ISSN No:-2456-2165

A New Type of Renewable Resource: The Natural Thermal Expansion and Contraction Energy of Matter

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Abstract:- A new type of renewable resource is suggested. Permanent temperature changes in the environment are accompanied by enormous flows of energy. The forces that arise by the natural thermal expansion and contraction of liquid and solid matter, due to day and night temperature differences in the environment, can be deployed to generate useful energy. The problem is how to transform the very slow processes of expanding and contracting into fast linear or circular motion. Here, we present a pilot model of a device that implements a way of accelerating the thermal motion of a working liquid to produce electrical energy. The power of the new type of machine depends on the initial volume of the working liquid, the coefficient of thermal expansion of the liquid, the pressure in the sealed balloon that holds the liquid, and the rate at which the environmental temperature changes. The working principle of the device, and the experimental results obtained for the chosen parameters and design, are described. Our results show that the use of a working liquid with a higher thermal expansion coefficient, a larger initial volume, and a higher working pressure can potentially generate much more power.

Keywords:- *Contraction; Expansion; Natural; Renewable; Thermal.*

I. INTRODUCTION

The world's demand for electrical energy is increasing year by year. The share of renewable resources in the generation of electricity is growing too, but it cannot meet the demand. In 2016, 79.5% of the energy consumed was produced using exhaustible fossil resources [1]. This encourages the search for new types of renewables. According to [2] , the main renewable energy resources are hydropower, wind, solar, geothermal, biomass, ocean waves, offshore wind, marine current, ocean thermal energy, tides, and osmotic power. Here, in the present paper, we suggest a new type of renewable energy resource: the natural thermal expansion and contraction energy of matter. So, let us first discuss whether thermal expansion and contraction energy can fall within the category of renewables.

Several definitions of renewables can be found on Wikipedia. The main requirement is that the resource must be natural, renewable, and ecological and can operate without the efforts of humans. The thermal expansion of solids and liquids is associated with an increase in the kinetic energy of individual atoms [3]. Conversely, a decrease in the kinetic energy of atoms accompanies contraction of matter. The increase or decrease in the kinetic energy of atoms is governed by the increasing or decreasing temperature of the substance, which in turn depends on the environmental temperature. The environmental temperature will constantly change in nature, and day and night temperatures are usually considerably different. Thus, each day, all matter will periodically expand and contract under the influence of the temperature in the environment. This expansion and contraction will continue year-round regardless of whether the day is sunny or not. Therefore, the process of natural thermal expansion and contraction of matter is renewable and matches with the definition of a renewable resource. The forces that arise during these processes can be used for generating useful energy. In addition, according to the definition mentioned in [4], the term "renewable energy" covers energy flows that occur naturally and repeatedly in the environment, and the ultimate sources of such energy are the sun, gravity, and the earth's rotation. If start from these determinations the expansion and contraction of matter are the results of environmental temperature changes. The natural temperature changes caused by sunlight, weather, and earth's rotation for a given locality per unit of time can be regarded as energy flows. These environmental energy flows will be transferred to liquid and solid matter, and the kinetic energy of the individual atoms of which will increase or decrease resulting in expansion or contraction.

The immensity of the natural flows of this renewable resource is obvious [5]. Temperature changes on the globe constitute inexhaustible energy flows. Under the influence of these energy flows, heat transfer occurs from the environment to matter or vice versa depending on the difference in temperature between matter and environment. The heat transfer will force matter to expand and contract periodically. The rate of these processes depends on the environmental temperature ramp, and it is in principle considerably slow but continuous. Not taking into account of expansion and contraction of matter can sometimes result in undesirable consequences. For instance, if railway tracks are laid without any interval between them, the heavy thrust forces that arise by increasing temperature of the rail can lead to curved rails. Heating of a sealed liquid will lead to high pressures, while cooling will result in contraction of the liquid and a high vacuum. Thus, when discussing thermal expansion, one should know about its hazards and the ways to avoid them. Nevertheless, there are plenty of useful applications of thermal expansion and contraction [6]: for solids, bimetallic strips, hot riveting, and tire fitting processes; for liquids, liquid-in-glass thermometer; for gases, dough rising processes, motor engines, and hot air balloons. Here, we offer a new way of using thermal expansion and contraction of matter: production of electrical energy. Our research on obtaining useful energy from thermal expansion and contraction forces started in 2015. The main concept, basics, and capabilities of this form of energy production, and some related work, are discussed in [7]. The patent for the invention of the method of generating electricity from thermal expansion and contraction of matter was registered in May 2018 [8]. The pilot model of the device, which can transform forces arising from temperature changes in a liquid into targeted mechanical motion to produce electricity, is presented in this work. The rest of the paper is organized as follows. Section 2 describes the choice of working liquid. The construction, details, and working principle of the machine are presented in Section 3. Experiments and a discussion of the results are provided in Section 4. Conclusions and future plans are presented in Section 5. Finally, Section 6 gives acknowledgment and the references are listed in Section 7.

