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# MOTOR WITH EXTERNAL HEAT SUPPLY BASED ON THERMO-ACOUSTIC EFFECT FOR AN AUTONOMOUS THERMAL POWER PLANT

**Abstract.** The problem of efficient power supply has not been fully resolved yet. One way to solve this problem is to develop a micro thermal power plant that can operate on almost any fuel. Using your own energy source will reduce the cost of its production. Significantly increase the reliability indicators of power supply and ensure its uninterrupted supply to the consumer. Our proposed power plant is driven by a heat engine with an external supply of heat. The goal is to create an alternative cogeneration energy source for remote rural consumers, capable of operating on almost any type of fuel or waste that has been burned. This will allow the villager to produce locally without paying for transport losses of electricity, to produce electric and thermal energy in the complex. In our work, we take into account the positive results, experience and achievements of foreign ones, to create our own design.

The solution to the problem of efficient power supply to rural consumers can be the introduction of micro thermal power plants. The basis of a micro thermal power plant is an engine with an external supply of heat operating on the Stirling principle. The analysis of the level of modern achievements in the field of microelectric power plants. The direction of development of scientific research on the development of an engine with an external heat supply is established. The task is to ensure that it is able to function on local low-calorie fuel. It is necessary to completely exclude the use of diesel fuel, coal, fuel oil and other imported fuel, which does not allow to achieve low cost of energy produced.

There are a number of advantages of the design features of microthermal power plants. Firstly, it is his so-called omnivorousness, any source of thermal energy from wood to nuclear fuel. Laboratory models worked from the heat of heated water, the flame of a candle and a gas burner, and we also tested household wastes exposed to burning various organic fuel mixtures from dried plant residues mixed with animal waste. Secondly, it is possible to make a simpler design of the heat engine, since it does not have a valve system and gas distribution with a shaft, a high-voltage ignition system. If the engine is accurately and correctly manufactured, then it will not require adjustment and adjustment during the entire operation. Thirdly, the simplicity of the design will increase its service life with the right choice of seals and heat exchanger material will allow it to go through without repair for about 20 thousand hours, which will ensure its autonomy. Fourth, a few times fewer number of parts will provide a large motor resource and minimum oil consumption, making its operation inexpensive.

The advantages of using cogeneration micro thermal power plants in rural areas with external combustion engines using local fuel in the regions of the Republic of Kazakhstan can be identified:

- independence from the price of hydrocarbon fuel, as well as the rejection of the costs of its storage and transportation.
- multi-fuel and the use of available fuel for a given area, as well as the prospect of creating enterprises for its processing.
- refusal to lay electric lines and the costs associated with their maintenance.
- the cost of 1 kW / h of generated electricity using a cogeneration plant will be from 3 to 5 tenge, which is 2-3 times cheaper than existing tariffs.
- when burning fuel, the CO content in the exhaust gases is 3 times lower than that of ICE and the content of NO and CH is much lower, which corresponds to the most stringent world environmental standards.

- payback period of cogeneration plants of 2 - 3 years.

The article shows the dependence of the developed mechanical power on the number of revolutions of the crankshaft at various pressure values, as well as the dependence of torque on the pressure in the cylinders at various values of the crankshaft rotation speed. A conclusion is drawn based on the presented graphs.

**Key words:** Thermal power station, Stirling engine, cogeneration, electric energy, thermal energy, integrated production, power supply, heat supply, alternative energy, heat engine.

