OPPORTUNITIES OF EXHAUST HEAT RECOVERY AND CONVERSION TO ELECTRICITY

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Abstract

The maximum efficiency of the conventional spark ignition engine is 33%, in the case of diesel engines is 42%. The conclusion is that the energy contained in the fuel and "released" in the combustion process is converted into mechanical work only in a small degree. The rest of the energy is unfortunately lost by heat, friction, or used to drive the engine accessories. It should also be noted that these values are peak efficiency, which is achieved only when the engine works in optimal parameters. At most used parameters engines reach efficiency on the level of 10% to 25%. In modern cars with a hybrid powertrain are solutions that can improve the efficiency of conventional internal combustion engines. It is worth to notice that there are few ways to improve the efficiency of a reciprocating engine. The main technological trends on which research is underway are knock ignition and heat recovery from the exhaust. More development seems to be the second solution, because it can be used to design new engines such as the replacement of the alternator on the generator of electricity from exhaust heat. Besides, it will be possible to adapt these systems to in-use units, which improve the energy balance of riding vehicles. In article, you will find information of literature analysis for exhaust heat recovery and conversion to electricity solutions, computerized exhaust modification with flow calculations, real modification, test bench creation, researches and scores, analysis.

Keywords: *combustion engine, heat recovery, simulation, efficiency, environmental protection*

1. Introduction

The maximum efficiency of the conventional spark ignition engine is 33%, in the case of diesel engines is 42% [2-5]. The conclusion is that the energy contained in the fuel and "released" in the combustion process is converted into mechanical work only in a small degree. The rest of this energy is unfortunately lost by heat, friction, or used to drive the engine accessories. It should also be noted that these values are peak efficiency, which are achieved only when the engine has optimal parameters. In the extent of engines work by the most of their useful life, the efficiency is from 10% to 25%. Nowadays cars with a hybrid power transmission system are solutions, which improve efficiency of conventional internal combustion engines. It is worth to note that there are other ways to improve the efficiency of a reciprocating engine. The main technological trends over which the research is in progress are detonation combustion and recovery of thermal energy from exhaust fumes. The second solution seems to be more development, as it can be used to design new engines with replacement for example, an alternator for a generator of electricity from thermal energy of exhaust fumes. Besides, it will be possible to adapt these systems to in-use units, what improve the energy balance of driving vehicles

2. Solutions for straight heat recovery

Following the subject, an analysis of the literature shown available solutions about conversion of thermal energy into electricity. Energy conversion is the conversion of one form of energy into another. In accordance with the principle of conservation of energy, the total energy does not change. While the components of the total energy can increase or decrease. If the aim it to turn thermal energy into electricity, can be seen two ways [2]:

- direct, where thermal energy is simply converted into electricity,
- indirect, where initially thermal energy is converted into mechanical energy and then into electricity (Stirling, WASE 2, classical generator, alternator, generator of "American” type).

Direct methods are based on the phenomenon of the thermoelectric effect [1]. This is the effect occuring between two points of the bodies temperature difference, which generates an electrical voltage, or vice versa. Thermoelectric phenomenon, due to the transition direction is divided into Seebeck effect, Peltier effect and Thomson effect. In the case of the conversion of thermal energy into electricity has to deal with the Seebeck effect. It is based on the creation of thermoelectric power in a closed circuit consisting of two dissimilar metals - semiconductors, provided that the place of contact of these metals is in the middle of a different temperature than their opposite ends. Nowadays the following devices are available which use the phenomenon of Seebeck: thermocouple, Peltier/Seebeck cell, and nanoantenna. Below you can find description of nanoantenna, which is brand new in this technology. The latest invention are nanoantennas that can convert heat into electricity with very high efficiency, about 80-90%. During using nanotechnology created batteries, which acquire energy from the visible spectrum as well as infrared range. In this solution applies to the process of gluing small spiral made of electrically conductive material on a plastic plate (Fig. 1).