II. CHOICE OF WORKING LIQUID

The basic problem of producing energy by natural thermal expansion and contraction is how to transform the relatively slow processes of expansion and contraction of solids and liquids into fast linear or circular motion to generate electricity. The linear expansion of solids, Δl , is proportional to the change in temperature ΔT [9]:

$$\Delta l = \alpha l_0 \Delta T, \quad (1)$$

where α- is the coefficient of linear expansion and l_0 – is the initial length of the material. The volume expansion is

$$\Delta V = \beta V_0 \Delta T, \quad (2)$$

where β - is the coefficient of volume expansion and V_0 – is the initial volume. Experiments and calculations show that $\beta \approx 3\alpha$. Table 1 presents the linear and volume expansion coefficients for some solids and liquids.

Material	Linear expansion coefficient, α $(^0C)^{-1}$	Volume expansion coefficient, β $(^0C)^{-1}$
Solids		
Aluminum	$25{\cdot}10^{-6}$	$75{\cdot}10^{-6}$
Copper	$17{\cdot}10^{-6}$	$50{\cdot}10^{-6}$
Iron or steel	$12{\cdot}10^{-6}$	$35{\cdot}10^{-6}$
Liquids		
Ethyl alcohol		$1100{\cdot}10^{-6}$
Gasoline		$950{\cdot}10^{-6}$
Glycerine		$500{\cdot}10^{-6}$
Water		$210{\cdot}10^{-6}$

Table 1:- The Linear and Volume Expansion Coefficients of Some Materials (T=20 ^{O}c) [9]

In the case of solid materials, high precision hardware is required to catch the fine movements and transform them into fast motion because of the small thermal expansion coefficients. Liquids have some advantages in this respect. There are two factors that are beneficial in liquids: first, as seen from Table 1, the expansion coefficients are several times bigger in liquids than in solids; second, for solids, only linear expansion can be used, whereas for liquids volume expansion can be employed, increasing the effect threefold. For these reasons, a liquid was used in our pilot model. Table 1 shows that ethyl alcohol can give the best results due to having the highest coefficient of thermal expansion, followed by gasoline, glycerin, and water. It is important to comply with the safety conditions when ethyl alcohol or gasoline is used because both are highly flammable. Although glycerin is safer, we decided to start our experiments with water, which has the smallest coefficient of thermal expansion of the liquids listed, for cost, availability, and safety reasons. Another reason for this decision is that if we get the desired results with water, then obtaining better outcomes with the abovementioned liquids is obvious. Note that the anomalous expansion of water [10] will not affect our results because our experiments were carried out at higher temperatures.

III. CONSTRUCTION, DETAILS AND PRINCIPLE OF OPERATION

The function of the pilot model (Fig. 1) is to show whether it is possible to generate energy with slight environmental temperature fluctuations. Because of the availability of details and parts, the pilot model was designed for a small temperature diapason. This diapason can be shifted along the entire temperature span that encompasses changes in temperature from night to day. Shifting can easily be realized by closing the release valve of the filled balloon at a certain temperature, and this temperature will serve as the central point of the temperature diapason observed. The model consists of widely available materials: a 0.065 m^3 volume balloon for car fueling made from iron, a hydraulic cylinder with a 0.04 *m* diameter of the piston, a flexible communication tubing used in farming machine hydraulics, a lever system made from a steel strip, and a clock gearbox with a micro generator from a smart phone. The balloon, the flexible and impermeable communication tubing, and the cylinder are filled with the working fluid, pure water.