Our goal is to create an alternative cogeneration energy source for remote consumers in rural areas, able to work on virtually any kind of fuel or waste that has been burned. This will allow the villager to produce on site without paying transport losses of electricity, to produce electrical and thermal energy in the complex. The high cost of energy leads to significant costs in the production of agricultural products and makes it expensive, that is, it decreases its competitiveness. In all regions of Kazakhstan, an annual increase in tariffs is observed, not only for electricity, but also for heat. About 300 small rural settlements do not have a centralized energy supply at all. To build a system of its own autonomous power supply, modern industry can offer, besides gasoline and diesel electric power stations, the cogeneration sources of which are based on the Stirling cycle engine with external heat supply. There are foreign developments of micro thermal power plants (MTES) using engines with external heat supply, with economic indicators and technical characteristics superior to internal combustion engines (ICE) and gas-turbine installations (PG). A preliminary scientific analysis showed that in the last century, many modifications were developed with external heat supply engines operating according to the Stirling cycle with the participation of foreign firms Philips, STM Inc., Daimier Benz, Solo, United Stirling, and serial samples operated in transport, household and agriculture, but these MTES are not adapted to the fuel available in rural regions of Kazakhstan [1-3]. The engine with external heat supply DVPT was improved and patented by Pastor Stirling in 1817. There are examples of certain successes, the Philips company producing compact electric generators used DVPT, this type of engine was also used together with a solar concentrator, its efficiency was about 40%, which is not yet achievable for modern solar modules [4-5]. It is also necessary to take into account the experience of modern manufacturers: Ecopower, WhisperGen, Microgen, Lion-Powerblock, Honda, EcoGen using similar technologies. The samples developed by them allow the complex production of electric and thermal energy for an autonomous energy supply system, while 5 kW of thermal energy is produced for 1 kW of electric energy for a heating system [6]. Modern foreign samples have high efficiency and cost per 1 kW of power, while working mainly on natural gas. For example, WhisperGen with a power of 1 kW costs about 6 million tenge. We completely reject the copying of sample data and set ourselves the task of developing an engine of a high-temperature combustion engine of our own design and is able to work effectively on almost any kind of fuel available in rural areas or waste burned, and also to be easy to operate. The second point is to solve the problem of its further production at the lowest possible price using materials and technologies that have Kazakhstan content. The maximum exclusion of imported components and the designed DVPT greatly complicates the task at the initial stage, but future scientific and experimental design should serve as the basis for the successful implementation of the project and the relevance of our development. To do this, we will make a number of changes to the typical known structures of the high-temperature structural element, including the mechanical and electrical parts. It is necessary to work out its design of the heater, regenerator, cooler and seals, to achieve the highest possible efficiency. The cooling system will be a liquid cooler with a blown radiator [7-8].

As it was said earlier, the basis of our development is DVPT working according to the Stirling cycle. but on a completely different principle in contrast to classical structures and this difference is the use of the thermoacoustic effect [9]. This is a well-known method of exciting sound with the help of heat, described in 1877 by Relem in the book Theory of Sound. In the mid-20th century, scientists worked to study thermo-acoustic oscillations in combustion chambers of installations with large temperature differences, and in the 70s of the last century N. Rott discovered that a sound field can create a unidirectional heat flow. Using the above theoretical and practical achievements, we have developed various laboratory samples, on which we perform the testing of our future thermo-acoustic DVPT, for a cogeneration thermal power plant of super low power. The advantage of thermo-acoustic DVPT in relation to the classic variants of the Stirling engine "Alpha", "Beta" and "Gamma", as well as freely piston, is a higher efficiency and a resource of more than 100 000 hours [10-11].

An analysis of world experience showed that in various years of the past and the present century, scientists worked on the creation and improvement of a thermo-acoustic engine (TAE) with an external supply of heat. For example, PH Ceperley for the first time described the effect of a traveling sound wave, T Yazaki demonstrated his sample TAE, S Backhaus and GW Swift developed a thermoacoustic engine with a reversed Stirling cycle in the regenerator [12]. A more complex TAE design than Yazaki allowed to achieve higher thermal efficiency - 30%, which corresponds to 41% Carnot efficiency. Recently, for the same engine type, Tijani and Spoelstra set a new record at 49% Carnot efficiency. Using the accumulated world experience in this field of science, we conducted a number of studies to develop our own design of a thermo-acoustic engine with an external supply of heat. For this calculation, the DeltaEC computer program (Design Environment for Low-amplitude Thermo-Acoustic Energy Conversation - developed by Los Alamos National Laboratory, USA, free license) was used [13-15].