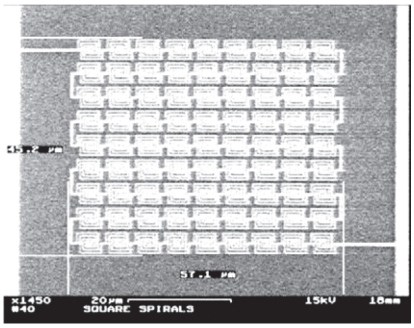


Fig. 1. Nanoantenna [1]

After connecting the spirals are closed electrical circuit working in electromagnetic resonance, which absorbs radiant energy waves in the same way as TV antenna. As the device is small in size it is able to absorb infrared energy in the range of the spectrum, which is invisible to the human eye. The plates on which are mounted spirals are flexible, which perfectly adapts to the shape required to connect elements necessary for occupancy. Unfortunately, this technology has one big drawback. The voltage, which is generated by nanoantennas, reaches the frequency of one GHz, which is necessary to transform the secondary voltage. In addition, it is hard to straighten out current and to charge the battery, for example. Currently, research is carried out using micro capacitors directly on nanoantennas structure, which would enhance the adverse event.

3. Exhaust calculations and modifications

Environmentally friendly drive systems can be observed that in most solutions still have internal combustion engines, which a side effect of the combustion are hot gases. In every solution there are the systems that require cooling of individual components. So the solution that is the subject of this argument can be applied to various types of structures and technical implementations in vehicles. Entities that do not use electrical power to propel the vehicle can use this energy to supply additional systems, which are located in each vehicle (for example lighting). In this analysis there was used Seebeck cell for thermal energy conversion into electricity and gel battery for storage the energy. To put into practice there should be modified exhaust system of an internal combustion engine, in order to allow assembly of the designated analytical recovery system exhaust heat from the conversion into electricity. The next task is to choose the Seebeck cells and mounting them in the exhaust system. As is apparent analysis of the literature these cells require heating of one side, which will be performed by flowing exhaust gas, but also the cooling of the other. As the system of heat, importer aluminum radiators were applied. In the case of the cars a cooling system does not require further develop, as underbody air turbulence caused by the movement of the vehicle is sufficient for the heat from the radiators. During the tests on an engine dynamometer should be force the extra airflow around the radiators. The modification consisted of changing the geometry of the exhaust system to allow the installation of rigid Seebeck links in the form of rectangular prisms based on 40x40 mm square. This is achieved by making the profile of the regular hexagon with bevelled pyramids in order to connect with a classical exhaust pipe. The base portion is made of stainless steel. Cut the sheet size 200x324mm, which was formed on a bender in the form of a cross-section profile of a regular hexagon and butt weld welded together at the connection place. Then cut the truncated triangles in order to connect to the exhaust pipe part, which have been welded in the manner. For the construction of the exhaust flow calculations were performed in the software Fluent. The next task was the installation of Seebeck cells. It was decided to use a variety of cells widely available for testing and giving an answer to the question: Using which cell is the most favourable energy-system? In the research used three cells (Tab. 1). Names of cells that have been assigned and are further used are Link 1 - TEC 12705, Link 2 - TEC 24106, Link 3 - TEC 12715. To measure actual temperatures occurring in thermoelectric cell attachment, installed thermocouple type K. Digitized 3D model together with the mounted cells is shown in Fig. 2.

