



The energy harvesting from waste heat

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ABSTRACT

The article focuses on the use of thermoelectrics for the energy harvesting from waste heat. There were discussed the thermoelectric effects and the solutions of converting the waste heat into electricity were shown. The application and operation of thermoelectrics for heat recovery from cars, the cogeneration of heat for home and in wristwatches were presented. An analysis of the possibilities of using Peltier cells in municipal and long-distance transport was conducted. The aim of the study was to evaluate the possibility of reducing fuel costs by obtaining electricity from the Peltier cells instead of the alternator. The efficiency tests of operation the Peltier cells were carried out. On their basis was possible to determine the amount of recovered energy thanks to their use. On the basis of calculations it was concluded that at the current price of unit cell, the use of this solution is not fully economically justifiable. However, there are possible solutions that could increase the efficiency of the cell. The advantages of using cells is reducing the vehicle engine wear and emission of harmful substances into the environment. It was found that most justifiable is the mounting of cells in vehicles equipped with multiple electrical receivers with low efficiency of the engine. It was indicated that more and more new thermoelectric materials that provide efficient and cheap energy harvesting on a large scale are looking for. In Google Patents and Espacenet are posted many solutions of waste heat recovery, which indicates that this field is constantly evolving.

Keywords: waste heat harvesting, thermoelectric effect, thermoelectric generators, a Peltier cell

1. INTRODUCTION

There are many ways of waste energy management. One technology with great potential is the method of heat recovery using thermoelectric effect. Thermoelectric effect is the result of direct transformation of electric voltage occurring between two points of the system on the difference of temperatures between these two points or the temperature difference on the voltage. This phenomenon is used to:

- heating,
- cooling,
- temperature measurement.

Because electrical voltage is easy to operate and can be accurately record, the devices using thermoelectric effect allow on very precise temperature control and automation of processes of cooling and heating.

Depending on the direction of transformation thermoelectric effects are divided into:

- Seebeck effect,
- Peltier effect,
- Thomson phenomenon,
- Joule effect.

2. THERMOELECTRIC PHOENOMENONS

2. 1. SEEBECK EFFECT

Seebeck Effect (the thermovoltaic phenomenon) is one of the thermoelectric effects, consisting on the electromotive force formation called thermoelectric power in a circuit composed of two different materials, which contacts have different temperatures. It is the result of contact dependence of potentials differences between the materials from the temperature. A contact voltage is created by diffusion through the contact surface of electrons from one material to another. As a result, at the contact surface of the material having a lower concentration of electrons their excess creates and on the opposite side of the pin in the second material their scarcity creates. The difference is even greater when the higher is temperature of joint, because then the diffusion of electrons across the joint is stronger. The greater is the temperature difference of joints, the greater is the thermoelectric power. Seebeck noted, connecting the two conductors of different materials in the closed circuit and heating one of the splices, that tilting of the compass needle is the result of its magnetic field, which arises due to temperature difference of splices, so that the observed phenomenon is the thermal magnetic phenomenon. He examined this phenomenon for couples combinations of many materials, finding even the couples, that allowed to use this phenomenon to generate electricity with a capacity up to about 3%. The dependences described by Seebeck shows a formula:

$$V = (S_B - S_A) \cdot (T_2 - T_1) \quad (1)$$

where:

S_A and S_B - Seebeck coefficients characteristic for a given material,

T1 and T2 - temperature of conductors.

2. 2. THOMSON PHENOMENON

Thomson phenomenon consists on separation or absorption of heat at the flow of electrical current through the uniform conductor over its entire length if there is a difference of temperatures between its ends. The phenomenon describes the relation:

$$Q = \tau \cdot I \cdot \Delta T \quad (2)$$

where:

τ - Thomson coefficient.

It occurs when the electrons pass through the one irregularly heated conductive material. The effect shows that the electrons can move even in one and the same material (with a temperature gradient). Thomson effect also works in reverse way, when conducting a current through the material causes the formation of a temperature gradient. When the current flow follows in opposite direction to the temperature gradient, the absorption of heat occurs, while in the same direction its secreting.