The scientific novelty of our work is to obtain new dependences of the parameters of the thermo-acoustic engine with structural differences from their analogues. The difference is the presence of an additional regenerator from the side of the hot heat exchanger, this allows you to increase the efficiency from 4 to 6%. A steam-air mixture is used as a working fluid, this allows to increase engine power without increasing its mass by 12-15%, which is the scientific and practical novelty of this work. From a practical point of view, foreign authors consider a thermo-acoustic engine only as an electric generator or cryogenic installation, but do not consider it as a cogeneration source capable of complex production of electric and thermal energy with a total efficiency of up to 80% of energy. The simplicity of the design ensures reliable operation and low cost of production, therefore, it is possible to use these sources for power supply of low-power remote autonomous consumers of thermal and electric energy [16-18].

Thermo-acoustic motor with a traveling wave, converts thermal energy into acoustic energy, due to the completion of the thermodynamic cycle closest to the Stirling cycle. Acoustic energy obtained by heating its heat exchanger is converted into electrical energy, which is produced using a linear permanent magnet alternator or a bi-directional turbine by a synchronous generator. Thermal energy is removed from the cooling circuit and can be directed to the heating system of an autonomous object. Structurally, a DVPT is obtained with a minimum number of moving parts and an electrical efficiency of 30–50% of the Carnot cycle efficiency, while it lacks a piston and a displacer, without which the Alpha, Beta and Gamma DVTT cannot work [19]. Accordingly, a number of difficult problems with seals and piston friction simply do not exist, there are simply no friction parts in the engine. After analyzing the materials of the study and the design of engines with an external heat supply, we developed a laboratory sample, which is shown in figure 1.

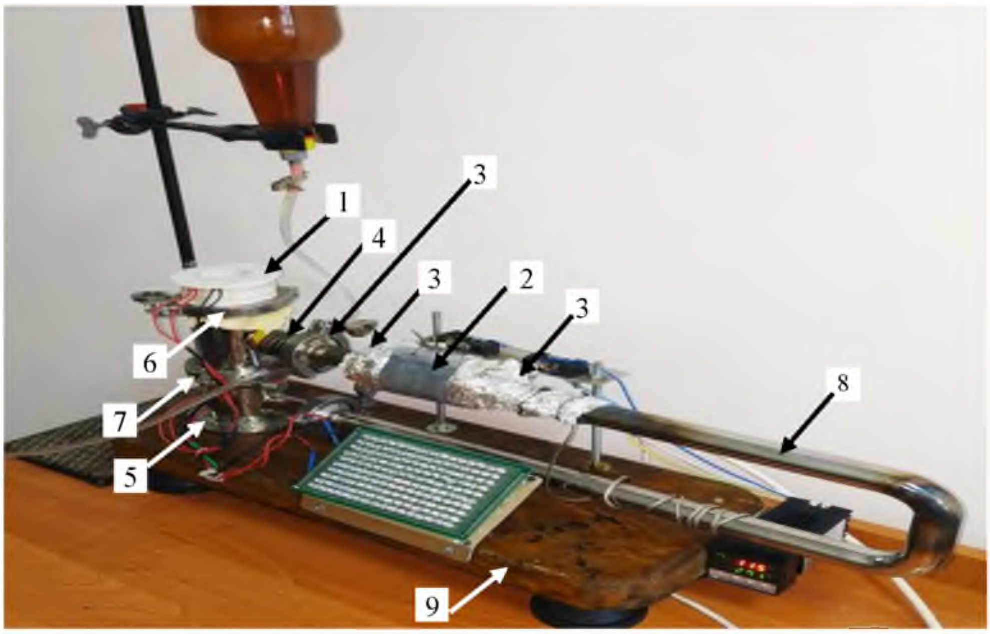


Figure 1 – The current model of thermo-acoustic engine with an external heat supply

As stated earlier, one of the advantages of this type of DVPT is the absence of pistons and propellant with seals, a massive flywheel and other rotating parts. Its metal consumption is orders of magnitude smaller than that of the Alpha, Beta and Gamma DVPTs, this allows competing in weight / size / power parameters to any even a turbocharged diesel engine. At the same time, the simplicity of the design makes it possible to make available materials and, in contrast to a free piston DVPT, high-precision fitting of parts and adjustment of elastic elements are not required. As the main parts, it is possible to single out a linear generator 1 that has a coil wound on a frame with a copper enameled double wire with a diameter of 0.4 mm and three 5 x 30 mm podomovy magnets. The coil is wound by hand in bulk, without strictly observing the sequence of a series of approximately 2500 turns. The material is stainless steel AISI310, which is not the best thermal conductivity of the heat exchanger wall. Heating is carried out using an open flame of a gas burner or a dry fuel in the heating zone 2. The wire regenerator is located in area 3, made of steel wire with a diameter of 1 mm, its length is about 7 cm. Cooling the working fluid (air) is carried out in area 4.