Fig.1:- The picture of the pilot model

The scheme of the lever system, which is used as a motion preamplifier, is presented in Fig. 2. The bottom and upper ends of the lever perform a rotational movement, while the piston displaces linearly and, owing to this linear movement, is amplified about 10 times and simultaneously transformed into circular motion.

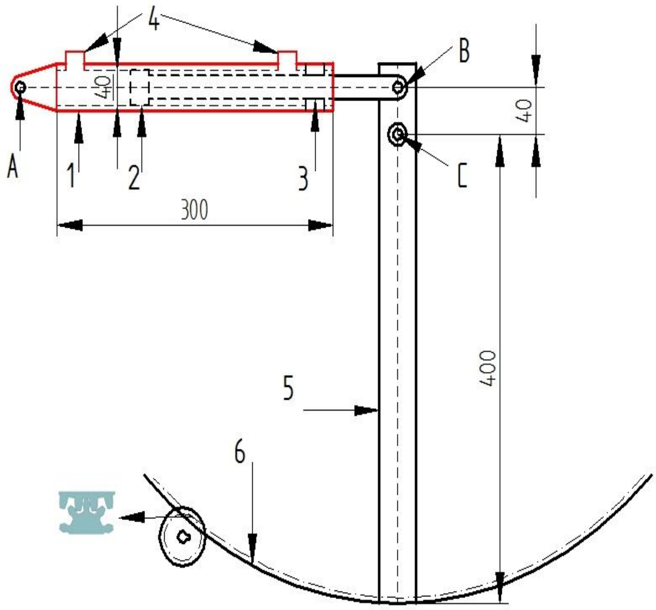

Fig. 2:- The scheme of the motion preamplifier, showing the hydraulic cylinder (1), piston (2), guide ring (3), apertures (4), lever (5), main gear (6), bearing joints (*A* and *C*) fixed to the frame, and the *B*-bearing joint of the piston and the lever.

The body of the hydraulic cylinder (1) is mounted to the frame by a bearing assembly (point *A*), which allows the hydraulic cylinder to turn in a vertical direction and adjust linear movement of the piston into a circular motion of the upper end of the lever (5). Points *B* and *C* are also mounted using the bearing assembly, where the latter is fixed to the frame. The main gear (6), which represents a part of the flat surface of the steel disk with a *0.4 m* outer radius, *0.04 m* width, and *0.005 m* thickness, is welded to the bottom end of the lever (5). Point *B* of the piston performs a rotational motion with a *0.04 m* radius. Accordingly, the main gear (6) rotates with a *0.4 m* radius. The teeth of the worm gear (see Fig.3) are mounted to the outer surface of the disc so as to rotate the leading gear of the clock gearbox. A microgenerator from a smartphone is installed to the clock gearbox using a complementary plastic gear.

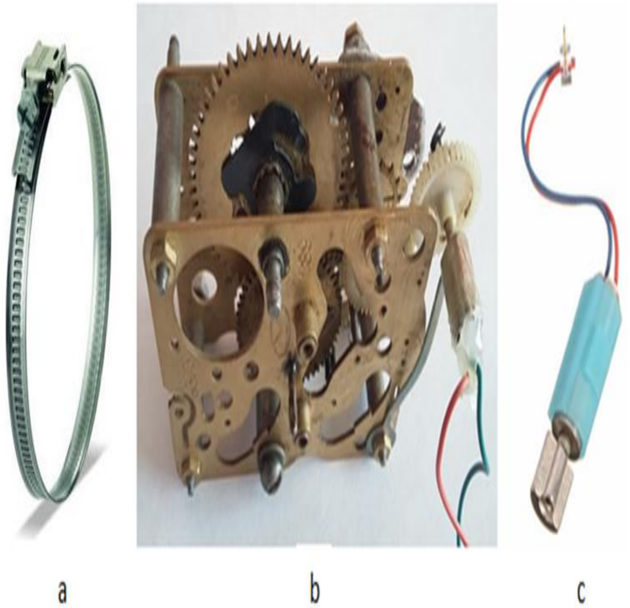

Fig. 3:- The worm gear (a), clock gearbox with mounted microgenerator (b), and microgenerator from a smartphone (c).