2. 3. PELTIER EFFECT

The Peltier phenomenon is one of the thermoelectric phenomena occur in solids, consisting of secretion or energy absorption by a flow of electric current through the connector. As a result of energy absorption on a one connector and secretion of energy on the other, the temperature difference between the connectors develops. This phenomenon is opposite to the Seebeck effect, but does not depend on the size and shape of the connector. The Peltier effect takes place on the border of two different conductors or semiconductors (NIP) joined by two connectors (Peltier connector). When the current flow one of the connectors is heated and the other cooled. The joint in which electrons pass the conductor of a lower Fermi level to the conductor with a higher level becomes cool. After changing the direction of current flow on the opposite a phenomenon beforehand is reversed (because of the symmetry of the joints). The amount of heat generated Q is proportional to the value of the current of a magnitude and passing through the system and to the values of the Peltier connector Π depending on temperature. It describes the relationship:

$$\Pi_{AB} = \Pi_A + \Pi_B \quad (3)$$

$$Q = \Pi_{AB} \cdot I \quad (4)$$

Absorption or heat generation depends on the direction of current flow through the connector and the Peltier coefficient of materials A and B. The Peltier effect is the consequence of the change of carriers entropy of electric charges flowing through the connector.

2. 4. JOULE EFFECT

The Joule effect allows to determine the amount of heat that is released during the flow of electric current through the electrical conductor. This relationship may be expressed

by the formula:

$$Q = R \cdot I^2 \cdot t \quad (5)$$

where:

Q- the amount of heat generated,

I - the amperage,

R - electrical resistance of the conductor,

t - time current flow.

Dependence expresses the principle of conservation of energy for current flow and means that the energy of current changes on the internal energy of the system. This phenomenon is irreversible, that is, conversion of electric energy into heat takes place in just one direction.

Using the above phenomena allows for direct conversion of thermal energy into electrical energy and vice versa, ie. on the "pumping" the heat using electricity. In the following section the solutions of conversion the waste heat into electricity were discussed. The oldest solution of transformation the waste heat into electricity is a Peltier element. Currently we are looking for alternative solutions which constitute the liquid, organic cells and polymers.

2. 5. PELTIER CELL

Thermoelectric generator (Peltier element) is a device in which thermoelectric effects (thermoelectric power generation) are used for the direct conversion of heat into electricity. Unlike the traditional dynamic thermal engine, thermoelectric generators contain no moving parts and they are completely muted. The main part of the generator is a thermoelement (or thermocouple) formed of a pair of distinct conductors (in the initially constructed generators) or a semiconductor n-p (in the currently constructed generators) with a conductivity of electron n and hole p, where the temperature of the hot and cold junction are different (Pasek 2006, Langman et al. 2007).

These generators are used reliably for over 30 years to power satellites and space probes like Voyager. They have been used in medicine, eg. in heart pacemakers. Also they play an important role in the military to power radio stations, radio sets, buoys, lighthouses. They are a lower yield in comparison to large, conventional heat engines. However, for smaller applications they can become competitive because they are compact, simple, inexpensive and scalable.

Thermoelectric systems can be designed to exploitation low heat source with a small temperature difference. Small generators can be mass-produced for heat recovery from the automotive industry or home in the cogeneration of heat and electricity. The invention utilizing thermoelectrics are the wristwatches which are powered by the warmth of the human body (Snyder 2008, Królicka et al. 2012). With other applications can mention the bracelet supplying the mobile phones, mp3 players or thermoelectric clothing (Królicka et al. 2012).