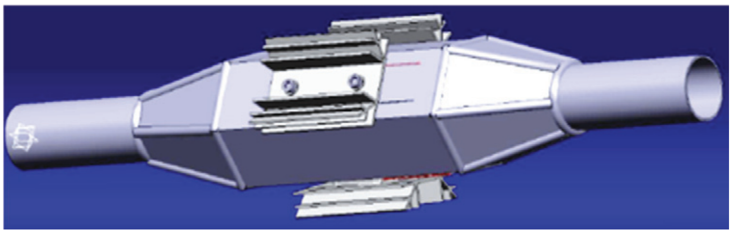


Fig. 2. Digitized 3D model together with the cells - isometric projection [1]

Tab. 1. The cell apply

Parameter/Cell	TEC 12705	TEC 24106	TEC 12715
Max. input power	77 W	150 W	180 W
Max. output power	46.5 W	101.2 W	137 W
Current	4A (max 5A)	5A (max 6A)	12A (max 15A)
Voltage	12V	24V	12V
Resistance	2.3-3.2 Ω	3.79 Ω	1.4-1.6 Ω
Dimensions	0.04x0.04x0.004 m	0.04x0.04x0.0032 m	0.04x0.04x0.0033 m

Construction of the electrical system relied on connection enables measuring the amount of regenerative energy (voltage, current). Cells are connected by a three-position rotary switch, double circuit to a fixed resistor. The system also has a voltmeter and an ammeter. In addition, connected a thermocouple to measure the actual temperature in cell attachment. Thermocouple is connected directly to a digital indicator with built-in compensation. For such modifications were also made calculations flow. The program GAMBIT discredited the 3D model. Then, the program FLUENT made simulations. ANSYS Fluent is a software that allows you to model all phenomena related to flows (combustion, turbulence, multiphase flows, chemical reactions, heat conduction, radiation, etc.). The program uses the finite volume method.

Software Gambit is equipped with an interface for creating and applying the grid geometry, the discretization of the real object on the digital representation. The development of a computer model using software Gambit runs the following processes. First, create the geometry and create a grid discretization, which consists of: outer layer, discretization edge, discretization walls, discretization volume. As the end result of work in the software GAMBIT is created a 3D model of the applied grid that will be used to carry out numerical calculations (Fig. 3). Grid was imposed as the cubes of edge 8 mm. This is enough value to ensure the accuracy of the results of the flow.

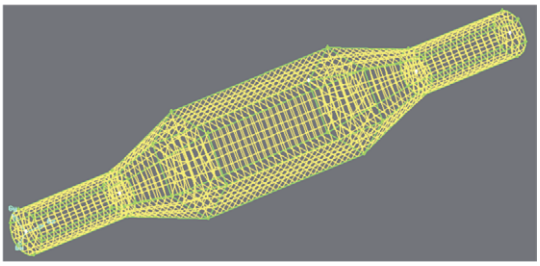


Fig. 3. Discretized model of the modified exhaust system [1]

The last operation performed in the software Gambit is the introduction of the initial boundary conditions. By introducing appropriate plane defined their type. On the one hand of the model was placed inlet velocity (Inlet), on the other single outlet (Outflow), the other planes which make border model was defined as the wall. The next step is to perform numerical calculations. Fluent program used in 3D. Calculations were performed only for one model of geometric parameters where variables were temperature and velocity of the inlet gas. In Fluent environment made - check the correctness of the construction of the model and the grid - established as turbulent flow model - introduced in the unit mm - found that the calculations should take into account energy. The next step was to give the boundary conditions. Found the temperature of walls cold exhaust as 300 K and the wall thickness as 0.002 m. It was assumed that the material of which is made the exhaust system is a steel and flowing gas are exhaust gases. The internal diameter of the inlet pipe is 46 mm. From the literature matched the mean velocity exhaust catalysts (system installed at the installation site of the catalyst). Performed six calculations, in which the variable parameters were given by Tab. 2.

Tab. 2 The parameter values for numerical variables

Calculation	Inlet velocity [m/s]	Exhaust fumes temperature [K]
1	9	473
2	14	473
3	18	473
4	9	573
5	14	573
6	18	573

On Fig 4 is a graph showing the dependence of the convergence of calculations carried out as a function of the quantity.

After the approximately 100 calculations give a satisfactory convergence value, which translates to the accuracy of the calculations.