The length and configuration of the hydraulic cylinder and lever allow a maximum piston movement of ±0.02 *m*, which corresponds to a turning of the main gear for an angle of about ±15 *grades* from its initial position. Temperature fluctuations of the working fluid of about ±2 °C can provide such a movement. If the temperature of the water in the balloon rises by 1°C, its volume will increase by $1.365{\cdot}10^{-5}\ m^3$ according to equation (2). It is obvious that the volume of the balloon will increase as well. The volume increment of the balloon $\Delta V=2.43{\cdot}10^{-6}\ m^3$ can be calculated using the following expression [9] :

$$\Delta V=3\alpha V_0\Delta T\,, \qquad (3)$$

where $\alpha=1.2{\cdot}10^{-6}/^{o}C$ is the linear thermal expansion coefficient of iron, $V_0=0.065\ m^3$ is the initial volume of the balloon, and $\Delta T=1^{o}C$ is the change in temperature. Subject to this the extra volume of water is $1.131{\cdot}10^{-5}\ m^3$, which will move to the cylinder. Neglecting the insignificant expansion of the cylinder, we can conclude that the piston moves by about 0.009 *m*.

ISSN No:-2456-2165

IV. EXPERIMENTS AND DISCUSSION OF RESULTS

The balloon used in our device was tested with a strength of $300{\cdot}10^5$ *Pa* water pressure. In our experiments, we ensured that the pressure will be not higher than $200{\cdot}10^5 Pa$. Impermeable filling is a very important procedure. The presence of air in the balloon can affect the movement of the piston due to its compressibility. The balloon, cylinder, and flexible communication tube were separately filled with water and then connected together to avoid air in the system. The experiments were undertaken in three steps. The first task was to show whether the device can convert the thermal expansion and contraction energy of the liquid into any work. A small plastic propeller was mounted to the output gear to demonstrate this effect (Fig. 4). The device was adjusted and put in direct sunlight, and the experiment started. After some time, with the increasing temperature of the air and the working liquid, the piston began to move the load (the lever system, clock gear with the propeller) slightly, and the propeller started to rotate. The angular velocity of the output gear and consequently that of the propeller increased gradually with time, and the motion was performed within enough long time until the temperature of the working liquid ceased to rise. After that, in order to speed up the process of cooling the working liquid in the balloon, the device was moved into the shade, and the balloon was swilled out with cool water. It was expected that the piston would start to move in a backward direction. The weak force to move the lever in the reverse direction was observed with the decrease in temperature of the working liquid, but it was not strong enough to rotate the leading clock gear backward. When the piston was unloaded, it easily moved back to the initial position.

Fig. 4:- The small plastic propeller mounted to the output gear

In the next experiment, a microgenerator from a smartphone was installed to the clock gear instead of the propeller in order to show that electricity can be produced. Good repeatability of results was observed with temperature changes. The output voltage of the microgenerator was about 2 *mV*. The movement of the piston was sometimes interrupted because of its friction with the inner surface of the cylinder. The pressure of the water in the balloon was not higher than $2{\cdot}10^5 Pa$ during all the experiments, and it was enough to move the piston with the above mentioned load.

Finally, the movement of the piston versus the air and balloon temperatures was analyzed. These parameters were measured continuously for more than 7 hours. The results are presented in Fig.5. Straightforward measurement of the temperature of the working liquid will require a built-in thermometer inside the balloon. In our experiment, we measured only the air temperature and the temperature of the surface of the balloon. The device is ready for the experiment when, after being filled with water, the output valve is closed. The experiment started at about 9:30 on the morning of May 20, 2018. Within the first 2.5 hours, the air temperature rose from *23.7 ºC* to *28.3 ºC*, and the total change in temperature was *4.6 ºC*. The balloon surface temperature rose from *25.4 ºC* to *31.5 ºC*, and the total change was *6.1 ºC* within the same time period. For the next 1.5 hours, the air temperature fell until *25 ºC* and the balloon's surface temperature fell until *26.1 ºC*. Sharp changes in temperature were not observed for the next 3.5 hours, and both the temperature of the air and the temperature of the balloon's surface were almost equal to about *26 ºC*.