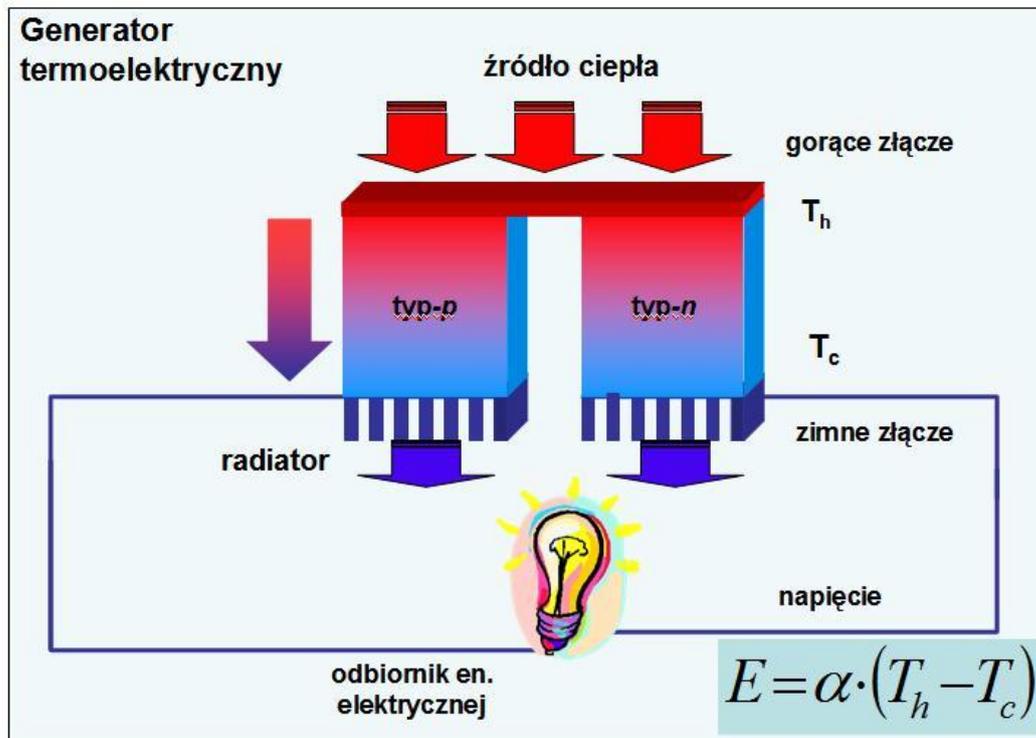


Figure 1. Thermoelectric generator.

The Peltier cell is a semiconductor element, which is constructed of two thin ceramic tiles between which are serially arranged semiconductors of bismuth telluride doped appropriately with antimony and selenium. On each tile are separate copper tracks between which semiconductors are arranged. To draw current from the cells, it is necessary to have an electric cable attached to semiconductors. The cell uses the Peltier effect, which consists in separation or energy absorption (depending on the side of the device) by a flow of electric current through the connector. As a result of energy absorption on one connector and power secreted on the other develops a temperature difference between terminals. The situation can also be reversed and instead to connecting to cell, the electric current for cooling one and warming another its part, you can put the cell between temperature differences in order to obtain an electric current, the cell can be put between temperature differences in order to obtain an electric current. With such an operation can be obtained the Seebeck thermoelectric phenomenon involving on the formation of electromotive force in a circuit (which contains two metals or semiconductors) when the connectors are located at different temperatures. The Peltier element is a thermal machine, which can act as an engine, refrigerator and heat pump. It is a small element containing any moving parts in contrast to conventional thermal machines. The work is here the work of electrical current equal the product of voltage, current and time. The efficiency of a Peltier element remains significantly lower than the limit, so the research work are conducted continuously in order to lift it. The materials for building the Peltier cells having both high value of Peltier coefficient, low resistivity ρ and a low coefficient of thermal conductivity K are looked for.