On Fig. 5 is chart of the temperature distribution in the exhaust system modified according to the indicated variable parameters (Fig. 5).

As is apparent from the above listed temperature distribution graph is similar for all parameters, but only with the different temperature in the various parts of the exhaust system.

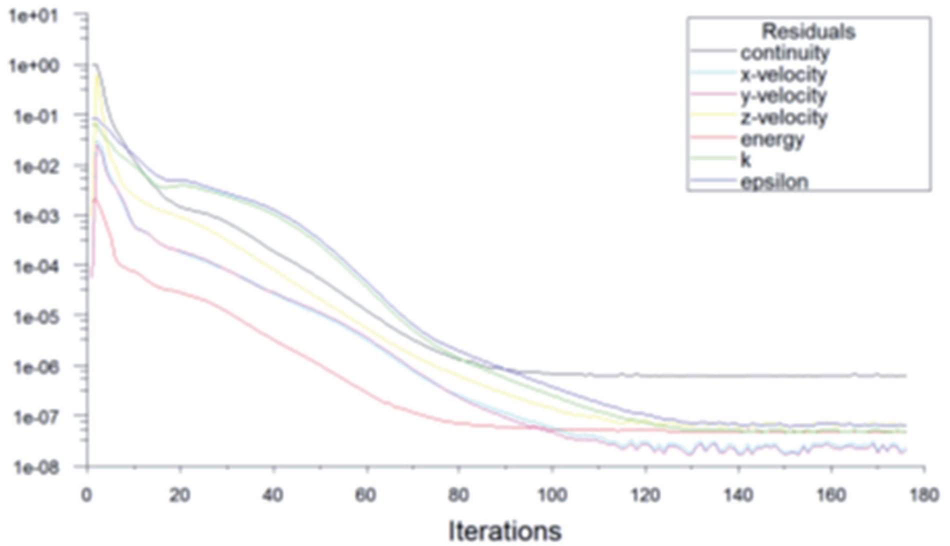


Fig. 4. Dependence of convergence of the calculations as a function of quantities

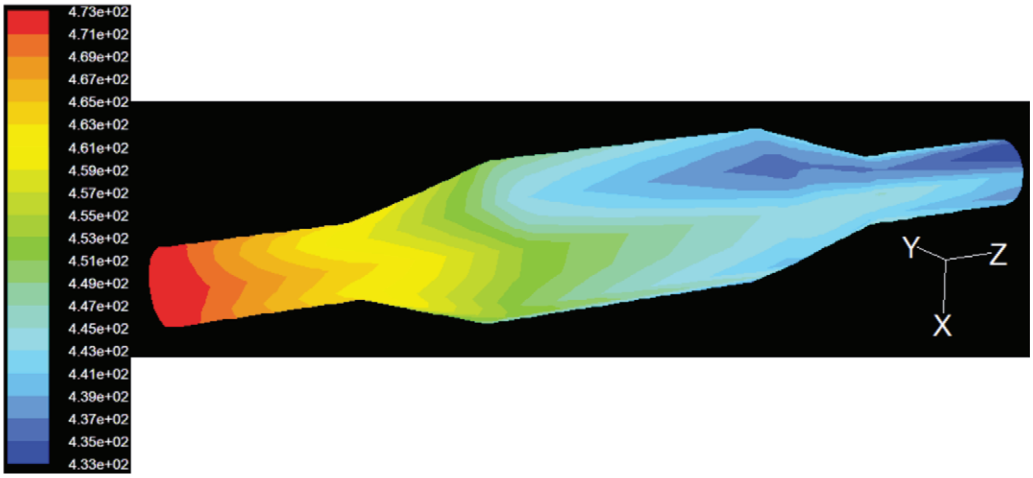


Fig. 5. Diagram of the temperature distribution (V = 14m / s, T = 473oK) [1]

4. Resarches

The next task to complete the issue was the construction of the test bench. The test stand is constructed with hydraulic brake of Heenan & Froude Limited. The object of research is the compression ignition engine designed by PERKINS UR AD3.152 type of data: The measurements were made by 13-phase test. In the following part presented the results of the tests and their interpretation. Description of 13-phase test. The way to know based on these parameters is to conduct experiments. Description of the operation of the engine is presented by characteristics.

