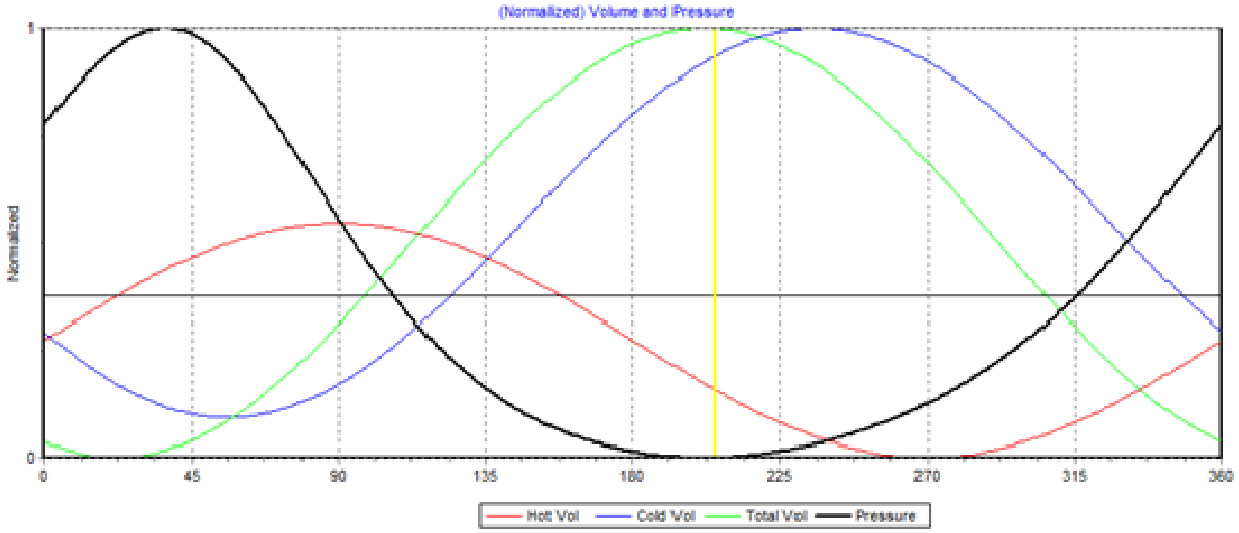


Figure 4 – Dependence of pressure and volume at different positions of the pistons

Conducted research allows us to find the optimal parameters of the structural parts of the heat engine, to establish the dimensions of the piston and the displacer, and also the magnitude of their stroke with the optimum phase shift value.

**Conclusion.** The use of an engine with external heat supply for a multi-fuel microelectric station capable of working effectively in rural Kazakhstan is very promising and requires a comprehensive scientific study. We believe that the most promising design of the drive of the power unit is a free piston engine with external heat supply.

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## ҚАЗАҚСТАННЫҢ АУЫЛДЫ АЙМАҚТАРЫНДА ТИІМДІ ЖҰМЫС ЖАСАЙ АЛАТЫН СЫРТҚЫ ЖАНУ ЖЫЛУ ҚОЗҒАЛТҚЫШЫ БАР КӨПОТЫНДЫ АЗ ҚУАТТЫ ЭЛЕКТР СТАНЦИЯСЫ

**Аннотация.** Энергияны тиімді пайдалану мәселесі бүгінгі күнге дейін толық шешілмеген. Бұл мәселені шешудің бір жолы – кез келген жанармайда жұмыс істеуге қабілетті микро жылулық электр станциясын дамыту болып табылады. Энергияны өндіру үшін жергілікті аймақтағы әр түрлі отын түрлерін қолдану кететін қаражат көлемін азайтады. Электрмен қамтамасыз ету сенімділігі айтарлықтай артады және оны тұтынушыға үздіксіз жеткізу қамтамасыз етіледі. Ұсынылған электр станциясы сыртқы жылумен қамтамасыз ететін жылу қозғалтқышымен басқарылады. Стирлинг принципіне сәйкес жұмыс жасайтын сыртқы жылумен жабдықтаушы қозғалтқышты компьютерлік модельдеудің кейбір нәтижелері келтірілген. Жасалып жатқан қозғалтқыштың дизайн ерекшеліктері қарастырылған.

Жүргізілген зерттеулер жылу қозғалтқышының құрылымдық бөліктерінің оңтайлы параметрлерін табуға мүмкіндік береді.

**Түйін сөздер:** жылу электр станциясы, Стирлинг қозғалтқышы, когенерация, жылу энергиясы, комплексті өндіру, альтернативті энергетика.

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## МНОГОТОПЛИВНАЯ ЭЛЕКТРОСТАНЦИЯ СВЕРХМАЛОЙ МОЩНОСТИ С ТЕПЛОВЫМ ДВИГАТЕЛЕМ ВНЕШНЕГО СГОРАНИЯ, СПОСОБНАЯ ЭФФЕКТИВНО РАБОТАТЬ В УСЛОВИЯХ СЕЛЬСКОЙ МЕСТНОСТИ КАЗАХСТАНА

**Аннотация.** Проблема эффективного электроснабжения не решена в полном объеме до сих пор. Одним из путей решения данной проблемы является разработка микро тепловой электростанции, способной функционировать практически на любом топливе. Использование собственного источника энергии позволит снизить затраты на ее производство. Существенно повышаются показатели надежности электроснабжения и обеспечивается ее бесперебойная поставка потребителю. Предложенная нами электростанция приводиться в действия тепловым двигателем с внешним подводом теплоты. Приведены некоторые результаты компьютерного моделирования двигателя с внешним подводом тепла, который работает по принципу Стирлинга. Рассмотрены конструктивные особенности разрабатываемого двигателя.

Проведенные исследования позволяют найти оптимальные параметры конструктивных частей теплового двигателя. Точно установить геометрические размеры поршня и вытеснителя, а также величину их хода с оптимальным значением фазового сдвига.

**Ключевые слова:** тепловая электростанция, двигатель Стирлинга, когенерация, тепловая энергия, комплексное производство, альтернативная энергетика.

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**ISSN 2518-170X (Online), ISSN 2224-5278 (Print)**

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Верстка *Д. Н. Калкабековой*

Подписано в печать 11.06.2019.
Формат 70x881/8. Бумага офсетная. Печать – ризограф.
15,7 п.л. Тираж 300. Заказ 3.

*Национальная академия наук РК*
*050010, Алматы, ул. Шевченко 28, т. 272-13-19, 272-13-18*