Rys. 1. Budowa i zasada działania modułu Peltiera

Figure 2. The construction of Peltier cell

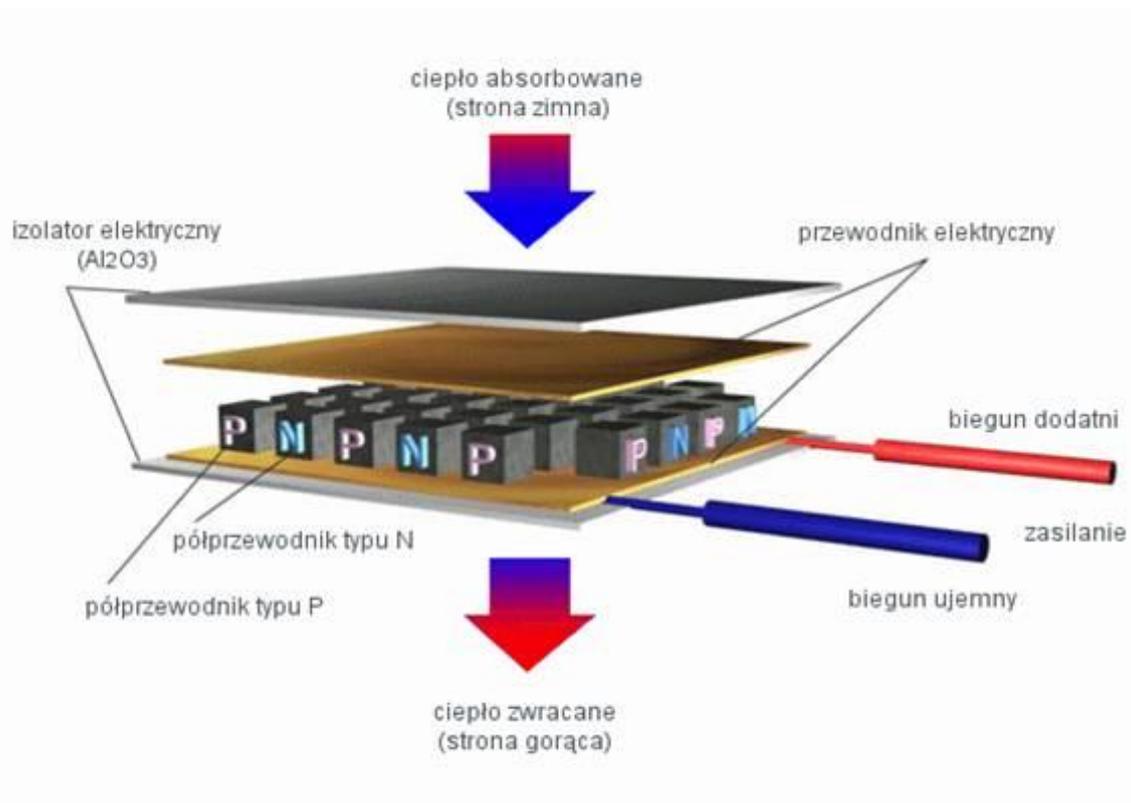


Figure 3. The principle of operation of Peltier cells

Thermoelectric produces electricity as a result of the heat flow across a temperature gradient. The resulting voltage is proportional to the temperature difference and Seebeck coefficient. By connecting the conducting electron (n-type) and the conducting hole (p-type)

of material in a number, the net voltage which can be driven by the load is generated. Good thermoelectric material has a Seebeck coefficient between of 100 mV / K and 300 mV / K. To achieve a few volts voltage in a charge the many thermoelectric couples must connect in series to form a thermoelectric device (Snyder 2008). Thermoelectric devices with dimensions about 1mm³ in the form of thin films converting heat energy can produce powers exceeding 775 $\mu\text{W}/\text{mm}^3$ at a temperature difference of 9K. The most modern thermoelectric modules using thin-film technologies are available in sizes less than 1mm³. It is expected that the thin films of thermoelectrics of sizes 1 mm³ and a temperature difference of 1K will be able to produce powers about values of more than 100 $\mu\text{W}/\text{mm}^3$ (Królicka et al. 2012).

For a broad application of electricity generation the traditional dynamic thermal methods (Rankin, Brayton or Stirling) have several times more efficiency than thermoelectric systems. The internal combustion engines are cost-effective and efficient in the the power range from 100 W to 100 kW, but they have a tendency to be noisy. However, they are expensive and it is not easily to resize them for small applications. So, for applications requiring power below 100W, the scalability of thermoelectrics gives them an advantage over conventional thermal methods (Snyder 2008).

More often thermogenerators are used to generate energy from waste heat in vehicles (Martins et al. 2015, Bass et al. 1994, Matsubara 2002), ships, for recovery in exploited heat in steel mills, refineries, cement plants and for conversion of heat coming from natural sources (generators of solar and geothermal energy, waste incinerators). In view with the directives issued in 2009 by the European Parliament, connecting with tightening the requirements for CO₂ emission in passenger cars in the future, currently all the leading automobile companies conduct the programs connecting with conversion of the recovered heat into electricity (Królicka et al. 2012). Cars have limited efficiency about 20%. 1/3 of the power generated is wasted through the exhaust, and another 1/3 by the heat sink. But the exhaust system has a higher temperature, making it more suitable for thermoelectric applications (Snyder 2008). With a capacity of about 1 kW, even relatively inefficient thermoelectrics can be used for acquiring waste heat from car exhaust. Thermoelectric generator will extract waste heat from exhaust gases that allows to recharge the battery. The engine load is then reduced, which increases fuel efficiency even up to 10% (Snyder 2008). Scientists from the AGH created a prototype of the thermoelectric generator which using a car exhaust heat can generate electricity with a power of 200 W (Królicka et al. 2012). In (Chmielewski) demonstrated that, thermoelectric generators are outstandingly suitable as components of passive energy recovery irretrievably dissipative in the exhaust system of the internal combustion engine. Their use in a flue gas exhaust system requires the surface preparation, which must be flat (most vehicles on the road is equipped with exhaust systems of circular cross section), suitably cleaned from contaminants. In addition the tests of increased number of generators were performed. It has been found that thermoelectric generators should be mounted in packages, combining them in series and parallel (Chmielewski).