Characterization - this is dependence of operating parameters presented graphically, which was determined experimentally. The relationships that form the characteristic can also be described by using numerical arrays or functions obtained by the mathematical approximation; such a provision is preferable to computer calculations. There are two types of characteristics. Static set at the steady state engine operation. This is precisely the relationship of one engine operation parameter of the other and dynamic variables show progress over time, depending on the selected input parameters.

The first thing to do is to determine the external characteristics of the engine Ne = f (n). Then the graph is applied to specific points, to 50% and 70% of engine power - Ne (Fig. 6). Which is loaded with torque motor is taken up on the brake hydraulic system. The speed of the crankshaft and the load is read from the analogue gauges.

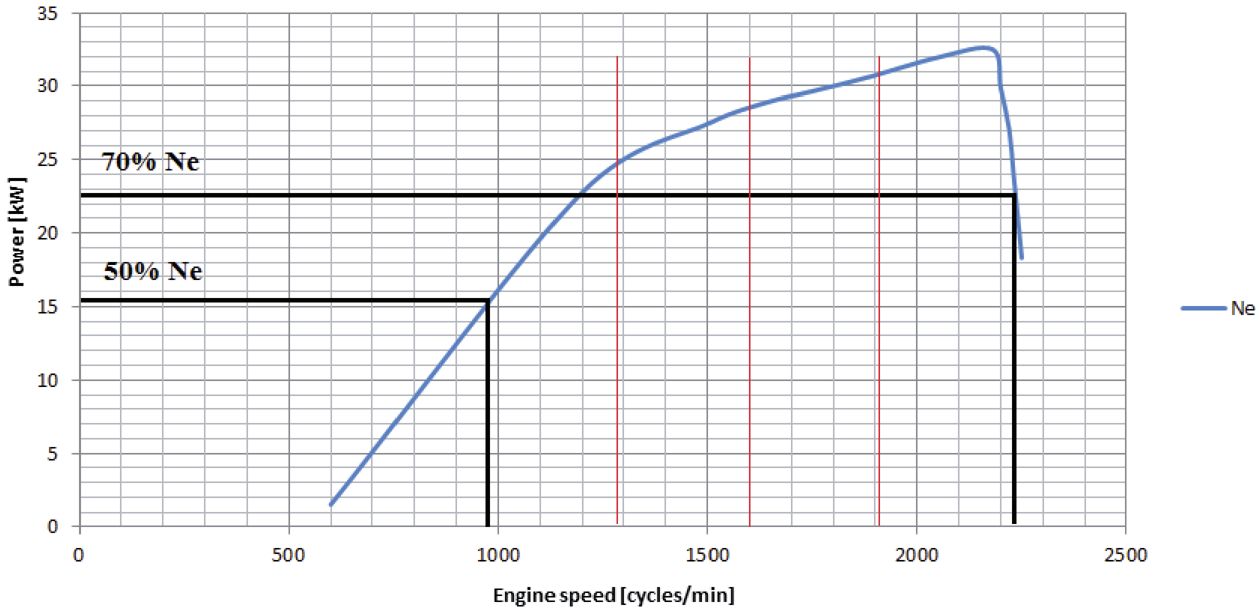
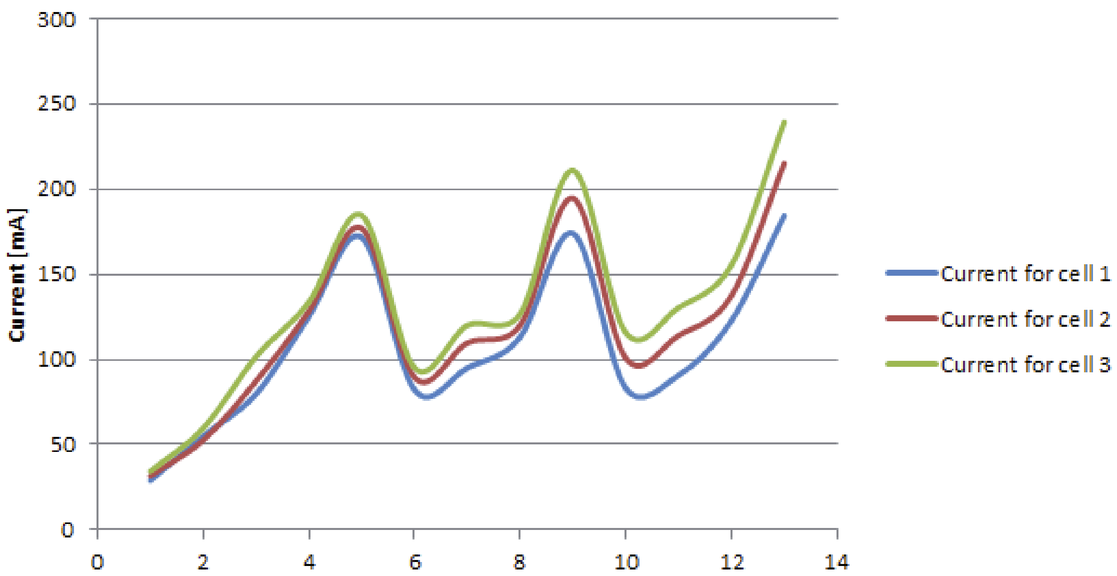