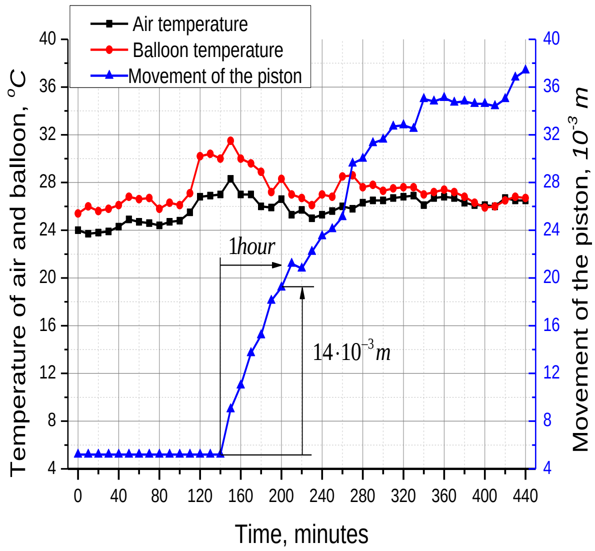

Fig. 5:- Changes in air and balloon temperature and movement of the piston.

The piston was not moved at the beginning of the experiment. The temperature of the air and the balloon were increasing, but the piston was motionless. Only after 2.5 hours, at a temperature of the balloon of *31.5 ºC*, it started to move with a slow speed and continued moving for the next 5 hours. The clock gear started to rotate, and electrical energy was produced. The maximal traveled distance of the piston was $3.74{\cdot}10^{-2}$ *m* within 7 hours and 20 minutes. The volume of the working liquid continued expanding, and the process could last even longer. But as mentioned above, the construction of the pilot model cannot afford to move the piston anymore. Such a small diapason design was predicted mainly by the diameter of the piston we used. If we used a hydraulic cylinder with a small inner diameter, it would allow the piston to move over a longer distance, and we can avoid the lever system and some energy loss.

The reason that the piston stayed motionless for 2.5 hours after the experiment was started is simple. The force that will move the piston should reach a certain value to overcome the breakaway force [11]. The piston, as well as the lever and the clock gearbox including the microgenerator, have their own friction. According to [9], the propulsive force is proportional to the pressure and the area of the piston. In turn, the pressure depends on the temperature of the working liquid. Thus, the temperature and consequently the pressure increased gradually until the force was enough to move the piston when the balloon temperature reached $31.5\ ^oC$. At that moment, the force peaked and soon remained constant. After that, the piston starts a steady motion, and the pressure should not change because the excess of the pressure will be compensated by the increasing volume of the working liquid.

It was observed that the piston movement was accompanied by short stops. The stop durations were 2-5 seconds, and the stop frequency was 5-6 times per hour. We suggest that the jerk [12] is responsible for this phenomenon. The roughness of the inner surface of the cylinder and the side surface of the piston can cause stick-slip. The smooth motion of the piston can be provided by using a proper cylinder that is designed for the water environment.

As observed in all experiments, the piston moves in a forward direction, displacing the lever and rotating the propeller or the shaft of the microgenerator with raising of the temperature by the expansion of the working liquid. The piston is pushed forward until the temperature of the working liquid reaches its maximum. It stops when the temperature gets the maximum value and the process of expansion ceases. After that, when the temperature of the working liquid starts to decrease, the liquid begins to contract, and a vacuum arises in the closed balloon. As a result of this vacuum, the piston should be pulled and moved in a backward direction. However, it was found that the pulling force is small compared with the pushing force, so the piston was not able to move the lever and rotate the propeller or the shaft of the microgenerator. When the load was removed, the piston could easily displace the lever in a backward direction.

In our opinion, the phenomenon described above can be explained by intermolecular forces. One knows that the process of thermal expansion of matter causes the distance between molecules to increase because of the excess of kinetic energy. The kinetic energy decreases during cooling, as does the distance between the molecules. The molecular attractive forces are different in liquids and solids. As stated in [13], the attractive forces in liquids are not strong enough to keep neighboring molecules in a fixed position, whereas in solids the intermolecular forces between neighboring molecules are strong enough to keep them locked in position. In our experiment, when the balloon is cooling, the temperature of water decreases, and a vacuum arises. But this vacuum is not powerful enough to pull the loaded piston because of weak attractive forces of the water molecules. Thus, the pilot model produces electricity during the expansion of the working liquid and returns to its initial position in a no-loaded way during the cooling of the liquid. If the initial volume of the working liquid increases several times, an infinite number of the water molecules will contract at the same time during cooling, and the collective vacuum can be enough to pull the loaded piston, albeit with less force compared with the pushing force.