In the project "Swiss roll" the catalytic combustion is located in a small area in order to maintain the high temperature of the source, while the exhaust is routed through a counter-flow heat exchanger to heat the coming gases. Thermal efficiency of such combustion chambers may reach 80-95%. The way to achieve high efficiency of such a device is the use of the fuel cell just prior to catalytic combustion. Single-chamber fuel cell produces electricity when it is placed in a hot air-fuel mixture. Unreacted fuel can be subsequently incinerated by

the catalyst and used by thermoelectric (Snyder 2008).

Great potential using of waste heat gives cogeneration of energy. It is a technological process simultaneous production of electricity and useful heat. Due to lower fuel consumption, the use of cogeneration gives great economic savings and is beneficial in ecological terms. In the cogeneration of electricity and heat, electricity is produced with almost 100% efficiency, because the remaining energy is used for heating. It seems preferable to use thermoelectrics in cogeneration for home, due to quieten, no vibration and no maintenance. Cogeneration of electricity in homes and recovery of waste heat from cars are two examples where "small" systems could have an impact on global energy consumption if they are implemented on a large scale (Snyder 2008).

Thermoelectrics enable the collection of a very small amount of heat for low-power applications such as wireless sensor networks, mobile devices and for medical applications because they are smaller and lighter than conventional batteries. An example of the thermoelectric energy generation is a wristwatch. The watch is powered by body heat converted into electricity by thermoelectric. Under normal operating conditions using thermoelectric modules the watch generates 22 μ W of electricity with only 1.5K temperature drops. The use thermoelectrics is justified here, because the production costs of these devices fall in series production, and in the view of the increasing demand for remote power sources, such the real applications will undoubtedly arise (Snyder 2008).

In study [9,10] the use of the thermoelectric generator for converting thermal energy of the human body into electricity were discussed. The proposed thermoelectric generator composed of polydimethylsiloxane (PDMS), substrate and thermocouple. The use of PDMS ensured the flexibility of the thermoelectric generator and a low thermal conductivity which helps to minimize heat losses flowing through the thermocouple. Thermoelectric generator was attached to the human body, generating electricity of 50 NW, when the temperature difference between the human body and the environment was 7 °C (Jo, et al. 2012, Mahalakshmi et al. 2014).

3. THE POSSIBILITY OF USING PELTIER CELLS IN MUNICIPAL AND LONG-DISTANCE TRANSPORT

The research on the possibilities of mounting Peltier cells in the municipal and long-distance transport services were conducted. The aim of the study was to evaluate the possibility of reducing fuel costs by obtaining electricity from the Peltier cells instead of the alternator. The following devices were used in the research:

- exhaust simulator (ejector, radiator, Peltier cells, water temperature and gas sensors in the pipe),
- electric pump with a power of 50W,
- oscilloscope with instrumentation,
- adjustable heat source (heat gun for wood with a power of 1000W).

The tests of operation efficiency of Peltier cells were conducted on the basis of which it was possible to determine the amount of recovered energy through their use. Measurements were performed at room temperature (about 20 °C). It begins after running the heater and setting the temperature on 100 °C. After 20 min, a first measurement result were obtained

with the following parameters:

- temperature of simulator pipe,
- temperature of the water (liquid),
- the voltage of the cell 1 and 2.

Then, the temperature was increased of 20 °C and after 5 minutes above parameters were recorded again. Studies a cell efficiency was conducted for the following temperatures: 100 °C, 120 °C, 140 °C, 160 °C, 180 °C and 200 °C. Subsequent measurements were started when the indicators of water temperature and gas in the exhaust pipe simulator were fallen to initial values and were close to room temperature (+/- 5 °C). All data on the basis of which the experience was made has been read from the oscilloscope. Averaged data reading during the measurements are given in Table 1.