A cotton cloth moistened with water is used as a cooler. The design of the ring resonator is attached to a wooden board 9, 5 cm thick, with the help of 4 screws and a flange 5. Without rigid attachment of the flange to the baseboard 9, normal operation of the resonator 8 is not possible. The resonator is made of a steel tube 25 mm in diameter 10 to the outlet is 450 mm. In the experiments, we used resonators 250 and 350 mm long, but the best performance was shown by a 450 mm long resonator. The resonator is welded to two tubes with a diameter of 63 mm. The main working element is two membranes 6, made of gley balloons or you can use medical gloves. As a load, 160 LEDs with a power of 0.06 W are used. Linear generator consisting and two parallel coils produces a total electric power of alternating current of about 10 W, with this voltage reaches 12 volts, frequency up to 58 Hz, depending on the heating intensity of the working fluid in the heat exchanger in region 2. The engine has the ability to self-start (self-start) , unlike the classic Stirling engines.

The principle of action of our engine is based on the effect of acoustic waves that are generated when the regenerator is heated and transmitted through a resonator with two membranes that create a resonance. Three permanent magnets are fixed on the upper membrane, which vibrate with the frequency of the acoustic wave. The magnetic field intersects the winding of the inductor and alternating current is generated [20]. The second membrane 7 is necessary to prevent circular circulation of the working fluid (air) in the resonator 8. The important point is good sealing by the joint where the membranes and the resonator are installed, for this we use a clamp 10 with a screw clamp and seals. Most of the resonator does not heat up and remains cold (ambient temperature of the room), so it can also be performed with ABC plastic or polypropylene, which can significantly simplify the design and reduce the cost.

Main working areas resonators: cooling zone; heating zone; regenerator zone. The working fluid performs an alternate movement from the heater to the cooler and back passing through the regenerator, giving partial heat to the air flow (working fluid) and then taking it as it moves to the cooling zone. The plate heat exchanger must be installed in the region of 1–16 the length of the resonator tube from its beginning of the membrane 6, while the end of the resonator is awakened by the membrane 7.

Using the well-known effect, Rayleigh, which leads to the excitation of sound vibrations described as far back as 1877 when the wire regenerator is heated, and also opened in 1859 by P. L. Rijke, professor of physics at the University of Leidon in the Netherlands. Subsequently, this design was called the Rijke tube, we made a resonator operating on these effects. Figure 3 shows the movement of the working fluid inside the resonator. The working medium, the air circulates in a confined space, going through a heating and cooling cycle. Circulating air drives the membrane. There is a permanent magnet on the upper membrane, under the weight of which it bends and to be in the lower position when the resonator is inoperative. With heating and expansion of the working fluid, the membrane rises to the top. After cooling air in the cooling zone, the working fluid is compressed, and the membrane is drawn into the cavity tube. This DVPT works according to the Stirling principle.