Fig. 6. Power output depending on the rot. speed of the crankshaft with marked measuring points ESC test [1]

Reads the value of turnover for the designated points and based on them the test table is built for the engine. The test is performed on an engine dynamometer. Before each measurement for each phase shall be allocated to 120 seconds to stabilize the engine operating conditions. Permitted speed error in the individual phases up to 50 rev / min. While the torque error may be ± 2% of the maximum torque developed by the motor for a given speed. The particular phases are measured in working time of two minutes, with the exception of the first phase (idle) for which working time is four minutes. Results of the measurements are shown on figures.

On the Fig. 7 and 8 depending of voltage, current, power and temperature as a function in the order of the phases carried out.

The last graph shows the characteristics of cells, that is, the relationship of the power input as a function of temperature (Fig. 9).



Phases

Fig. 7. Individual cell intensity as a function performed in test phases ESC [1]

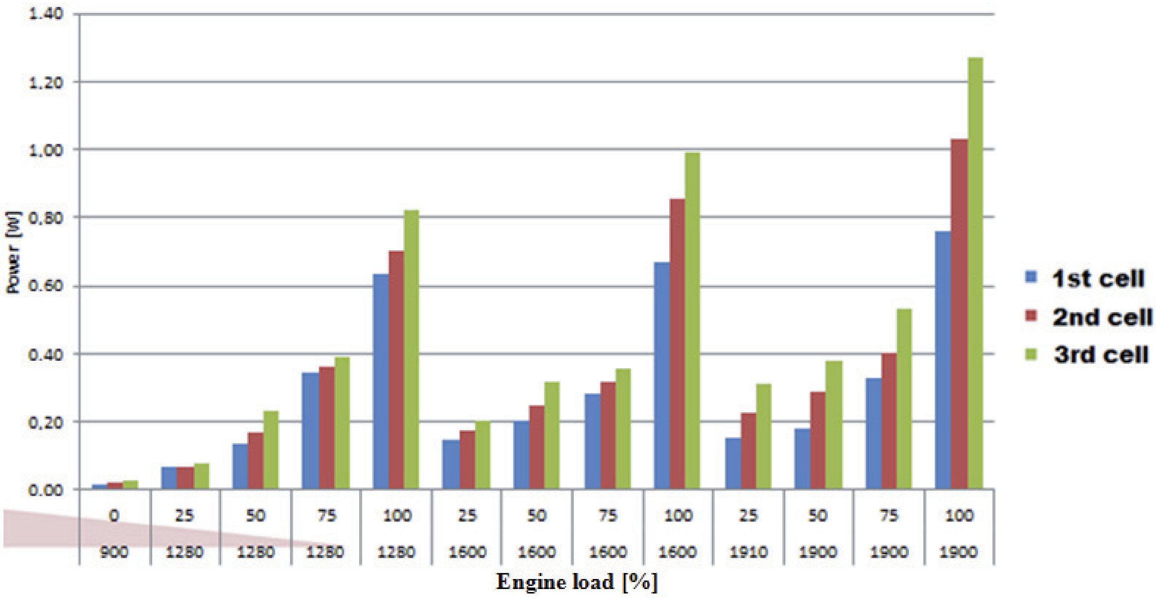


Fig. 8. Power of the cells according to the measuring points [1]