Table 1. The average results of the measurements [Own study].

Temperature set on the heat gun [°C]	Pipe temperature reading from the oscilloscope [°C]	The water temperature reading from the oscilloscope [°C]	Pipe temperature [°C]	Water temperature [°C]	Temperature differences on the oscilloscope	Cell voltage [V]	Resistance [Ω]	Quantity of water received [W]
120	90,2	20,4	43,3	9,79	33,5	1,2	3,55	0,4
140	102	21,2	48,96	10,18	38,78	1,4	3,55	0,55
160	112,4	22	53,95	10,56	43,39	1,58	3,55	0,7
180	120,4	22,2	57,79	10,66	47,14	1,78	3,55	0,89
200	138	25,6	66,24	12,29	53,95	1,98	3,55	1,1
220	145,4	28,4	69,79	13,63	56,16	2,19	3,55	1,35

In Table 1 the temperature difference at the cell were calculated based on the temperature differences of the pipe and water. Data concerning the cell voltage were read from the oscilloscope. It also contains a resistance obtained from the cell energy. In Table 1 is presented the amount of power produced by the cell, which is dependent on the size of temperature variation. The more is the temperature difference between the parties of cells, they produce more electricity.

Heat Gun at temperature of about 200 °C has used less than 50% of its power (the

maximum temperature that the device can achieve is 600 °C). On each of the walls of the simulator exhaust accounted for less than 125W. The efficiency of one cell is thus approximately 5%. It is also worth to pay attention to the fact of insufficient energy recovery. Although the warm air in the simulator pipe had a maximum temperature of about 220 °C, in reality the same temperature of exhaust simulator have never exceeded 70 °C. Installation of cells directly on the exhaust is hardly effective due to the fact that the tiles located closer to the heat source will produce significantly more energy than those located further away, because there is much cooler. Another problem is the uneven distribution of heat on the cell. This causes that in fact most of the current produce the center of a tile and its side portions much less. This phenomenon is shown in Fig. 4. The color red indicates the places where is the most heat.

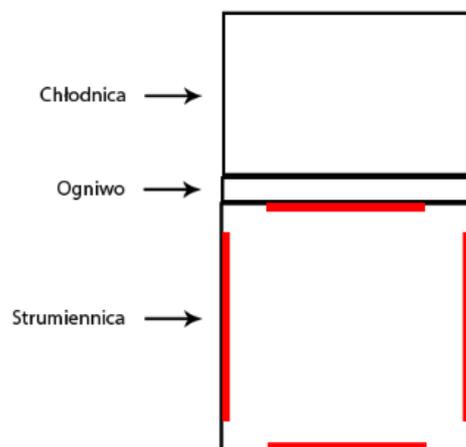


Figure 4. Distribution of heat inside the exhaust simulator - cross section (own work)

Specification of the cell operation comes down for application it in a place where there is a large temperature range. In vehicles with internal combustion engine it can therefore be mounted for example near the following places:

- exhaust system,
- cooling system,
- engine.

For the needs of study, as exemplary vehicles, in which is possible to mount the cell, the city bus and long-distance bus were selected, and a vehicle exhaust system was selected as a place of assembly. The data of the quantity of power absorbed by the receivers, the amount of power produced by the cell and data of engine and alternator efficiency of vehicle were needed to simulate the assembly of the cell. There was simulated the installation of cells recovering heat energy in the city bus Volvo 7000K and long-distance bus Van Hool Altano TDX27.

3. 1. CALCULATION OF ENGINE EFFICIENCY OF 7000K CITY BUS VOLVO

To achieve the necessary information about engine efficiency first it was calculated the angular velocity of the engine crankshaft given by formula:

$$\omega_s = i_c \cdot V/r_d \quad (6)$$

where:

i_c - overall gear ratio drivetrain = 6.2, adopted on the basis of the vehicle's technical data,
 V - speed bus during transport = 12 m/s. It was assumed that the average speed of the bus in motion in the city is not more than 43 km/h,

r_d - dynamic radius of the wheel tires = 0.43, which was adopted on the basis of the vehicle's technical data.