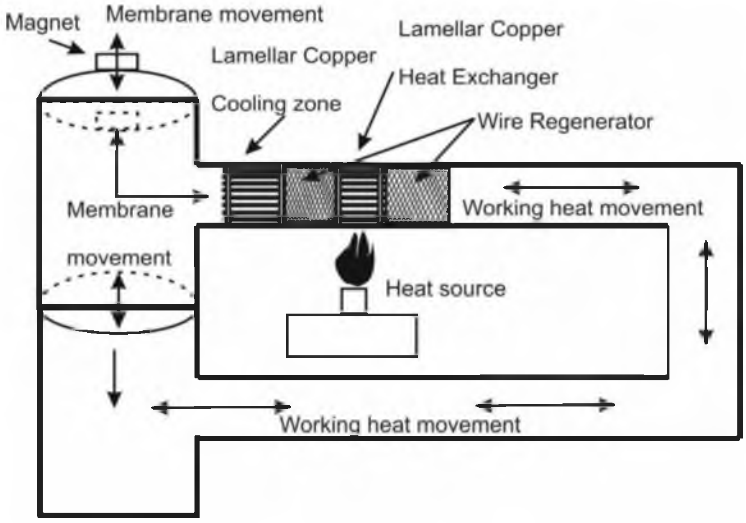


Figure 3 – The movement of the working fluid inside the resonator

Figure 4 shows a graph of pressure and speed of the traveling acoustic wave as a function of time. When heated inside the resonator, noise with a wide frequency spectrum is generated. The resonator amplifies exactly that sound frequency of sound vibrations, the wavelength of which is equal to the length of the tube and the engine starts to work. Minor initial sound vibrations are amplified to the maximum possible value. The maximum sound volume inside the engine occurs when the sound amplification power using heat exchangers is equal to the power loss, i.e. the sound attenuation power. The maximum value reaches a value of about 160 dB. This is more than the sound of a jet taking off, such sound pressure can cause injury to the human ear, but the sound is not able to go beyond the resonator, which is airtight. The warmed DVPT is practically not heard. Sound amplification occurs in the regenerator.

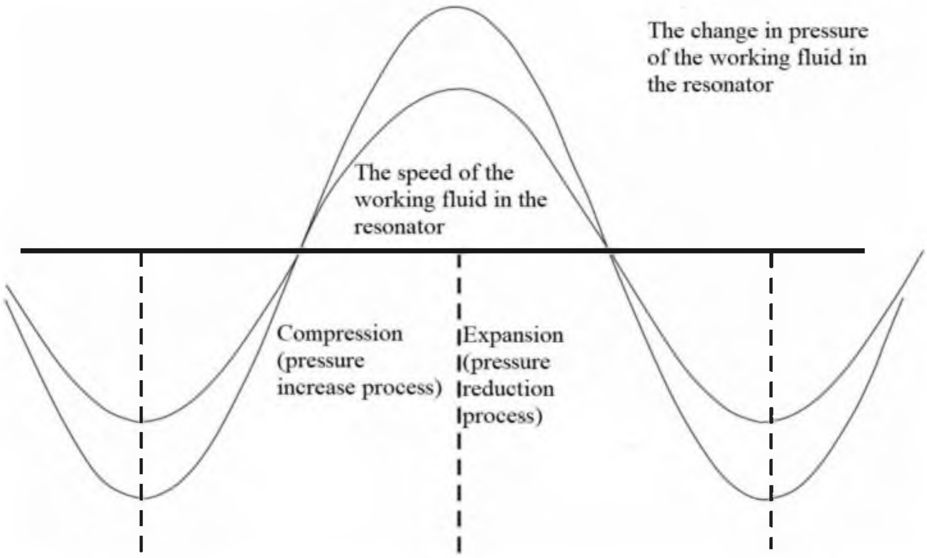


Figure 4 – Graph of changes in pressure and speed of a traveling acoustic wave as a function of time

Figure 5 shows some of the results of our experiments, the results were processed using a third-degree polynomial approximation with a certain regressive value of the reliability of the experimental results. Graph 1 was built in the experiment with the heating temperature of the working fluid up to 430°C, allowed to reach a sound pressure of 187 dB, graph 2 was built in the experiment with the heating temperature of the working fluid to 390°C, allowed to reach the sound pressure of 173 dB. Increasing the pressure and temperature allows you to increase the power of the thermo-acoustic engine with an external heat supply, also reduces the time of self-starting and the beginning of its work.