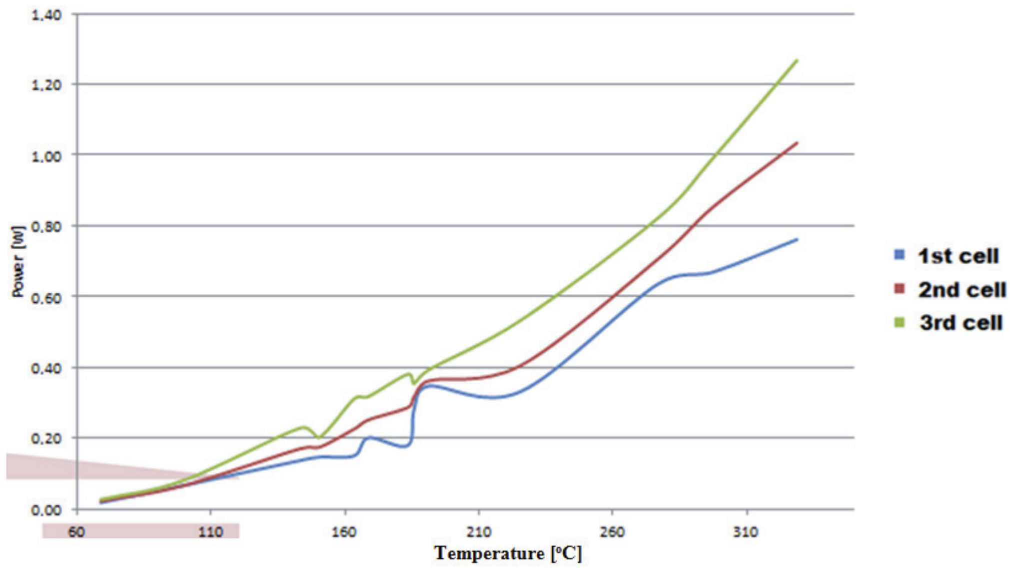


Fig. 9. Power of the cells as a function of the temperature of the hot [1]

5. Conclusion

The most important conclusion is the answer to the question whether it is possible to exhaust heat recovery engine and convert it into electricity? Yes – the research shows that the possibility exists. By using Seebeck cells can be improved the energy balance of internal combustion engines. Third cell (TEC 24106) gave the most power at each measurement point. This cell has the highest value of the internal resistance and the maximum capacity extract are included in the average values for the studied solutions. From Fig. 29 it can be concluded that the recoverable amount of power is directly dependent on the temperature of the hot cell. Dissertation topic lends to further research that should focus on placing the cells as close to the exhaust manifold, where is the highest temperature and to improve the cooling of cold side, for example by the use of coolant. Such cells can be connected in series to obtain a higher power. This issue is a new solution that can be used as a replacement for alternator or additional power source for vehicles.

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