Then were made the calculation of effective power engine from the relationship:

$$M_e = P_e \cdot V_{ss} / \pi \cdot \tau \quad (7)$$

where:

P_e - the average effective pressure engine = 700000Pa adopted on the basis of the vehicle's technical data,

V_{ss} - cubic capacity of engine = 0.007284 m³, which was adopted on the basis of the vehicle's technical data,

τ - the number of thrust of piston per one operating circuit = 8, adopted on the basis of the vehicle's technical data.

The effective power of engine was calculated from the formula:

$$N_e = M_e \cdot \omega_s \quad (8)$$

where:

M_e - power output of the engine [Nm],

ω_s - angular velocity of the engine crankshaft.

Subsequently, the temporal fuel consumption of the vehicle was calculated from the relation:

$$G_e = G/3600 \quad (9)$$

where:

G_e - temporal fuel consumption,

N_e - power output of the engine.

Finally, the required engine efficiency was calculated from the formula:

$$\eta_e = \gamma_{on} / g_e \cdot W_d \quad (10)$$

For the selected model Volvo 700 k, the following data should be substituted to the formula:

γ_{on} - density of diesel oil = 0.84 g / cm³;
 W_d - calorific value of diesel oil = 43000 J / cm³,
 g_e - unit fuel consumption.

3. 2. CALCULATION OF THE AMOUNT OF SAVING FUEL FOR THE CITY BUS VOLVO 7000K

It was assumed that the bus during the work consumes about 1385 W which covers:

- Low beam front - 2*55W,
- Low beam - rear 2*10W,
- Brake lights - 4*40W,
- Lighting registration – 2*5W,
- Indoor lighting – 16*30W,
- The injection system – 50W,
- Car radio and a radio for communication with the dispatcher – 300W,
- The monitoring system – 100W,
- Monitor – 50W,
- The locator – 5W,
- Displays a "Pixel" type - 100 W.

The above data shows that to supply the entire bus it would be necessary to use about 2100 units of cells with a total weight of about 42 kg. In the case of retail prices of the cell of amounting about 20 PLN, the cost of cells would be around 41 140 PLN. To calculate the quantity of saved fuel by the vehicle it was assumed that the efficiency of the alternator in a vehicle is 95%. For the calculation of amount of fuel which is needed to produce a power of 1385 W, the following formula defining the actual amount of energy needed to produce was used:

$$E_{zs} = E_{po} / n_e \quad (11)$$

where:

E_{po} - the energy that the engine has produce = 1385W, which was adopted on the basis of the sum of the energies of all the receivers necessary for the operation of the bus,
 n_e - the engine efficiency.

On the basis of calculations the actual amount of energy needed to produce power of 1385 W was amounted to 3551,28 W.

Subsequently, the additional energy losses connected with the efficiency of the alternator was calculated from the relationship:

$$E_{zo} = E_{zs} / n_o \quad (12)$$

where:

E_{zs} - actual energy, which must be obtained,
 n_o - the efficiency of alternator, adopted on the basis of the vehicle's technical data.

After substituting the data into the formula a value of 3738,19W was obtained. Thus to receive a power of 1385 W, the engine with the alternator needs a capacity of about 3738,19 W. The hourly fuel consumption of the engine was calculated by the following formula:

$$E_{zah} = E_{zo} \cdot 3600 \quad (13)$$

Obtained value amounted 13,457,489.88 J.

Thus if the vehicle's engine will run under a load of all electrical appliances for an hour, it will consume about 13,45 MJ of fuel. A liter of diesel fuel has a calorific value of around 43 MJ. So the engine consumes about 312,79 ml of fuel only for the vehicle lighting within an hour. Assuming that the vehicle will travel around the city with an average speed of 35 km/h, it will consume about 8,9 ml of fuel for 1 km.

3. 3. CALCULATION OF THE CELL INSTALLING COSTS FOR THE CITY BUS VOLVO 7000K

The annual cost of fuel needed to power all electrical devices in the city bus during working days was calculated based on the formula:

$$K_a = s \cdot n_d \cdot k_p \cdot t_r \quad (14)$$

where:

s - combustion for 1 km, which is needed to achieve the necessary amount of electricity = 0,00894.

n_d - the average daily number of kilometers driven = 248,

k_p - the price of fuel,

t_r - working days.