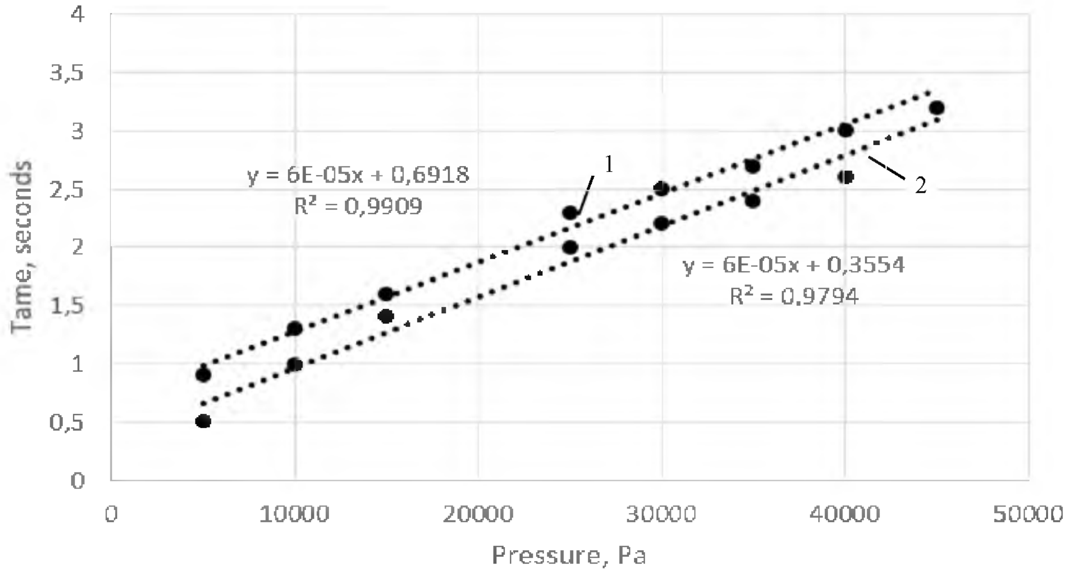


Figure 5 – Graph of growth of pressure and sound pressure at a temperature of the working fluid, 187 dB 430$^0$C Graph 1 and 173 dB at 390$^0$C Graph 2.

The conclusion is, the engine without moving parts and theoretically capable of achieving the efficiency of the Stirling cycle, and hence Carnot. In reality, the best performance is 40-50% of the efficiency of the Carnot cycle. The use of an engine with an external heat supply based on a thermoacoustic effect will make it possible to develop an autonomous thermal power plant of cogeneration type with high efficiency indicators (Efficiency) and environmental friendliness compared to ICE. MTES is capable of comprehensively generating electrical energy using a linear generator and thermal energy through a cooling circuit approximately in the ratio of 1 to 5. The constructive simplicity of the engine, and the absence of rubbing and rotating parts will ensure a high resource of more than 100 000 hours of continuous work, and can also compete in relation to the weight / size / power parameters for any turbocharged diesel engine. The only problem is the resource of the membranes, which in the process of testing were often out of order.

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## ШАЛҒАЙДА ОРНАЛАСҚАН АУЫЛДАҒЫ ТҰТЫНУШЫЛАРДЫ ЭЛЕКТРМЕН ҚАМТАМАСЫЗ ЕТУГЕ АРНАЛҒАН КОҒЕНЕРАЦИОНДЫ МИКРОЖЫЛУ ЭЛЕКТР СТАНЦИЯСЫ

**Аннотация.** Бүгінгі күнге дейін тиімді электрмен қоректендіру мәселесі әлі толық шешілген жоқ. Бұл мәселені шешудің бір әдісі – кез келген отынмен жұмыс істей алатын шағын жылу электр станциясын пайдалану. Жеке қуат көзін пайдалану оны өндірудің өзіндік құнын төмендетеді. Электрмен жабдықтаудың сенімділік көрсеткіштерін едәуір арттырып, оны тұтынушыға үздіксіз жеткізуді қамтамасыз ету өте маңызды. Біздің ұсынып отырған микро электр станциямыз сыртқы жылу көзі бар жылу қозғалтқышымен басқарылады. Мақсаты – шалғайдағы ауылдық тұтынушылар үшін кез келген дерлік жанармай түріндегі немесе жағылған қалдықтармен жұмыс істей алатын балама когенерация энергия көзін құру. Бұл ауыл тұрғынына электр энергиясының көлік шығындарын төлемей, жергілікті жерде өндіруге, кешенде электр және жылу энергиясын өндіруге мүмкіндік береді. Біз өз жұмысымызда шетелдік дизайнерлердің оң нәтижелерін, тәжірибелері мен жетістіктерін ескере отырып, өз дизайнымызды жасаймыз.