Using approximate calculations allows us to evaluate the amount of energy produced by the device in real time. Considering a small energy loss, it can be assumed that the energy generated in the piston-cylinder system is equal to the energy obtained in the microgenerator in accordance with the law of conservation of energy. The piston moves and performs some work due to the expansion of the working liquid at constant pressure with increasing temperature. The expansion work W or energy change ΔE in a hydraulic system is [14]

$$W=\Delta E=P_\alpha \Delta V, \quad (4)$$

where $P_\alpha=2\cdot 10^5\ Pa$ is the pressure and ΔV is the volume expansion. The latter $\Delta V=1.759\cdot 10^{-5}\ m^3$ is defined for one hour from the time that the piston started to move:

$$\Delta V=\pi r^2\cdot L, \quad (5)$$

where $r=0.02\ m$ is the inner radius of the cylinder and $L=14\cdot 10^{-3}\ m$ is the distance travelled by the piston for one hour (see Figure 5). So, the work done for one hour is $W=3.518\ J$. The energy produced is $E=3.518\ Wh$. This is a small amount. But if we take into account that the device can support a pressure of $P_\alpha=200\cdot 10^5\ Pa$, it is able to produce100 times more energy. Table 2 presents the maximal energy produced by the pilot model for 1 hour evaluated using equation (4) for the above mentioned working liquids at a pressure of $200\cdot 10^5\ Pa$ if the temperature increases by 1 ºC. Note that friction and other losses are not taken into account and that ΔV is calculated using equation (2).

Working liquids	$\Delta V,\ m^3$	Energy, *Wh*
Water	$13.65\cdot 10^{-6}$	273
Glycerine	$32.5\cdot 10^{-6}$	650
Gasoline	$61.75\cdot 10^{-6}$	1235
Ethyl alcohol	$71.5\cdot 10^{-6}$	1430

Table 2:- Expected maximal work for one hour of the device at a pressure of $200\cdot 10^5$ *pascals* and if the temperature increases by 1 ºC for one hour

According to equation (4), the power of the device depends on the pressure and the change in volume. The higher the pressure and change in volume, the higher the power. The pressure can be increased until the value that can be supported by the balloon. The change in volume depends on the thermal expansion coefficient of the working liquid, its initial volume, and the rate at which the environmental temperature changes.

V. CONCLUSIONS AND FUTUTE WORK

An alternative renewable resource is presented. The offered method, which is based on using thermal expansion and contraction forces to generate electrical energy, is attractive because of the primitive construction of the device, the small number of elements and moving parts, and the possibilities to increase the power. The applied solution of transforming the slow thermal expansion and contraction processes into a powerful rotational motion is simple. Good repeatability of the results with increasing environmental temperatures proves the reliability of the device. The thermal expansion coefficient of the working liquid plays an important role. A higher coefficient of thermal expansion means that the necessary power and acting force can be obtained at lower pressures. So, using ethyl alcohol instead of water increases the power by almost 5 times. Including the solid working parts and developing the construction, it is possible to create a device that can operate in full power during both expansion and contraction of matters.

Using a solid material's thermal expansion and contraction requires efficient and high-ratio gears to amplify the slow thermal processes into rapid circular motion. However, supporting high pressures (respectively high powers) in small volumes is not a problem for today's technology. A relatively small device would be good enough to meet the needs of a family. On the other hand, a device designed with a sufficiently large volume of the working liquid that can withstand high pressures can provide small and middle farms in remote communities with electricity.

Future plans include developing a high-ratio gear system; improving the device and launching a commercial version for a larger diapason of temperature; performing experiments with pure water, glycerin, gasoline, and ethyl alcohol; and calculating the energy losses in the cylinder piston system, gear drive, and generator and evaluating the efficiency.

The research did not receive any specific grant from funding agencies in the public, commercial, or non-profit sectors.

ACKNOWLEDGMENT

The authors gratefully acknowledge Ms. Murodova Umida Abdulnabievna, English teacher at the Academic Lyceum of Jizzakh Polytechnic Institute, for her contribution to improving the English of the paper.

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