Annual fuel cost amounted 2882,85 PLN for working days and 1366,09 PLN for free days, which gives a total cost equal to 4248,94 PLN. So, assuming that the bus would move without any major malfunctions in the year, the MPK of Wroclaw could save about 4249 PLN. If each of the buses Volvo 7000 would have mounted the cells during production and would travel a similar number of kilometers, these investment would return in about 10 years and at the end of 2015 the carrier would achieved already a profit of about 5599 PLN, which after multiplication by the number of buses (10 pieces) gives a sum of about 55 999 PLN.

3. 4. CALCULATIONS FOR LONG-DISTANCE BUS VAN HOOL ALTANO TDX27

Analogous calculations were made for the long-distance bus. It differs from the urban bus in terms of installed electrical power receivers. It has been assumed that the long-distance bus during the work consumes power of about 1815 W. The specified list of electrical devices (given below), among which there are also energy used by passengers. It is the power, which is taken from the electrical outlets under the seats. It was calculated based on the average power consumption equal to 50 W for 20% of the average number of passengers of the carrier (25 people). The efficiency of the electrical converter is omitted. List of electrical power receivers in the long-distance bus is as follows:

- Low beam - front 2*55 W,
- Low beam - rear 2*10 W,
- Brake - 4*40 W,
- Lighting registration – 2*5 W,
- Indoor lighting – 25*30 W,
- The injection system – 50 W,
- Car radio and sound system – 400 W,
- The monitoring system - 100 W,
- The locator – 5 W,
- Displays type of Pixel" - 20 W,
- The power used by passengers - 5*50 W = 250 W,
- Router with Wi-Fi - 20 W.

Assuming that two cells allow to produce about 1,35 W of power. To power the entire bus is necessary to use about 2689 units of cells with a total weight of more than 53kg. In the case of retail prices cells about 20 PLN, the cost of cells would be around 53778 PLN. To calculate saved fuel by the vehicle, it was assumed that the efficiency of the alternator in a vehicle is 95%. It has been calculated that if the vehicle's engine will run under a load of all of the electrical appliances for one hour, it will consume approximately 13,75 MJ. A liter of diesel fuel has a calorific value of around 43 MJ. So the engine consumes about 319,90 ml of fuel for vehicle lighting only within an hour. Assuming that the vehicle will travel along the route at an average speed of 70 km/h, the 1 km you it will burn about 4,57 ml of fuel for 1 km. If the bus would move without any major failures in the within a year, thanks to the use of cells, the carrier could save about 5028 PLN. In order the cost of cells could return, the bus should drive in the company's fleet of the similar annual mileage of kilometers for about 11 years.

4. CONCLUSIONS

Based on the analysis of the possibility of using the Peltier cells in buses it can be concluded that at the current price of one unit of the cell, the use of this solution is not fully economically justified. However, there are possible solutions that could increase the efficiency of the cell. For example a water tank for heat recovery instead of the cell which is mounted directly on the heat source (for example the exhaust system) can be used. For a better distribution of the heat the exhaust gases can also be used to warm water tank so that each cell would be heated equally. It should be also examine the justification for applying the cells with higher heat resistance, which can provide more power. Besides being economically beneficial an advantage of using cells is to reduce the vehicle's engine wear and emission of harmful substances into the environment. The conducted calculations show that the most justifiable is the installation of cells in vehicles equipped with multiple electric receivers with low efficiency of the engine.

Thermoelectric devices for energy recovery can be used to power small devices such as wifi, sensors, watches. More and more new thermoelectric materials that provide efficient and cheap energy generation on a large scale are looked for [11-16]. In the Google Patents database and in Espacenet there are many solutions relating to waste heat recovery, which

indicate that this field is constantly evolving. Considering the keywords in these databases the following number of records can be found:

- *harvesting thermal energy* - there are 190 of such solutions in the database Espacenet, 28252 in Google Patents, and in the past 3 years in Google Patents appeared 7453 solutions
- *harvesting thermoelectric generator* - in the database Espacenet there are 14 records that meet this criterion and in Google Patents 11263, in the last 3 years in Google Patents appeared 2057 such solutions,
- *thermoelectric generator* - in the database Espacenet is 3367 records of this type and in Google Patents appeared 26938 solution in the last 3 years.

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