Ауыл тұтынушыларын тиімді электрмен жабдықтау мәселесінің шешімі микро жылу электр станцияларын енгізу болуы мүмкін. Микрожылулық электр станциясының негізі – бұл Стирлинг принципіне сәйкес сыртқы жылу берілісі бар қозғалтқыш. Микроэлектр станциялары саласындағы заманауи жетістіктер деңгейіне талдау жасалды. Сыртқы жылумен қамтамасыз етілген қозғалтқышты дамыту бойынша ғылыми зерттеулердің даму бағыты анықталды. Жұмыстың міндеті – жергілікті төмен калориялы отынмен жұмыс істей алатын микро электр станциясының можедін жасау. Дизель отынын, көмірді, мазутты және басқа импортталатын отынды пайдалануды толығымен алып тастау қажет, бұл өндірілетін энергияның төмен бағасына қол жеткізуге мүмкіндік бермейді.

Микрожылулық электр станцияларының дизайн ерекшеліктерініц бірқатар артықшылықтары бар. Біріншіден, бұл оның бәріне танымал, ағаштан бастап ядролық отынға дейінгі кез келген отын көзін пайдалана алу мүмкіндігінде. Зертханалық модельдер жылытылған судан, шамнан және оттықтың жалынынан жұмыс істеді, сонымен қатар жануарлардың қалдықтарымен араластырылған кептірілген өсімдік қалдықтарынан әртүрлі органикалық отын қоспаларын жағуға арналған тұрмыстық қалдықтарды тексердік. Екіншіден, жылу қозғалтқышыныц қарапайым дизайнын жасауға болады, өйткені онда клапан жүйесі және білікпен газ тарату, жоғары вольтты тұтану жүйесі жоқ. Егер қозғалтқыш дәл және дұрыс жасалған болса, онда ол бүкіл жұмыс кезінде түзетуді және реттеуді қажет етпейді. Үшіншіден, дизайнның қарапайымдылыгы оның қызмет ету мерзімін ұлгайтады, тыгыздагыш пен жылу алмастыргыш материалын дұрыс таңдау оны 20 мың сағатқа жөндеусіз өткізуге мүмкіндік береді, бұл оның дербестігін қамтамасыз етеді. Төртіншіден, бөлшектердің бірнеше есе аз болуы үлкен мотор ресурсын және майдың минималды шыгынын қамтамасыз етеді, оның жұмысын арзан етеді.

Қазақстан Республикасының ауылды аймақтарында сыртқы қозгалтқышы бар жылу электр станцияларын пайдаланудың бірнеше артықшылықтарын бөліп қарастыруга болады:

- көмірсутегі отынының бағасынан тәуелсіздік, сондай-ақ оны сақтау мен тасымалдау шыгындарынан бас тарту;
- кез-келген отын түрін пайдалана алу қабілеті. Жергілікті шыгарылатын отынды өндіру өнеркәсібін салу перспективасы;
- электр желілерін салудан бас тарту және оларды ұстауга байланысты шыгындардың болмауы.
- когенерациялық қондырғыны қолдана отырып өндірілген электр энергиясының 1 кВт / сағ құны 3-тен 5 теңгеге дейін болады, бұл қолданыстағы тарифтерге қарағанда 2-3 есе арзан.
- отынды жағу кезінде пайдаланылған газдардағы CO мөлшері қарапайым жағдайдан 3 есе төмен, ал NO және CH мөлшері әлдеқайда төмен, бұл ең қатаң халықаралық экологиялық стандарттарға сәйкес келеді.
- когенерациялық қондырғылардың өтелу мерзімі – 2-3 жыл.

Мақалада дамыған механикалық қуаттың әртүрлі қысым мәндеріндегі иінді біліктің айналу санына тәуелділігі, сондай-ақ моменттің цилиндрлердегі қысымға иінді біліктің айналу жылдамдығының әртүрлі мәндеріндегі тәуелділігі көрсетілген. Ұсынылған графиктердің негізінде қорытынды жасалған.

**Түйін сөздер:** жылу электр станциясы, Стирлинг қозғалтқышы, когенерация, электр энергиясы, жылу энергиясы, жылумен қамтамасыз ету, эльтернативті энергетика, жылу қозғалтқышы, электрқоректендіру, комплексті өндіріс.

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## МИКРОТЕПЛОВАЯ ЭЛЕКТРОСТАНЦИЯ КОГЕНЕРАЦИОННОГО ТИПА ДЛЯ ЭНЕРГООБЕСПЕЧЕНИЯ УДАЛЕННЫХ СЕЛЬСКИХ ПОТРЕБИТЕЛЕЙ

**Аннотация.** Проблема эффективного электроснабжения не решена в полном объеме до сих пор. Одним из путей решения данной проблемы является разработка микротепловой 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 приводится в действие тепловым двигателем с внешним подводом теплоты. Целью является создание альтернативного когенерационного источника энергии для удалённых потребителей сельской местности, способного работать практически на любом виде топлива или отходах, подверженных горению. Это позволит сельскому жителю производить на месте без оплаты транспортных потерь электроэнергию, производить электрическую и тепловую энергию в комплексе. В своей работе мы учитываем положительные результаты, опыт и достижения зарубежных стран для создания собственной конструкции.

Решением проблемы эффективного электроснабжения сельских потребителей может быть внедрение микротепловых электростанций. Основой микротепловой электростанции является двигатель с внешним подводом теплоты, работающий по принципу Стирлинга. Выполнен анализ уровня современных достижений в области микроэлектростанций. Установлено направление развития научных исследований по разработке двигателя с внешним подводом тепла. Задача сводится к тому, чтобы она была способна функционировать на местном низкокалорийном топливе. Необходимо полностью исключить использование дизельного топлива, угля, мазута и другого привозного топлива, которое не позволяет добиться низкой стоимости произведенной энергии.

Можно выделить ряд преимуществ конструктивных особенностей микротепловых электростанций. Во – первых, это его так называемая всеядность, любой источник тепловой энергии от древесины до ядерного топлива. Лабораторные модели работали от тепла нагретой воды, пламени свечи и газовой горелки, а также нами опробованы бытовые отходы подверженные горению различные органические топливные смеси из высушенных остатков растений, смешанных с отходами животноводства. Во-вторых, есть возможность изготовить более простую конструкцию теплового двигателя, так как в нем нет системы клапанов и газораспределения с валом, система высоковольтного зажигания. Если точно и правильно изготовить двигатель, то он не будет требовать настройки и регулировки в течении всей эксплуатации. В третьих, простота конструкции позволит повысить срок его эксплуатации при правильном выборе уплотнений и материала теплообменника позволят пройти ему без ремонта около 20 тыс. часов, что обеспечит его автономность. В – четвертых, меньшее в несколько раз количество деталей обеспечит большой моторесурс и минимальный расход масла, делает недорогой его эксплуатацию.

Преимущества использования в сельской местности когенерационных МТЭС с двигателями внешнего сгорания на местном топливе в регионах Республики Казахстан можно выделить:

– независимость от цены на углеводородное топливо, а также отказ от затрат на его хранение и транспортировку;

– многотопливность и использование доступного топлива для данной местности, а также перспектива создания предприятий по его переработке;

– отказ от прокладки электрических линий и затрат, связанных с их обслуживанием;

– стоимость 1 кВт/ч производимой электроэнергии с помощью когенерационной установки будет составлять от 3 до 5 тенге, что в 2–3 раза дешевле существующих тарифов;

– при сгорании топлива содержание СО в отработанных газах в 3 раза ниже, чем у ДВС и значительно ниже содержание NO и CH, что соответствует самым жестким мировым экологическим стандартам.

– срок окупаемости когенерационных установок 2 - 3 года.

В статье приведена зависимость развиваемой механической мощности от числа оборотов коленчатого вала при различных значениях давления, также зависимость крутящего момента от давления в цилиндрах при различных значениях частоты вращения коленчатого вала. Сделан вывод на основе представленных графиков.

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

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